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Airport Landside Planning Techniques

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Transportation Research Record 1199

Contents

Introduction

GEOFFREY D. GOSLING

The airport landside is commonly defined as those parts of the airport that do not handle aircraft. Landside planning is concerned not only with activities in the terminal building and at the curbside, but also with the airport ground transport system and the impact of the airport operation on its environs. Landside planning concerns therefore arise to some extent at every airport. It is at the larger airports, with their greater traffic volumes and greater complexity, however, that landside planning questions often become of great concern.

Increasing levels of air traffic translate into larger volumes of people and vehicles to be handled by the landside facilities, the capacity of which is often severely constrained by local site considerations or inadequate investment. The situation is often complicated by the large number of different organizations that must be served by the airport landside facilities and that frequently are responsible for constructing or operating different components of the landside system. The many changes in the airline industry since deregulation have further complicated the landside planning task by changing the nature and scale of the problems and by introducing considerable uncertainty into projections of future requirements. The rapid growth of large connecting hubs in the airline network, with their high volumes of transfer traffic and very peaked demand patterns, has created difficult challenges at those airports selected by airlines to be network hubs.

Recognizing the increasing attention being given to landside problems and the need for more guidance on how to address them, the Federal Aviation Administration (FAA) sponsored a Transportation Research Board (TRB) study of airport landside capacity assessment techniques (*1*). As a follow-up to this study, the TRB Committee on Airport Landside Operations organized two sessions on the broader topic of landside planning techniques at the 1988 TRB Annual Meeting. The papers in this Record were presented at those sessions.

The paper by Andrew Lemer, the project director of the TRB study, describes the study findings and provides a general introduction to the current state of the art of landside planning. The paper discusses the landside decision-making context, describes the importance of level of service concepts to an understanding of landside capacity, and discusses the capacity assessment process developed in the study as well as the pressing need for a program of landside research to support this process.

LEVEL OF SERVICE CONSIDERATIONS

The motivation for developing landside level of service measures is twofold. First, since one of the goals of landside planning is to improve, or at least maintain, the level of service experienced by the airport user, it is necessary to be able to measure level of service in order to know whether this goal is being achieved. Second, landside improvements are rarely without expense. To know whether a particular expenditure is justified, it is necessary to be able to measure the change in level of service resulting from it. Merely striving to meet arbitrary performance standards, without regard to the cost of doing so, is likely to lead to misallocation of resources.

Although the need to incorporate level of service considerations into landside planning is increasingly recognized (*1*), there is currently no agreement even on how to define level of service, let alone on how to assess the influence of particular projects on the resulting levels of service experienced by facility users. On the airside, aircraft delay has become widely accepted as the appropriate measure of the level of service provided by the system. (It should be noted, however, that the practice of aggregating aircraft-minutes of delay, without regard to aircraft type or nature of each delay, oversimplifies the problem.) The airport landside, on the other hand, involves so many distinct activities that it is extremely difficult to express level of service by a single measure. The range of possible measures identified by Brink and Maddison (*2*) includes some that are relatively easy to quantify and others that are much harder.

A number of attempts have been made to define a framework for measuring landside level of service. Apart from simply attempting to measure appropriately each aspect of level of service, such as minutes of travel time or walking distance in meters, these approaches have been based on either defined standards or user satisfaction.

The standard-based approaches have often followed the practice of the *Highway Capacity Manual* (*3*) and specified ranges of a particular measure on a lettered scale, such as A to F (*4*). This approach has the attraction of seeming consistent with what is already done in the highway area. It is not clear, however, where the appropriate divisions between levels should lie for many of the measures of concern in the airport landside (e.g., walking distance, waiting time, or crowding) or even how to measure some factors, such as the availability of information. Even if these difficulties can be overcome, there is no assurance that a given level of service for one measure bears any meaningful relation to the same level for a different measure.

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Satisfaction-based approaches, on the other hand, attempt to define levels of service on the basis of judgmental user assessment of different conditions. It can be argued that this approach reflects the perceptions of the users of the facility. There are difficult questions, however, concerning the basis from which the users came to their assessment and the role of expectation in influencing the value assigned, as well as how consistent assessments are over time and how transferable they are to other situations. Perhaps more important, this approach provides little or no normative guidance for planning. Although it may be possible to determine the measures necessary to achieve a particular percentage of users rating a facility good or excellent, it is not so clear how to determine what percentage is an appropriate goal.

Some of these difficult issues are addressed in this Record. The paper by Norman Ashford provides a review of different level of service criteria in use in Europe and North America, and describes some recent research on a user satisfaction approach in the United Kingdom. The paper by Farooq Omer and Ata Khan presents a different approach to linking user perceptions of level of service to the Canadian standards-based criteria.

ANALYTIC TECHNIQUES

The wide range of problems to be addressed in landside planning has led to the development of a diverse set of analytic techniques. In general, these techniques fall into two categories: general purpose techniques that can be applied to a wide range of problems and specific techniques that have been developed to address a particular landside planning need.

General purpose techniques include queuing theory, network flow analysis, choice models, demand models, optimization techniques, and simulation models. More specific techniques include aircraft gate assignment procedures and curbfront capacity models. The recent TRB Special Report 215 (*1*) provides a summary of many of these techniques.

Simulation Models

The complexity of many landside planning problems and the need to account for the effect of stochastic variations in traffic have led to fairly extensive use of simulation models. An early use of simulation by Baron (*5*) investigated the effect of terminal layout and ramp use strategies on passenger walking distance. More recent studies have used commercial simulation software to model the interaction of different landside processing activities (e.g., Mumayiz and Ashford [*6*]). Many airport planning firms have developed general purpose simulation computer programs that can be adapted to a variety of analytical tasks, and the FAA has sponsored the development of similar capabilities in the public domain (*7*). These programs typically represent a facility as a network of activities, such as check-in or baggage claim, with vehicles, passengers, and baggage following specified paths from node to node, where a service process determines the amount of time spent at each node. The program keeps track of delay distributions and other statistics of interest. Such programs often have graphic display capabilities that can generate distribution curves or histograms of selected statistics or display the flow pattern in the facility at any time.

As with so many other computer analysis techniques, the development of landside simulation programs that can be run on microcomputers has greatly increased their potential utility. By simulating flows in each part of the facility, rather than modeling every transaction and keeping track of each passenger, the computational effort can be significantly reduced. The paper by Francis McKelvey describes an analytical network queuing model in which delays experienced by passengers at each processing activity are calculated using closed-form queuing equations. The volume of traffic using each processing node is determined by means of transition matrices that define the proportion of traffic leaving each node that proceeds to every other node.

Terminal Requirements

A key factor in planning the terminal facilities to handle a given level of traffic is the number and mix of gate positions required, since this constrains the terminal building layout and in turn affects demands on other functional areas. A common approach to determining gate mix requirements is to develop a hypothetical future schedule and assign these flights to specific gates (*8*). Various computer techniques have been developed to assist in this process (*9–12*).

In the fifth paper in the Record, S. Bandara and S.C. Wirasinghe present another approach to determining the number of gates required at a terminal, based on an analysis of the variability of the airline schedule.

Intraairport Transportation

As airports expand to accommodate ever larger volumes of traffic and distances between facilities become too far to walk, the problem of moving passengers and baggage within the airport itself becomes increasingly severe. The sixth paper in this Record (by McKelvey and Sproule) examines the influence of terminal configuration and connecting passenger volumes on the relative costs and travel times of different transportation technologies, from small buses to automated people-mover systems.

ENVIRONMENTAL PLANNING

The need to consider the impact of all aspects of an airport's operation on the surrounding communities is an increasingly important aspect of airport landside planning. At many airports the two most pressing local concerns are aircraft noise and ground traffic generated by the airport. Well-established analytical techniques exist for both problems, but effective community participation is required to generate politically acceptable solutions.

The final paper in this Record (by Dubbink) presents a new approach to explaining the technical complexities of aircraft noise in the context of a public presentation by making use of acoustic recordings and computer displays, tailored to a specific situation.

SUMMARY

Landside planning problems are becoming increasingly complex, and their solution is critical to the continued operation and expansion of many major airports. Although a variety of analytical techniques exist, many of the issues that need to be addressed present a significant challenge to currently available tools. There is a pressing need to establish standards for analytical procedures and support data and to better understand the validity and limitations of different techniques, so that appropriate computer software can be made widely available and landside planning can be based on analysis using sound and well-documented techniques.

The lack of an accepted framework for measuring landside level of service seriously limits effective analysis of alternative solutions to landside problems, since there is no rational basis for examining trade-offs between project costs and the benefits of improved operation. In view of the huge costs that will be involved in the future development of many major airports, the need for improved landside planning techniques is of continuing concern.

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Use of an Analytical Queuing Model for Airport Terminal Design

FRANCIS X. MCKELVEY

This paper is an examination of the application of a computer-based model to the airport terminal design process. It includes a discussion of the inherent features of the modeling process as a framework for assessing terminal design alternatives. The paper examines the methodology used by the model and assesses the research needs for improving the model's capabilities to predict terminal performance. A review of an analytical network queuing model that has been developed for analyzing the performance of airport terminal systems for capacity and delay is undertaken. This includes a presentation of the theoretical modeling equations, the mechanism for representing the structure of the passenger processing network, and various measures available within the model for estimating the service quality associated with the terminal design. A simple application of the model to a terminal design that highlights the model's features for its use in evaluating and assessing the terminal design performance is included. The model is critically assessed relative to its capability to present a realistic assessment of the performance of the terminal system. Recommendations are made relative to the types of research and development that might be undertaken to enhance the capability of models to predict terminal performance in the design process to influence and enhance decision making.

This discussion of terminal planning models is confined to the airport area that traditionally is called the airport landside. The landside is the airport subsystem that includes those facilities located within the airport boundary that are necessary to process the inbound and outbound passengers. The airport operator and airlines serving an airport normally have specific issues that must be addressed in what may broadly be called airport landside planning and design. These include master plans to determine the overall facility requirements to meet changing airport needs, design plans to specifically lay out and size construction modifications to airport facilities, operating plans to optimize the use of existing facilities, and cost projections to ascertain the economic and financial viability of airport modifications. The specific focus of this paper is the utilization of modeling procedures to assess the capability of proposed physical or operational changes in the airport terminal design to meet specified objectives.

Considerable attention has been focused on the airport landside in recent years (*1,2*) because of a greater realization of the need to balance both airside and landside capacity to implement effective and efficient airport systems in a rapidly changing environment. Although sophisticated and relatively accurate models exist for an analysis of airside systems, the modeling capabilities for landside systems are very diverse and have had limited application and acceptance (*3–5*). The reasons for this seem clear. The airside is highly systemized, with strict methods of operation greatly simplifying the task of mathematical modeling. The landside system, on the other hand, is not as clearly defined and is subject to a considerable degree of variation in its operation; that makes mathematical modeling a relatively complex problem. A model's ability to simulate accurately the performance of a system is highly dependent on the complexity of the system, which is often characterized by the mathematical rules by which system activity is governed. For this reason, it is doubtful that the modeling of such a system will result in accurate results unless very strict rules are imposed upon passenger behavior and the service capabilities of passenger processors become highly automated. The analyst is therefore faced with the choice of either abandoning the process of modeling the landside system or improving upon existing modeling capabilities. Assuming that the first alternative is not acceptable, a modeling process is presented that offers the potential of responding in a meaningful way to the second alternative.

OVERVIEW OF THE MODEL

The Federal Aviation Administration's (FAA's) Airport Landside Model (*6*) presents a framework within which an airport landside may be analyzed with respect to capacity and delay. This model is a computer-based, analytical queuing model utilizing closed-form mathematical equations and network analysis to study the airport landside. The model represents a first approximation to the analysis of the airport landside. Much of the model's theoretical basis is derived from research conducted by Pararas (*3*). Subsequent research has been performed to improve upon the original model (*7*) and to include a representation of intraairport transportation systems for passengers connecting between flights in different terminal units (*8*). The model is efficiently executable on microcomputers.

The model is configured to analyze the average passenger delay experienced at enplaning terminal facilities, deplaning terminal facilities, and in the ground access system.

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This paper presents the model's capabilities to assist in the assessment of terminal design alternatives; therefore, a detailed discussion of the ground access component of the model is not undertaken.

The basic premise upon which the model is founded is that the airport terminal can be represented by a series of passenger processors that are linked together to form a sequenced network through which passengers must pass to enplane or deplane aircraft. The processors themselves are mathematically represented as queuing mechanisms in which a unit of demand enters the processor, service is performed, and the unit of demand moves to the next processor. The model computes the average passenger delay and service time at each processor in the network and the average travel time between processors. These three time elements are then added to compute the average passenger processing time through the network. Conceptually, the model is very simple and conforms quite well to the functional nature and operation of the airport terminal building.

Modeling Equations

Most of the passenger processors within the terminal building are modeled through the use of two closed-form mathematical queuing equations (*7*). The models are multiple-channel queuing models with a first-in first-out (FIFO) queuing mechanism. Both models assume that the demand is random and may be characterized by a Poisson arrival distribution. The first model assumes that the service rate at a processor is random and is characterized by an exponential distribution, the MMK model. This type of model is normally used in situations where the service time is influenced by individual passenger characteristics. In design studies at Fort Lauderdale-Hollywood International Airport (FLL) it was found to reasonably approximate delays in situations where the passenger service time is relatively small, such as at security locations.

The second model assumes that the service rate is a general random variable characterized by its mean and variance, the MMG model. This type of model is useful in situations where service times are similar for all passengers and therefore lie within clearly defined limits. It was found at FLL that this model form presented reasonable delay approximations at processors where a discrete service time was required for passengers, such as at ticketing. The average delay for the MMK model is given by

$$W_{\mathrm{MMK}} = D^k S^{k+1} \bigg/ \left[(k-1)!\,(k-DS)^2 \sum_{n=0}^{k-1} \frac{(DS)^n}{n!} + \frac{(DS)^k}{(k-1)!\,(k-DS)} \right] \quad (1)$$

and for the MMG model by

$$W_{\mathrm{MMG}} = \frac{v + S^2}{2}\, W_{\mathrm{MMK}} \quad (2)$$

where

D = the mean passenger arrival rate;
S = the mean processor service time;
v = the variance of the mean processor service time; and
k = the number of processors.

By collecting data at various processors within the airport terminal, the average service time and the variance of the average service time at processor may be determined and Equation 2 used to model the terminal system. The preceding equations are valid only when the average demand rate, D, on a processor is less than the average service rate, k/S, of the processor. When the demand rate approaches the service rate, the delay approaches infinity and the processing system becomes saturated. To account for periods of saturation when the queues would continue to grow as additional demand enters the system, an additional delay term was derived using a deterministic model. This model assumes that the demand and service rates remain constant over the saturation period; therefore, the delay may be represented as the area that exists between the demand and delay curves over this period (*6*). It was assumed that the saturation period would be relatively short since additional personnel would normally be assigned to alleviate these queues. This delay term, W_S, is

$$W_S = \frac{T(D - k/S)}{2k/S} \quad (3)$$

where T is the period of time over which saturation occurs. The average delay at the baggage claim device, W_B, is computed through another relationship that defines passenger delay as the time difference between the arrival of the passenger at the claim area and the point at which the passenger claims all baggage. Therefore, the average delay at the baggage claim is given by

$$W_B = T_B + T_U - T_T \quad (4)$$

where

T_B = the average time to unload baggage from the aircraft and transport it to the claim area;
T_U = the average time to unload baggage from the transport vehicles to the claim device; and
T_T = the average time for a passenger to travel from the aircraft to the baggage claim device.

When the results of Equation 4 are negative, the model assigns no passenger delay at the baggage claim facility. The first term in Equation 4, T_B, is fixed in the model based upon studies conducted at several airports. The second term is given by the relationship

$$T_U = \frac{n}{n+1}\,\frac{B}{rc} \quad (5)$$

where

n = the average number of pieces of checked baggage per passenger;
B = the total number of pieces of checked baggage on the flight;
r = the baggage unloading rate from the transport vehicles to the claim device; and
c = the number of baggage devices used for the flight baggage.

The last term in Equation 4 represents the time for the average passenger to move from the aircraft to the baggage claim area. This time is a function of the distance from the aircraft to the claim device and the speed at which a passenger travels to the device. The model assumes an average passenger walking speed of three feet per second.

Network Representation

As noted earlier the model considers the airport terminal a series of linked and sequenced passenger processors. Figure 1 illustrates a typical representation of the passenger movement through the enplaning network in a terminal building. The passenger enters the terminal building through the terminal doors, D, proceeds to the passenger check-in facilities for ticketing only, T, or ticketing and baggage checking, B, through the security checkpoint, X, and to the gate area for seat selection, S, and boarding, G. Each of these processors serves the passenger demand imposed upon it; therefore, passenger delays and waiting lines may occur at each. The links between these processors indicate the possible paths that passengers may take from one processor to another. The percentage of total passengers at one processor proceeding directly to the next processor and the average distance between these processors are also shown in Figure 1.

In the model the various passenger paths through the network, as shown in Figure 1, are represented by a transition matrix indicating the passenger splits between components and the travel distances between components. This transition matrix is computationally efficient for determination of the total passenger demand on each of the passenger processors. An example of the transition matrix for the passenger splits between the components shown in Figure 1 is illustrated in Table 1. A specific row of the transition matrix indicates the percentage of passengers at one component proceeding directly to the next component. Therefore, the first row of the transition matrix shown in Table 1 indicates that of all the passengers entering the terminal through the terminal doors, D, 60 percent proceed directly to ticketing, T; 30 percent proceed directly to ticketing and baggage check-in, B; and 10 percent proceed directly to security, X. A unique feature of the transition matrix representation of the network is that the passenger demand on the system may be varied without reconstructing the network. This allows the analyst to determine service quality parameters for the given system under various levels of demand.

In a similar manner, the distances passengers travel between components may also be represented by the transition matrix, as shown in Table 2.

An example of a typical deplaning passenger network is shown in Figure 2. In this figure passengers arrive on aircraft, A, and proceed from the aircraft to the gate area, G, down the concourse to an escalator, E. From the escalator, passengers proceed either to the baggage claim device, B, rental car areas, R, or directly to the terminal doors, D. The percentage of passengers and the distances between the processors are also shown in Figure 2.

AN EXAMPLE OF MODELING RESULTS

The model may be used to evaluate the performance of an airport's enplaning and deplaning network. Using an airport enplaning about 1 million passengers annually with a total peak-hour passenger demand of 700 passengers, the model was run for the enplaning passenger network shown in Figure 1 and the deplaning network shown in Figure 2. Typical values for the service rates for the various processors were used in this example. Sources may be consulted for reasonable estimates of facility service characteristics (*6, 7, 9*), or original data collection may be performed to arrive at these values. The results of the analysis are displayed in Tables 3 and 4.

As may be seen from the information in Tables 3 and

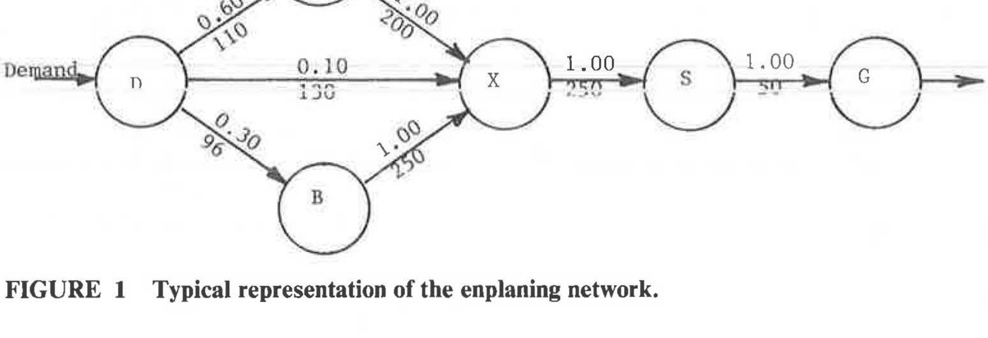

FIGURE 1 Typical representation of the enplaning network.

TABLE 1 TRANSITION MATRIX FOR PASSENGER FLOWS BETWEEN PROCESSORS FOR A TYPICAL ENPLANING NETWORK

	To	D	T	B	X	S	G
From	D		0.60	0.30	0.10		
	T				1.00		
	B				1.00		
	X					1.00	
	S						1.00
	G						

TABLE 2 TRANSITION MATRIX FOR AVERAGE DISTANCE BETWEEN PROCESSORS FOR A TYPICAL ENPLANING NETWORK

	To	D	T	B	X	S	G
From	D		110	96	130		
	T				200		
	B				250		
	X					250	
	S						50
	G						

4, the model determines several performance measures for the individual processors and the overall performance of both the enplaning and deplaning networks. The average passenger delay time and average waiting line length during the peak hour may be used to measure the performance or service quality afforded by individual processors. The average total passenger delay time, service time, travel time, and total processing time may be used as measures of the overall performance or service quality of the enplaning and deplaning system. As noted earlier, this model's approach lends itself very well to changes in the service features of the network's processors without modification of the network itself. Therefore, if the performance of one or more processors does not meet design standards, the number of processors or their service features may be modified and the results of these modifications readily ascertained. Similarly, if the system does not meet design standards, the demand on the system may be modified to determine the level of demand at which unacceptable performance is reached. This is a measure of the capacity of either the processors or the system itself and indicates those processors most susceptible to degraded performance at higher levels of passenger demand.

APPLICATIONS OF THE MODEL

The model just described presents an interesting conceptual framework for the analysis of terminal building performance. It is well suited for three types of applications. In the first, the model may be used to analyze the performance of an existing terminal building and compare the results to those of problem areas observed within the airport. In this context, design or operational modifications may be made to the number, orientation, or service features of processors to alleviate congestion. It was found, by utilizing this model, that high levels of congestion experienced in the main terminal building at Palm Beach

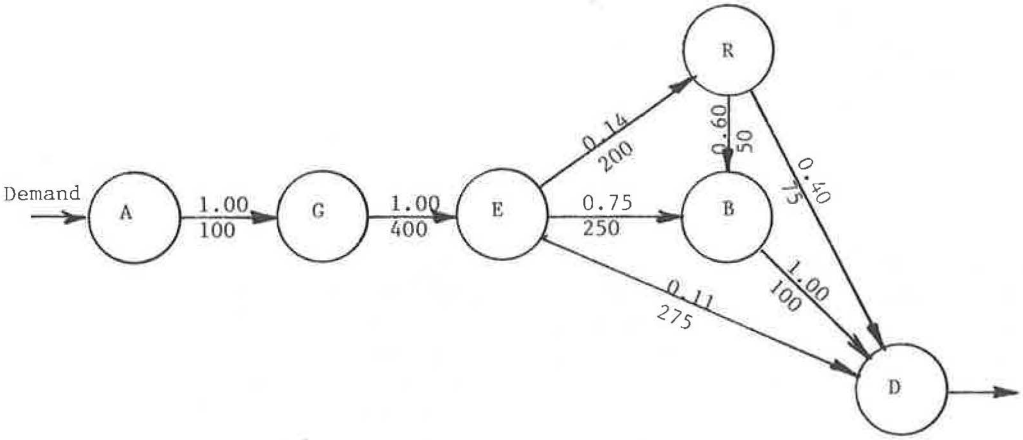

FIGURE 2 Typical representation of the deplaning network.

TABLE 3 TYPICAL MODEL OUTPUT FOR AN AIRPORT ENPLANING TERMINAL UNIT

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                      AIRLINE ENPLANING NETWORK

PROC   NUMBER    ARRIVALS    TOTAL      UTILIZ.     PER PAX    LINE LENGTH

       OF        PER SEC     SERVICE    FACTOR      DELAY      WAITING

       SERVERS               PER SEC                (MIN)      (PERSONS)

DOOR      2       .0959       .200        .48          0.              0.

EXCH      3       .0585       .050       1.17          2.              3.

TIX       6       .0293       .020       1.46          6.              2.

XRAY      2       .1111       .100       1.11          8.             27.

SEAT      8       .1128       .178        .63          0.              0.

GATE      8       .1128       .800        .14          0.              0.

                          PEAK HOUR SUMMARY

          DELAY TIME:             10.8 MIN     4365. PAX-MIN

          SERVICE TIME:            3.2 MIN     1300. PAX-MIN

          TRAVEL TIME:             3.3 MIN     1360. PAX-MIN

          TOTAL TIME:             17.3 MIN     7025. PAX-MIN
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International Airport (PBI) could be reduced considerably and the useful life of this facility extended by reallocating leased airline terminal space (*10*).

In the second type of application, the model may be used to examine the performance of proposed terminal designs in both the conceptual development and schematic design phase of the design process. In the recent terminal design study conducted at Fort Lauderdale-Hollywood International Airport, the model was used to examine the validity of the facility space allocations obtained from secondary sources (*11–14*) and the orientation of these facilities for the various airlines serving the airport. The model enabled a response in a timely manner in evaluating the impact of modifications to facilities proposed by the airport operator, the airlines, and the design team. The model also proved helpful in this study in determining the passenger volumes that would occur in different areas of the airport. This information was of considerable value in establishing the location of specific concession activities within the terminal complex.

In the third type of application, the facilities, service rates, and network representation are considered fixed and the peak-hour passenger demand is increased until unacceptable measures of service quality are exhibited at individual processors or for the enplaning or deplaning network as a system. Although there are no universally accepted measures of service quality, such metrics as queue length and waiting time at a processor, or overall passenger processing time through the network, may be considered valid indicators of performance.

CRITICAL ASSESSMENT OF THE MODEL AND FURTHER RESEARCH NEEDS

It is not the intent of this paper to propose that this specific model present the definitive procedure by which airport terminal buildings should be analyzed in terms of capacity, delay, or service quality. On the contrary, the model has several deficiencies that need to be addressed in future research. The model does, however, present an effective methodology through its use of a sequenced network of passenger processors that offers a unique and conceptually realistic approach to the study of the airport terminal system.

The model does not explicitly consider the variation of demand on downstream processors that might occur because of delays at earlier processors in the sequence. The model assumes that the demand on each processor is the maximum peak-hour demand proportioned to each processor and that this demand is independent of delays at previous processors. This is a deficiency in the model that can be addressed only by assessing the variations in downstream demand associated with such delays. At both FLL and PBI, it was found that the demand on downstream processors was typically more uniform and of lesser magnitude than that represented by the model, resulting in an overestimate of delay. It was also found, however, that the overstatement of such delays was not large enough to affect component design.

The network through which passengers proceed is normally chosen so as to represent all of the facilities through

TABLE 4 TYPICAL MODEL OUTPUT FOR AN AIRPORT DEPLANING TERMINAL UNIT

AIRLINE DEPLANING NETWORK						
PROC	NUMBER OF SERVERS	ARRIVALS PER SEC	TOTAL SERVICE PER SEC	UTILIZ. FACTOR	PER PAX DELAY (MIN)	LINE LENGTH WAITING (PERSONS)
ARCF	6	.1128	1.000	.11	0.	0.
GATE	6	.1128	.600	.19	0.	0.
ESCR	2	.1128	.333	.34	0.	0.
RENT	4	.0134	.013	1.01	4.	1.
BAGS	3	.0799	.960	.08	22.	35.
DOOR	2	.0959	.200	.48	0.	0.

PEAK HOUR SUMMARY

DELAY TIME:	15.9 MIN	6460. PAX-MIN
SERVICE TIME:	1.1 MIN	463. PAX-MIN
TRAVEL TIME:	4.7 MIN	1889. PAX-MIN
TOTAL TIME:	21.7 MIN	8812. PAX-MIN

which passengers proceed for a given airline or group of airlines located in a particular gate complex. When depicted in this manner, the network considers all paths between processors so that parallel paths that might be taken to bypass peak period delays are included in the network. Similarly, the proportioning of demand between network processors should represent those percentages associated with peak period activity.

Considerable research should be undertaken to study the overall functional performance of airport passenger processing facilities for the purpose of formulating more accurate mathematical relationships for describing these processors. The degree of variation between the operating procedures and the state of automation used by the various airlines indicates that the type of mathematical model used to represent a specific type of facility is subject to change. The limited database upon which the queuing relationships and service parameters are formulated should be expanded and analyzed to decrease the margin of error inherent in the existing modeling process. One approach that has been recommended is to attempt to model component performance through regression models (*4*). Another would assume a generalized service distribution, a family of distribution functions, representing the performance of a service mechanism in the system. The service mechanism could be represented by the Erlang distribution given in Equation 6.

$$f(t) = C_x\, t^{(x-1)}\, e^{-xt/S} \tag{6}$$

where

$f(t)$ = the frequency with which service time, t, occurs;
S = the mean service time;
e = a constant, the base of natural logarithms; and
x = an integer related to the Erlang parameter C_x, which defines the dispersion of distribution.

The Erlang constant, C_x, is given by Equation 7.

$$C_x = \frac{x^x/S}{(x-1)!} \tag{7}$$

The variance of the service time in the Erlang distribution is given by Equation 8.

$$v = \frac{S^2}{x} \tag{8}$$

Therefore, if a component in a system is observed and both the average service rate and the variance of the service rate are computed, the integer x may be found from Equation 8 and this value substituted into Equation 7 to find the Erlang constant, C_x, in Equation 6. Once this x is known, the specific service distribution for the component is defined. For example, in a single server system with a Poisson arrival distribution and Erlang service distribution, the average waiting time at the processor, W_{ERL}, is given by Equation 9.

$$W_{\mathrm{ERL}} = \frac{1 + x}{2x} \frac{DS^2}{(1 - DS)} \tag{9}$$

This equation can be reduced to Equation 2 by substituting the relationship for the variance of the mean service time, Equation 8, into Equation 9 for the quantity x.

The characteristics of airline passengers at different airports vary to a great extent, and the model does not adequately address this fact. Airports with a large proportion of business passengers perform differently than airports with a large proportion of tourist passengers. The facilities used by various types of passengers can differ, or at least the manner in which the facilities are used are often different. At tourist airports, most passengers are preticketed and have a considerable amount of baggage. Their knowledge of the airport is usually very limited; therefore, these passengers often spend more time within the terminal building moving between passenger processors than does a typical business traveler.

The original model does not consider visitors who may accompany passengers through certain areas of the terminal complex. These visitors add congestion to queuing areas around processors, waiting areas, and concourses; and they use certain processors, such as the security checkpoint. Consideration of the impact of visitors on processors has been included in an updated version of the model (*8*), but explicit measures of congestion that are of considerable importance in evaluating a facility design and service quality afforded by a facility should also be incorporated into the model.

Although not discussed in detail in this paper, the manner in which the model treats ground access traffic and its effects on terminal area performance requires additional research. In its analysis of the ground access system, the network and the vehicular splits between processors are fixed within the model, and it is not possible to configure a particular network representation of a specific airport ground access system. Attention should also be directed to the models used to represent the performance of ground access system components. Considerable research has been performed on the ground access system that may be utilized to structure the model to conform to specific airport requirements (*15–20*). Provisions do not exist within the model to distinguish between the location or nature of short-term, long-term, and remote parking facilities. Similarly, the provision and performance features for queuing areas for taxis and public transit vehicles should be addressed. These features can readily be incorporated in the model through use of a transition matrix for the ground access system and the development and testing of the relevant component models.

SUMMARY

The model discussed and assessed in this paper offers considerable merit in terms of its structure, computational technique, and network representation in addressing the need for a reliable and universally adaptable analytic procedure for evaluating airport terminal systems for capacity, delay, and service quality. Considerable refinement is necessary in the formulation of several of the processor modeling formulations to improve the model's ability to predict terminal system performance. Additional measures of performance must be incorporated in the model to enable consideration of other factors that are important in assessing service quality. The overall framework used by the model is adaptable to such changes, however. In general, the model in its present form offers an alternative to the application of discrete event simulation models (*5*) to the analysis of queuing in terminal building processing components. It also improves upon the information obtained through the application of simple space approximation techniques (*12–14*) in sizing terminal building components for aggregate measures of terminal building demand. The model is adaptable to meeting the analytic needs of specific airport projects and is unique in its ability to be integrated into the terminal design process. The accuracy of the results predicted by the existing model appears to be reasonable, based on its limited application in terminal design processes and the degree to which accurate passenger demand forecasts can be made. It is apparent that considerably more use is required before sufficiently definitive statements can be made about the level of overall accuracy obtainable through its use.

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Measuring Airport Landside Capacity

ANDREW C. LEMER

At the request of the Federal Aviation Administration (FAA), the Transportation Research Board (TRB) undertook to develop guidelines for assessing the landside capacity of individual airports. A special 18-member committee, representing airport operators, airlines, and airport planning and design professionals, directed and participated in this study. This paper reviews the study's principal findings and recommendations, presented in the final report published in September 1987. An airport's landside capacity is its capability to accommodate passengers, visitors, air cargo, ground access vehicles, and parked or parking aircraft. Of these, the broad demands of air passengers traveling between their homes, offices, and other points of departure to the aircraft—or in the opposite direction when their aircraft arrives and they deplane—are most important to judging capacity at most commercial service airports; and they are the focus of the study. Airport passengers, then, are in most cases the basis for measuring landside capacity. Nevertheless, at some airports employee access and parking, cargo operations, or aircraft servicing may become constraining. While airport operators, airlines, and passengers may often recognize when an airport's landside facilities and services are approaching the limits of their ability to accommodate additional demand, there are no generally accepted procedures and standards for judging airport landside capacity. Current FAA forecasts of more than 70 percent growth over the next decade in the annual number of airline passengers in the United States indicate that consistent bases for making decisions about operation and development of airport landside facilities will continue to be needed. Research to collect data on service conditions over the wide variety of airports, passenger markets, and airline operations should be undertaken to support development of landside service-level measures that can be used by airport operators, airlines, and the FAA to make consistent decisions about needs for airport facilities.

The Federal Aviation Administration (FAA) forecasts that the number of annual commercial air carrier enplanements will increase from their 1986 level of 409.6 million to 696.8 million by 1998, an average growth rate of more than 4.7 percent annually. Passenger enplanements by commuter and regional airlines are expected to grow even more rapidly—6.7 percent annually—from their 1986 level of 26.1 million to 56.9 million in 1998. While continuing trends toward higher aircraft passenger load factors and the use of aircraft with greater seating capacities may lead toward more modest growth in the number of aircraft operations, these forecasts presage greater demands than ever on the nation's commercial service airports.

To meet these demands, many airports must add new facilities or make better use of existing facilities, or do both. Airport management and local officials will be faced with tough decisions about airport use and expansion, decisions that must be made within a context of community concerns about airport-related noise and the broader economic consequences of jobs and commerce related to good air transportation. Airlines, operating in an often fiercely competitive postderegulation environment, want to maintain their freedom to operate their systems efficiently and economically. Air passengers are pleased with lower air fares but at the same time are increasingly vocal in their objections to delays and other perceived evidence of declining service standards. The FAA, responsible for assuring both the high quality of the nation's air transport system and free competition within the airline industry, must operate under broad policies intended to control government spending.

NEED FOR GUIDELINES

Regardless of their different perspectives, each of these groups needs an understanding of airport capacity. Reliable capacity estimates are essential to making informed judgments about how existing facilities can be used, when new facilities are needed, and what it may cost to take action on these judgments.

Unfortunately, airport capacity is a particularly complex problem, and there is no generally agreed-upon meaning of capacity. Even when operating at what many people might intuitively feel is a capacity limit, most parts of an airport could accommodate a few more cars or people or aircraft if some measure of speed, comfort, or safety were sacrificed. Demands fluctuate and are typically concentrated at certain times of day or in certain parts of the airport. Airport professionals have tried for years and with some success to come to grips with these problems (*1*).

An airport may be described in two parts: runways, taxiways, and air traffic control systems used by aircraft and their pilots make up the *airside*. Extensive research and practical experience have produced widely accepted procedures for assessing airside capacity in terms of numbers of takeoffs and landings that a particular airport's airside can safely and effectively handle in an hour (although adverse weather conditions can sharply reduce

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these numbers). The FAA sanctions these procedures, and they are used throughout the United States and in many other countries (*2*). Even so, airlines responding to traveler preferences and competitive pressures may schedule more flight operations during peak hours than some airports can accommodate under the best of conditions. The delays that may result from an airport's airside capacity problems can spread through each airline's system, to be felt far beyond the one busy airport, with consequences for the airlines' public image as well as their corporate profits.

No such generally accepted guidelines exist for measuring capacity of an airport's *landside*—the aircraft gates, terminal buildings, baggage services, parking structures, and ground access facilities used by passengers and cargo traveling by air, and by the businesses and employees seeking to offer air transport services. Crowded terminal waiting areas, queues at check-in and baggage claim areas, filled parking lots, and congested roadways may be among the more visible symptoms that demands on the landside are more than the airport can accommodate. When such symptoms influence airlines' ability to operate effectively and their customers' choices about travel and business, the consequences of landside capacity problems may be felt throughout the metropolitan area an airport serves.

The FAA requested that the Transportation Research Board (TRB) take a first step toward developing guidelines for landside capacity assessment. The TRB assigned staff and convened a special 18-member committee representing airport operators, airlines, and airport planning and design professionals to review current practice and recommend procedures for measuring an airport's landside capacity. The study, scheduled for approximately one year's duration, began in November 1985 (*3*).

The committee quickly found that even among experienced professionals in the field, there was often disagreement as to the precise meanings of many of the terms and concepts that underlie landside capacity measurement. They also found that the diverse interests involved in an airport's development, operation, and use make it difficult to reach agreement quickly.

Each airline schedules its own flights and chooses the types of aircraft to be used. However, a substantial degree of centralized management of airside operations is provided by the federal government's air traffic controllers. In many cases these controllers can act when they spot a capacity problem and thereby reduce or avoid serious consequences. Aircraft may, for example, be required to wait at their parked positions or on taxiways until congestion in the airside system is reduced to acceptable levels. Yet even with this centralized management and generally accepted ways of measuring airside capacity, many of the nation's busiest airports have recurring problems of passenger and aircraft delay because demand exceeds capacity during those periods when people want to travel.

Efforts to adjust demands to fit capacity require greater cooperation among competing airlines, airport operators, government agencies, and the public than can usually be achieved within the context of continuing and often intense political debate about free enterprise and local control. (Allocation of operations "slots" and coordination of competing airlines' schedules, two of the ways of that have been considered for avoiding excess delay, have possibly serious implications for the relative competitive advantage of the companies involved. The federal government is unable or reluctant to make decisions that affect local communities' prerogatives.)

The landside presents an even more difficult situation: The airport operator's ability to respond to landside problems is often restricted by long-term airline leases on terminal building space. There are large numbers of small operaters of services who also have leases and may not all hold similar opinions about how they would like the airport to operate. Individual consumers who are the users of a typical airport's landside present a wide variety of needs and concerns related to their ages, social and economic backgrounds, and reasons for travel. The local community may express mixed feelings about the airport, reflecting both the concerns of neighbors about aircraft noise and safety and the desire by the community for better air service and airport access. The federal government, responsible for the safe and effective overall operation of the air transport system, has very limited authority to deal directly with landside concerns.

When an airline wants to offer new or expanded service at an airport, federal interstate commerce laws generally require that the airport provide space for aircraft and passenger services. While a few communities have attempted to restrict airport use and airline operations (John Wayne Airport in Orange County, California, and Westchester County in New York are outstanding cases), airlines, the FAA, and these communities have avoided testing the legal validity of capacity restrictions by reaching out-of-court settlements about facilities' expansion and use. (Local noise control plans, prepared under FAA-administered programs, are considered an acceptable basis for limiting airline operations at an airport, an action that the FAA otherwise views as a probable violation of laws to protect interstate commerce and free enterprise.)

Some airport operators have seen the levels of activity at their airports explode as airlines establish new hub-and-spoke route structures. The revenues and jobs generated by such increased airline activity can be very attractive to the airport operator and local government, although needs for new facilities and complaints by the airport's neighbors who are exposed to increased noise may cause political problems.

Reflecting on the likely continuing growth of air passenger volumes and changes of airline route structures, the study committee quickly concluded that landside capacity measurement guidelines would indeed be useful. Appropriately crafted guidelines would give users the basis for measuring the landside capacity of an existing airport in a reliable and consistent manner so that airport operators and airlines could use results to discuss short-range solutions to problems as well as longer-range needs for facilities and operating policies, and airport planners and operations professionals could use them to discuss facility construction and use decisions in the public forum. Developing such guidelines was the goal of the study.

LANDSIDE DECISION-MAKING CONTEXT

The context within which an airport's landside is managed is complex. There are multiple decision makers:

- the airport operator, which may operate as a quasi-private enterprise under local or state enabling legislation or as a government agency;
- the airlines;
- the public at large, operating as individual airport users (travelers and businesses using air transport services), airport neighbors, special interest groups, and local and state governments;
- the Federal Aviation Administration.

Each of these groups has concerns that may be immediate or span longer periods, extending as long as the ten- to twenty-year horizon often used in airport master planning and system planning analyses. Such decisions as those regarding facilities development, terminal area leasing, and facilities management are made over progressively shorter time spans, in response to information about the airport's past performance and expectations about future demands. These decision-making groups may not always agree about whether an airport is performing adequately or needs new facilities or operating policies.

Landside capacity measurement is necessarily a short-term activity. Assessment is intended primarily to yield a snapshot view of the airport landside's performance and how that performance may change in response to short-range changes in demand or operating practices. Measures of landside capacity are most meaningful with respect to periods of one to two hours, although the appropriate period may be as short as ten to fifteen minutes or as long as a day. Estimates of landside capacity with respect to longer periods inevitably involve assumptions about distributions of demand and operations—by time of day and from place to place throughout the airport—that limit the validity of the estimate.

Furthermore, landside capacity depends on how facilities are operated, so management action becomes an essential element of landside capacity measurement. Considering these management actions ties the capacity assessment process inseparably into longer-term airport facilities planning. A conclusion that landside capacity is inadequate can imply needs for new facilities, major changes in operating practices for existing facilities, and shifts in policy regarding growth of airport activity. Recognizing these needs and their potential financial, managerial, and community impacts may spur reconsideration of basic goals and expectations about what "adequate" landside capacity means, and may lead eventually to agreement among all parties that problems are well understood and that proposed solutions are reasonable. This is the most important end of airport landside capacity measurement.

DEFINING LANDSIDE AND LANDSIDE CAPACITY

The landside is a complex collection of individual functional components, such as ground access, parking, check-in, baggage claim, aircraft parking, and support systems (e.g., water supply, sewer, and power supply), that interact to serve air passengers and cargo moving between aircraft and origins or destinations within a large area served by the airport (Figure 1). The TRB study defined landside to include the apron parking areas. These areas require land that could otherwise be used for terminal buildings (rather than taxiways and runways), and their geometry directly influences facilities and equipment needed for moving passengers and cargo between aircraft and terminal buildings.

Landside capacity refers to the capability of these functional components (individually and working together as an airport system, including staffing and other operating policies that determine how facilities are used) to accommodate demands of passengers, visitors, cargo, ground access visitors, and aircraft. Demand characteristics include distribution of passenger arrivals over time, modes of travel to and from the airport, number of bags carried and checked, trip purpose, and myriad other factors. In the face of these demands, some components may become bottlenecks and cause crowding, delay, or other symptoms of inadequate capacity.

Because the landside and its capacity are so complex, the TRB study focused on passengers. Although baggage handling, cargo shipment, and aircraft storage and maintenance are important at all airports and may represent limits on landside capacity at some airports, the measurement of their influence on capacity remains a topic for future research.

Factors such as waiting time, processing time, crowding, and availability of passenger amenities for comfort and convenience are indicators of *service level.* Some of these factors are interrelated, and there may be others that are important at a particular airport. For example, the number of passengers waiting in a departure lounge depends on the size of the aircraft being served, when boarding begins, and how quickly boarding proceeds. The rate at which people can move from check-in counters to departure lounges may depend on how many people are in the corridor areas. In either case, conditions in the airport if a substantial fraction of the passengers are vacationers or elderly people may be quite different than if the travelers are mostly business executives or other frequent travelers. Conditions that may be judged acceptable for one situation may be completely inadequate for the other.

There are no generally accepted standards for describing service levels or judging adequacy of service at U.S. air-

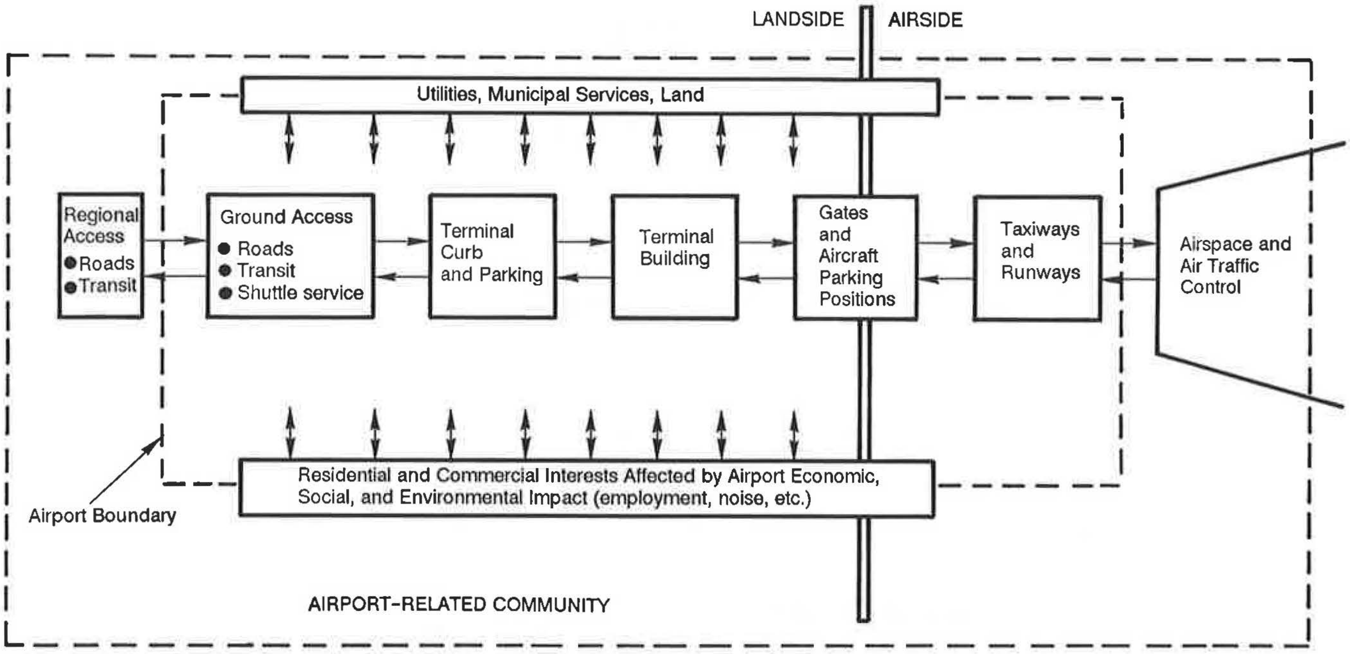

FIGURE 1 Airside and landside: functional view of the airport (*3*).

ports. Further, after extensive review of published reports and personal experience, and despite efforts to assemble field observations and expert opinion, the TRB study committee concluded that available data are inadequate for development of a single set of valid and defensible targets suited to the varied conditions encountered at different airports throughout the United States. Targets for desired or minimally tolerable service levels may be determined case by case, with participation of relevant decision makers at a particular airport; such targets may then become part of the measurement of landside capacity.

Passenger flow through a functional component or group of components is limited in principle by the maximum processing rate at which the component can operate. In practice, however, this maximum throughput is typically sustained for only brief periods of time, because excess passenger demand usually produces significant passenger delays, crowding, or other indications of declining service level that disrupt operations. Capacity is measured by a usually lower *service volume*, the number of passengers who can be accommodated in a given period of time at a given service level, given the pattern of demand placed on the components. Together, service level and service volume represent the "snapshot" view of the airport's landside performance. Whether this performance represents a limit of available capacity depends on the judgments of the various decision makers who are participants in the measurement process, and on the purpose for which the judgment is being made.

Limits are usually encountered only in a part of the airport, and only at particular times of day. Relatively minor changes in staffing practices or facilities utilization may improve service levels and relieve such bottlenecks. Sometimes service levels of components that feed passengers into the bottleneck component may be adjusted to improve the match between demands on these adjacent components and to improve overall service volume. For optimal use of facilities, all components would perform at similar service levels, assuming that such service levels can be defined in a consistent fashion for different types of components; usually, however, there are localized bottlenecks that limit landside capacity. (Determining what is inadequate service is often difficult without reference to specific situations.)

Airport operators may set service-level targets to guide assessment and decision making at their particular airports, taking into consideration the unique combination of passenger demand, airline operations, and community interests they face. Although Canada and some European countries have adopted service-level targets that may be adaptable to some U.S. airports (*4*), substantial research is needed to assemble a suitable database for the range of domestic airports and the airline operations and air travel markets they serve.

CAPACITY ASSESSMENT PROCESS

Measures of landside capacity may be needed to address a variety of airport management, planning, and design problems. The purpose for which a capacity assessment is made will influence the level of detail and focus of the assessment.

In the absence of generally accepted service-level targets, the process for assessing landside capacity must address both service levels and service volumes of landside components (see Figure 2). Passenger demands, as well as

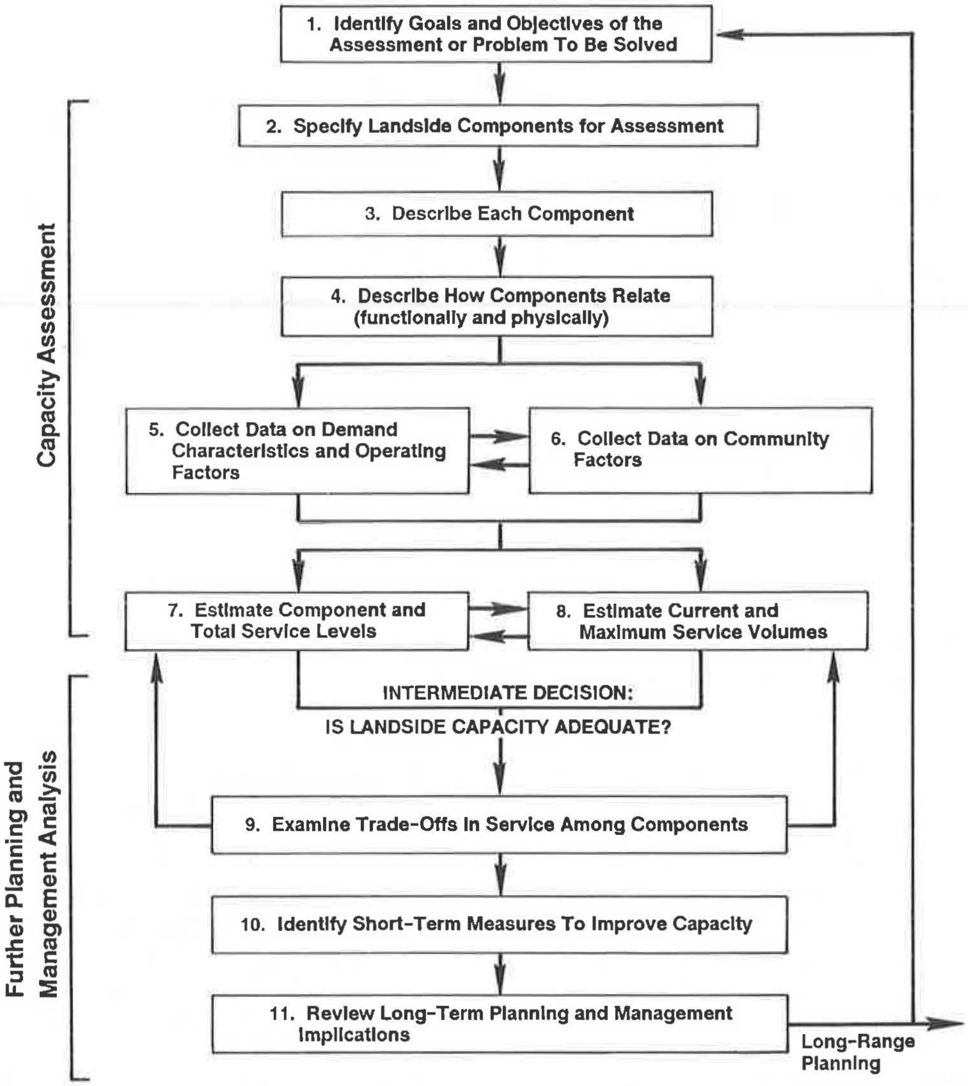

FIGURE 2 **Landside capacity assessment, management, and planning process (*3*).**

relevant airline and airport operating policies and procedures, must be known or assumed. Because service levels and service volumes are interdependent, and because an individual landside component may influence performance of other components and the landside system as a whole, interaction and feedback among steps in the assessment process are critical.

The ability of individual components to accommodate passenger demand is the basis for measuring landside capacity. For an existing or proposed set of facilities and operating characteristics that comprise functional components of the landside, the given patterns of demand determine which individual components may become bottlenecks at particular times of day or for particular parts of the airport. If these patterns of demand remain steady, a bottleneck may represent a limit on total airport activity. However, new demand might still be accommodated at other times or in other parts of the airport.

Assessments of individual components may be used to indicate capacity of the landside system as a whole, by calculating total service volume for the landside system when the capacity-constrained components are operating at their minimally acceptable target service levels. This system capacity measure is much less clearly identifiable than component capacity, however, because shifting the pattern of demand among components can improve service levels and service volumes. Determination of capacity for a group of components involves iteration and feedback to match services levels among the individual components.

All landside components are important to an airport's satisfactory operation, but not all are likely to cause passenger delay and crowding or to become significant in determining the airport's landside capacity. Public telephones, restaurants, restrooms, and newsstands are essential public amenities, yet they are seldom a basis for measuring capacity. The TRB study concentrated on the following components as the most likely focus of most landside capacity assessments:

- aircraft parking positions
- passenger waiting area
- passenger security screening
- terminal circulation (primarily corridors, stairs)
- check-in (ticket counters and baggage check)
- terminal curb
- ground access
- automobile parking area
- baggage claim
- customs and immigration
- passenger transfer (primarily to connecting flights)

Community factors may influence landside performance and capacity and must be considered in the assessment process. In addition to air passengers, the community includes shippers and other airport users, neighboring residences and businesses, and state and local government. Airport management must work with this community, the airlines, and the FAA to operate and develop the airport to meet demand for aviation services.

When the community appreciates the benefits of the airport, its members may support airport management efforts to promote airport development to attract new users and economic investment in the region. If community members perceive that the benefits of meeting aviation demand are outweighed by such concerns as airport-related noise or highway traffic or the amount of land used for airport activities, however, they may seek to restrict airport operations or limit the airport's ability to invest and alter its facilities. The FAA's noise exposure planning procedures have helped to relieve the conflict among community goals that can become a landside limit on capacity at some airports, but continuing unrestrained land development around other airports threatens to lead to future problems.

If the snapshot assessment of landside capacity results in a decision that capacity is inadequate, analysis may continue within a context of ongoing management and planning. The first line of response to apparent capacity limitations is to search for ways to balance service among components or for other short-term solutions to improve capacity. For example, curbside congestion may be relieved temporarily by stricter enforcement of traffic regulations (recognizing that some airport users may view this as a loss of service quality) while changes in management of taxi dispatching and courier service access are implemented.

Serious capacity problems may require more major changes in facilities management or construction. Such actions cannot be accomplished within the short time frame during which capacity assessment is conducted and take the decision makers into the areas of long-term planning and management. Over the longer term, local and national economics, airline management, and interairline competition may produce changes in patterns of demand that seriously alter the airport's landside performance. The process of landside capacity measurement may then be repeated as part of the airport's ongoing management.

TOOLS AND PROCEDURES OF ANALYSIS

While many of the wide range of analytic procedures, mathematical models, and experience-based rules developed for airport planning and design may be adapted for landside capacity assessment, relatively few such tools are tailored specifically to answer questions about service volumes and service levels. Efforts to characterize landside components and their interaction have frequently applied mathematical queuing and network flow theories, leading to often complex, computer-based models. The declining costs of computers and their increasing availability and sophistication seem to be encouraging the development of newer, more easily used models of landside operations, but data requirements are still extensive and expensive.

The landside capacity analyst choosing procedures typically must strike a balance between simplicity, speed, and ease of use, on one hand, and more detailed and accurate representation of the facilities and services of interest on the other. Greater detail usually means greater need for data, more technically trained analysts, and higher costs. Although methods employing greater detail are generally presumed to yield more reliable results, this may not hold true for forecast data, which are inherently uncertain. Analytic tools and procedures are most useful when they help analysts and decision makers to understand better the sources of current problems and the possible consequences of selecting among alternative solutions to these problems.

Many of the analytic tools are applied to a single component within the landside system, and the level of sophistication in available tools varies substantially among the components the TRB study considered. Gate utilization analyses, for example, can be relatively sophisticated if one of the computerized simulation models now available is used. Analyses of curbside operations and airport road access can use procedures adopted from TRB's *Highway Capacity Manual* (*4*) or the Institute of Transportation Engineers. Passenger security screening, on the other hand, is often handled adequately with simple queuing models that are easily calculated by hand. A number of rules of thumb may be adapted from planning guidelines to yield quick estimates of potential landside capacity.

The great deal of interaction among components composing an airport's landside may be poorly reflected in capacity assessment that depends only on analyses of the individual components. To reflect better the landside's complexity, analysts have tried to develop complete simulations of the landside system as a whole. These models require computers and have had only limited success to date, although some government organizations and private consultants use them regularly. The advent of more powerful, microcomputer-based, general purpose simulation languages and spreadsheet accounting packages that are also easier to use may lead to the development of new capacity assessment tools.

RESEARCH AND DEVELOPMENT NEEDED

TRB's *Highway Capacity Manual* was frequently cited in the TRB landside capacity study as the model for airport landside capacity guidelines. However, the TRB study was at best only a first step toward achieving such guidelines. The manual is a result of three decades and millions of dollars of research and development effort. Much remains to be done to produce a similarly effective guide to measuring airport landside capacity.

Current quantitative knowledge about landside operations and service levels is poorly developed. There are few statistics to support comparisons of landside performance among airports. Airline staffing and operating practices are seldom available. Research is needed to fill these knowledge gaps.

The TRB study highlighted four areas in which research could yield valuable results:

- collecting comparable and detailed data on passenger behavior and facilities utilization at a representative cross section of U.S. airports to provide a sound basis for developing service-level measures;
- collecting data on aircraft delay due to landside problems in a format comparable to that of data already collected on airside delays;
- continuing testing, refinement, and documentation of the procedures and measures for landside capacity analysis;
- testing and validating the overall assessment process presented in the TRB study.

The Canadian Airport System Evaluation (CASE) program (*5*) undertaken by Canada's Ministry of Transport and Communications is a model the TRB study concluded could be adapted to U.S. airports, despite differences in the two countries' regulatory and management environments of airports. Recommendations for the assessment process and needed research were made with this model in mind. The TRB study recognized, however, that there are major barriers to establishing a program of airport landside research and to adopting uniform procedures for landside capacity measurement, because no single agency or organization is responsible for the landside aspects of airports in the United States. In the absence of such a central focus of responsibility, the FAA could take the research lead.

CONCLUSION

Establishing common bases for discussion of airport landside capacity and an explicit process for measuring capacity represents a valuable first step toward definitive guidelines for capacity assessment, but much remains to be done. A database is needed to describe in common terms the operating conditions encountered at various airports throughout the United States. The FAA's records on aircraft delays should be expanded to include all flight delays attributable to landside as well as airside causes and other indicators of passenger service level. The database should represent the full range of different airports' travel markets, airline operations, airport sizes, and airport system roles. Such a database is essential for developing generally acceptable service-level targets for landside capacity assessment. If the United States' high-quality air transport system is to be maintained and future demand met, the means to make rational and consistent judgments about airport landside capacity must be developed.

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The author was project director for the airport landside capacity study, conducted in 1986–1987, and this paper is based on experience gained in that study. The views expressed herein, however, are those of the author and may not reflect those of the Airport Landside Capacity Study Committee or the Transportation Research Board.

Level of Service Design Concept for Airport Passenger Terminals: A European View

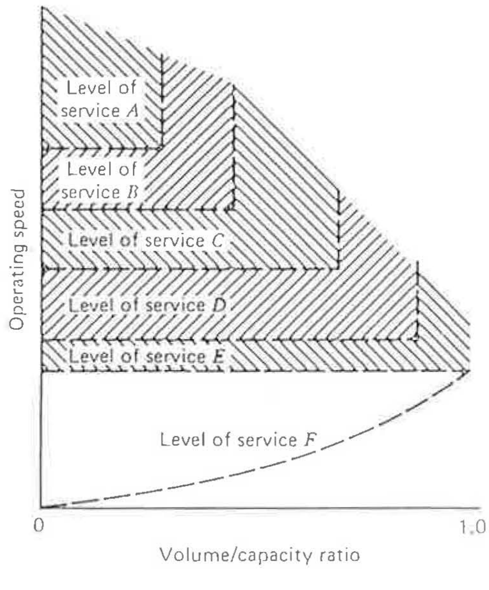
NORMAN ASHFORD

The concept of level of service has been developed by planners and designers to provide some degree of sensitivity in the processes of design and capacity analysis for transport facilities. By designating a number of service levels in lieu of a single capacity figure, a designer is able to evaluate the performance of a facility under the varying load conditions that might reasonably be anticipated in the life of that facility. Level of service analysis provides, to some degree, a measure of the comfort and convenience experienced by system users when the facility is operating at the various possible levels of design and service volumes. Allied with cost, the level of service criterion is a useful input to the design or operation of a transport facility.

The earliest widespread use of the concept of transportation level of service emerged in the area of highway capacity analysis. The earliest forms of highway capacity analysis defined capacity in three ways. *Basic capacity* was the maximum number of passenger cars that could pass a given point on a roadway in one hour under ideal road and traffic conditions. *Possible capacity* was defined as the maximum number of vehicles that could pass a given point during one hour under prevailing road and traffic conditions. *Practical capacity* was the maximum number of vehicles that could pass a given point without the traffic density being so great as to cause unreasonable delay, hazard, or restriction to the driver's freedom to maneuver under prevailing road conditions (*1*). These definitions were irritatingly vague, and highway engineers were unable to judge the effect of operating significantly above or below what had been designated as the practical capacity of a facility.

To provide better sensitivity in the processes of highway design and capacity analysis, the concept of level of service was introduced in 1965 (*2*). Figure 1 shows the now familiar, six-service-level diagram that defines the basic relationship between speed, volume/capacity ratio, and level of service. Using a methodology based on this concept, the *Highway Capacity Manual* described a series of techniques that could be used to determine the levels of service provided by a range of facility types (rural roads, freeways, city streets, etc.) under varying traffic mixes and traffic loads. The original 1965 manual has recently been updated (*3*) to conform with more recent experience and improved data, but the basic concept remains essentially unchanged. The modern *Highway Capacity Manual* enables the highway engineer to evaluate how altering traffic throughput affects the level of service provided by a highway facility and permits the determination of the "capacity" of a facility in terms of a design service volume.

The considerable improvement of the 1965 *Highway Capacity Manual* over its predecessor led Fruin to apply a similar methodology to the design of pedestrian spaces (*4*). In this work, it was stated that the dimensional design of pedestrian spaces involves the application of traffic engineering principles and the consideration of human convenience and the design environment. Fruin further noted that the maximum capacity of a pedestrian traffic stream is attained only when there is dense crowding of pedes-



(Courtesy Transportation Research Board.)

FIGURE 1 General concept of relationship of level of service to operating speed and volume/capacity ratio (not to scale).

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trians. It was noted that such crowding results in significant reductions in pedestrian convenience, as normal human walking speeds are restricted by a lack of freedom to maneuver in the traffic stream. Since convenience is a primary consideration in the environmental design process, Fruin suggested that pedestrian design standards should be based on a scale related to convenience. Using the six-level structure originally developed by the highway engineers, a set of walking design standards was proposed based on the relationship between pedestrian flow and the area provided per pedestrian. This relationship is shown in Figure 2. This work also provided guidelines for service standards for stairways and queues. Table 1 summarizes these findings.

The highway capacity work was based on many thousands of hours of traffic observations. The conclusion drawn was that level of service could be viewed as dependent on ease of flow and freedom of movement. The criteria on which these could be evaluated were:

1. ability of individual drivers to choose their own speed;
2. ability to overtake; and
3. ability to maneuver in the traffic stream.

Fruin's work was based not only on many observations in the terminals of the Port Authority of New York but also on anthropometry and ergonomics. For pedestrian flow, the level of service was also viewed as being dependent on the ease of flow and freedom of movement. The criteria by which these were evaluated were rather similar to those used in highway capacity analysis:

1. ability of an individual to choose walking speed;
2. ability to overtake; and
3. ease of cross- and reverse-flow movement.

Success with applying the level of service concept to vehicle and pedestrian facilities has generated considerable

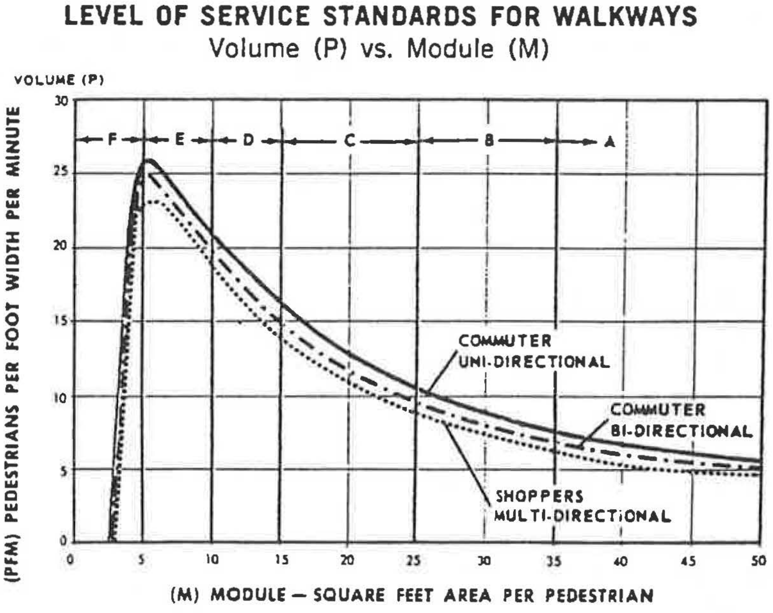

FIGURE 2 Pedestrian flow levels of service (*4*).

TABLE 1 SUMMARY OF PEDESTRIAN SPACE STANDARDS (SQUARE FEET PER PERSON) (*4*)

	Level of Service					
	A	B	C	D	E	F
Walkways	35 or greater	25 - 35	15 - 25	10 - 15	5 - 10	5 or less
Stairways	20 or greater	15 - 20	10 - 15	7 - 10	4 - 7	4 or less
Queues	13	10 - 13	7 - 10	3 - 7	2 - 3	2 or less

interest in the application of a somewhat similar methodology to terminal facilities. Evaluation and selection of terminal designs have been problems for a number of years, and no generally agreed-on procedure has evolved. Some evaluation methods concentrate on optimizing a single parameter. Simple cost-benefit analysis that ignores externalities would come into this category. Some authors have concentrated on optimizing nonmonetary parameters; passenger orientation is regarded by some as the major functional requirement of a transportation terminal (*5*). Partial solutions to design evaluation have been recommended on a basis of functional adjacencies (*6, 7*). These and other techniques, including planning balance sheets (*8*), decision effects matrices as used for the Atlanta Hartsfield design, matrix evaluation sheets (Baltimore Washington International), and the Emphasis Curve Technique (Hong Kong Airport), deal mainly with overall design evaluations. Designers and operators, however, frequently require an evaluation technique that provides information on the suitability of individual facilities or chains of individual facilities within a system. Level of service analysis, analogous to that used in highway engineering, would seem an excellent method of providing such a measure.

Determining the level of service provided by an airport terminal is not a straightforward process. A terminal must provide space for three different classes of passenger activity: processing, holding, and circulation/mode transfer.

- processing: check-in, bag drop, immigration, customs, security, baggage claim;
- holding: departure concourse, departure lounge, gate lounge, transit lounge, arrivals concourse; and
- circulation and mode transfer: drop off/pick up, corridors, airside interface (*9*).

It is clear that each of these three functional areas is likely to require different techniques for evaluating level of service.

Processing normally requires some form of queuing. Fruin's work dealt with queues, but it is not clear that the individuals observed using the Port Authority of New York terminals are similar to airport passengers. The acceptability of a queue is, according to Fruin, determined by space provided. It is more likely that the queue process is more truly evaluated by the air passenger in terms of time spent in the queue, although there may be an interaction effect in terms of space provision.

Holding areas are normally evaluated in terms of space provided per passenger, but here again it is likely that any perception of service level should consider space and time interactively. For example, it is entirely possible that passengers would evaluate space provision differently in a

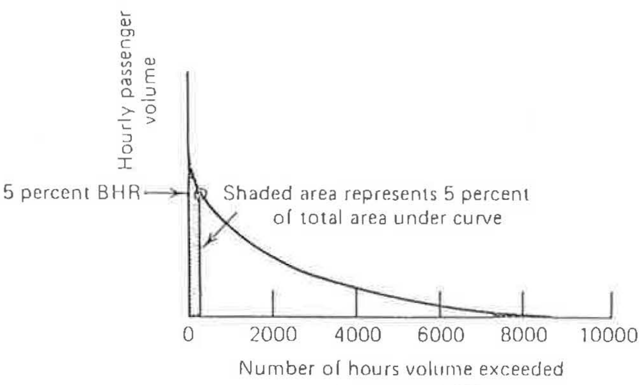

FIGURE 4 Location of 5 percent busy hour rate (*10*).

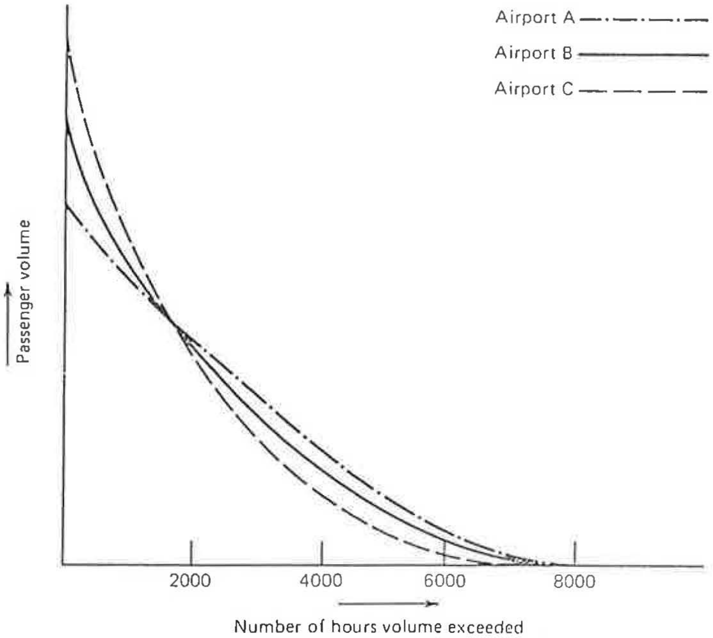

FIGURE 3 Variation of passenger volume distribution curves for airports with different traffic (*10*).

main departure lounge, where waits of about an hour are anticipated, from the way they would evaluate it in a forward gate area, where much shorter waiting periods are normal.

Circulation areas in airports are not really functionally different from circulation areas in the type of terminal that formed the basis of Fruin's investigations. It is likely, therefore, that his approach can be used for airport terminals. The validity of applying his results directly to airport terminals is questionable, however, because the mix of passengers (age range) and degree of encumbrance with hand luggage and baggage trolleys (if available) are quite different.

Like most transport facilities, airport terminals suffer from the problem of having to cope with very large variations in passenger flow. Unlike railway and urban rapid transit stations, this variation is seasonal as well as daily. It is also important to remember that when considering airport terminals, the nature of traffic is important to traffic peaking characteristics. In North America the predominance of domestic air traffic is quite different from the situation in Europe, where traffic is mainly international, and a large proportion of it of a leisure nature. It has been pointed out elsewhere (*10*) that the form of the passenger volume distribution curve differs between airports carrying different forms of air traffic. For example, more than half the total annual passenger movements at Almeria Airport in southern Spain occurs in a two-month vacation period during the summer; this degree of peaking is unknown in the typical North American context. Figure 3 indicates how the normalized shape of the volume curve could be expected to differ among various airport functional types:

TABLE 2 ANNUAL, PEAK, AND SBR FLOW RATES FOR LARNACA AIRPORT, CYPRUS

Year	1981	1981	1983	1984
Annual passenger volume	1.053m	1.222m	1.363m	1.530m
SBR	796	677	905	929
Peak	981	904	1442	1226
Peak SBR ratio	1.23	1.34	1.59	1.32

- Airport A: a high-volume airport with a large amount of short-haul domestic traffic (a typical U.S. hub);
- Airport B: a medium-volume airport with balanced international-domestic traffic and balanced short-, medium-, and long-haul operations (a typical North European hub); and
- Airport C: a medium-volume airport with a high proportion of international traffic concentrated in a vacation season (a typical Mediterranean airport serving a resort area).

Airport C carries a much higher proportion of its traffic during peak periods; therefore, its graph has a leftward skew in comparison to that for Airport B. A high-volume domestic airport hub, however, carries an even greater

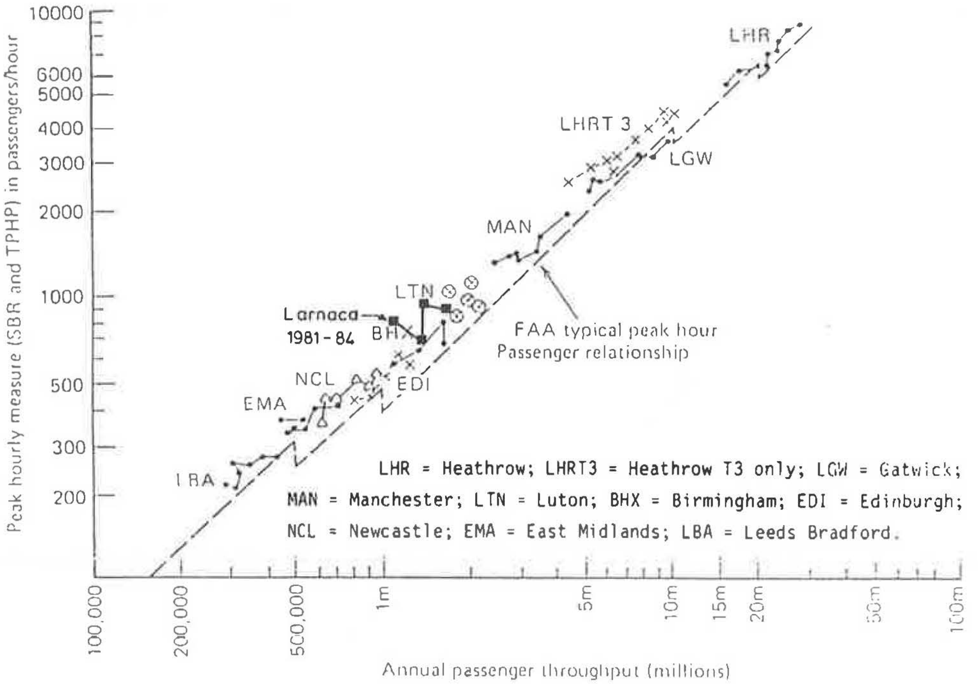

FIGURE 5 Relationship between standard busy rate, typical peak-hour passenger volume, and annual passenger volume for selected airports (Sources: Civil Aviation Authority and Federal Aviation Administration).

volume over the entire year, decreasing the leftward skew to give the flatter graph form shown for Airport A.

Because designers in general do not have the resources to design for the absolute peak flow, it is customary to choose a design criterion that will accommodate the actual peak without serious overload. In selecting such a measure, airport designers have in the past tended to fall back on the standard highway engineering practice of designing for the thirtieth highest hour. In airport practice this is called the standard busy rate (SBR), and its location on the passenger volume distribution curve is shown in Figure 4. American practice differs from this approach by using averaged conditions, such as the peak hour of the average day of the peak month. Experience has shown that, by allowing volume overload for a limited number of hours, an acceptable service level can be provided to passengers. Various European authorities favor different standards. Schiphol Airport Amsterdam uses the twentieth highest hour, while Aéroports de Paris prefers the fortieth highest hour. Until the early 1970s, the British Airports Authority (BAA) adopted the thirtieth highest hour as its design standard. Subsequent experience has led them to use the 5 percent busy hour rate (BHR), which means that 5 percent of the total annual passenger traffic operates at volumes in excess of the total design level. The location of the 5 percent busy hour rate is shown in Figure 4. In practice there is little difference between these measures. Table 2 shows the relationship between SBR and peak flows for Larnaca Airport, Cyprus, for the years 1981–1984. The Larnaca figures are also shown in conjunction with SBR annual volume relationships plotted for a number of British airports (both BAA and non-BAA) in Figure 5. As could be anticipated from the vacation traffic orientation of the Larnaca traffic, the SBR/annual traffic ratio for this Mediterranean airport exceeds the less peaky British airport figure and considerably exceeds the peak-hour passenger estimates using FAA guidelines, which are also indicated in Figure 5.

There is no standard method of dealing with a design passenger volume in terms of levels of service or design

TABLE 3 SELECTED BAA AND IATA DESIGN AND SERVICE STANDARDS—DEPARTURES

Facility	BAA Standards		IATA Standards	
	Space Standard	Time Standard	Space Standard	Time Standard
Check-in Baggage Drop	0.8m^2 per pass. with hold baggage 0.6m^2 per pass. with cabin baggage	95% of pass. < 3 min.	0.8m^2 per pass. with baggage 0.6m^2 for visitors	95% of pass. <3 min; at peak times 80% < 5 min.
Departure Concourse	1.0m^2 per seated person 1.0m^2 per standing person. Seating for 10% of those present	None	None	None
Departure Passport Control	0.6m^2 per pass. without hold baggage. 0.8m^2 per pass. with hold baggage	95% of pass. < 1 min.	0.6m^2 per pass. without hold baggage. 0.8m^2 per pass. with hold baggage	95% of pass. < 1 min.
Central Security	0.6m^2 per pass. without hold baggage	95% of pass. < 3 min.		95% of pass. < 3 min; for high security flights. 80% < 8 min.
Departure Lounge	1.0m^2 per seated pass. 1.0m^2 per standing pass. Seating for 60% present.	None	1.0 - 1.5m^2 per seated pass. 1.2m^2 per standing pass, with trolley. 1.0m^2 per standing pass. Seating for 50% of throughput.	
Gate Lounge	1.0m^2 per seated pass. 1.0m^2 per standing pass. Seating for 60% of those present.	None	0.6m^2 for queueing pass. without hold baggage. 0.8m^2 for queueing pass. with hold baggage 1.0m^2 per pass. within gate lounge	80% should queue less than 5 min. for gate check-in.

service volumes, as is now well established in the sphere of highway engineering. Although airport operators and designers individually have a clear idea of what acceptable service levels are, these are not universally agreed on within the airport community; nor is the design service level set within a range of service levels, as has been shown to occur in highway design. Service levels are currently set simply in terms of standards that the authority attempts to meet either in terms of design (space standards) or in terms of operation (time standards). In a number of facilities, standards are set in terms of both time and space, but the interaction of time and space has never been examined.

In 1982, the BAA/International Air Transport Association (IATA) study group examined BAA standards in comparison with those of IATA at that time. Some of these comparisons are contained in Tables 3 and 4, which show design standards for departing and arriving passengers, respectively. In general the BAA adds additional space for circulation. Notwithstanding the waiting time standards that the BAA attempts to provide, it is recognized that during peak periods delays considerably greater than the standards are observed. The delays cause considerable queuing, which can cause extreme overcrowding. Therefore the BAA has recently modified its design standards to

TABLE 5 TIME-RELATED SPACE STANDARDS (BAA)

Facility	Space to be provided for waiting time up to
Check-in	10 min.
Passenger search	5 min.
Passport control	1 min.
Immigration:	
UK/EEC	12 min.
Others	30 min.

TABLE 4 SELECTED BAA AND IATA DESIGN SERVICE STANDARDS—ARRIVALS

FACILITY	BAA Standards*		IATA Standards	
	Space standards	Time standards	Space standards	Time standards
Immigration	0.6m^2 per pass.	UK/EEC 95% < 4 min. Others 95% < 12 min.	0.6m^2 per pass.	95% of all pass. < 12 min. 80% of nationals < 5 min.
Baggage reclaim	1.25m^2/domestic passenger. 2.0m^2 per short haul international passenger, 3.25m^2 per long haul passenger	Max of 25 min. from first pass. out of immigration to last bag on unit	0.8m^2 per domestic and short haul international pass. 1.6m^2 for long haul passenger	Max of 25 min. from first pass. in hall to last bag from unit. 90% of pass. wait < 20 min. for baggage
Customs	None	None	2.0m^2 per pass. interviewed	None
Arrivals Concourse	1.0m^2 per standing person; 0.8m^2 per seated person. Seating for 20% of people present	None	0.6m^2 per standing meeter; 1.0m^2 per seated meeter. 0.8m^2 per short haul pass, 1.6m^2 per long haul pass.	None

*** Additional Standards**

Forecourts: 95% chance of finding space

Piers: Walking distances: < 250m unaided
< 650m with walkway (of which 200m unaided)
Rapid transit for point-to-point journeys over 500m

Pier service: Loading bridges for at least 75% of passengers.

TABLE 6 SCHIPHOL AIRPORT DESIGN STANDARDS

SPACE STANDARDS

Waiting Lounges	$1 m^2$ per passenger for the expected number of departing passengers taken over the average of the 20 highest peak hours. Provision of seating for 30 per cent of these passengers.
Gate Lounges	$1 m^2$ per passenger based on the capacity of the largest aircraft to be handled at that gate. Provision of seating for 50 per cent of these passengers.

HANDLING TIME STANDARDS

Overall handling time	< 30 minutes
Check-in	< 5 minutes
Passport control (departure)	< 5 minutes
Passport control (arrival)	< 5 minutes
Baggage claim waiting time (narrow body)	< 15 minutes
Baggage claim waiting time (wide body)	< 20 minutes
Embarking/disembarking passengers from aircraft	< 15 minutes

provide space standards that are related to waiting times. These are shown in Table 5. Broadly, this comes to 25 percent for concourses at departure lounges and 20 percent for gate rooms. The BAA design standards are such that under design conditions 95 percent of passengers receive the desired level of service. For comparative purposes, the design standards for the Schiphol Airport Authority are shown in Tables 6 and 7. From an examination of Tables 3 through 6, it can be seen that the current approach to design is to set a space standard in conjunction with operational standards where necessary, rather than to use any quantification of the variation of level of service with the various throughputs.

In a paper presented to the then-extant Western European Airports Association, the results of a survey of operating criteria of 20 west European airports were summarized (*11*). The range of space provisions is shown in Table 8.

A more comprehensive level of service approach was suggested in 1979 in Canada (*12*). This method, which has subsequently been proposed by IATA as a method of determining airport passenger terminal service levels, relies on setting different levels of space provision with respect to six levels of service, A to F, as shown in Table 9 (*13*). Unfortunately, the linearity of the relationships between space provision and service level suggests that the values provided by this table may not correspond with level of service as perceived by airport users.

It was reservations such as these that led to the proposal of a perception response model for approaching level of service analysis (*14*). This work attempted to tie the passengers' perception of level of service to the time spent in various processes. A three-category level of service structure was proposed: A, good; B, tolerable; and C, bad. Initially, passengers were asked to indicate their perception of service level on a more refined, six-level scale, but the results indicated that the respondents were confused. The method used in the perception response model was quite simple. As passengers proceeded through the various airport processing points on both arrival and departure, they

TABLE 7 AEROPORTS DE PARIS DESIGN STANDARDS

	Space Standard	Time Standard
DEPARTURE		
Check-in	30m^2 per check-in unit 10m min. dimension in front of desk.	80 per cent of passengers queue < 15 minutes.
Departure concourse	3.0m^2 per passenger with luggage 1.5m^2 per passenger without luggage 1.0m^2 per greeter No seating provision	
Departure passport control	20m^2 per check point unit	80 per cent of passengers queue < 15 minutes.
Central security		80 per cent of passengers queue < 15 minutes. Average processing time 7 passengers per minute.
Terminal departure lounge	1.5m^2 per seated passenger 1.0m^2 per standing passenger Seating for between 50 and 75 per cent of people present 20 per cent of area for circulation.	
Departure coach-gate	1.5m^2 per seated passenger 1.0m^2 per standing passenger 50 per cent of passengers seated.	
Gate lounge	0.6m^2 per queueing passenger	80 per cent of passengers queue < 5 min.
ARRIVAL		
Immigration	0.6m^2 per passenger	95 per cent of passengers queue < 12 minutes.
Baggage reclaim units	Reclaim frontage of 1.0m for every 5 passengers Length of 60m for B747 sized a/c Length of 45m for A300 sized a/c Length of 30m for B727 sized a/c.	Max. of 25 minutes between arrival of first passenger in hall and reclaim of last bag from unit
Baggage reclaim	Space set by dimensions of reclaim units as above, with 8m min. between units and 4m min. between unit and wall.	
Customs	1m per passenger along searching bench.	
Arrivals concourse	As for departure concourse above.	

TABLE 8 SPACE PROVISIONS IN WAITING AREAS (*11*)

Area per seated passenger	1.0 - 1.5m^2
Area per standing passenger	1.0m^2
Average seating provided as a per cent of occupation at capacity:	
landside concourse - departures	30 - 50%
- arrivals	20%**
airside - departure lounge	40 - 80%***
- gate holding areas	50 - 80%

*** Higher end of range applies where there is high transfer traffic (e.g. Kastrup and Frankfurt)

** In predominantly domestic traffic airports (e.g. Hamburg) short dwell times require only 5% seating.

* Reported ranges from survey of twenty west European airports (1976).

TABLE 9 AIR TERMINAL BUILDING SPACE STANDARDS (SQUARE METERS PER OCCUPANT)

Level of Service:	A	B	C	D	E	F
Check-In	1.6	1.4	1.2	1.0	.8	
Wait/Circulate	2.7	2.3	1.9	1.5	1.0	
Holdroom	1.4	1.2	1.0	.8	.6	
Bag Claim Area (Without Device)	1.6	1.4	1.2	1.0	.8	
Pre-PIL	1.4	1.2	1.0	.8	.6	

Level of Service	**Description**
A	Excellent level of service; condition of free flow; no delays; direct routes; excellent level of comfort.
B	High level of service; condition of stable flow; high level of comfort.
C	Good level of service; condition of stable flow; provides acceptable throughput; related subsystems in balance.
D	Adequate level of service; condition of unstable flow; delays for passengers; condition acceptable for short periods of time.
E	Unaccaptable level of service; condition of unstable flow; subsystems not in balance; represents limiting capacity of the system.
F	System breakdown; unacceptable congestion and delays.

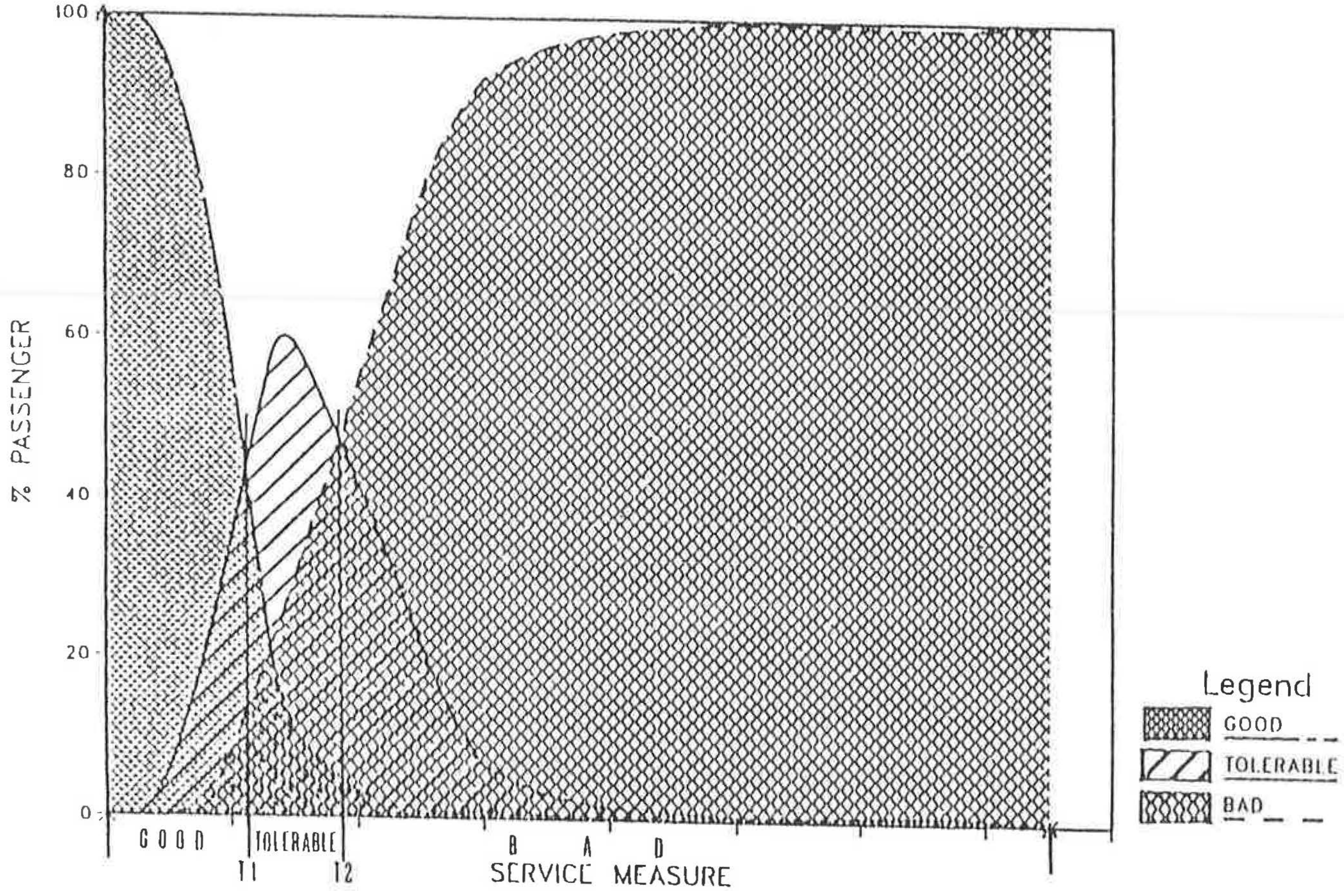

FIGURE 6 Concept of perception response model (*14*).

TABLE 10 LEVEL OF SERVICE OF PROCESSING TIMES (MINUTES) FOR BIRMINGHAM INTERNATIONAL AIRPORT, GREAT BRITAIN (*14*)

	Level of Service - A (GOOD)	Level of Service - B (TOLERABLE)	Level of Service - C (BAD)
Check In			
Charter	< 11	11 - 21	> 21
Scheduled - Long Haul	< 15	15 - 25	> 25
Scheduled - European	< 7.5	7.5 - 14	> 14
Security Check	< 6.5	6.5 - 10.5	> 10.5
Passport Control (outbound)	< 6.5	6.5 - 10.5	> 10.5
Immigration (inbound)	< 6.5	6.5 - 14.5	> 14.5
Baggage Claim	< 12.5	12.5 - 22.5	> 22.5
Customs Control	< 6.5	6.5 - 11.5	> 11.5

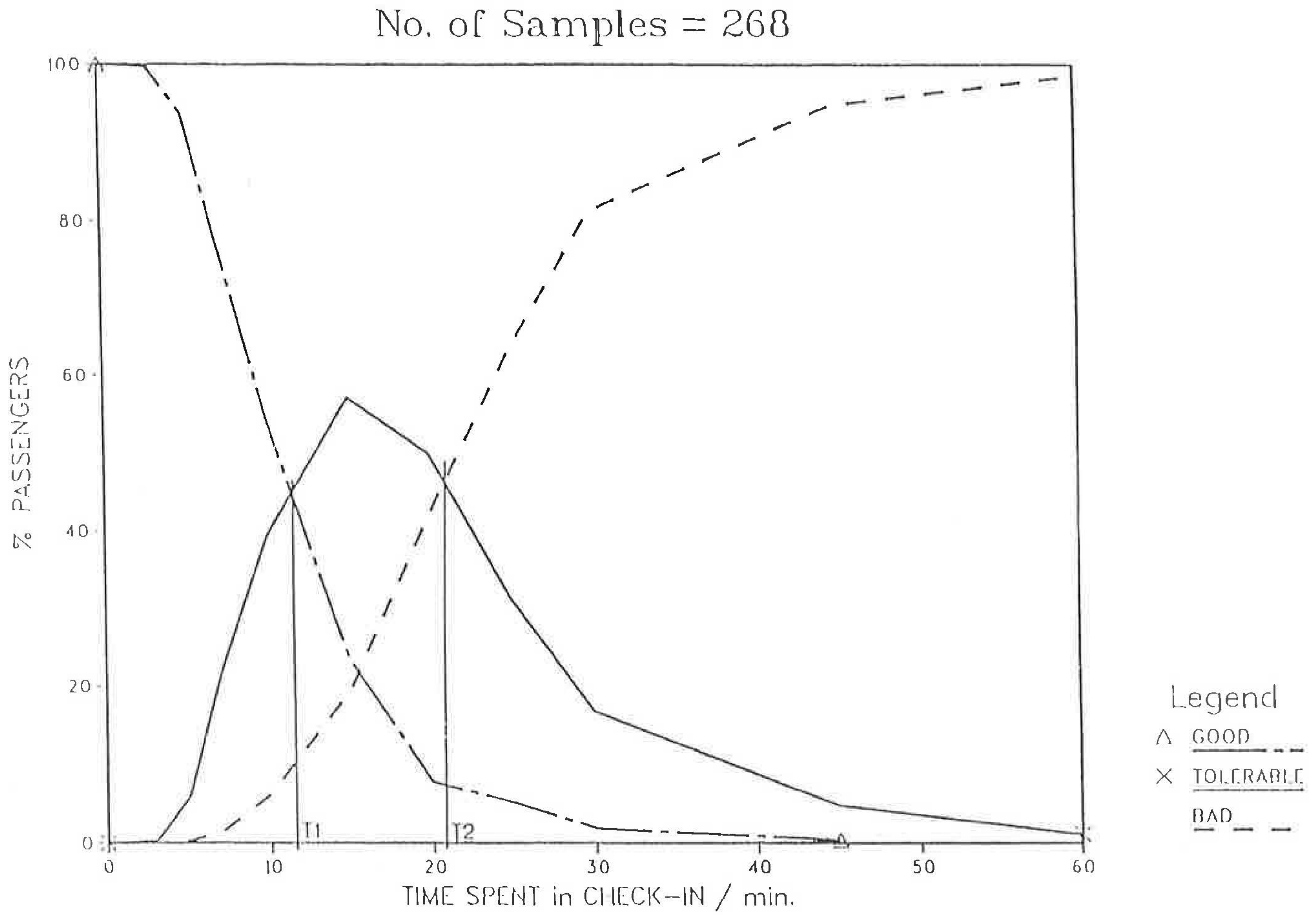

FIGURE 7 P-R model for charter I.T. check-in (Birmingham International Airport) (*14*).

were asked to rate the service as good, tolerable, or bad. The response rate for each type of answer was plotted against the time spent in each facility. Conceptually, it was expected that the responses would form a diagram of the shape shown in Figure 6. For short processing times, the number of "good" responses would be high and both "tolerable" and "poor" would have a low response rate. As processing time increased, the number of "good" responses would fall, the number of "tolerable" responses would peak, and the number of "bad" responses would grow.

Level of service A, or *good*, is defined as those times for which the "good" curve exceeds the "tolerable." Level of service C, or *bad*, is defined as those processing times for which the number of "bad" responses exceeds the number of "tolerable" ones. Level of service B, or *tolerable*, falls between these two limits. This model was calibrated at Birmingham, Manchester, and East Midlands airports in the United Kingdom. Table 10 summarizes the findings for Birmingham Airport, and Figures 7 and 8 show the observed forms of two of the curves that led to results for charter and scheduled long-haul check-in in the table.

The method described by Mumayiz and Ashford (*14*) also indicated a way of defining facility capacity on the basis of delay experience in the process. This was done by modeling processing time versus flow using the SLAM simulation program. Figure 9 shows that if capacity is defined as occurring at that point where levels of service A and B are contingent, then for inward immigration this amounts to 6.5 minutes (from Table 10), yielding a facility capacity of approximately 400 passengers per hour.

At the moment, the perception response model must be considered only prototypical, requiring considerable development before it can be applied widely to level of service analysis. The work, which was carried out by the University of Technology at Loughborough, is deficient in a number of areas:

1. The findings were obtained from a relatively small sample of respondents. For greater certainty of the validity of the values found in Table 10, a considerably larger survey would be necessary.
2. As carried out, that is, at one airport, there was no possibility of investigating any interaction between space

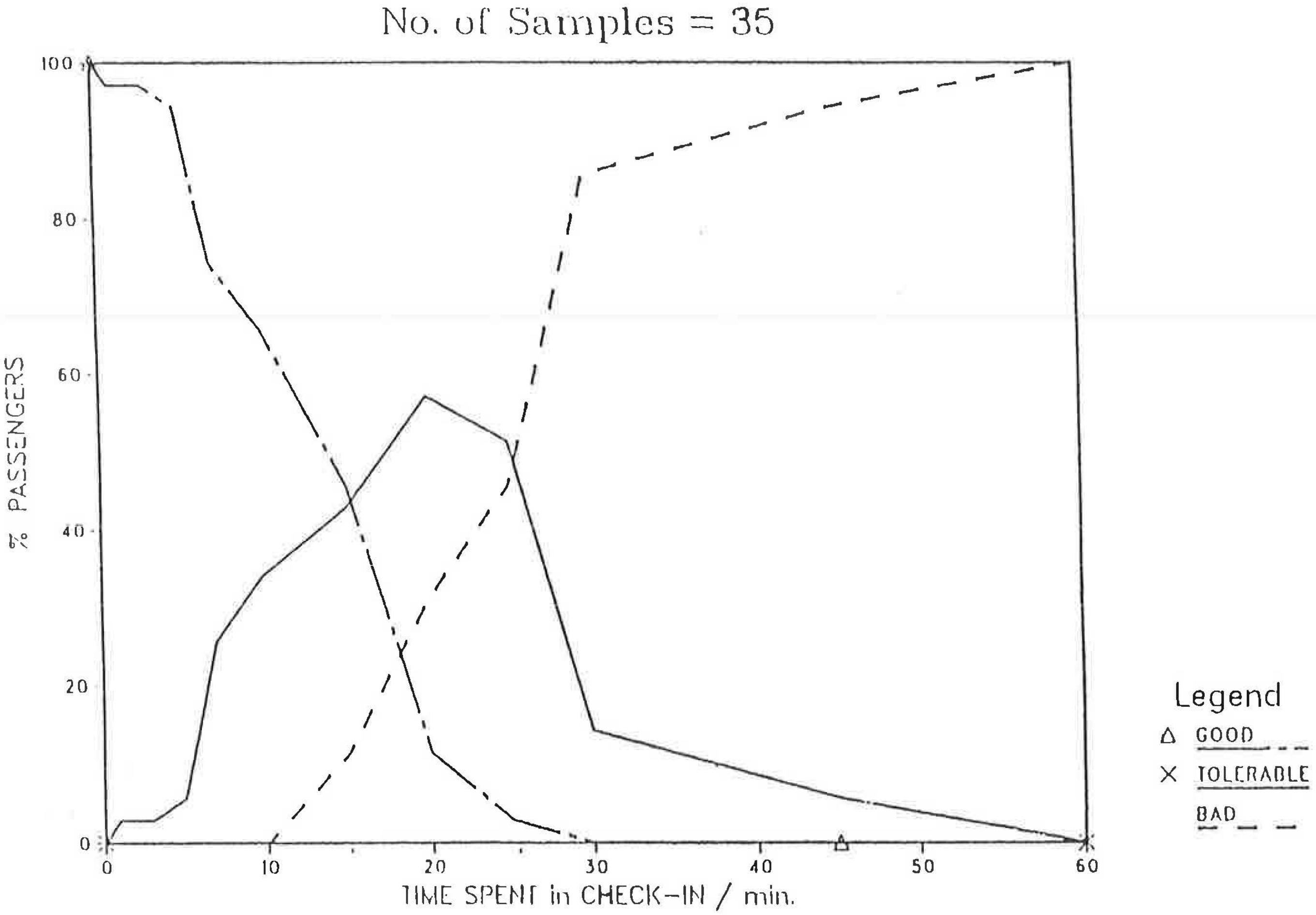

FIGURE 8 P-R model for scheduled long-haul check-in (Birmingham International Airport) (*14*).

provision and time spent in the process. In fact, both may affect a passenger's perception of service level, and there may well be a strong interaction between the two variables. The most effective way of determining this would be by conducting passenger perception surveys at a number of airports. If performed internationally, the surveys would indicate the transferability of results from country to country. (There is no reason to assume that perceived level of service standards are necessarily the same in developed and developing countries or across other cultural differences.)

3. As currently applied, the method has supplied criteria only for airport processing areas. The same methodology could well be applied to holding areas.

Properly developed, the perception response graph for both holding areas and processing facilities is likely to be a three-dimensional response surface, as indicated in Figure 10, with two principal independent variables—space provision and time.

CONCLUSIONS

In comparison with the status of level of service analysis in highway engineering, in airport design it is in a rudimentary state of development. Level of service standards have been set, but these are essentially straightforward design and operational criteria that provide no indication of sensitivity to overload conditions. To produce more comprehensive level of service standards, an industrywide approach to data gathering will be necessary to enable cross comparisons of design and operational standards across a large range of airports. Especially in Europe, where airports see themselves as in competition with one another, such an effort is clearly beyond the capability of any single airport or airport authority. Yet individual airports and airport authorities have a vital role to play in developing a more sophisticated level of service analysis. Most airports that have set performance standards (such as queuing time, bag delivery time, and the like) have some form of performance monitoring procedures. If pooled and linked to

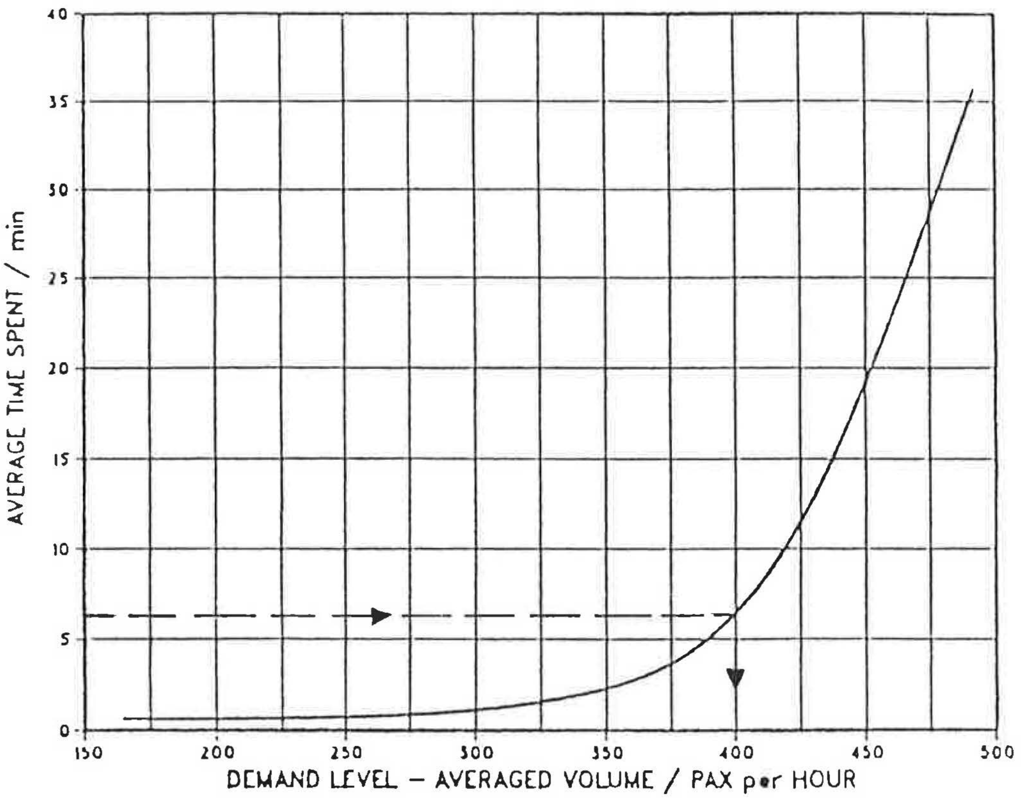

FIGURE 9 Computing capacity from the delay/volume curve (*14*).

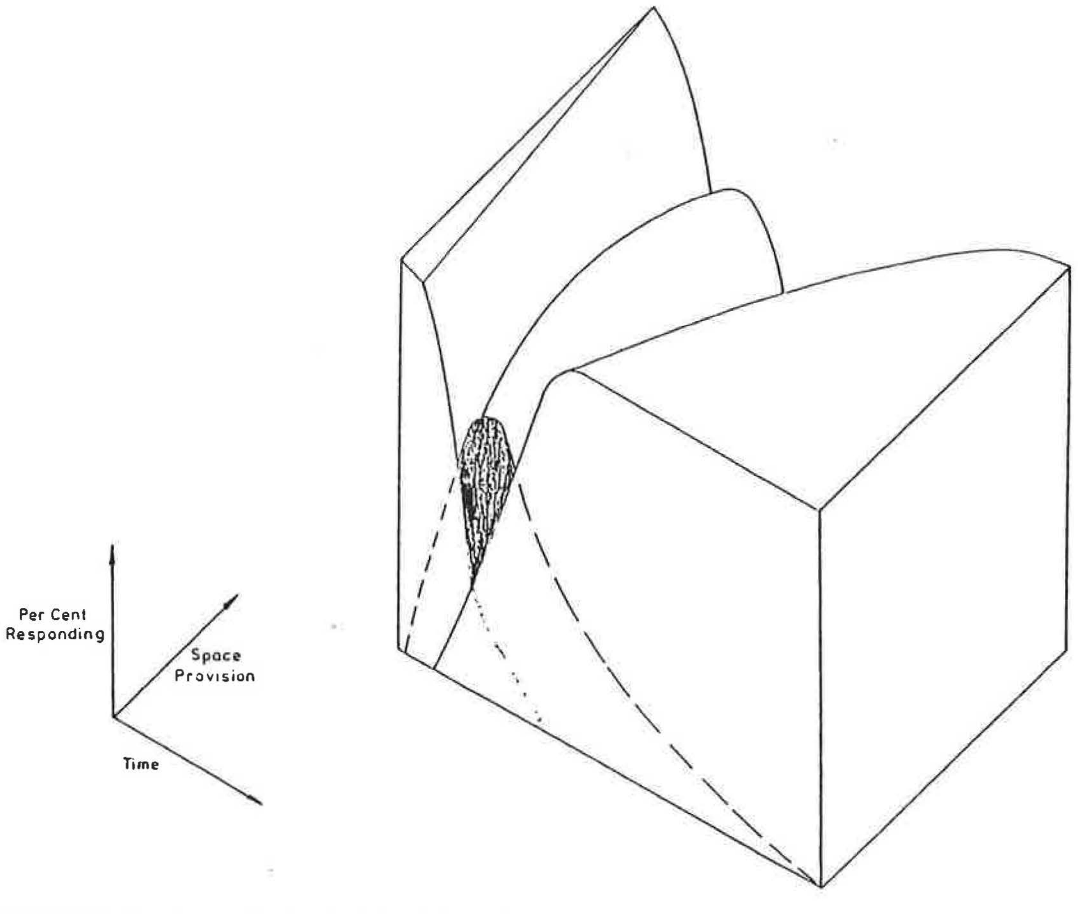

FIGURE 10 Isometric sketch of level of service concept.

passenger perception of service, these procedures can form the basis of a much more comprehensive level of service construct developed on both national and international data. It would be extremely helpful if one of the international bodies, such as IATA or ICAA, could be induced to back a research program into terminal design standards. Without this, the present rather unsatisfactory status quo is likely to continue indefinitely.

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Airport Landside Level of Service Estimation: Utility Theoretic Approach

K. F. OMER AND A. M. KHAN

The need for research on level of service criteria and standards for the design and evaluation of existing or proposed new landside facilities arises from the requirement that they reflect technical developments, enhanced knowledge of user preference and behavior, the need to increase the efficiency and cost-effectiveness of the airport system, and the uncertainties of air travel demand. In air transportation, by and large, reliance has been placed on arbitrary standards with hidden assumptions. This paper reports recent research on the interrelationship between space/service standards, user perceived value or utility of level of service, and cost. A framework is described for the study of level of service, based on the principles of utility and cost-effectiveness theories. Criteria for design and evaluation of landside facilities are discussed, and recommendations for further research are made.

Airport landside level of service and capacity have been topics of research interest over the past two decades or so (*1*, *2*). More recently, owing to the critical nature of airport level of service issues, a number of studies have been initiated on the identification of the landside problem in general, and on capacity and service measures in particular. Some progress has been made in terms of defining service levels, based on degree of crowding and delays and so forth. A joint Federal Aviation Administration (FAA)/Transportation Research Board (TRB) study, published recently, serves as a background document on the various facets of the problem as well as international practices and standards (*3*). More research is needed, however, to define level of service gradations and capacity standards (*4*, *5*).

A high priority placed on landside research is hardly surprising, given the critical need for innovative research on this topic. A number of agencies, which have established criteria and standards for the design of airport landside facilities, have come to realize that, by and large, reliance has been placed on design criteria that are limited in terms of accounting for the demand as well as the supply side concerns. It is now believed that design standards developed in the past were largely arbitrary, with hidden assumptions. Consequently, oversized facilities have been provided at a number of airports. Also, because of insufficient attention paid to strategic planning, inadequate understanding of user value structure, absence of studies on the cost-effectiveness of level of service, and lack of flexibility to adapt to changing traffic conditions, imbalances of demand and capacity have become apparent at some busy airports.

The objectives of the research reported here are twofold. First, it is intended that the importance of the interrelationship between the level of service and the cost (to users as well as suppliers) of facilities be highlighted, thus making a case for enhanced knowledge of measures for the design and assessment of airport landside facilities. Second, it is also intended that a framework be developed for estimating the utility (value in use) and cost-effectiveness of levels of service, based on the principles of utility (value) and cost-effectiveness theories.

In this research, application of utility and cost-effectiveness theories is illustrated for measuring user-perceived levels of service and for establishing economical design criteria. In contrast with previous approaches, airport terminal users are not asked to distinguish, directly, in the form of a single question, between various gradations of service quality consisting of multiattributes. Instead, through the use of the attitudinal survey technique, users are asked to indicate the relative importance of level of service factors (e.g., waiting time, processing time, space availability) and to rate each level of service attribute/factor through a semantic scaling method. In accordance with utility theory, the weighted rates are transformed to a relative value scale and then combined into a utility measure. From these utility values, level of service offered by a facility under prevailing conditions is inferred.

Through the investigation of a facility under various levels of usage and the correlation of user-perceived service quality (i.e., value in use or utility) with objectively measured performance indicators, space and service (e.g., time spent in a subsystem) thresholds can be defined. Also, through use of the principles of cost-effectiveness, the economics of providing various levels of service can be established. In this paper, following a discussion of the level of service issues and framework, the utility theoretic approach to level of service estimation and cost-effectiveness of level of service (and resulting facility size/designs) are covered.

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LEVEL OF SERVICE ISSUES

Historically, airport facilities have been planned and investment decisions made without much assistance from scientific research in refining design criteria and standards. The transportation profession is very familiar with the amount of research that went into the highway capacity area, which recently produced a third-generation capacity manual. Consequently, it is hardly surprising that in recent years, airports, more than any other type of transportation facility, have been criticized—in some cases, as examples of wasted resources and, in others, as a focal point of user discontent with the level of service. Indeed, the imbalance between demand and capacity at key components of airport terminals is a common occurrence.

There is apparently a genuine lack of knowledge about user acceptance of conditions at airports, as well as about the cost implications of providing various levels of service. Furthermore, the airport planning profession has not yet standardized its gradations of levels of service in the manner that the highway planning profession has done since 1965. The absence of an appropriate definition of level of service ranges and guidelines for design and evaluation criteria and standards has hindered efficiency in airport planning and operations (*6*).

Recent reviews of airport planning and investments in Canada have concluded that, in general, the level of service and unit cost of providing that service at airport systems are excessive. It was stated that a significant reduction in level of service could be achieved with minimum impacts on the air traveling public and the air carrier industry (*7*). Experience gained from Pearson (Toronto) and Dorval (Montreal) airports was quoted as evidence to suggest that some additional crowding does not lead airlines and passengers to curtail their use of airports (*8*).

While the aforementioned reviews give the impression of past oversupply of airport facilities, there are also cases where a number of interest groups are concerned about insufficient capacity to serve the growing demand. Considering that undesirable consequences exist for oversupply as well as for undersupply, the search for a balance between demand and supply over time should be an important objective of airport planning. An improved knowledge of appropriate design criteria and standards and the means to deal with the uncertain nature of future demand for services are of paramount importance. Table 1 describes some of the possible impacts of oversupply and undersupply of airport facilities.

Clearly, given the increasingly complex nature of airport planning, design, and investment decision making, the nonscientific treatment of capacity and level of service subjects is hardly acceptable. In fact, as is evident from the previously noted reviews, an improved knowledge of the interrelationships of level of service, capacity, and cost (to facility users as well as suppliers) is essential. A number of associated requirements are to be met as well. These include refining the measures for assessing the performance of airport landside subsystems and dealing with the uncertain nature of future air travel demand.

LEVEL OF SERVICE FRAMEWORK

Requirements for Facility Design and Evaluation

The landside part of the airport system consists of a number of interlinked subsystems that are intended to serve as processors, holding areas, and links (Table 2). The design process, in broad terms, is expected to yield cost-effective size and configuration of facilities, to ensure efficient interchanges between facilities, and also to meet other criteria (e.g., safety and security) (*9*).

In the design process shown in Figure 1, a key initial step is to estimate "peak traffic," which requires the forecasting of traffic for the design year, the design day, and the design hour. The prediction of profiles of aircraft and person/goods traffic demand is a necessary prerequisite for design and analysis of facilities. Given that future demand, especially beyond a five-year period, cannot be forecast with any degree of certainty, a recognition of sources of uncertainty and methods of coping with the uncertain nature of demand are required.

An airport's landside facilities are designed to serve a peak-period traffic that is supposed to represent the design year's busy period conditions (*10*). It is expected that the various landside subsystems will have to cope with a usage level higher than the design peak level for a number of hours/periods during the year. There is little agreement among airport agencies, however, about the definition of, or the approach to, measuring the planning and design peak period. Methods that have been used, namely, the *x*th (e.g., 90th) percentile traffic and the *n*th (e.g., 30th) highest hour in the year, are known to be deficient in capturing the true nature of the peak traffic profile (*6, 11*).

Airport planners in Canada, who have used the 90th percentile traffic in the past, are attempting to shift to a more realistic measure—the highest representative peak hour in the composite hourly traffic profile representing the busiest season. The busiest season is considered the year's three consecutive months with the highest average daily passenger traffic volume. To compare the two approaches, this new criterion would yield 91st–93rd percentile traffic for Pearson International Airport (Toronto) and would equate to 85th–88th percentile traffic at smaller airports (*11*).

As for other agencies, the Federal Aviation Administration (FAA) of the United States has suggested flexible guidelines that define the design peak hour as 6.25 percent to 20.00 percent of the busy day's total operations. Scheduled airlines in the United States generally design their facilities for the peak hour of the average day of the peak month of the selected design year. The British Airports Authority (BAA) applies its design standards in association with 95th percentile traffic. The Western European Air-

TABLE 1 POSSIBLE IMPACTS OF LANDSIDE FACILITY OVERSUPPLY AND UNDERSUPPLY

Interest Group[a]	Negative Impacts of Oversupply	Negative Impacts of Undersupply
Users	Increased charges to pay for oversized facilities	Congestion, delays; reduced level of service (inconvenience, cost of time, discomfort)
Carriers	Increased charges (fees, leases)	Cost of delay; reduced level of service offered; diversion of customers to other airports (carriers) and modes
Government (as airport owner)	Reduced revenues; political backlash	Political backlash; social loss due to congestion costs
Airport authority	Reduced revenue; increased overhead	Operational problems; complaints from travellers and carriers; loss of potential customers
Airport concessionaires	Increased charges (leases, fees); reduced revenue	Reduced level of service offered to customers; loss of potential customers

[a] Other interest groups are also impacted (e.g., land developers, adjacent property owners, environmentalists).

TABLE 2 ENPLANING AND DEPLANING PASSENGER SUBSYSTEMS (*9*)

	Enplaning	Deplaning
Sector	Domestic Canada–U.S.A. International	Domestic Canada–U.S.A. International
Reservoir	Ticketing queue area Check-in queue area Preclearance queue area Waiting (general) Security queue area Holdroom, etc.	Primary inspection (PIL) queue area Baggage claim hall Secondary examination queue areas Waiting, etc.
Processor	Ticket counter Check-in Preclearance Secondary examinations, etc.	Primary inspections line Baggage claim devices Secondary examinations, etc.
Links	Corridors Escalators Elevators Doorways People movers, etc.	

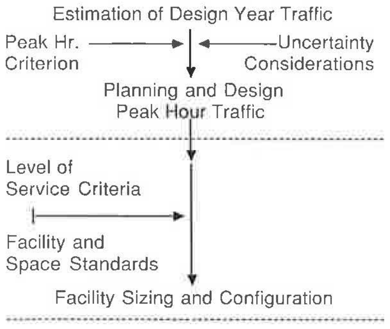


FIGURE 1 The design process.

ports Authority (WEAA) applies different criteria depending upon the site. A commonly used criterion, however, is the 30th busy hour (*9, 11, 12*).

Realistically, the proportional share of peak-hour traffic out of average-day, peak-month/season movement cannot be assumed with any degree of confidence to be a constant (e.g., 9 to 10 percent), particularly for large airports. As schedules are spread throughout the day at major airports, this percentage logically drops. Also, experience gained from airport studies suggests that the characteristics of peaking are largely airport-specific, depending upon the airport's location within the network. Recent experience indicates that the peaking phenomenon can be influenced through policies in pricing, marketing, incentives/disincentives, and especially (voluntary or imposed) scheduling.

For the development of supply strategies (i.e., type, size, and configuration of facilities and implementation schedule), level of service criteria and the associated space standards are required. Currently, widely recognized level of service criteria are not available. A more basic deficiency is the general absence of well-researched knowledge on this subject.

Airport planners in Canada have adopted the level of service framework used for planning and design of highway and pedestrian facilities for specifying operating conditions at airports. Table 3 presents a description of the various levels of service (LOS), ranging from LOS A (excellent) to LOS E (capacity) and LOS F (system breakdown).

In this research, level of service is defined as a measure that describes user-perceived operating conditions (e.g., the degree of congestion) at various processors, reservoirs, and links. The capacity of a subsystem (facility) is the maximum (saturation) level throughput (i.e., density or volume, depending on the nature of the subsystem) that can be served under prevailing conditions. Attempts have been made to study user-perceived level of service and behavioral aspects of landside operations (*13*). There are a number of reasons for adopting the LOS framework shown in Table 3 for the planning and design of landside facilities. As the experience of the highway transportation profession suggests, a framework based on the concepts of "ultimate" and "practical" capacities is difficult to operationalize and inflexible, because of the absence of a continuum of level of service falling from ideal conditions, to saturation, and ultimately to jam cases.

Another scheme, based on three levels of service, suffers from similar weaknesses without offering any advantages. It is recognized here that adopting LOS A to F does not simplify the essential task of identifying the most appropriate performance measures and ranges of performance that correspond to the various levels of service. From a planning and design perspective, the wider gradation of conditions represented by the LOS framework used for highway transportation has a logical appeal.

TABLE 3 LEVEL OF SERVICE (LOS) FRAMEWORK (*2, 6, 9*)

Level	Description
A	Excellent level of service; very low density; condition of free flow; no delays
B	High level of service; low density; very little traffic interference and delay
C	Good level of service; acceptable level of density and delay; related subsystems in balance
D	Adequate level of service but delays incurred; high density; condition acceptable for short periods of time
E	Unacceptable level of service; represents limiting capacity of the facility; very high density; subsystems not in balance
F	Subsystem breakdown; unacceptable congestion and delay

As for implementation of the LOS framework, a knowledge of the capacity of landside facilities as well as throughput at varying levels of service (i.e., densities, service flows) is required for planning and design activities. Also, information on acceptable levels of service as well as their cost-effectiveness is of growing interest. An important research finding is that the economic variable must be considered, given that a desired throughput level and the resulting quality of service are joint products with cost implications for airport authorities, airlines, and the traveling public. Economic considerations of landside planning and design have also been investigated in the past (*14*).

Design Criteria

In recent years, three types of criteria have become relevant for landside subsystem planning and design. These can be categorized as functional performance (i.e., operational effectiveness, safety and security, comfort, and convenience), flexibility (i.e., change/growth), and economy (i.e., cost and revenue/benefit balance) (*12*).

The operational effectiveness criterion is intended to ensure the smooth (without disruptions or other problems) functioning of the facility itself, as well as its interchanges with other facilities. The criterion's measures, which are diverse, relate to flow of traffic and delay. As for safety and security, the design of landside facilities is beginning to respond to these requirements. The passenger convenience/comfort criterion deals with a large number of factors, namely, travel time, walking distance, accessibility to amenities, service convenience, clarity of signage, and passengers' opportunity for communication about orientation and information (*12*).

Flexibility to accommodate growth and change is an important criterion, given the uncertainties of future traffic (in terms of numbers, user characteristics, and requirements) (*15, 16*). As noted earlier, there is a growing emphasis on economic factors in the provision of airport facilities. Therefore the criterion of economy is an important one, given pressures to reduce the level of service and economic constraints for capacity expansion or facility modernization. Operational measures include economic efficiency or cost-effectiveness as the basis for investment decisions. The airport research community has come to recognize that life-cycle costs (i.e., costs of construction, operation, maintenance, and rehabilitation) as well as airline and traveler costs are to be included in design (capacity, level of service) and investment decisions.

UTILITY THEORETIC APPROACH TO LEVEL OF SERVICE ESTIMATION

The state of knowledge is deficient in capacity and level of service characteristics of landside subsystems in their present form or as they can be affected by technical developments. According to current practice in airport planning and design, an ultimate capacity and a practical capacity are defined where an "acceptable" level of delay is used as a measure for practical capacity. The conceptual practical weaknesses in practical capacity approach have already been mentioned. In addition, the acceptability (to the user) of the amount of delay is subjectively established by planners, without definitive field studies.

The use of level of service framework (shown in Table 1), if appropriately supported with research on estimating the levels of service, would be an improvement on existing practice in the sense that a wider classification of user density or volume indices could be used to specify design standards and trigger points for capacity expansion. Table 4 provides a summary of performance measures for landside subsystems (*17, 18*). Criteria and standards for these facilities are not well developed. For apron/gates and the constituent parts of the terminal building, the practices and standards used by a number of organizations differ widely and are not supported by analyses.

In all cases reviewed, single values for space standards are quoted. Transport Canada's recently adopted space standards for selected landside subsystems, shown in Table 5, are a step in the right direction because they correspond to the various levels of service. The gradations are rather narrow, however, and were set subjectively.

The application of utility theory is advanced here for measuring the levels of service and establishing realistic density/capacity or volume/capacity ratios (i.e, indices) that correspond to the various LOS and space standards for landside facilities. The use of density (i.e., occupancy per unit area at any time) as a measure of the intensity of usage level is appropriate, given the nature of airport terminal processors.

A user under prevailing conditions of traffic and service at a subsystem perceives a state of the subsystem with a bundle of impacts (e.g., waiting time, processing time, congestion). For a given subsystem, the performance measures $pm_1, pm_2, \ldots, pm_q$ are defined. Table 4 shows such measures. For example, for the check-in area, performance measures include waiting time in the queue, processing time at the counter, and density of space use in the check-in area. In an attitudinal survey, users are asked to declare their preferences for each of the multiple performance measures, which can be transformed into relative weights.

For a design study, the facility size alternatives $a_1, a_2, \ldots, a_m$ result from the combination of level of service (and associated standards) and demand state (i.e., peak hour/period traffic). An alternative facility size will result in the occurrence of exactly one outcome state o, unknown beforehand, in a set of outcome states O, with elements $o_1, o_2, \ldots, o_k$. An outcome state consists of a bundle of impacts of various levels of performance attainment, pm_{gh}

TABLE 4 PERFORMANCE MEASURES FOR LANDSIDE FACILITIES: TERMINAL BUILDING AND APRON (*17, 18*)

Subsystem	Activities	Performance Measures
Apron/Gates	Aircraft circulation; parking and servicing; transfer of passengers, baggage and cargo	Service time, delays to aircraft, interference and congestion, queue length and waiting time
Baggage claim area	Processing of incoming, transfer, and outgoing baggage	Waiting time and queue length at baggage claim area, delay to aircraft, congestion, number of bags not transferred, number of outgoing bags not loaded
Entrance/exit	Airside processing	Queue length, waiting time, congestion
Boarding lounge	Entrance processing and storage	Queue length, waiting time, congestion
Security	Processing and storage	Queue length at entrance, waiting time, congestion
Customs and immigration	Processing and storage	Queue length at entrance, waiting time, congestion
Corridors and other links	Walking and circulation	Space per pedestrian, speed
Ticketing counter	Processing of passengers and baggage	Queue length, waiting time, congestion

TABLE 5 AIR TERMINAL BUILDING STANDARDS (SQUARE METERS PER OCCUPANT)

	Level of Service					
	A	B	C	D	E	F
Check-in	1.6	1.4	1.2	1.0	0.8	
Wait/circulate	2.7	2.3	1.9	1.5	1.0	
Holdroom	1.4	1.2	1.0	0.8	0.6	
Bag claim area (without device)	1.6	1.4	1.2	1.0	0.8	
Pre-PIL	1.4	1.2	1.0	0.8	0.6	

SOURCE: Transport Canada Standards.

(i.e., gth level of hth measure). Such impacts, revealed through an attitudinal survey of subsystem users, can be transformed into relative or utility numbers through the use of value functions. The individual or "pure" outcomes are combined by logical operations (by means of *and, not*) to form outcome states:

$$o_1 = pm_{11} \wedge pm_{21} \wedge \ldots \wedge \sim (pm_{12} \wedge pm_{22} \wedge \ldots) \wedge \sim (pm_{13} \wedge pm_{23} \ldots)$$

$$o_2 = \ldots$$

where

pm_{11} is the first level of performance measure 1,
pm_{21} is the first level of performance measure 2, etc.

The value functions are allowed to undergo the following linear transformations, which keep intact the performance achievement structure as perceived by users of the subsystem:

$$u_g(pm_{gh}) = y_g v_g\,(pm_{gh}) + b_g \qquad \text{for all } pm_g,\ g = 1, 2, \ldots, q$$

where

u_g = a numerical function on the gth performance measure,
$u_g(pm_{gh})$ = the transformed value of pm_{gh} (measured on a relative value scale),
$v_g(pm_{gh})$ = the original value of pm_{gh},
y_g and b_g = constants for criterion g.

The performance measures can be weighted and then combined:

$$U(o_j) = w_1 u_1\,(pm_{1h}) + w_2 u_2(pm_{2h}) + \ldots + w_g u_g(pm_{gh})$$

where

$U(o_j)$ = the utility of outcome state j in relative value units—units measured on a scale of 0 to 1,
u_g = a numerical function on the gth performance measure,
w_g = a scale transformation parameter on u_g—a relative "weight" reflecting user preferences for measures of effectiveness (obtained from the strengths of preferences expressed as rank numbers).

To allow planners and designers the opportunity to use their subjective judgment of the occurrence of an outcome state o_j, a conditional probability distribution $p(o_j \mid a_i, d_\iota)$ can be used that expresses the planner's assessment of the conditional probability of the occurrence of outcome state o_j in O under the facility size alternative a_i and demand state d_ι combinations. The need to express such subjective judgments is clear since technical developments (e.g., machine-readable tickets/passports) and innovative procedures may change the existing relationships between throughput and performance of a subsystem (*19, 20*). The p's are assigned so that all but a finite o in O have $p = 0.0$, and the sum of the p's equals 1.0 for the subsystem size alternative-demand state combination.

For a given demand state d_ι, the utility of an alternative can be computed as:

$$U(a_i, d_\iota) = \sum_{j=1}^{k} p(o_j \mid a_i, d_\iota) U(o_j)$$

where $U(a_i, d_\iota)$ is the utility of size alternative i and demand state ι for $i = 1, 2, \ldots, m$ and $\iota = 1, 2, \ldots, n$.

The likelihood of the occurrence of demand states can now be treated as a variable. Let $P(d)$ be the planner's probability of a proposition that d_ι is the true state of demand. The expected utility of an alternative a_i can now be given as:

$$U(a_i) = \sum_{\iota=1}^{n} P(d_\iota) \cdot U(a_i, d_\iota)$$

From surveys of users at selected subsystems and analyses performed in accordance with the preceding theory, user reactions to quality of service could be obtained. A semantic scale of 1 to 7 could be used for obtaining user reactions on subjective as well as objective performance measures. Appropriate descriptors could be used for holding areas, time (delay) for processors, and so forth. In addition to getting a rating for each attribute, the relative importance of the attributes could be obtained. Simultaneously, using video cameras, the density levels (i.e., number of occupants per unit area) could be developed. A survey and associated analysis result in a utility number (between 0 and 1) for the subsystem under known conditions. For the saturation case, the utility rating could be zero or nearly zero, corresponding to LOS E. The corresponding density index (d/c) or volume index (v/c) would be 1.0, and space/service factors such as space/occupant and time spent in the subsystem could be found.

Likewise, for the various conditions of traffic studied, ranging from low traffic to very high usage levels, plots of utility against space use and utility against time levels could be developed. These are expected to show breaks reflecting thresholds. From threshold levels (breaks in the utility curve), LOS transition from E to D and from D to C could be found (Figure 2). In the absence of well-pronounced breaks, the planner and the airport authority can divide the utility axis into LOS ranges.

Figure 2 shows a utility function that exhibits the properties of diminishing marginal utility (value) (*16*). It can be seen that under congested conditions (e.g., LOS E), reduction in delay would result in relatively large gains in the utility (value) of users compared to less congested conditions, such as those experienced during LOS B or even LOS C. Also, it can be seen that there are certain threshold levels of delay that, when eliminated, result in substantial gain in utility.

The interrelationship of the level of service, density, or space indices and space standards is illustrated in Figure 3 for two selected processors. Also shown in this diagram is the influence of the sector (i.e., domestic vs. international) in terms of duration (i.e., up to 15 minutes, more than 15 minutes) on the level of service. For instance, a subsystem that experiences a *v*/*c* ratio of 0.75 for less than 15 minutes (as may be the case with domestic service) would be offering a level of service D. On the other hand, if duration exceeds 15 minutes, the LOS should be regarded as E (Figure 3).

Experience in Canada suggests that larger airports involve higher occupancy times because of such factors as airport access distance/time, reliability of access to airport services, airline requirements, and so forth. When applying LOS criteria in planning and design, in the absence of actual survey data, estimated *v*/*c* ratios should be considered for durations exceeding 15 minutes at a time. Subject to detailed studies, larger airports with a higher percentage of long-haul flights should offer more space per passenger than smaller airports. Of course, as can be noted in Figure 3, any processor operating above LOS C (i.e., LOS A and B) should be able to operate throughout a 24-hour period at these levels of service.

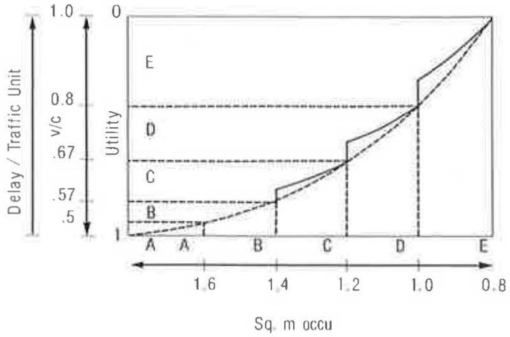
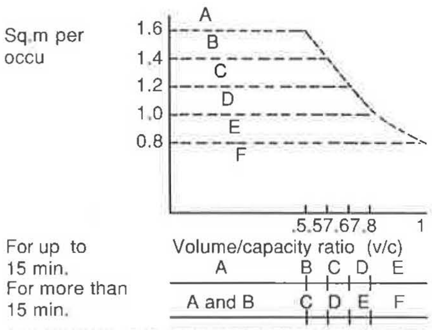


FIGURE 2 Level of service and utility: check-in and baggage claim.



Note: Sq. m/occu. correspond to Transport Canada's new space standards.

FIGURE 3 Level of service and space standards: check-in and baggage claim.

Finally, as noted earlier, technical developments are likely to increase processing rates and reduce airport occupancy times in the future. This means that space standards should be revised. For medium- and long-range planning, such advances should be assessed. Technological innovations and operational means that are likely to change the interrelationship of level of service and space or facility standards of landside subsystems include self-service check-in systems, machine-readable tickets and passports, new methods of enhanced security and improved throughput, and increased use of moving belts and people movers.

COST-EFFECTIVENESS OF DESIGNS

The optimal facility size and therefore the associated LOS can be established by using a number of methods for decision making under uncertainty. These are the expected value approach (based on use of the Laplace criterion of equal likelihood of the occurrence of demand states or other subjective probabilities), the Horowicz method (based on use of an index of optimism), the regret approach, and the criteria of minimin and minimax. These approaches are described in most engineering economics, operations research, and systems analysis textbooks.

In the event that the planner prefers to work with cost matrices, the expected overall cost of an alternative can be found as:

$$\text{Expected} \quad C^*(a_i) = \sum_{\iota=1}^{n} P(d_\iota) \cdot C(a_i, d_\iota)$$

where

$P(d_\iota)$ = the probability of the occurrence of demand state d_ι, and

$C(a_i, d_\iota)$ is the cost of facility size alternative i and demand state ι for $i = 1, 2, \ldots, m$ and $\iota = 1, 2, \ldots, n$.

The alternative with minimum expected social cost is the optimal alternative. Alternatively, the analysis could be carried out by working with savings of costs (i.e., benefits) through an incremental net value method. The level of service that corresponds to the optimal alternative is the best one for facility design.

Figure 4 illustrates the identification of the optimum number of gates by minimizing the present worth of total costs. Expected social costs were estimated under three demand states (i.e., growth rates). Level of service designations are noted that represent various degrees of delays to the airlines and passengers. As for capacity expansion decisions, Figure 5 shows that subjecting users to congested

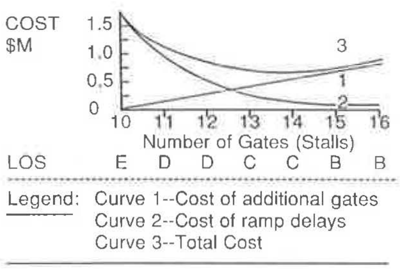


FIGURE 4 Facility size, cost, and level of service.

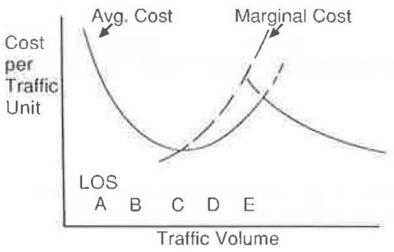


FIGURE 5 Capacity expansion at LOS E.

conditions associated with LOS E prior to capacity additions would be uneconomical owing to the unacceptably high cost of congestion.

CONCLUSIONS

This paper has demonstrated that a utility theoretic approach can be used to estimate the utility or user-perceived value of levels of service for landside subsystems, and to establish corresponding density or volume indices and space/service standards. It has also illustrated a methodology for assessing the cost-effectiveness of various levels of service and associated facility sizes within the uncertainty of future travel demand. The methodology can also be used to establish the most cost-effective level of service and optimal facility size.

The level of service framework based on LOS A to F is the most appropriate one for airport landside facilities. The most cost-effective LOS for the design of landside facilities is LOS C. LOS D could be used as the trigger point for capacity additions. Operations at LOS E are uneconomical from a "social cost" viewpoint.

The methodological framework advanced herein provides a mechanism for incorporating changes in the interrelationship of the level of service, density or volume indices, and space standards. Such changes are expected to occur as a result of technological developments and operational innovations that have the potential to change processing rates and throughputs of landside facilities.

ACKNOWLEDGMENT

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Airport Gate Position Estimation Under Uncertainty

S. BANDARA AND S.C. WIRASINGHE

The aircraft gate requirement for a planned airport terminal is usually estimated using deterministic methods, although the relevant parameters—aircraft arrival rate, gate occupancy time, and aircraft separation time at a gate—are random quantities. An empirically determined "utilization factor" normally is used as a surrogate variable for separation time. The validity of the utilization factor is questionable because of its dependence on the number of gates available and the existing schedule at the airport at which it is calculated. The mean and variance of the gate requirement can be estimated if the means and variances of the aircraft arrival rate, the gate occupancy time, and the aircraft separation time can be estimated. It is shown that the gate requirement is likely to follow certain probability distributions. The design gate requirement is then chosen to satisfy a given reliability that is defined as the probability that there are sufficient gates to ensure zero delay to aircraft seeking gates. The method is applicable under common and preferential gate use policies, as well as for estimating the required number of remote aircraft stands for use in overflow situations. The gate requirement at Calgary International Airport is analyzed for common and preferential gate use policies.

The gate position requirement at an airport is an essential parameter in terminal planning. The passenger terminal and apron design is governed largely by the gate position requirement. It influences the configuration of the terminal building and the layout of the apron area and affects passenger walking distances and aircraft taxi lengths.

The number of gate positions required to accommodate a given number of flights will depend on the airline schedules, airport operating policy, the type of gates available, and the efficiency with which each gate position is used.

A number of studies have been done to investigate the gate position requirement, gate utilization, and the staging of gate position construction. Horonjeff (*1*) proposed a deterministic model to compute the required number of gate positions, based on the design volume for arrivals and departures in aircraft per hour (C), mean gate occupancy time in hours (T), and a utilization factor (U). The number of gate positions (G) was given by

$$G = CT/U \tag{1}$$

The aircraft arrival rate at gate positions varies with the hour of the day, day of the week, and month of the year. The gate occupancy time is dependent not only on the aircraft type but also on the type of operation: turnaround, continuing, originating, and terminating. If the aircraft arrival and departure times are known, the gate requirement can be determined exactly. However, exact schedules are not available in the planning stage of a terminal. Even if schedules are available, aircraft do not operate exactly on schedule. Therefore, the preceding parameters must be treated as random quantities.

McKenzie et al. (*2*) used the probability distributions of the preceding two parameters and simulation techniques to study the effect of adding one extra gate to the existing ones. Steuart (*3*) developed a stochastic model, based on empirical information relating actual flight arrivals and departures to the schedule, to study the influence of "bank operation" on the gate requirement. He found that a uniform schedule generates the minimum requirement and that banking tended to increase the number of gates.

In this paper the number of gates (G) required to provide a given reliability is estimated based on the aircraft arrival rate at the gates (A), the gate occupancy time (T), and the aircraft separation (buffer) time (S), considering them as random quantities.

BASIC CONSIDERATIONS

Imagine an idealized situation in which a constant aircraft arrival rate at gate positions (A) and identical gate occupancy times (T) exist. The gate occupancy time is measured from the aircraft's wheel stop time at the gate to the time of moving out from the gate. If all gates are capable of handling any aircraft, a lower bound for the number of gate positions required (G_L) is given by

$$G_L = AT \tag{2}$$

This formulation does not account for the time separation required for maneuvering aircraft between a departure from a gate position and the next arrival; thus it underestimates the gate position requirement.

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The estimated lower-bound number of gates can be increased either by introducing a "utilization" factor, as suggested by Horonjeff (*1*), or by adding a time period that represents the aircraft separation time (buffer time) at a gate (S) to the gate occupancy time, as suggested by Transport Canada (*4*).

If the utilization factor—which represents the amount of time a gate position is occupied with respect to the total time available—is used and is determined empirically, its validity is questionable because of its correlation with the total number of gates available and the existing schedule at the airport where it is estimated.

The aircraft separation time can be defined as the time between a departure from a gate position and the next arrival; it consists of the push-out or power-out time, the time required by departing aircraft to clear the apron area, and the time required by arriving aircraft to move in from the apron entrance to the gate position. Although the aircraft separation time is influenced by the apron and terminal layouts, it can be estimated in a manner that is independent of the existing schedule. Further, it will be shown that the gate position requirement is less sensitive to the aircraft separation time than to the utilization factor. Hence the aircraft separation time (S) is selected to modify Equation 2, and the modified gate position requirement is given by

$$G = A(T + S) \tag{3}$$

The parameters A, T, and S are random variables. Hence G is a function of three random variables. Simply substituting the mean values of A, T, and S in Equation 3 will provide an estimate of the mean value of G. Designing a terminal for the mean value of G, however, will result in a low level of reliability (approximately 50 percent) since an aircraft queue will form whenever the gate requirement exceeds the mean gate requirement.

STOCHASTIC MODEL

The number of aircraft arrivals varies with the hour of the day, day of the week, and month of the year. The maximum number of aircraft arrivals at gates is partially governed by the airport's runway capacity. In addition, some of the originating flights may come from a hangar, and some terminating flights may not use a gate. Hence the aircraft arrival rate (A) is defined as the hourly aircraft arrivals at gate positions.

The mean and variance of the arrival rate can be obtained either from arrival patterns observed at an existing airport or from arrival patterns generated for the future. The observed values could be used for short-term planning situations, to check the gate requirement of an existing airport, and to study the effects of different gate allocation policies. For long-term planning, the necessary values may be obtained from computer-generated arrival patterns (*2, 5*) or by increasing the present mean arrival rate in proportion to the expected growth of air traffic and assuming that the variance will not change with time.

Gate occupancy times will vary depending on the aircraft size and the type of flight: originating, terminating, continuing, and turnaround. Available aircraft service facilities also have an effect on the gate occupancy time. None of the aforementioned factors are dependent on the total number of gates available. Further, McKenzie et al. (*2*) have shown that there is no significant dependence between aircraft arrivals in each hour of the day and the gate occupancy time for those arrivals. Therefore, independently observed gate occupancy times for different sizes of aircraft and types of flights can be used to calculate the mean and variance of the gate occupancy time for a given aircraft mix, if the aircraft service facilities are assumed to remain unchanged. When existing conditions are not applicable, the critical path network analysis method suggested by Braaksma and Shortreed (*6*) can be used to estimate the mean gate occupancy time.

When excess gates are available, aircraft can stay at a gate position longer than required. For example, a turnaround flight that arrives in the morning and is scheduled to depart in the evening can stay at a gate position if that gate is not required for another aircraft. Otherwise, it can be towed away to an off-terminal stand and reassigned to a gate when it is required. Therefore, if empirical data are used, a maximum on-gate time should be imposed to avoid overestimation of the gate requirement due to aircraft with unnecessarily long on-gate times. Hence the actual gate requirement at a particular time can be defined as the minimum number of gates that would be sufficient to ensure zero delays to all arrivals and departures. The foregoing argument is valid only if the time period over which the data have been considered is large enough to accommodate any reassignment of delayed aircraft.

The aircraft separation time depends on the aircraft type, type of parking (nose in, parallel), taxi-out method (push-out, power-out), and terminal and apron layouts. Strictly speaking, it is necessary to consider the terminal configuration and the apron layout to estimate the aircraft separation time accurately. Since the magnitude of the aircraft separation time is on the order of one-tenth the magnitude of the gate occupancy time, the accuracy of the aircraft separation time will not have a significant effect on the estimated mean gate position requirement. Hence if the taxiing speeds for different aircraft are known, the aircraft separation time can be calculated with respect to an assumed average taxi length. For short-term planning this quantity may be obtained by a sample survey.

Data analysis performed on operational data from Calgary International Airport shows that there is no statistically significant correlation between any of the three input parameters: aircraft arrival rate at the gate position (A), gate occupancy time (T), and aircraft separation time (S). McKenzie et al. (*2*) and Steuart (*3*) also have shown the independence between the arrival rate and the gate occupancy time. Hence the three input parameters A, T, and S can be treated as independent random quantities with means $\bar{A}$, $\bar{T}$, $\bar{S}$ and variances σ_A^2, σ_T^2, σ_S^2, respectively.

If the means and variances of the preceding parameters are known, estimates of the mean and variance of G can be obtained using moment generating functions, as given in Appendix A:

$$\bar{G} = \bar{A}(\bar{T} + \bar{S}) \tag{4}$$

$$\sigma_G^2 = \sigma_A^2(\sigma_T^2 + \sigma_S^2) + \bar{A}^2(\sigma_T^2 + \sigma_S^2) + (\bar{T} + \bar{S})^2\,\sigma_A^2 \tag{5}$$

Reliability

If $\bar{G}$, σ_G^2, and the probability distribution of G are known, the number of gates to be provided (g) to satisfy a chosen reliability $(1 - \alpha)$ can be obtained using

$$P(G \leq g) = 1 - \alpha \tag{6}$$

where reliability is defined as the probability that there are sufficient gates to ensure zero delay to aircraft on the apron, in a given time period. Here the given period is the duration of time over which data have been considered in determining $\bar{A}$ and σ_A^2. The level of service provided will depend on the chosen reliability and the time period over which the aircraft arrival rate has been considered.

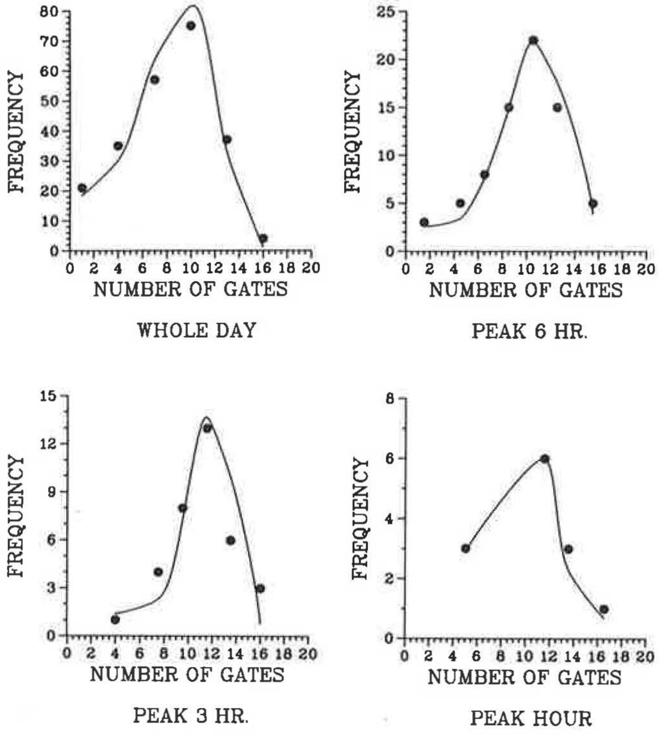
For example, if data from throughout the day for a one-month (30-day) time period are used in determining $\bar{A}$ and σ_A^2, a 95 percent reliability implies delays to some aircraft during 1.2 hours per day on average over the month considered ($30 \times 24 \times 0.05/30$). Thus delays are likely during each peak hour. If data for the 30 high-activity hours of the year are used, a 90 percent reliability implies delays to some aircraft during 3 hours per year on average ($30 \times 1 \times 0.10/1$).

Thus the time period should be specified for the reliability to be meaningful, and the level of service is dependent on the expected number of hours in which delays will occur during the specified period.

Probability Distribution of *G*

The probability distribution of G cannot be obtained unless the probability distributions of A, T, and S are known. The distribution of G is related to the time period over which data are collected. For example, if the data for only peak hours are used, the type 1 extreme value distribution of largest values will likely provide a good fit. On the other hand, if all the hours of a month are used, the type 1 extreme value distribution of smallest values will be likely to provide a good fit, since many of the hours will have low arrival rates.

Data analysis performed on operational data from Vancouver International Airport Terminal for a one-week period showed that it is possible to accept the hypothesis that G can be approximated by a type 1 extreme value distribution of smallest values except for the case of peak-hour distribution of gates. For gate requirements based on peak-hour data, type 1 extreme value distribution of largest values was more appropriate (Figure 1).



WHOLE DAY

PEAK 6 HR.

PEAK 3 HR.

PEAK HOUR

● Observed Frequency (mean number of 5 m intervals per day in which the gates were in use)

— Theoretical Frequency Distribution

FIGURE 1 Type 1 extreme value distributions.

Preferential Gate Use

In the previous analysis, it was assumed that any gate is available to any aircraft. Preferential gate use is common, however, where certain gates are dedicated to certain airlines and/or aircraft types. The method of analysis proposed can easily be extended to the case of preferential gate use if data for each airline/aircraft group, i, are available a priori for the arrival rate (A_i), gate occupancy time (T_i), and aircraft separation time (S_i). Then the gate requirement, g_i, for the group i is given by

$$P(G_i \leq g_i) = 1 - \alpha_i \tag{7}$$

where α_i is the reliability chosen for group i. The total gate requirement is then given by $\Sigma_i g_i$.

APPLICATION TO CALGARY INTERNATIONAL AIRPORT

Data on aircraft arrivals, gate occupancy times, and aircraft separation times were collected at Calgary International Airport on December 21, 1984, between 5 p.m. and 11 p.m.

At the time of data collection, Calgary International Airport had 23 gate positions under operation, two of which are off-terminal aircraft stands (Figure 2). Most of the gate positions have been allocated for use by specific airlines, but they have the exclusive right of use only for the connecting bridge. While the specific airline has preference over others for a particular gate, the airport manager has the power to assign gate positions to other airlines if required. The remaining gates are common gates. Six

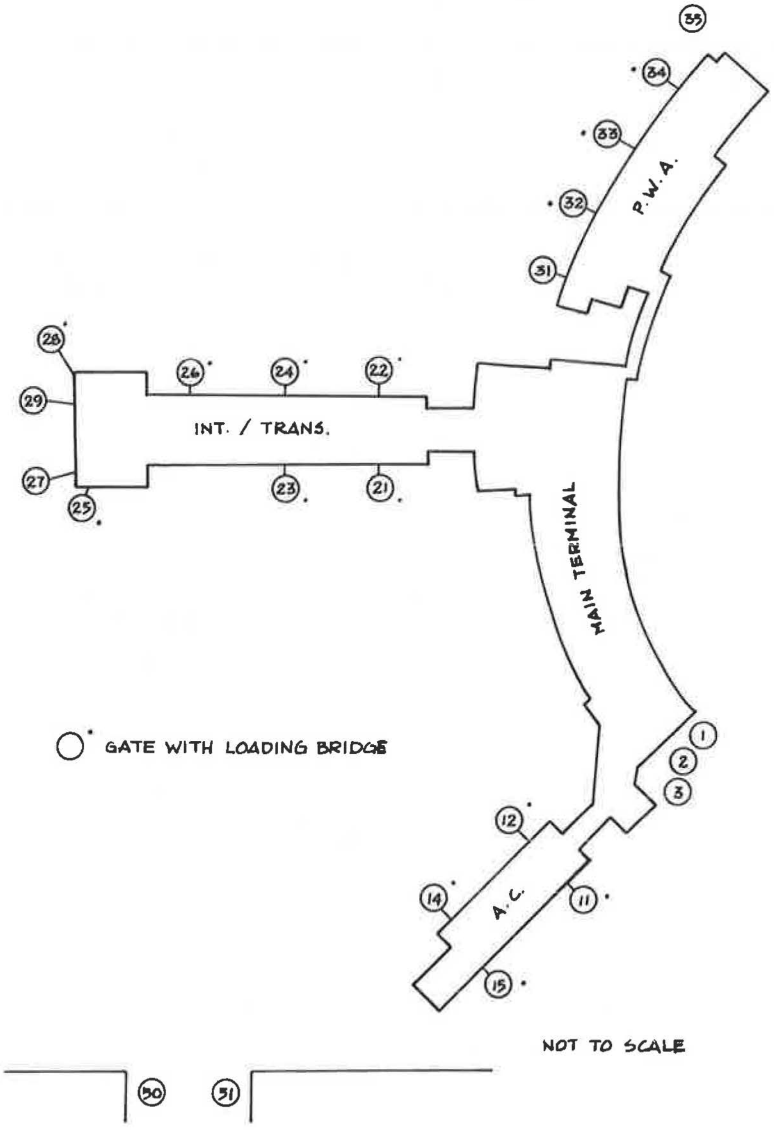


FIGURE 2 Calgary terminal layout plan.

different categories of gates are considered, as given in Table 1.

Table 2 shows the hourly aircraft arrivals at the different gate categories, and Table 3 shows the means and the variances of *A*, *T*, and *S* values observed at Calgary International Airport. The mean and the variance of the gate position requirement calculated using values in Table 3 and Equations 4 and 5 are given in Table 4.

During the period of time that the data were collected, no aircraft was delayed on the apron because of unavailability of gate positions. Hence the actual number of gates occupied during that time can be used to compare the results obtained from the model. Table 5 shows the means and the variances of the actual gate requirements obtained from the actual number of gates that were in use during the period of data collection and the 95 percent probability interval for the mean gate requirement. Five-minute intervals were considered for the preceding calculations. Further, the maximum on gate times suggested by Transport Canada (*4*) were used when calculating the properties of gate occupancy times and estimating the gate usage. It can be seen from Tables 4 and 5 that all the estimated mean values reported in Table 4 fall within the 95 percent probability interval for *G*.

The gate position requirement for reliabilities of 90 percent and 95 percent, respectively, calculated based on the extreme value distribution of smallest values as well as the normal distribution, as given in Appendix B, and the maximum number of gates that were in actual use at a particular time are given in Table 6. The values within the parentheses show the fraction of time that the actual gate requirement exceeded the estimated number of gates. It can be seen that the normal approximation tends to overestimate slightly the gate position requirement.

Horonjeff (*1*) has suggested two ranges of the utilization factor: 0.6 to 0.8 and 0.5 to 0.6 for use with common and preferential gate use, respectively, when the arrival rate is not available by airline/aircraft group. If the arrival rates are available for each group, however, the gate requirement for each group can be estimated using the common gate use utilization factor, and the total requirement under preferential gate use is estimated by summing the individual group requirements. As shown in Table 7, the two methods do not give consistent results.

Consider that only 13 gates are available at the Calgary International Airport. These gates can serve on average at 90 percent reliability if a common gate use policy is used. If a preferential gate use policy is used, 14 gates are required

TABLE 3 MEAN GATE OCCUPANCY TIMES, ARRIVAL RATES, AND GATE SEPARATION TIMES

	Gate Occupancy Time		Aircraft Arrival Rate		Aircraft Separation Time	
Gate Category	$\bar{T}$ (hrs.)	σ_T	$\bar{A}$ (per hr.)	σ_A	$\bar{S}$ (hrs.)	σ_S
All	0.69	0.52	8.50	3.78	0.09	0.02
1	0.41	0.36	1.14	0.98	0.04	0.01
2	0.64	0.21	2.00	1.41	0.09	0.02
3	0.61	0.25	0.50	0.55	0.10	0.02
4	0.81	0.50	1.83	0.75	0.10	0.02
5	1.05	0.59	0.33	0.52	0.09	0.02
6	0.59	0.18	2.67	1.37	0.08	0.01

TABLE 1 CALGARY INTERNATIONAL AIRPORT GATE ASSIGNMENT

Category Number	Category Name	Number of Gates Available
1	Time Air	1, 2, 3
2	Air Canada (Domestic)	11, 12, 14, 15
3	C.P. Air	21
4	International & Transborder	22, 23, 24, 25, 26, 28
5	Military and Others	27, 29
6	P.W.A.	31, 32, 33, 34, 35

TABLE 4 MEAN AND VARIANCE OF GATE REQUIREMENT

Gate Category	$\bar{G}$	σ_G^2
All	6.63	32.13
1	0.51	0.48
2	1.46	1.33
3	0.36	0.18
4	1.66	1.45
5	0.37	0.48
6	1.79	1.14

TABLE 2 CALGARY INTERNATIONAL AIRPORT HOURLY ARRIVAL RATE

	December 21, 1984 (5 p.m.–11 p.m.)					
Gate Category	5–6 p.m.	6–7 p.m.	7–8 p.m.	8–9 p.m.	9–10 p.m.	10–11 p.m.
1	1	3	1	0	1	1
2	0	4	1	2	3	2
3	0	1	0	1	0	1
4	1	2	3	2	1	2
5	0	1	0	0	1	0
6	1	3	2	2	3	5
All	3	14	7	7	9	11

TABLE 5 MEAN AND VARIANCE OF ACTUAL GATE OCCUPANCIES

Gate Category	$\bar{G}$	σ^2_G	95% Probability Interval for $\bar{G}$
All	7.18	22.28	6.09–8.27
1	0.67	0.71	0.48–0.86
2	1.59	1.90	1.27–1.91
3	0.36	0.23	0.25–0.47
4	1.72	1.27	1.46–1.98
5	0.40	0.24	0.29–0.51
6	1.89	2.82	1.50–2.28

TABLE 6 NUMBER OF GATES FOR GIVEN RELIABILITY

	Estimated No. of Gates for Given Reliability				Actual Maximum Number of Gates Required
	g_{90}		g_{95}		
Gate Category	Extreme Value	Normal	Extreme Value	Normal	
All	13(0.11)[a]	14	14(0.05)[a]	16	15
1	2(0.07)	2	2(0.07)	2	3
2	3(0.15)	3	3(0.15)	4	4
3	1(0.0)	1	1(0.0)	1	1
4	3(0.10)	4	4(0.0)	4	4
5	2(0.0)	2	2(0.0)	2	1
6	3(0.19)	4	4(0.12)	4	5

[a] The values in parentheses indicate the fraction of time that the actual gate usage exceeded the estimated value.

TABLE 7 GATE REQUIREMENT: HORONJEFF'S METHOD

Gate Category	Gate Requirement Estimate		
	$u = 0.6$	$u = 0.7$	$u = 0.8$
Common Gate Use Policy			
All	16	14	12
1	2	2	1
2	4	4	3
3	1	1	1
4	4	3	3
5	2	2	1
6	5	4	4
	18	16	13
	$u = 0.5$	$u = 0.55$	$u = 0.6$
Preferential Gate Use Policy			
All	20	18	16

to provide the aforementioned reliability. It can be shown that to provide a 99 percent reliability for common and preferential gate assignments, 16 and 17 gates, respectively, are required. For a reliability greater than 99 percent, the gate requirement tends to increase very rapidly for both extreme value and normal distributions. Hence the preceding estimates for 99 percent reliability can be considered the maximum gate requirements. Therefore a 90 percent reliability can be provided for gates, and a 99 percent reliability can be provided for accommodating all the aircraft at a gate or an off-terminal stand, by providing one more gate position in addition to the 13 available gates and three off-terminal aircraft stands.

SENSITIVITY ANALYSIS

One of the reasons for selecting the aircraft separation time rather than a utilization factor is its relatively small influence on the gate requirement estimation for a given reliability. If the aircraft separation time (S) is used for the estimation as shown in Equation 6, for a ΔS error in the estimate of S, the gate requirement estimate will change by an amount of $\bar{A}(\Delta S)$ if the other two parameters remain constant. On the other hand, if a utilization factor is used, as given by Horonjeff (*1*), for a ΔU increase in the value of the utilization factor U, the gate requirement estimate will decrease by an amount of $CT(\Delta U)/U^2$.

It can be seen that for the first case, an error in the gate estimate does not depend on the value of aircraft separation time. For the second case, however, the error is inversely proportional to the square of the utilization factor.

In general, the design hour volume (C) will be greater than or equal to $\bar{A}$, and U will be always less than 1. Since the mean gate occupancy time generally exceeds 0.5 hour, for most situations $\bar{A}$ will be less than CT/U^2.

As an example, even if $C = \bar{A}$, the foregoing will be true if $T = 0.5$ hours and $U \leq 0.7$ or if $U = 0.8$ and $T > 0.64$ hours. Hence the gate requirement estimate is more sensitive to the accuracy of U than to the accuracy of S. Consider a situation where the error in the estimate of S is as high as 20 percent or 2 min. For a unit change in the gate requirement estimate, $\bar{A}$ should be about 30 aircraft per hour. On the other hand, consider a situation where the design hour volume (C) is 30 aircraft arrivals per hour and T is as low as 0.5 hr. Even for a high utilization factor of 0.8, the estimate of gate requirement will change by 1.0, if the estimate of U is changed by an amount of 5 percent or 0.04. Thus the proper value of U is crucial for the use of Horonjeff's method.

Further, the magnitudes of $\bar{S}$ and σ^2_S are small compared to the means and variances of the other parameters, and has no major influence on the magnitude of G. Hence use of a constant value of S, which represents the mean aircraft separation time for the aircraft mix in question, may be sufficient for a reasonable accuracy.

CONCLUSION

The number of gates required at an airport in the future can be estimated for a given reliability during a specified period if the means and variances of the arrival rate, gate occupancy time, and aircraft separation time can be used as inputs.

ACKNOWLEDGMENTS

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APPENDIX A

For a continuous random variable X, suppose that there is a positive number h such that for $-h < t < h$, the mathematical expectation $E(e^{tX})$ exists. The preceding expectation is called the moment generating function of x.

$$M(t) = E(e^{tx}) = \int_{-\alpha}^{\alpha} e^{tx} f(x)\,dx \qquad \text{(a)}$$

Further, it has been shown (*7*) that

$$M'(0) = E(x) = \bar{x} \qquad \text{(b)}$$

and

$$M''(0) = E(x^2) = \sigma_x^2 + \bar{x}^2 \qquad \text{(c)}$$

where $\bar{x}$, σ_x^2 are the mean and the variance of x, respectively.

Let X and Y be two random variables with moment generating functions $M(t_1)$ and $M(t_2)$, respectively. Let

$$Z = XY \qquad \text{(d)}$$

If X and Y are stochastically independent, the moment generation function for the joint distribution $M(t_1, t_2)$ is

$$M(t_1, t_2) = M(t_1) \cdot M(t_2) \qquad \text{(e)}$$

that is,

$$M(t_1, t_2) = \int_{-\alpha}^{\alpha} e^{t_1 x} f(x)\,dx \cdot \int_{-\alpha}^{\alpha} e^{t_2 y} g(y)\,dy \qquad \text{(f)}$$

$$M'(t_1, t_2) = \int_{-\alpha}^{\alpha} x e^{t_1 x} f(x)\,dx \cdot \int_{-\alpha}^{\alpha} y e^{t_2 y} g(y)\,dy \qquad \text{(g)}$$

and

$$M''(t_1, t_2) = \int_{-\alpha}^{\alpha} x^2 e^{t_1 x} f(x)\,dx \cdot \int_{-\alpha}^{\alpha} y^2 e^{t_2 y} g(y)\,dy \qquad \text{(h)}$$

Then,

$$M'(0,0) = E(Z) = E(X) \cdot E(Y) \qquad \text{(i)}$$

and

$$M''(0,0) = E(Z^2) = E(X^2) \cdot E(Y^2) \qquad \text{(j)}$$

From Equation i,

$$\bar{z} = \bar{x}\,\bar{y} \qquad \text{(k)}$$

From Equations i, j, and c

$$\begin{aligned} \sigma_z^2 &= E(Z^2) - E(Z)^2 \\ &= E(X^2) \cdot E(Y^2) - E(X)^2 \cdot E(Y)^2 \\ &= (\sigma_x^2 + \bar{x}^2)(\sigma_y^2 + \bar{y}^2) - (xy)^2 \\ &= \sigma_x^2\,\sigma_y^2 + \bar{x}\sigma_y^2 + \bar{y}\sigma_x^2 \end{aligned} \qquad \text{(l)}$$

Letting $T + S = Y$ and $A = X$, the mean and the variance of G are given by

$$\bar{G} = \bar{A}\,(\bar{T} + \bar{S}) \qquad \text{(m)}$$

and

$$\begin{aligned} \sigma_G^2 = {} & \sigma_A^2\,(\sigma_T^2 + \sigma_S^2) + \bar{A}^2\,(\sigma_T^2 + \sigma_S^2) \\ & + (\bar{T} + \bar{S})\,\sigma_A^2 \end{aligned} \qquad \text{(n)}$$

APPENDIX B

The cumulative probability density functions of the type 1 extreme value distribution of the largest and smallest values are defined as:

$$F_z(z) = 1 - \exp(-e^{-\alpha(z-u)}) \qquad -\alpha \le z \le \alpha \qquad \text{(a)}$$

and

$$F_z(z) = 1 - \exp(-e^{\alpha(z-u)}) \qquad -\alpha \le z \le \alpha \qquad \text{(b)}$$

respectively. The α and u are two parameters that will be estimated from observed data such that

$$\begin{aligned} \bar{z} &= u + \frac{0.577}{\alpha} \qquad \text{for largest values} \\ \bar{z} &= u - \frac{0.577}{\alpha} \qquad \text{for smallest values} \end{aligned} \qquad \text{(c)}$$

and

$$\sigma_z^2 = \pi^2/6\alpha^2 \qquad \text{(d)}$$

A reduced variate w is defined such that

$$\begin{aligned} w &= (z - u)\alpha \quad \text{for largest values} \\ w &= -(z - u)\alpha \quad \text{for smallest values} \end{aligned} \tag{e}$$

and the cumulative distribution of largest values has been tabulated in terms of the reduced variate w by Benjamin and Cornell (*8*). The table can be used for both distributions, as shown in Equation f.

$$\begin{aligned} F_z(z) &= F_w\left((z - u)\alpha\right) \quad \text{for largest values} \\ F_z(z) &= 1 - F_w\left(-(z - u)\alpha\right) \quad \text{for smallest values} \end{aligned} \tag{f}$$

Consider the estimated gate requirement for the common gate use policy given in Table 4, where $G = 6.63$ and $\sigma_G^2 = 32.13$. The number of gates required to satisfy a reliability of 95 percent, g_{95}, is given by

$$F_G\,(g_{95}) = P(G \leq g_{95}) = 0.95$$

If G is assumed to be represented by a type 1 extreme value distribution of smallest values, from Equation d,

$$\alpha = \frac{\pi}{\sqrt{6}\,\sigma_G} = \frac{\pi}{\sqrt{6 \times 32.13}} = 0.226$$

and from Equation e,

$$u = \bar{G} + \frac{0.577}{\alpha} = 9.18$$

from tables for the type 1 extreme value distribution of largest values, and $w = -1.1$ for $F(w) = 0.05$. From Equation f,

$$1 - Fw\,(-1.1) = 0.95 = F_G\,(g_{95})$$

Therefore g_{95} can be obtained by solving Equation 3 for $w = -1.1$:

$$w = -(g - u)\alpha = -1.1$$

$$g_{95} = \frac{1.1}{0.226} + 9.18 = 14.04 = 14 \text{ gates}$$

If G is assumed to be normally distributed, using normal tables,

$$\begin{aligned} g_{95} &= 1.65\,\sigma_G + G \\ &= 1.65\sqrt{32.13} + 6.63 = 15.98 \\ &= 16 \text{ gates} \end{aligned}$$

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Applications for Intraairport Transportation Systems

FRANCIS X. MCKELVEY AND WILLIAM J. SPROULE

This paper presents the results of research undertaken to develop planning guidelines and unit cost estimates for the incorporation of intraairport transportation systems into terminal facilities. Procedures used for the development of cost estimates for the capital and operating and maintenance costs of such systems are outlined. Parameters are presented for evaluation of the unit and incremental costs of various types of intraairport systems being incorporated in various terminal applications. Techniques are presented to assess these, the unit and incremental costs, against the reduction in travel time and walking distance associated with such systems.

The process that was used in this research (*1*) to develop application guidelines for intraairport transportation systems is shown in Figure 1. A discussion of the essential elements of this process and an overview of the methodologies employed are contained below.

RESEARCH METHODOLOGY

Development of Schematic Terminal Systems

Generic terminals were developed using two basic modules for each of the four classical terminal concepts, namely, the linear, pier, satellite, and transporter. The first module was designed to contain eight aircraft gates for all four terminal concepts. It included a single terminal unit with the processing facilities necessary to serve the passengers using these gates. The second module was designed to contain sixteen aircraft gates for only the pier and satellite concepts. This module was developed to contain a single terminal unit containing the necessary processing facilities and was attached by two connectors, each with eight gates. Presumably the second module would accommodate twice the passenger demand of the first, but the terminal facilities would not be increased proportionately because of the inherent efficiencies in the latter module. As the passenger demand increased, modules were combined to form a configuration of terminal units necessary to meet the demand. By constructing terminal configurations in this fashion, it was possible to identify guidelines for intraairport transportation systems on the basis of passenger demand levels and the terminal concepts used. An approach similar to using modules was used in a 1973 study (*2*) to identify applicable terminal concepts relative to passenger demand levels.

Initial estimates indicated that an eight-gate module could accommodate approximately 1 million annual enplaned passengers. Estimates of typical levels of hourly passenger and aircraft activity associated with this level of annual demand were made so that terminal area requirements could be calculated using commonly accepted planning guidelines (*3*). It was necessary to lay out each of the terminal modules in sufficient detail to locate activities so that passenger walking distances could be approximated and the impact of passenger circulation in the module could be assessed.

For the eight-gate module, it was assumed that a single-level terminal and single-level curb would be required, all gate positions would be designed to accommodate Boeing 767 wide-bodied aircraft, aircraft would move to and from the gate complex in a power-in push-out mode, surface parking facilities would be provided, and passenger processing facilities would be arranged in a typical manner. The assumptions for the sixteen-gate module were similar except that a two-level terminal curb and structural parking were incorporated.

An analytical queuing model developed by the FAA (*4*) was used to verify the preliminary module layouts to ascertain that the passenger demands placed upon them could be accommodated at specified design levels of passenger processing time. For enplaning passengers, the average passenger processing time was not to exceed 20 minutes; for deplaning passengers, the average passenger processing time was not to exceed 30 minutes. Using these processing time limits as the control parameters, the layout of passenger processing facilities in each module was modified until the criteria were satisfied.

Terminal Module Combinations

The basic terminal modules were then combined in two fundamental configurations to form larger terminal units

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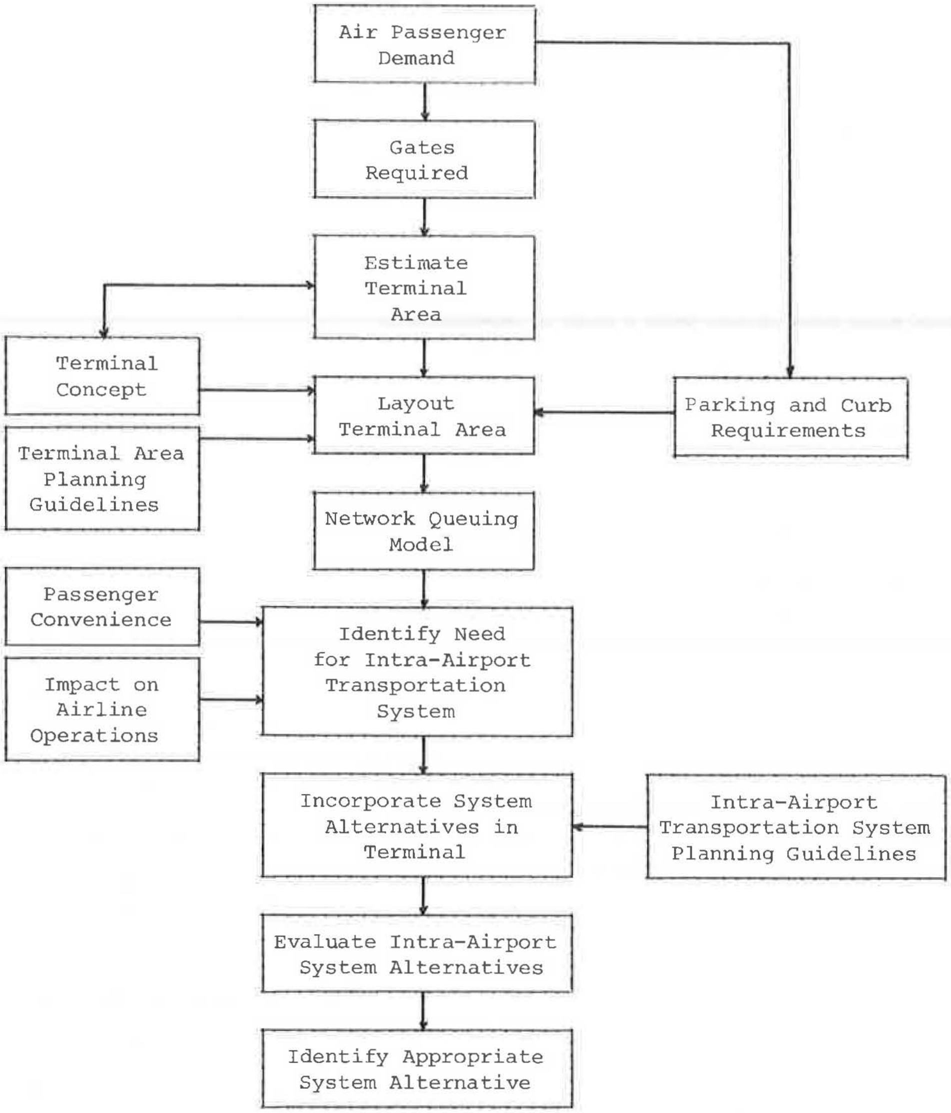


FIGURE 1 Methodology to determine appropriate intraairport transportation system.

for processing greater passenger activity. Modules were placed side by side in configuration A and on opposite sides of the parking facility in configuration B. When modules are placed side by side, the distance between pier and satellite modules is governed by the separation criteria for aircraft operations on the apron and taxi lanes, the distance between the taxi lane and gate positions, and the size of the gate positions. When the linear and transporter modules are placed adjacent to each other, however, it is only the aircraft dimensions and separation criteria at the gates that determine the size of the modules. When modules have been placed on opposite sides of the parking facilities, the parking was placed in the structure to maintain compactness of the terminal unit. Combinations of up to four modules were developed for this study. Figure 2 illustrates the difference between the two configurations and the results of combining the basic eight-gate modules into terminal units in the pier concept. Similarly, Figure 3 illustrates the same for the basic sixteen-gate module. Note that the basic eight-gate module was used to construct terminal units consisting of from eight to thirty-two gates, whereas the basic sixteen-gate module was used to construct terminal units consisting of from sixteen to sixty-four gates.

The selection of the appropriate arrangement or configuration of terminals at an airport is governed by many factors. These include the number and orientation of the runways, the layout of the ground access system, terminal area curb requirements, airline operation requirements, the number of transferring or connecting passengers, and site limitations and restrictions. An evaluation of the most appropriate combination of terminals for a specific case was beyond the scope of this study. The terminal units were developed in this manner only to assist in identifying guidelines for intraairport transportation systems. Such a mechanism, however, provides insights into terminal alternatives to accommodate a range in passenger demand levels as shown in Table 1.

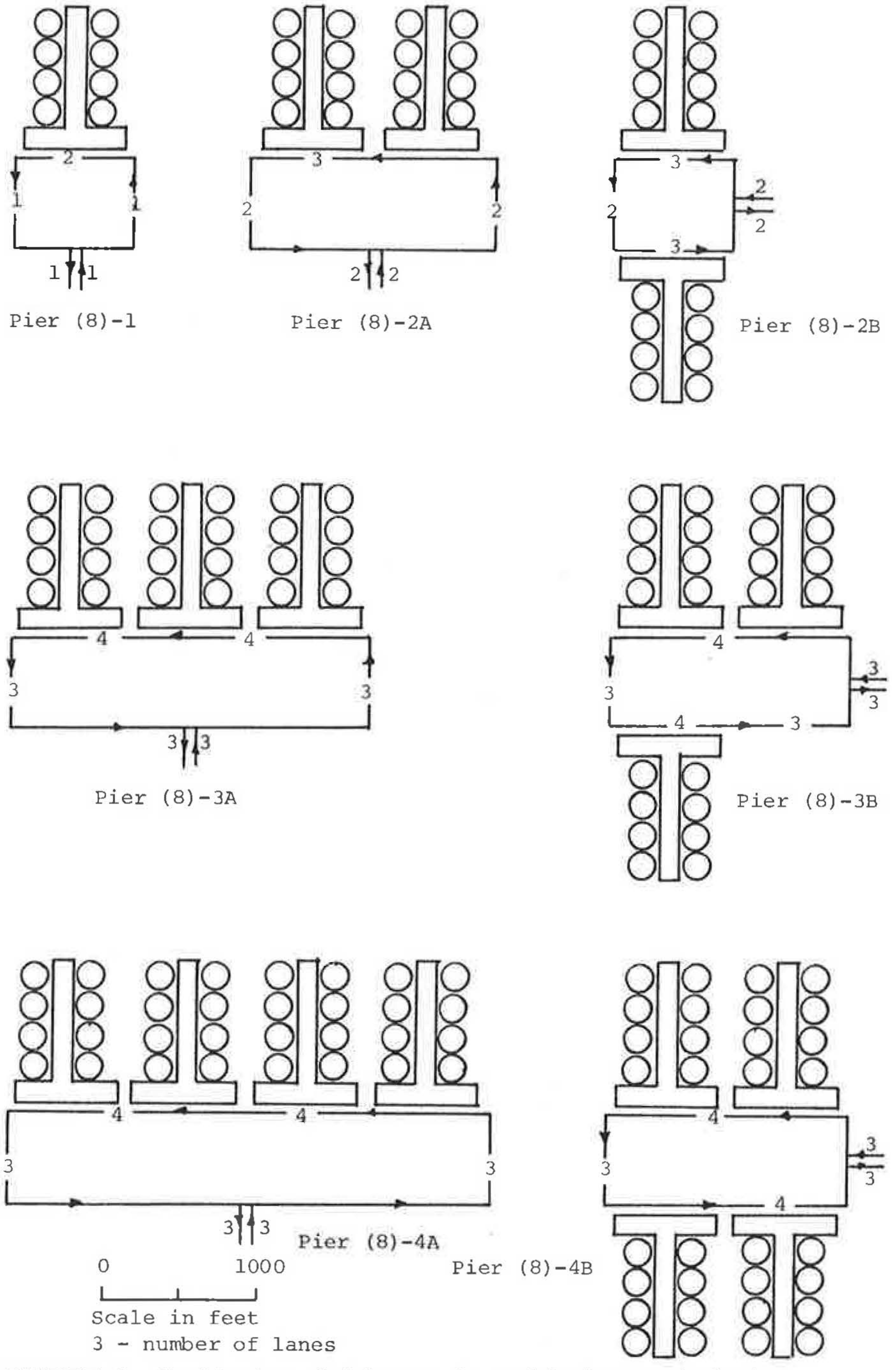


FIGURE 2 Combinations of eight-gate pier modules into terminal units.

Incorporation of Intraairport Transportation

Two route alignment alternatives were developed for all terminal systems. The shuttle alignment is the most direct route between terminals, whereas the loop alignment basically follows the terminal access road alignment. Figure 4 highlights the difference between the route alignment for the shuttle and loop systems for various combinations of terminal units for the satellite concept.

Three basic types of intraairport transportation systems were studied for these terminal units. These were moving walkways, bus transit systems, and automated guideway transit. For each of these types of systems, differing assumptions were made.

It was assumed that moving walkways would be installed on a shuttle alignment and be protected from the weather. Therefore, where modules are placed side by side, as in configuration A, additional terminal facilities are required for both the pier and satellite concepts. For configuration B concepts, the moving walkway is assumed to be incorporated in the parking structure so that additional adjustments to terminal area facilities are not required for the

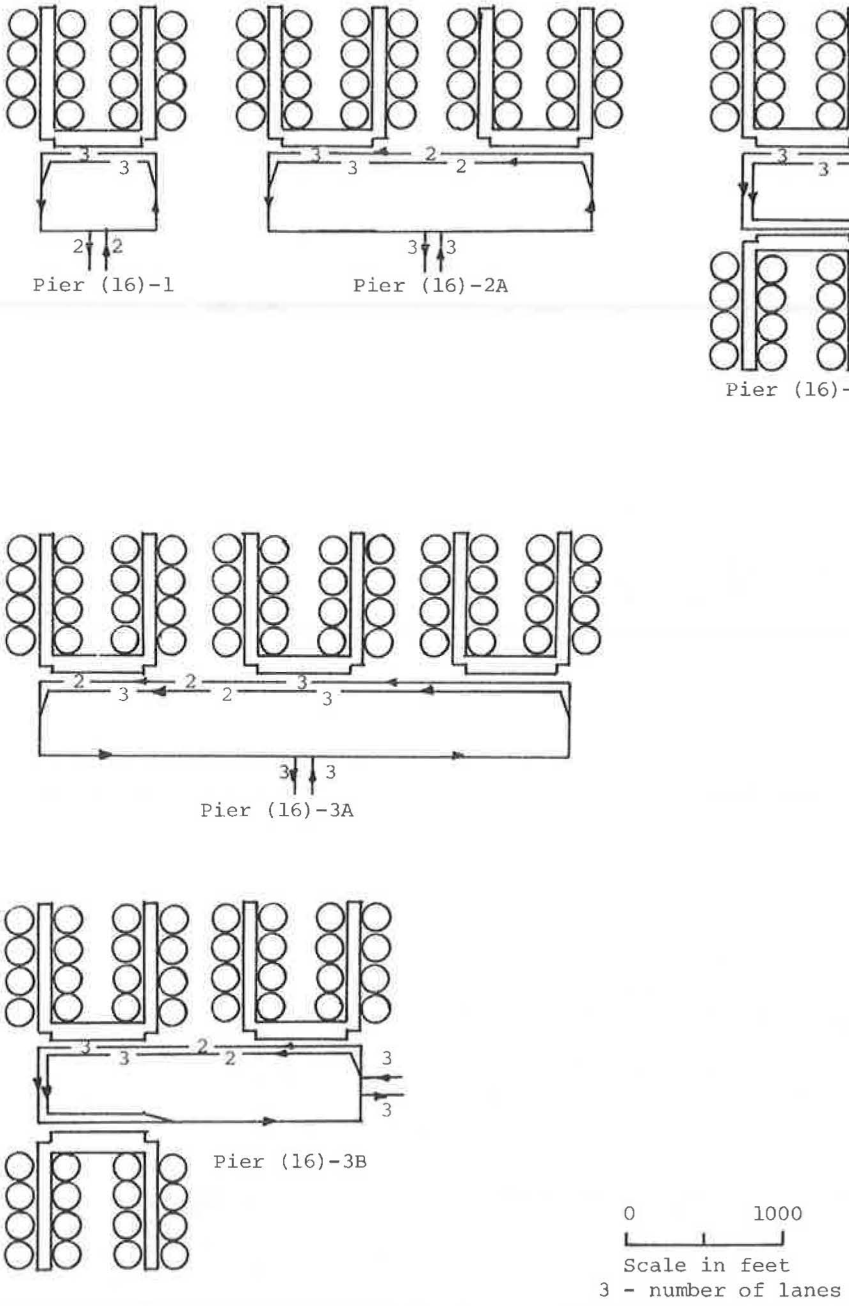
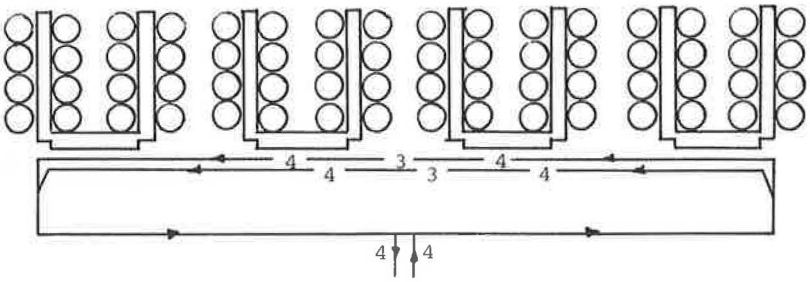


FIGURE 3 Combinations of sixteen-gate pier modules into terminal units.

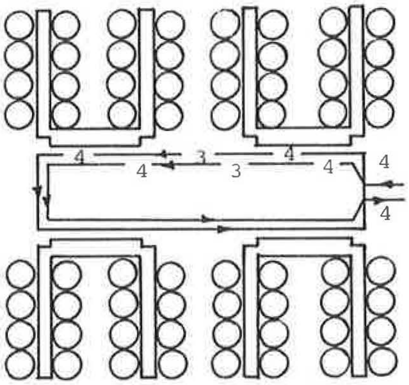
shuttle movement across the parking area. The maximum length of a moving walkway is assumed to be 600 feet.

For bus transit systems, it was assumed that the buses would circulate on a loop alignment on the terminal access road and that there would be one stop at each module.

Automated guideway transit (AGT) systems were allowed to operate on either shuttle or loop alignment. When they operated on a shuttle alignment, it was assumed that the vehicles operated in both directions and therefore no turnaround facilities were required. If only one vehicle was required for service, one guideway between stations was sufficient, whereas two parallel guideways would be necessary if two vehicles were required. There would be one online station for each module, and the guideway was considered an elevated structure. When these systems operated on a loop alignment, it was assumed that the vehicles operate in one direction. A system serving the terminal units in configuration B was assumed to be on an elevated structure, whereas those systems serving the terminal units in configuration A were assumed to be operating on an elevated guideway adjacent to terminals and at-grade on the remainder of the route.



Pier (16)-4A



Pier (16)-4B

0 1000

Scale in feet

3 - number of lanes

FIGURE 3 *continued*

TABLE 1 AIR PASSENGER DEMAND ACCOMMODATED BY VARIOUS TERMINAL UNITS

Number of Gates per Module	Number of Modules	Annual Enplaned Passengers	Peak Hour Passengers PMAD*
8	1	1 million	730
8	2	2 million	1460
8	3	3 million	2190
8	4	4 million	2920
16	1	2 million	1400
16	2	4 million	2800
16	3	6 million	4200
16	4	8 million	5600

* PMAD = Peak Month, Average Day

Cost Estimate Development

Terminal Costs

One aspect of cost that this study examined was the incremental change in the cost of the terminal area facilities caused by incorporating an intraairport transportation system. Unit costs were developed from various sources to estimate both the capital costs and the operating and maintenance costs for the terminal buildings, terminal access roads, parking, and apron area. Since these unit costs were extracted from several sources in different years, all were adjusted to 1984 dollars using the Consumer Price Index and the Engineering News-Record Cost Index. It is expected that these unit costs, which are presented in the original research (*1*), represent national average figures subject to adjustment in specific applications. For annual cost calculations, the capital costs of the terminal area were amortized over a twenty-year period using a 10 percent discount rate.

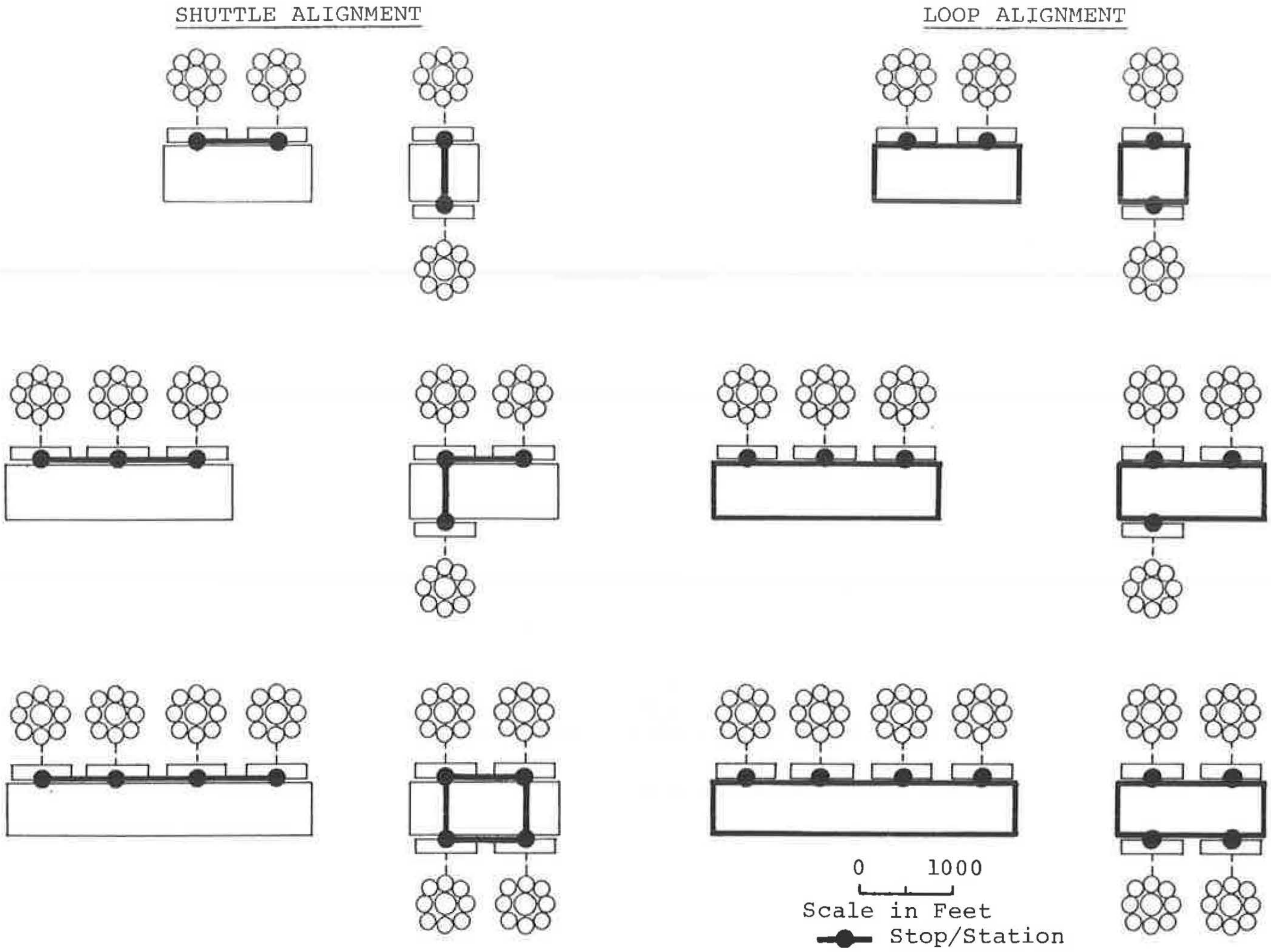


FIGURE 4 Intraairport transportation route system alternatives, satellite terminal units.

Intraairport Transportation System Costs

Unit costs were identified for both capital costs and operating and maintenance costs for moving walkways, bus transit systems, and automated guideway transit systems in airport applications. The cost of capital and operating costs of a moving walkway unit vary widely depending on the type of application and the area in which it is installed (*5*). Several sources (*6–8*) were reviewed, and costs based upon a linear foot measure were deemed appropriate for terminal concept planning. All costs were adjusted to 1984 dollars, as already noted. The approximate cost of installing a moving walkway unit, with a width of 40 inches and an operating speed of 120 feet per minute, is about $2,000 per linear foot. The annual operating and maintenance cost for such a unit is about $80 per linear foot.

It was assumed that the capital cost of a bus transit system for intraairport transportation consisted only of the cost of the vehicles required for service, since these vehicles would use existing terminal access roads. Normally, vehicle maintenance is performed off-site, and the system is operated on a contract basis. Costs were identified for two bus sizes, a conventional or standard urban diesel bus with a seating capacity of about 50 passengers and a minibus with a seating capacity of up to 25 passengers. The estimated capital costs in 1984 dollars for the conventional bus were taken as $125,000 and for the minibus, $80,000. Operating costs were developed on the basis of vehicle-miles of travel; these included such items as driver wages, maintenance, fuel, insurance, administration, and other variable costs associated with the provision of such service. Several sources (*6–11*) were reviewed to determine the approximate operating costs for bus operations on an airport site. The operating costs used in this study were $2.75 per vehicle-mile for the conventional bus and $2.50 per vehicle-mile for the minibus.

Since an automated guideway transit system requires the construction of an exclusive guideway and stations, the cost of these fixed facilities must be included as part of the capital cost estimate for such a system. A procedure developed in an Urban Mass Transportation Administration (UMTA) study (*12*) was used as the basis for preparation of cost estimates for the automated guideway transit system. Although the original procedure was prepared for downtown people-mover systems, it incorporated all of the required cost data for an airport application, and identified adjustments that should be considered when using the procedure for such an application. Data from all operating automated guideway transit systems were summarized in the UMTA study to develop unit costs. These costs were updated to 1984 dollars using the relevant cost indices and adjusted to include the most recent cost summary of such systems (*13*). Operating and maintenance costs for such systems were assumed to be $1.75 per vehicle-mile based on the UMTA study and other cost summaries.

The annual operating and maintenance costs of an automated guideway system are a function of the number of vehicles used in service, the service frequency or headway, the route distance, and the hours of system operation. These parameters have been estimated for each of the terminal modules used in this study. The annual capital costs have been calculated assuming a 10 percent discount rate and amortization periods of twenty years for moving walkways and automated guideway transit systems, ten years for conventional bus systems, and five years for minibus systems. Total annual costs were obtained by summing the annual capital, operating, and maintenance costs of each system.

Factors Affecting Needs for Intraairport Transportation Systems

Passenger Walking Distance and Travel Time Reduction

As an initial step in identifying the potential applications of intraairport transportation systems, approximate walking distances for passengers were calculated for each terminal unit. The distances shown have been derived using networks prepared for the development and testing of the terminal modules using the FAA queuing model (*4*). A typical distribution of passenger movement through a terminal unit was used. As might be expected, the lowest average walking distances between terminal curb and aircraft gate are observed for the linear and transporter modules, and the longest distances occur with the pier and satellite modules. A comparison of these calculated walking distances with the recommended guideline of a maximum passenger walking distance of 1,000 feet, the one recommended by the International Civil Aviation Organization (*14*) and the International Air Transport Association (*15*), suggests that intraterminal transportation systems be considered for inclusion in the basic eight-gate pier module and in both the basic eight-gate and the basic sixteen-gate satellite modules to reduce walking distance.

In determining the average walking distances for connecting passengers, several assumptions were made:

- that all connecting passengers transferred from one module to another module,
- that there was an equal distribution of connecting passengers among the modules,
- that all connecting passengers left the deplaning gate area of one module and proceeded through the central terminal area to the enplaning gate area of another module,
- that all connecting passengers used security in the module used for departure, and
- that connecting passengers did not use baggage check-in or claim facilities.

In virtually all cases, the average walking distance for connecting passengers transferring between modules is greater than 1,000 feet. Therefore, intraairport transportation systems were incorporated in all these terminal units to reduce the walking distances and related travel times for connecting passengers.

Trade-Off Considerations Used in Evaluation

Many factors could be included in an evaluation of the feasibility of incorporating intraairport transportation systems at airports, and these factors will vary from airport to airport to meet specific local concerns. Two factors, cost and convenience, were used in this study to provide a quantitative comparison that could then be used to identify trade-offs between system alternatives. The comparative measures that were used to evaluate cost were capital cost, operating and maintenance cost, total annual cost per passenger, and the incremental cost of including an intraairport transportation system in a terminal design plan. Those used to evaluate convenience included a reduction in passenger walking distance and its effect on passenger travel time.

RESEARCH RESULTS

Capital Costs

Using the unit costs and procedures presented earlier, estimates were made for the capital cost for each of the intraairport transportation systems for connecting passenger levels ranging from 10 to 50 percent of enplaned passengers. To illustrate typical results, the capital costs for 20 percent connecting passengers are given in Figures 5 and 6 for configurations A and B for each of the modules in both shuttle and loop alignments.

As would be expected, the cost of all transportation system alternatives increases as the number of modules increases. The costs of transportation system alternatives for configuration B modules are generally less than for configuration A modules because of the compactness inherent in the former. This results in shorter walking distances for connecting passengers and shorter guideway requirements for automated guideway transit systems. Because of the fixed guideway and station requirements, automated guideway transit system alternatives are the most expensive and the bus alternatives are the least expensive.

Similar conclusions result for other levels of connecting passengers, and the costs are approximately the same as the fixed facilities are required as a minimum cost for all passenger levels. The vehicle requirements vary with pas-

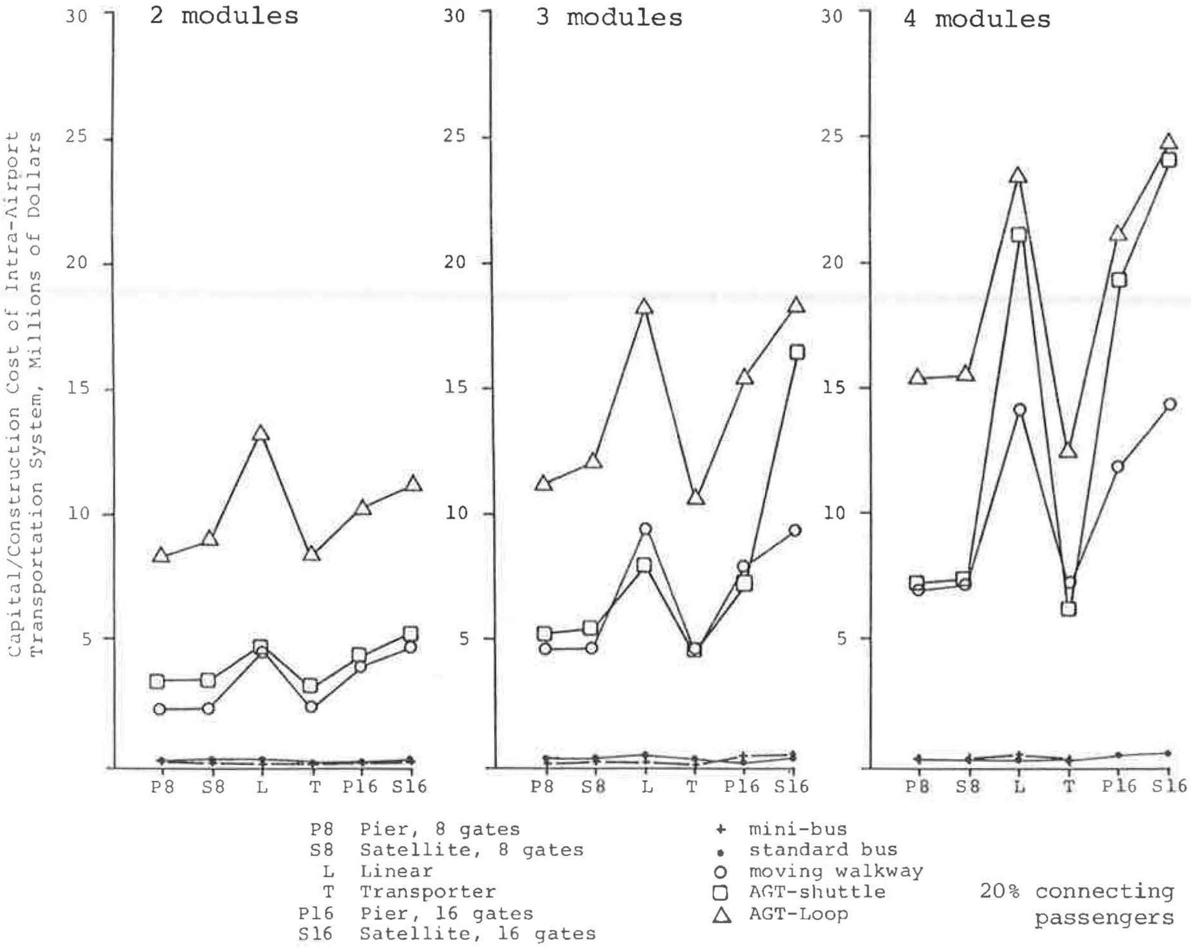


FIGURE 5 Capital costs of intraairport transportation systems, terminal configuration A.

senger levels. As a result, the capital costs of alternatives for higher connecting passenger levels are slightly higher, and the capital costs of alternatives for lower connecting passenger levels are somewhat lower. In many cases, however, the vehicle requirements are the same since headway requirements for the service govern this cost.

At low connecting volumes, the minibus is the least expensive alternative; as demand increases, however, additional buses are required and, at higher demand levels, the standard bus becomes the preferred alternative. When the demand exceeds 750 passengers per hour per direction at the maximum load point, the minibus cannot be used because its service capacity is exceeded. The capacity of conventional bus service is 1,500 passengers per hour per direction. Because of the greater length of fixed guideways, and that of routes on the terminal access roads, the capital costs of providing intraairport transportation service for the linear terminal concept are the highest.

Operating and Maintenance Cost

Another factor considered in assessing the cost of intraairport transportation system alternatives was the operating and maintenance costs. Estimates of annual operating and maintenance costs were made for each of the systems at connecting passenger levels varying between 10 and 50 percent of enplaned passengers using the unit costs and procedures discussed earlier. Figures 7 and 8 present illustrative cost estimates in a format similar to that used for capital costs.

The lowest annual operating and maintenance costs occur with automated guideway transit system alternatives, while moving walkways and bus alternatives involve the highest costs. Similar findings were observed for other connecting passenger levels.

Total Annual Costs

Total annual costs were estimated by amortizing the capital costs and adding the annual operating and maintenance costs. Two approaches have been used to compare annual costs. The first approach bases unit costs on annual cost per connecting passenger or user of the intraairport transportation system; the second bases them on the annual cost per enplaned passenger. Annual costs were developed for connecting passenger levels varying from 10 to 50 percent at various levels of annual demand. On the

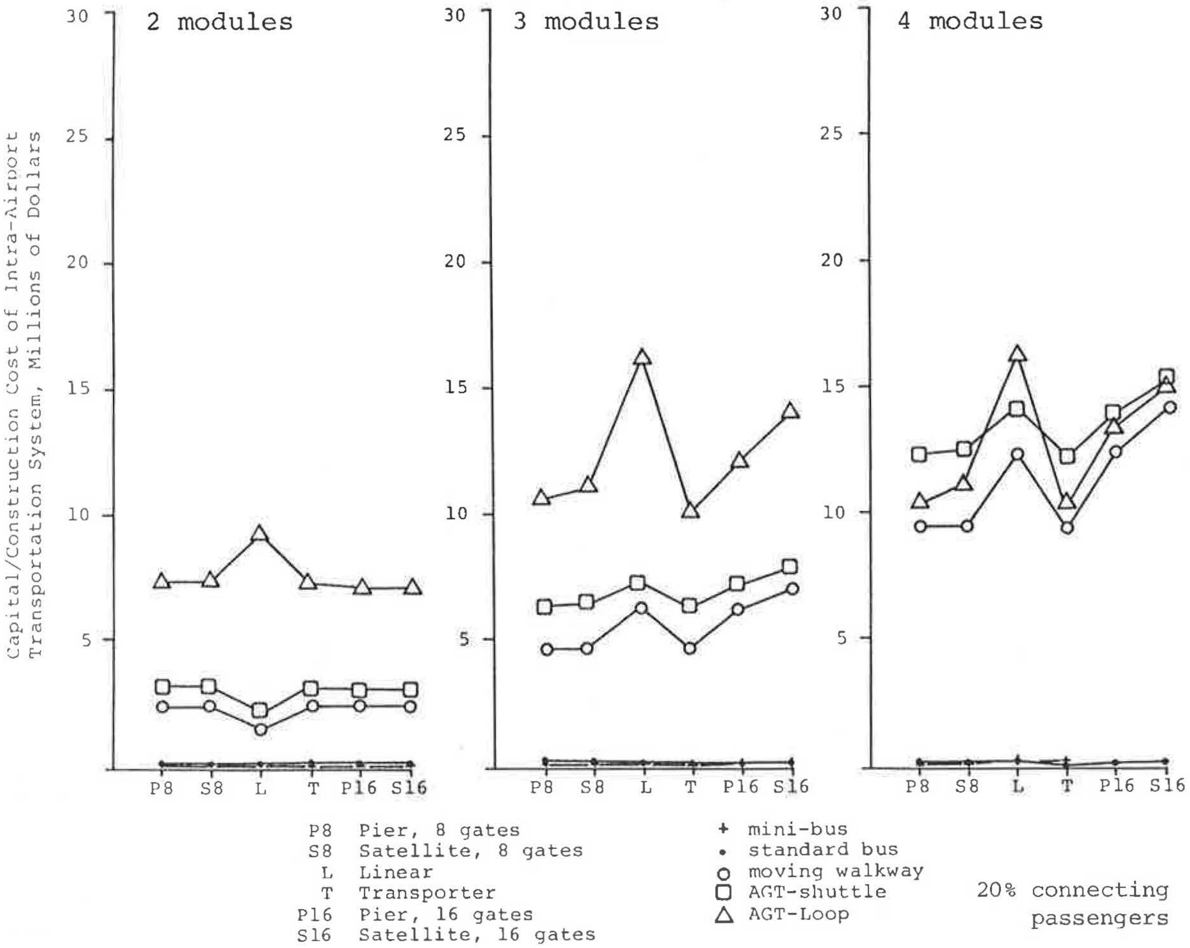


FIGURE 6 Capital costs of intraairport transportation systems, terminal configuration B.

basis of these cost studies, the expected ranges in total annual unit costs of five system alternatives based upon connecting passengers are presented in Table 2. This table indicates that the lowest unit costs are obtained for the pier configuration using the basic sixteen-gate module; the highest unit costs are obtained in the linear concept using the basic eight-gate module. By considering the connecting passenger demand on each of the terminal unit configurations, it was found that there were wide variations in annual unit costs for the loop and shuttle alignment of the automated ground transport systems, moving walkways, conventional bus, and minibus. Estimated average annual unit cost curves are presented for each of these systems in the original research (*1*).

Incremental Costs

The cost of incorporating intraairport transportation system alternatives into an airport was combined with terminal area costs to ascertain the impact of such systems on overall terminal development costs. The average percentage increase or decrease in annual cost per enplaned passenger caused by the addition of an intraairport transportation system for connecting passengers is summarized in Table 3 for each terminal concept and configuration. For this study, it was assumed that only one means of transfer would be provided for passengers between modules. As a result, negative values appear in this tabulation for cases where an intraairport transportation system that transfers passengers between terminal modules would have a lower cost than extending the terminals and providing a walking link. In actual terminal planning, modules that are located close to each other would be linked, and passengers may have several choices for movement within the terminal.

It is apparent from the data presented in Table 3 that the additional annual cost per enplaned passenger for the incorporation of intraairport transportation systems into terminal units at airports is relatively small, ranging up to a maximum of about 23 percent in the most costly case.

Travel Time

The automated guideway transit alternatives are naturally the most expensive options examined in the study. When evaluating intraairport transportation systems, however,

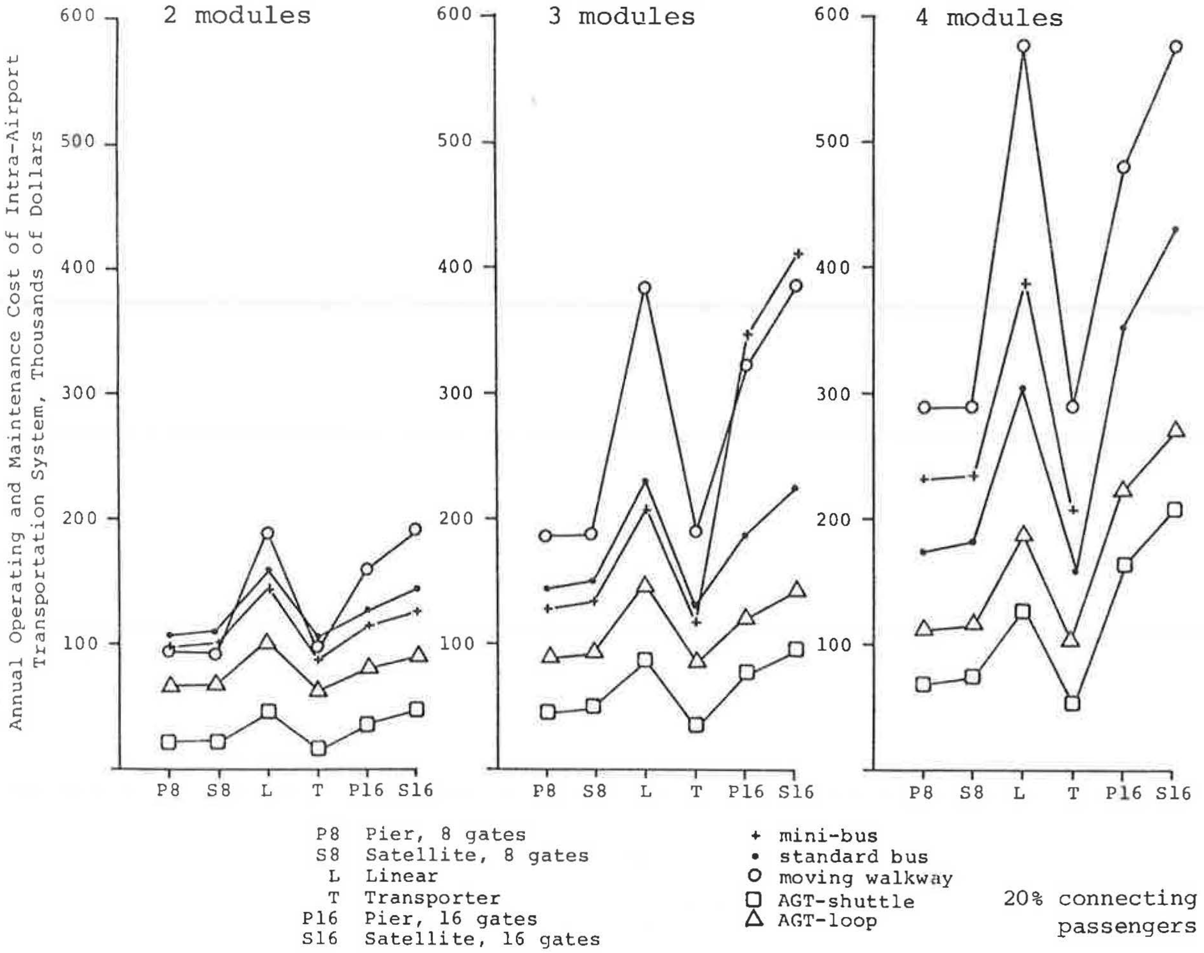


FIGURE 7 Operating and maintenance costs of intraairport transportation systems, terminal configuration A.

trade-offs are expected to be made. Because of higher operating speeds, it is anticipated that automated guideway transit would rank high in convenience measures. One measure of convenience that has been considered in this study is travel time. This time also has an impact on airlines in that increased connecting passenger travel time affects, at least to some extent, the minimum connecting time for passengers.

The average percentage increase or decrease in travel time with an intraairport transportation system compared to walking only is summarized in Table 4. The largest reductions in travel time are obtained by incorporating automated guideway transit on the shuttle alignment. This alignment would be similar to a direct route that a connecting passenger walking from arrival gate to departure gate would follow when automated guideway transit has been used to replace walking over a portion of the trip. Larger reductions may be achieved for the pier and satellite concepts by selecting an alignment that reduces the walking portion even further. Moving walkways are frequently used to replace walking on a direct trip. Since the operating speed of moving walkways is less than walking speed, however, the travel time from gate to gate with moving walkways may actually increase. Since both the bus system and the automated guideway transit system on a loop alignment follow the terminal access road, the routing is not as direct and the reduction in travel time is not as pronounced as those of the more direct routing of the latter system on a shuttle alignment.

Walking Distance

Often intraairport transportation systems have been incorporated in terminals to reduce the walking distances for connecting passengers. Average walking distances for connecting passengers have been determined both with and without an intraairport transportation system. Figures 9 and 10 show these results for configuration A and configuration B modules, respectively. It is apparent that the provision of such a system results in significant reductions in connecting passenger walking distance.

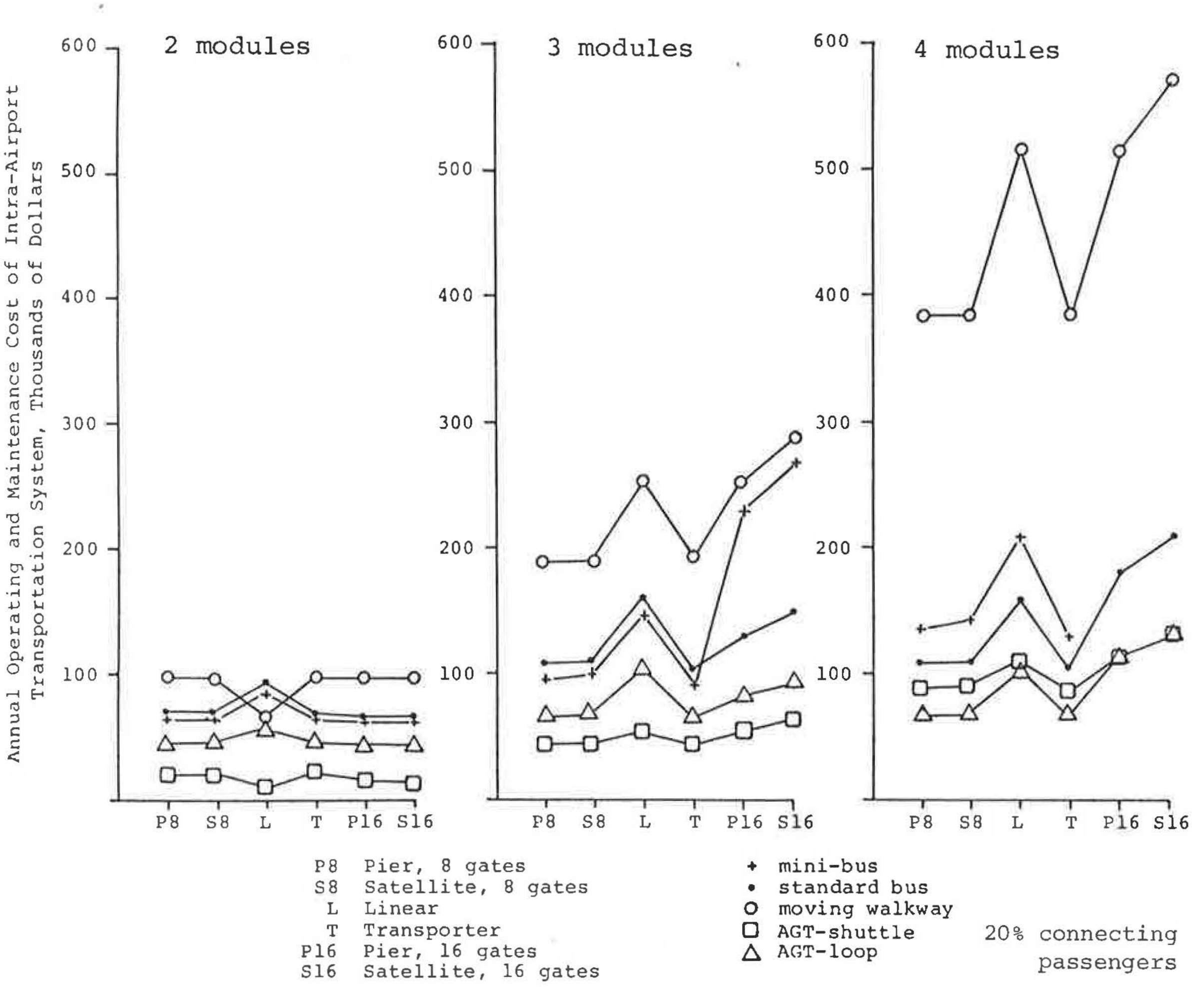


FIGURE 8 Operating and maintenance costs of intraairport transportation systems, terminal configuration B.

TABLE 2 RANGE IN ANNUAL COSTS PER CONNECTING PASSENGER OF INTRAAIRPORT TRANSPORTATION SYSTEMS (DOLLARS)

		Intra-Airport Transportation System *				
Terminal Concept	Terminal Configuration	Minibus	Standard Bus	Moving Walkway	AGT-Shuttle	ACT-Loop
Pier (8)	A	.16-.69	.14- .74	.38-2.83	.44-2.36	1.00-5.55
	B	.10-.46	.09- .49	.38-3.78	.41-3.90	.75-4.64
Satellite (8)	A	.17-.71	.15- .75	.38-2.83	.45-2.40	1.02-5.70
	B	.10-.47	.09- .50	.38-3.78	.41-3.99	.79-4.64
Linear (8)	A	.23-.94	.20-1.01	.76-5.76	.63-6.70	1.58-8.52
	B	.15-.63	.11- .67	.25-5.04	.28-4.49	1.08-6.74
Transporter (8)	A	.16-.56	.12- .60	.38-2.83	.40-2.04	.84-5.30
	B	.10-.43	.09- .45	.38-3.78	.44-3.86	.66-4.64
Pier (16)	A	.17-.56	.10- .42	.31-2.36	.29-3.00	.72-3.31
	B	.09-.26	.05- .28	.19-2.52	.20-2.23	.45-2.59
Satellite (16)	A	.20-.62	.11- .48	.38-2.83	.34-3.73	.73-3.83
	B	.10-.32	.05- .32	.19-2.83	.20-2.46	.45-2.95

* Low end of range is for 4 modules, 50% connecting passengers; upper end of range is for 2 modules, 10% connecting passengers.

TABLE 3 AVERAGE PERCENTAGE INCREASE OR DECREASE IN ANNUAL COST PER ENPLANED PASSENGER OF TERMINAL AREA WITH ADDITION OF INTRAAIRPORT TRANSPORTATION SYSTEM FOR CONNECTING PASSENGERS

		Intra-Airport Transportation System				
Terminal Concept	Terminal Configuration	Minibus	Standard Bus	Moving Walkway	AGT-Shuttle	AGT-Loop
Pier (8)	A	0.2	-0.2	6.6	4.6	12.1
	B	0.6	0.4	6.7	6.4	9.5
Satellite (8)	A	0.1	-0.2	6.2	5.0	12.3
	B	0.5	0.3	6.7	6.4	9.7
Linear (8)	A	3.5	3.0	13.6	13.2	22.7
	B	1.9	1.5	8.0	7.5	14.7
Transporter (8)	A	1.9	1.6	6.5	5.4	12.5
	B	1.2	1.0	6.5	6.9	9.7
Average for 8 Gate Modules		1.3	0.9	7.7	6.9	12.9
Pier (16)	A	-1.6	-1.7	5.1	3.2	6.0
	B	-0.6	-0.4	4.1	3.2	4.7
Satellite (16)	A	-3.6	-3.7	5.8	2.3	4.5
	B	-1.4	-1.2	4.4	2.6	4.0
Average for 16 Gate Modules		-1.8	-1.8	4.9	2.8	4.8

TABLE 4 AVERAGE PERCENTAGE INCREASE OR DECREASE IN TRAVEL TIME WITH INTRAAIRPORT TRANSPORTATION SYSTEM FOR CONNECTING PASSENGERS

		Travel Time with Intra-Airport Transportation System *					
Terminal Concept	Terminal Configuration	Average Travel Time ** Walking Only (minutes)	Minibus	Standard Bus	Moving Walkway	AGT-Shuttle	AGT-Loop
Pier (8)	A	11.9	-1	+1	+18	-22	-9
	B	11.1	-5	-2	+18	-17	-9
Satellite (8)	A	14.9	-4	-2	+16	-20	-9
	B	13.7	-3	-1	+15	-13	-10
Linear (8)	A	11.8	+1	+4	+62	-31	-12
	B	8.3	+16	+20	+39	-11	+6
Transporter (8)	A	6.5	+16	+21	+40	-18	+2
	B	7.1	-9	-4	+33	-25	-14
Pier (16)	A	19.4	-18	-18	+19	-35	-26
	B	15.4	-9	-8	+16	-19	-14
Satellite (16)	A	23.4	-20	-19	+19	-38	-29
	B	17.8	-11	-10	+14	-22	-16

* Compared to walking only.

** Travel time for connecting passenger, arrival gate to departure gate.

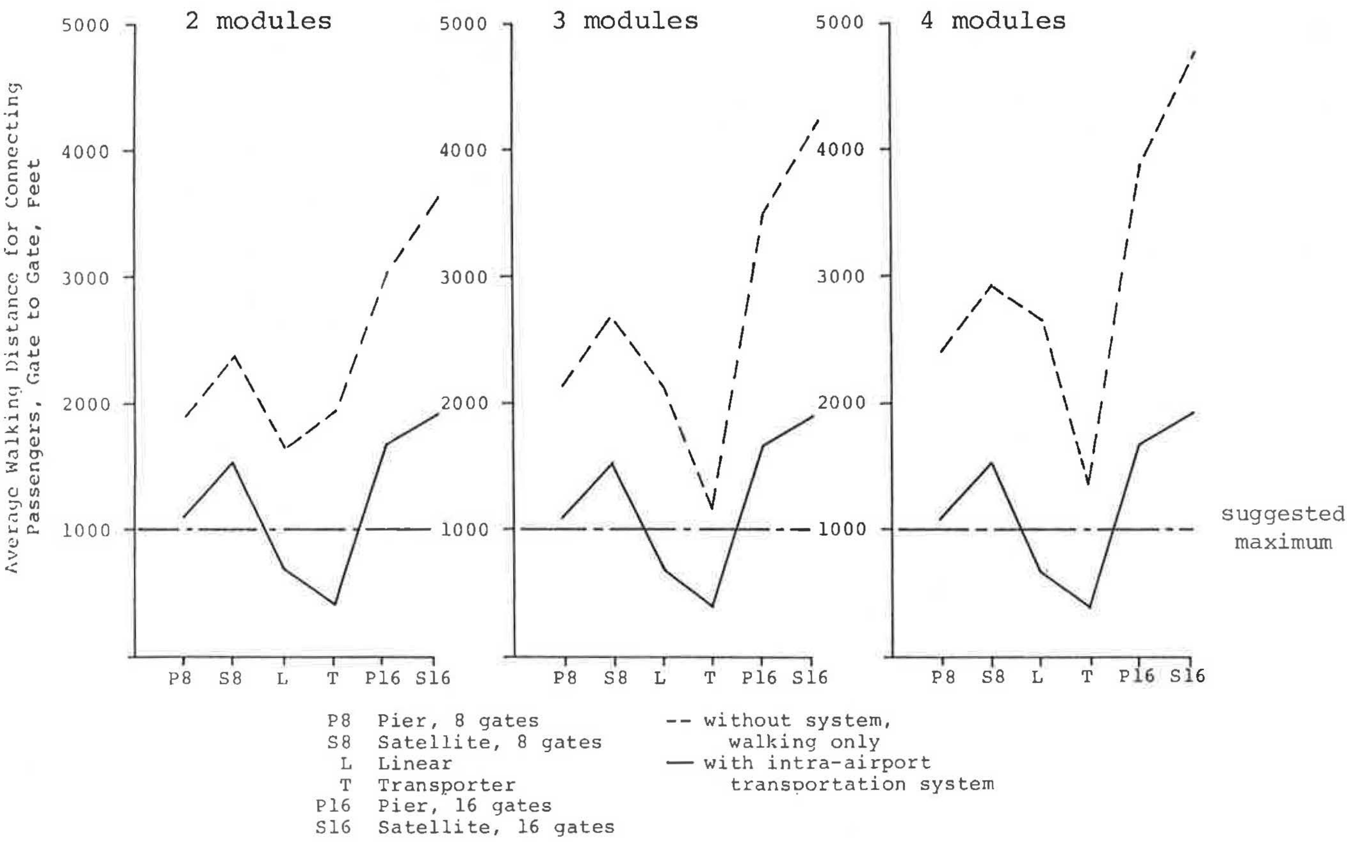


FIGURE 9 Average walking distance for connecting passengers, terminal configuration A.

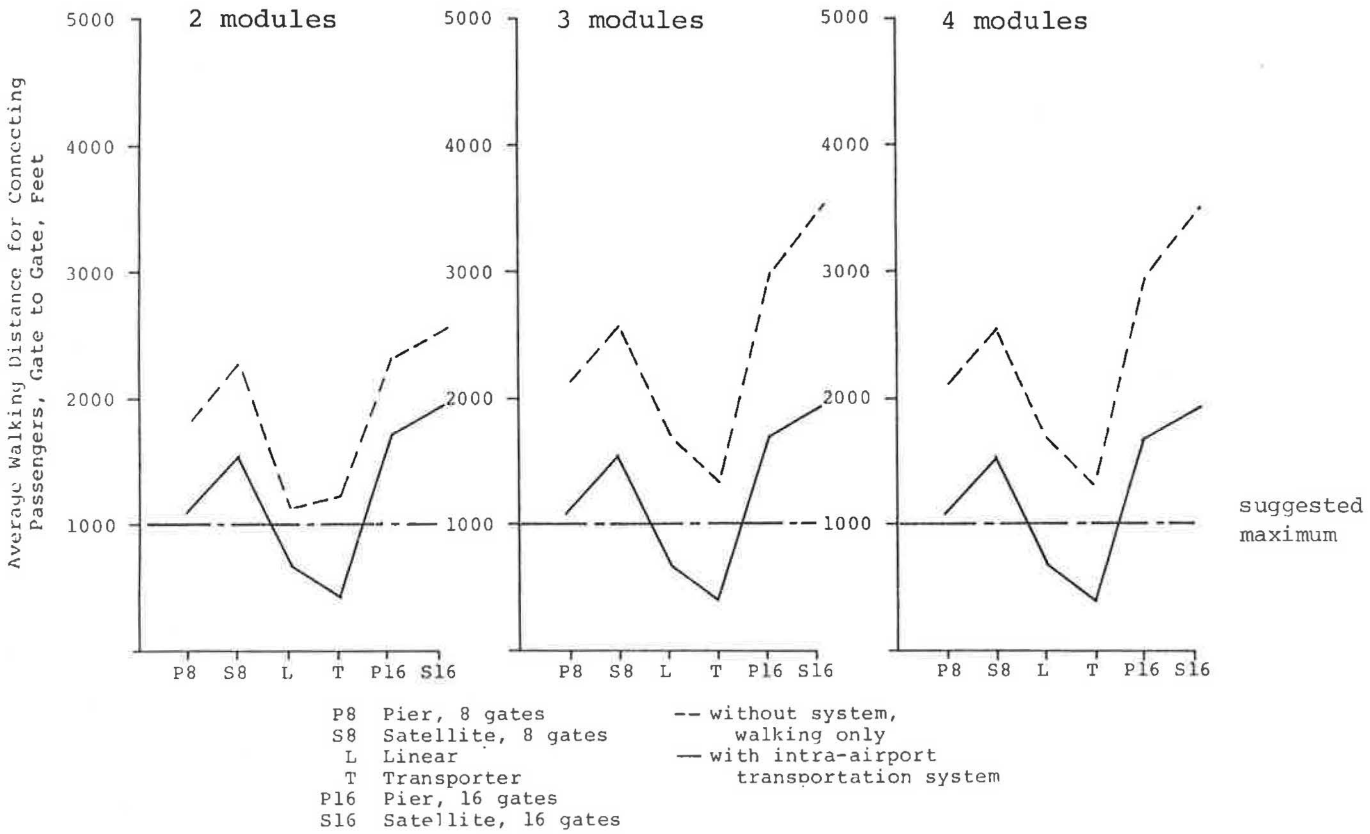


FIGURE 10 Average walking distance for connecting passengers, terminal configuration B.

SUMMARY AND CONCLUSIONS

This paper has presented research results that are of considerable value to airport operators, airlines, and planners considering the incorporation of intraairport systems into airport terminals for the purpose of improving connecting passenger circulation. Guidelines have been presented that will allow for a determination of appropriate applications for such systems, an estimation of the benefits in terms of reduced passenger walking distance and travel time, and an estimation of the total and incremental costs of such systems.

Overall, this research indicates that intraairport transportation systems operating in linear concepts are the most costly and that those operating in pier, satellite, and transporter concepts are the least costly on the basis of total annual costs per enplaned passenger. Bus systems have the lowest costs but are subject to capacity restraints at relatively low passenger volumes. Minibus systems are appropriate for annual demands ranging up to about 1 million annual connecting passengers. Automated guideway transit systems are the most expensive to incorporate, but they become appropriate for airport applications when the annual connecting passenger volume begins to exceed 2.5 to 3 million.

A direct or shuttle type alignment for intraairport transportation affords the greatest reductions in walking distance and travel time for connecting passengers and results in the lowest costs. The impact on the annual cost per enplaned passenger of incorporating an intraairport transportation system for connecting passengers varies with the system, terminal concept, terminal configuration, and level of connecting passengers. The largest impact occurs with the automated guideway system operating on a loop alignment in a linear concept. Finally, the walking distance guideline becomes an important consideration in identifying intraairport transportation system alternatives.

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DISCUSSION

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The issue addressed in this paper, development of planning guidelines and unit cost estimates for the incorporation of intraairport transportation systems into terminal facilities, is an important and challenging one. A proven set of guidelines is yet to be developed. The authors have made great efforts to include as many parameters as possible for evaluation purposes. What should be stressed most is the incorporation of the disutility associated with passenger walking, which has been neglected in most of the literature on this subject. Possibly because of the number and diversity of the parameters considered, the authors have failed to achieve their main goal of providing a clear set of guidelines for planners.

The analysis has been restricted to two basic unit terminals with eight and sixteen gates and their combinations. Since the authors admit that the terminal facilities would not be increased proportionately to passenger demand (number of gates), it would have been more appropriate if the proposed method was made capable of handling any size unit terminal. As an example for the pier concept, a terminal with three piers may have a lesser average passenger walking distance compared to an equal size terminal with two piers. On the other hand a single terminal with thirty-two gates may be more economical than two terminals with sixteen gates each.

The two measures that have been considered to represent the disutility associated with walking, the average walking distance and the change in travel time due to intraairport transportation system, have been calculated and compared mainly for connecting passengers. Average walking distance based on connecting passengers may not represent the actual walking distribution, because the walking distance for originating and terminating passengers is neglected. The preceding is more significant when the percentage of connecting passengers is relatively small. As an example, for the pier concept, four modules of eight-gate unit terminals may have a higher average walking distance than two modules of sixteen-gate unit terminals if only connecting passengers are considered. When all the passengers are taken into account, however, the preceding may not be true, especially when the percentage of connecting passengers is low.

In determining the average walking distance for connecting passengers, the authors have assumed that all connecting passengers transfer from one module to another. The distribution of connecting passengers among the modules is equal. By making these assumptions, they have missed the possible transfers within a terminal. This will be more significant when the module size increases while the number of modules decreases.

When defining the cost components for comparison purposes, the authors have clearly shown that the cost of the intraairport transportation system correlates with the percentage of connecting passengers by presenting the cost values on a per connecting passenger basis. Later, they neglect this fact, and the total cost of the system is compared on a per enplaned passenger basis. The preceding comparison may not be realistic as the number of connecting passengers has been defined as a percentage of the total enplanements (annual demand). Consider two different situations with an equal annual demand, D, and $P1$ and $P2$ percent connecting passengers. Let $P1 < P2$, and it is decided to provide an intraairport transportation system that costs $X1$ and $X2$ dollars, respectively, where $X1 < X2$. If the terminal cost, C, is assumed to be the same, the situation with $P1$ percent connecting passengers will have a lesser total cost per enplaned passenger. It is necessary, however, to consider the possibility that the cost of the intraairport transportation system per connecting passenger for the second case ($100*X2/(P2*D)$) is less than that for the first case ($100*X1/(P1*D)$). As the terminal facility is used by all the passengers and the intraairport transportation system is used by only the connecting passengers, it would have been more appropriate if the total of terminal cost per enplaned passenger and intraairport transportation system cost per connecting passenger were considered instead of the total cost per enplaned passenger. This will allow the planners to choose for a higher-cost alternative when the percentage of connecting passengers is high.

AUTHORS' CLOSURE

Bandara has made a good point about the consideration of the disutility associated with passenger walking. However, the two measures of disutility considered, walking distance and travel time, are the most predominant measures of disutility normally considered in passenger terminal planning. It is difficult to consider other disutility measures, such as the value of time, without a distinct consideration of the type of market being served, for example, business versus tourist. In the case of the research reported in this paper the results were not determined for a single type of airport but were generalized to provide some guidance to airport planners in a variety of situations. It is true that such a generalization may not result in findings that are applicable to a specific airport design, but it does provide a framework from which consideration of intraairport transportation systems might be initiated for a specific airport application. The study was limited in its scope to the consideration of only eight- and sixteen-gate modules because of resource constraints. It is expected that by presenting the relevant information associated with these data points, a determination of the approximate ranges in cost and utility might be possible. Since the cost data used in the study were average costs obtained from a variety of automated ground transportation and airport studies, it is possible that a given airport study may obtain different results owing to the specific costs associated with the project. It is reasonable, however, to expect that the overall ranges in costs and utility should not be significantly different from those obtained in this study. It should be emphasized that the paper presents a summary of the findings of the original research and does not contain all of the information found in that study. For example, Bandara indicates the potential variability of the results for differing percentages of connecting passengers and the fact that the paper presents annual costs in light of a cost per connecting passenger. The original research addresses both of these items in that varying percentages of connecting passengers were utilized in the analysis and the annual costs were also obtained on the basis of a cost per enplaned passenger. This research was not intended to stand alone as the definitive study of the incorporation of intraairport transportation systems but was meant to contribute to existing knowledge of such systems.

Use of Acoustic Examples in Airport Noise Planning and Decision Making

DAVID DUBBINK

A general understanding of noise measurement metrics is a critical element in applying land use/noise exposure criteria such as those contained in the Federal Aviation Administration's (FAA's) Airport Noise Compatibility Planning Program, FAR Part 150, or the military's AICUZ program. The author has developed a presentation system that blends computer-based training techniques with digital recording technology. An interactive presentation package has been created (for the FAA's Department of Environment and Energy) that treats the multiple elements of an airport land use/noise management program. Acoustic examples illustrate such concepts as differences between stage II and stage III aircraft, effects of flight track, and profile changes and alternate levels of building insulation. The presentation describes the system and its features. It then considers the political context of noise management decisions and how the introduction of specific noise examples might affect the decision process. Although experience with the system is not yet extensive, two effects have been observed. First, it appears that acoustic examples act to broaden the range of noise management strategies under public consideration. Second, because the system can produce site-specific noise data, it encourages personal questions about noise exposure from individual citizens. Although these features enrich the planning process and increase public understanding, they are not politically neutral. The paper notes that the broadening of strategies can also complicate decisions and that the personalization of noise impact can sharpen responses. Generally, the system has been successful in increasing community understanding of noise issues and the effectiveness of alternate noise management strategies.

This paper looks at a new technique for presenting information about noise in the airport environment. It uses acoustical examples to explore noise management questions. After briefly considering the ways in which acoustic examples have previously been used in decision settings, focus is placed on the features of the new system. With the technology explained, consideration is given to how such a system can affect the decision environment.

Noise problems exist at many airports in the United States. More than a third have adopted policies that restrict operations in ways that are intended to reduce aircraft noise to adjacent communities. The Federal Aviation Administration (FAA) and Congress have developed a process of airport planning that assigns significant responsibilities to local decision makers. Although the FAA cannot approve local programs that create an "undue burden on interstate or foreign commerce," it has sanctioned plans that include restrictions on operations of noisy aircraft. Such local regulations affect the whole national system of airports and air travel, since restrictions on a type of aircraft at one airport affect all airports served from that location, as well as the way airlines assign available aircraft over their route system (*1*).

Planning at the local level can be an intensely political and controversial process. In the case of airport planning, the already difficult process of rational plan making is complicated by the complex mix of elements involved in airport noise management and by the unwieldy metrics of noise measurement that most people do not really understand. These two issues, coupled with the national reliance on a multiplicity of local planning efforts, make the uniform and effective presentation of noise planning data a topic of great importance.

ACOUSTIC EXAMPLES

One obvious path to presenting easily understood information about aircraft noise is to use acoustic examples. There is an extensive but mostly unreported history of the use of such examples in public hearing settings. Engineers and planners with the responsibility for presenting information about noise usually include examples of some sort so that laymen can gain some perspective on what is being discussed. Practically every acoustic report on noise intended for nontechnical readers includes a table listing the decibels associated with a collection of familiar sounds. The reader uses memory and imagination to relate the tables to whatever noise management issues are under discussion. However, good acoustic memory is rare. Only 2 percent of the population have "perfect pitch," and such tables probably have little authentic ability to convey noise information.

More ambitious presenters have taken to the field, placing observers near an airport at what is estimated to be a noise exposure contour line, awaiting overflying planes, verifying the noise exposure level with sound level meters. This approach is not only unpredictable and awkward, it is also not portable and nonrepeatable, and is limited in

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its ability to describe noise remedies, such as noise abatement flight procedures, quieter aircraft, or soundproofing.

Other presenters have opted for the use of recorded sounds. This has the advantages of controllability and convenience. Modern recordings can be quite realistic, particularly wide-tape format, high-fidelity, or PCM digital recordings. The problem is that recordings sound "different" out of context, and the duration of a presentation requires an unusually patient and receptive audience.

Videos and movies have been produced for the specific purpose of informing the public about noise control methods. The New Jersey Highway Department has produced an excellent video explaining the capabilities of roadway noise barriers. The production of a movie or video is technically demanding, time-consuming, and expensive. Because such programs tend to be generalized and not problem-specific, an audience may become impatient when they are used in presentations. Several agencies that have sponsored films and videos for use at public hearings have reported that they seldom use them because of this problem.

INTERACTIVE SOUND INFORMATION SYSTEM

This discussion reports on experience with a new technique for presenting noise information to decision makers and concerned citizens. The concept borrows from interactive computer training methods and digital recording technology. The system, the Interactive Sound Information System (SIS), has been used for making presentations about issues such as highway noise, noise barrier construction, outdoor loudspeakers, and the features of local ordinances proposed for controlling noise. The system uses mostly standard computer and sound reproduction equipment; however, the software and some essential hardware are proprietary and unique to the ISIS package.

The FAA's Office of Environment and Energy has sponsored production of a presentation package based on the ISIS concept that is designed for use in airport noise/land use management programs. The FAA has purchased several complete packages that are to be made available to local planners for use in planning work. The FAA actively encourages and requires community involvement as a feature of all sponsored programs. Public law requires this, and it is carried into numerous department policies, orders, and advisory circulars (*2*):

> Public hearings, public information sessions, coordination meetings and other communications conducted for the purpose of ensuring that the planning study receives input and is fully coordinated with the public, and with interested parties (i.e., planning agencies, community organizations, affected jurisdictions, airport users) are extremely important and essential activities in a planning study.

The FAA sees the ISIS package as a mechanism for communicating technical information about airport noise to citizens and decision-making groups. The program was designed for consultation with federal officials and local airport planners around the country. The programming has been structured to reflect the presentation requirements of this group.

The system is intended to be a presentation maker's tool, as an aid in addressing individuals, small groups, or larger audiences. It uses acoustic examples (recorded digitally) to illustrate a variety of points related to airport noise management. A microcomputer randomly accesses the sounds and plays them back at precisely set volumes. Sounds are correct to the nearest 0.75 db (at a reference point in terms of sound pressure level [SPL]). Images on the computer's screen dramatize presentation points and control the direction of a presentation. Selections among program options are made using a "mouse."

The FAA Program

The FAA asked for a program that included both novice and expert levels. The novice mode is a turn-the-switch operation with a preset presentation. The expert mode allows for custom programming. It is organized in a simple loop structure with all presentation segments accessed from a central menu that shows all available program options (Figure 1). On termination, all options return to the same menu. The menu options can be selected in any order. Several features of this initial menu deserve mention. It has the graphic quality of a slide rather than a computer program. The text is in neat Helvetica type, in color and drop-shadowed on a gray background. Throughout, the program graphics have been designed to provide visual support and reinforcement to the acoustic points being made. A deliberate decision was made, however, to make very limited use of animation to avoid any resemblance to computer games.

It should also be noted that the divisions of this menu are not just a programming convenience. There is a not-so-hidden agenda here. The menu presents airport noise management issues as a collection of elements: aircraft,

FIGURE 1 Central menu of program options.

flight operations, land use compatibility, and sound insulation. The idea is to offer a framework for plan making that includes the full action agenda offered with this menu. As is discussed later, community debate on airport noise problems is often more limited than this.

Calibration Sequence

The calibration sequence has been given greater graphic attention, more than is normally associated with the calibration of a technical instrument (Figure 2). In earlier versions of the ISIS package, the programming of this segment was more pedestrian. It was found that the audience for a presentation was intensely interested in how closely the sounds produced by the system match the levels illustrated on the screen. With the system's 0.75 db resolution, a near-perfect match is normal. In a typical presentation, noise meters are provided to listeners so they can verify the accuracy of the system.

The boxes on the calibration screen ("ON," "OFF," "SWITCH," etc.) can all be selected using the mouse pointer. When the left side selected is "ON," a tone of 75 db is heard. When the "ADJUST" feature is selected, the pointer can be used to alter the volume level by dragging the bar shown on the center scale to the desired decibel level. An independently controllable tone is manipulated from the right side of the screen, and sounds are produced from the corresponding left and right stereo speakers of the sound system.

The setup can also be useful for presenting acoustic fundamentals (e.g., demonstrating the perceptual "doubling" of sound that takes place with 10-db changes, or that the limit of perceived differences in SPL is around 3 db).

Sound Library Sequence

The library sequence is the ISIS counterpart of that traditional page, found in so many consultant reports and texts, that lists the sound exposure levels of a collection of familiar sounds. The difference here is that you can hear any of these sounds individually or in pairs. The sound library includes a collection of environmental sounds as well as field recordings of the takeoffs and landings of the nation's most prevalent aircraft (Figure 3). The figure shows several screens from the collection of possible images. The underlying image represents a listing of commercial aircraft with two selected. The overlay shows images of the selected aircraft and associated peak sound (L_{max}) during takeoff. The sound levels presented are based on predictions produced by the FAA's Integrated Noise Model (INM).

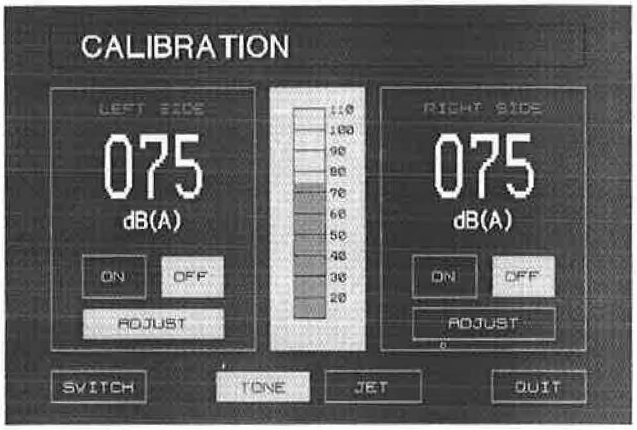


FIGURE 2 Calibration sequence.

Any sound pair could be selected, but primary use of the segment is to demonstrate the differences between stage II and stage III aircraft. The differences among aircraft can be dramatic. Most sequences include similar control boxes. In terms of general program design, it should be noted that the ISIS system makes heavy use of sounds presented as pairs. This reflects the psychoacoustic concept that sounds are perceived in relative rather than absolute terms. Perceived loudness is determined by context. As a result, people hearing the program at different distances from the equipment report similar experiences during these comparison sequences even though the sound pressure levels they hear are quite different from those heard at other room locations.

Distance Effects Sequence

The distance effects segment deals with flight-track and profile issues. The segment is quite simple in terms of its underlying structure. There is an index map that permits selections of local area maps (Figure 4). The underlying map is the index map, and the overlay shows a local area detail map. The numbered boxes in the detail maps are used to access recordings of aircraft flyovers as they might be heard at each location. Again, volumes used are based on predictions made through the grid report feature of the INM. Up to 81 locations can be coded into the maps.

Any sort of map or diagram can be inserted into the space above the controller boxes. The examples show maps originally produced by a commercial mapping system called LANDTRACK. Images can also be digitized from photos or through the use of a scanner. The presentation package includes a procedure for placing the boxes on the screens as well as for setting the volumes corresponding to each location. The presenter can choose from recordings of direct overflights, near distance, and remote aircraft flyovers.

Day/Night Levels Sequence

Day/night sound exposures are cumulative, twenty-four-hour composites where nighttime sounds are weighted with a 10-db penalty (Figure 5). This is a nationally

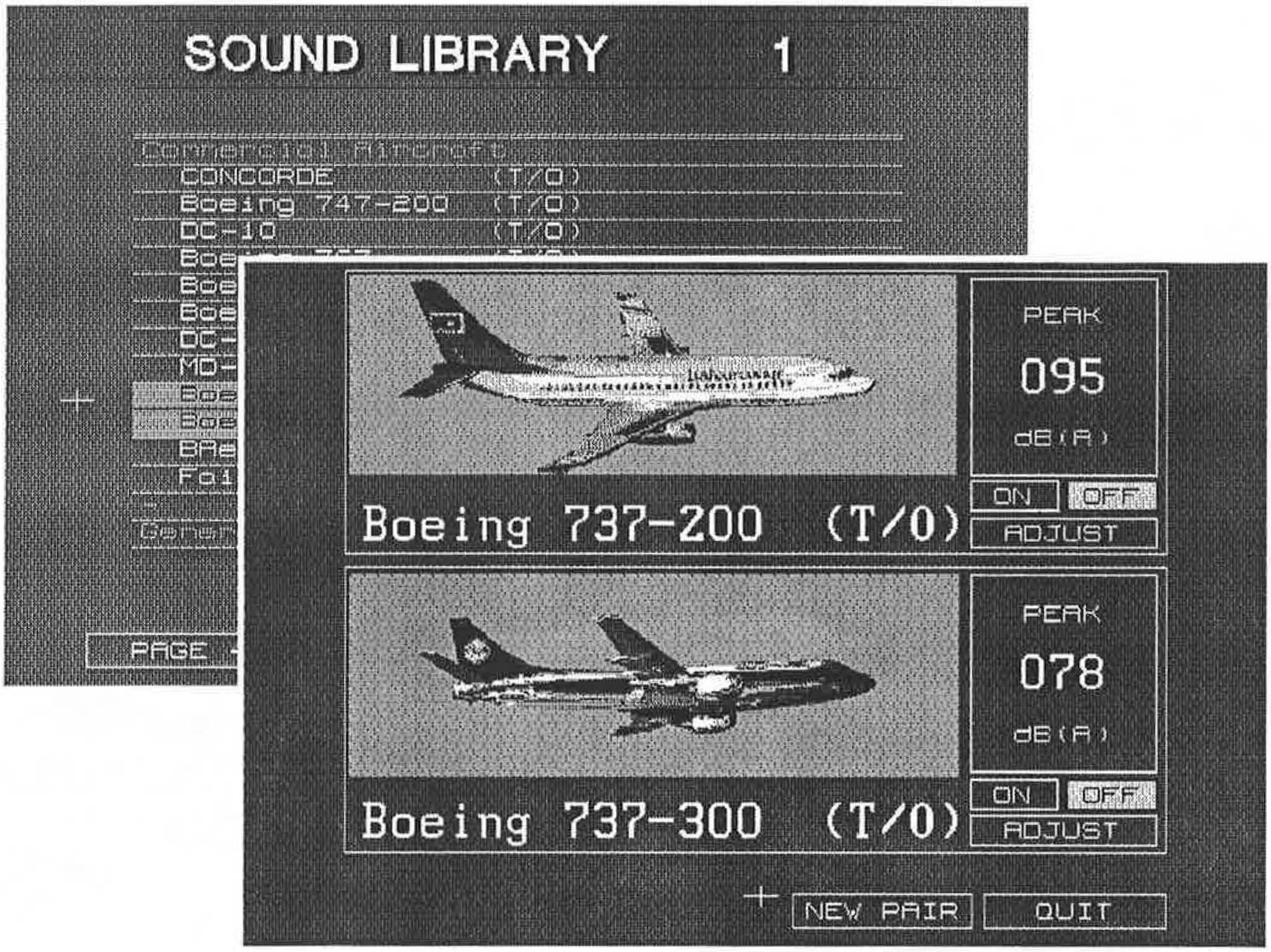


FIGURE 3 Sound library sequence: underlay shows the options; overlay shows how selections are presented.

recognized and useful standard for measuring airport noise but one that is exceptionally difficult to explain, particularly when it is presented as contour lines on a map. The underlying image shows daily flight operations for aircraft that are representative of operations at an airport.

Aircraft can be highlighted with the pointer. If the box labeled "Listen" is selected from the options arranged along the bottom of the screen, a picture of the highlighted plane will appear and a takeoff (or landing) will be heard, as shown in the overlay image. By selecting the "Edit" box, the numbers of day or night operations can be changed for any aircraft and, with these, the cumulative L_{dn}. The "Info" box produces a plane picture accompanied by some lines of text describing the aircraft's size and performance.

The control box labeled "Screen" swaps the entire page of listed aircraft with an alternate list of planes and operations. This feature permits a presenter to step quickly between alternate scenarios of flight operations. The feature is used to illustrate such concepts as differences between present and future airport use patterns. While it is not possible to hear L_{dn}, the sequence does permit an audience to hear individual noise events and, by adding them to and subtracting them from the airport mix, to see how the events affect L_{dn}.

Insulation Sequence

This sequence illustrates how sounds are heard outdoors and indoors at various levels of reduction reflecting acoustic insulation (Figure 6). The noise reduction levels shown correspond to FAA recommendations for noise-compatible land uses in different noise exposure areas.

This segment has a special comparative feature, a "TV" with an adjustable volume control. The TV volume can be adjusted to whatever the user thinks is a comfortable listening level, and the sounds of a flyover can be produced, attenuated to correspond to the specified level of sound insulation.

Other Details

The Definition Sequence is a collection of graphic screens designed to illustrate technical concepts and themes. The

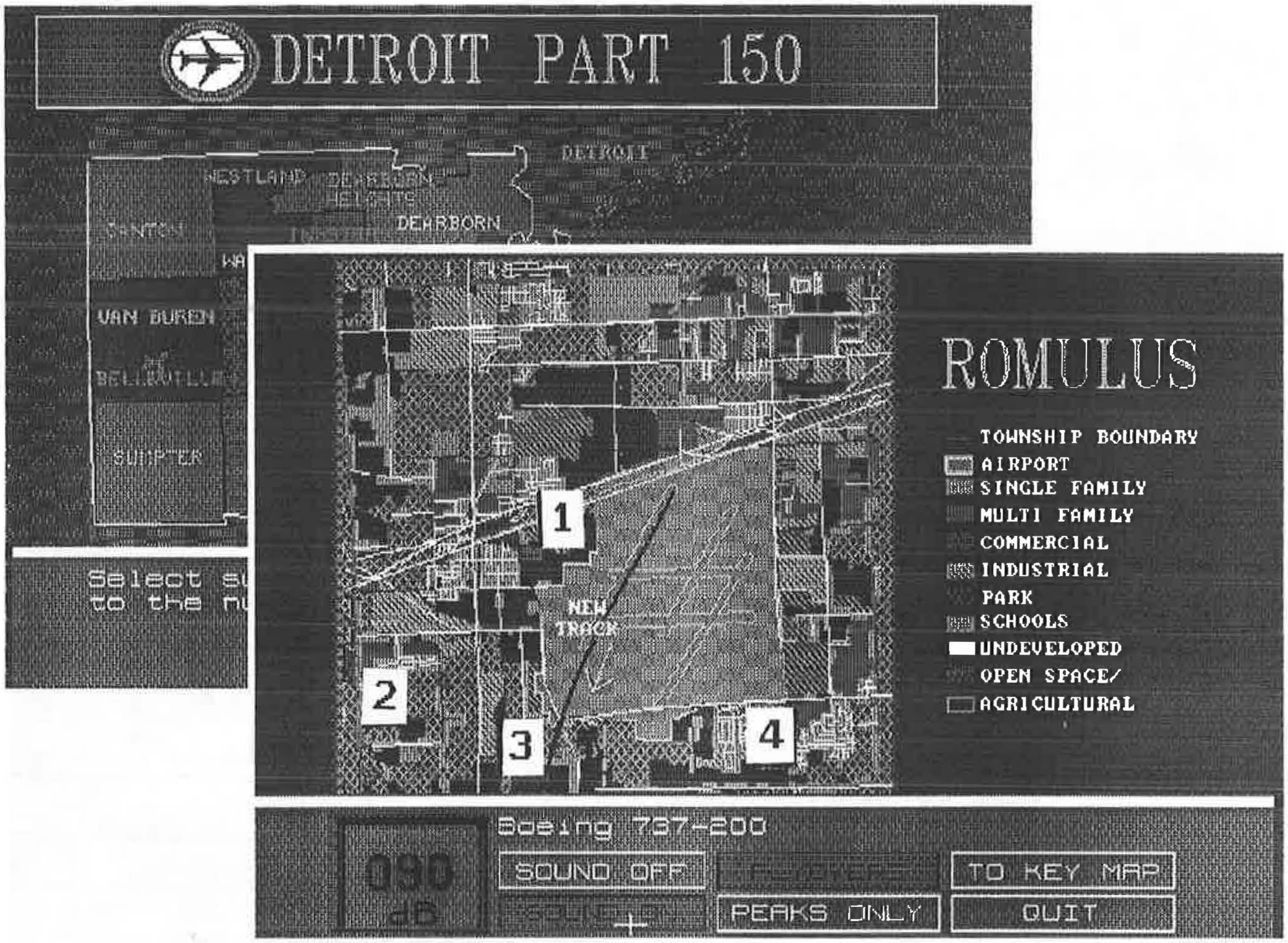


FIGURE 4 Distance effects sequence: underlay shows the key map; overlay shows one of the selectable detailed maps.

computer used is an IBM-compatible machine. The display is in a high-resolution, EGA mode and can be shown on a monitor or projected onto a screen. The program and graphics are stored on the system's hard disk. Sounds are recorded on a conventional compact disc being read by a CD-ROM drive. The sounds in the library were digitally recorded and digitally mastered. As mentioned, users can customize their presentations. The presentation sequences follow a "script" that approximates conventional English. Thus it is not necessary to change the program code to modify the pictures, numbers, and text that make up a presentation.

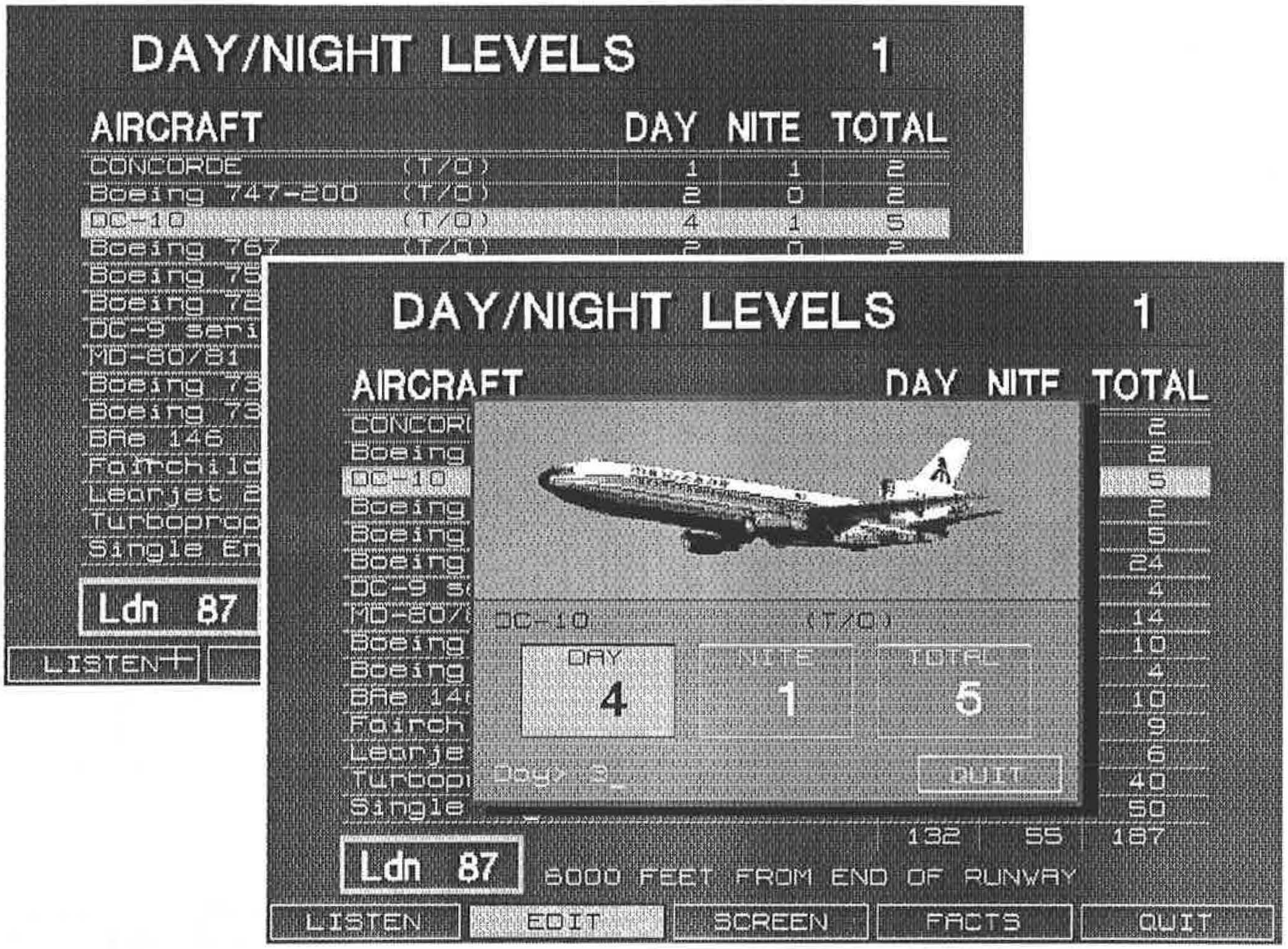
SYSTEM EFFECTS ON THE DECISION ENVIRONMENT

Credibility

The system has the power to command total credibility. Even fellow professionals, well seasoned in the difficult business of extracting sensible information from computers, seem disposed to accept the truth of the system's pronouncements. In presentations the calibration sequence is used to establish the correctness of the match between screen display and reproduced sounds. This demonstration, combined with the general mystique of computers and the popular belief that, being emotionless, they cannot lie, produces a willingness to accept as truth the information the system produces. The sounds and visual displays change simultaneously, and the drop-shadowed Helvetica text is boldly assertive. The images have the substantial quality of pages in a reference text.

Interest

The program has commanded total attention wherever it has been used. Some part of this has to do with its complete novelty, part to the program content, and part to the nature of an interactive session with a computer-moderated presentation system. A person entering a meeting room where a presentation will be made sees the unfamiliar but recognizable equipment: some impressive audio equipment and a computer with a monitor (or several) positioned to be seen. Yellow tape marks some seats or areas on the floor (where sound will be produced at volumes corresponding to those shown on the screen). The



AIRCRAFT		DAY	NITE	TOTAL
CONCORDE	(T/O)	1	1	2
Boeing 747-200	(T/O)	2	0	2
DC-10	(T/O)	4	1	5
Boeing 767	(T/O)	2	0	2
Boeing 75				5
Boeing 72				24
DC-9 seri				4
MD-80/81				14
Boeing 73				10
Boeing 73				4
BAe 146				10
Fairchild				9
Learjet 2				6
Turboprop				40
Single En				50
		132	55	187

Ldn 87 6000 FEET FROM END OF RUNWAY

DC-10 (T/O)

DAY	NITE	TOTAL
4	1	5

Day> 3_

FIGURE 5 Day/night levels sequence: underlay shows aircraft mix and L_{dn} at an airport; overlay image shows the screen with an aircraft selected for editing.

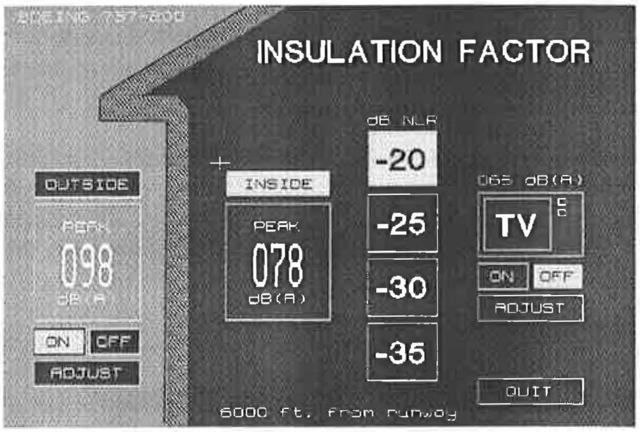


FIGURE 6 Insulation sequence; noise level reduction selections are arranged at the center.

council or commission may be moved to these special seats just before a presentation.

A well-organized, computer-moderated presentation is far more interesting than equally competent programs using slides or an overhead projector. A presentation has a live performance quality, in contrast to the predefined unfolding of a slide or video program. The screen responds to instructions. Elements can be delivered in any order at any speed. A presenter can answer "what if" questions, with appropriate displays and sounds seemingly created on the spot. With proper planning, the distance or insulation sequences can be used to give highly personalized reports on exactly what would be heard at specified locations. This feature of the system, the ability to personalize reports on noise exposure, has political significance, as is discussed in the next section.

SYSTEM EFFECTS ON THE DECISION PROCESS

The political environment surrounding airport noise management issues is undeniably rich and complex. Typically it involves economic trade-offs, contests between city and suburb, personalities, and egos, as well as groups using "airport noise" as a means of building their power base. Factual information about airport noise, however presented, can be only one element of the decision environment, facts about noise are weighed along with other facts, such things as facts about the likelihood of lawsuits, facts about how decisions could affect voters in the next elections, or facts about the preferences of influential groups.

The ISIS system includes some novel components that make it more than just another way of organizing a technical presentation. Two ISIS package features could work changes in the larger political setting for airport noise management decisions. These have to do with extending the agenda for decision making and what might be termed the individualization of issues.

In considering the ISIS package in the context of noise issue politics, it would be helpful to detour momentarily and consider the basics of community political organization as they have been presented by the dean of community organizers, the late Saul Alinsky. Alinsky's writings are noteworthy because of both their broad acceptance and their outspoken directness (*3*). "An organizer must stir up dissatisfaction and discontent: provide a channel into which people can angrily plow their frustrations." He suggested ten fundamental rules for organizers. These include two of special interest to technical presenters: the need to find issues that can be reduced to simple, easily understood demands and issues that involve broadly shared self-interest within a community. It is of interest that Alinsky viewed the issues as only a means to an end—the end being creation of an organized political force. Although Alinsky aimed his efforts at organizing depressed urban neighborhoods, his concepts can easily be applied in any setting and certainly apply to some noise protest movements.

The effect of issue simplification is apparent in the national pattern of airport noise controversies where policy contentions so typically focus on single issues or concepts. Proposals have been made for passenger enplanement caps, restrictions on particular aircraft, nighttime curfews, reductions in flight operations, redirection of flights to other airports, relocation of flight tracks, and changes in takeoff and landing procedures. While a robust noise management program could include all of these features, however, noise protest movements typically focus on the advocacy of single policies. This is so much the case that a listing of strategies immediately brings to mind a corresponding list of airports where these policies have achieved political dominance. As Alinsky observed, issues must be reduced to simple, easily understood demands if they are to be useful as a motivating force.

The initial menu of the ISIS system that lists multiple strategies for noise management is a quiet declaration that the management program ought to be comprehensive and consider multiple aspects of problems. It invites more comprehensive approaches, more subtle and complex solutions. Although this is comfortable for technical specialists, it works against interest groups that would build coalitions around simple, easily defined issues and solutions. In composing one custom ISIS presentation, the authors were asked to produce an opening menu showing fewer available options. The requester suggested that it was "too late" to look at some of the alternatives.

The system's ability to produce highly individualized reports of noise impact also has political significance. Community organizers of the Alinsky mode recognize self-interest as the dynamo energizing any protest movement. The ISIS system has the unique capability of being able to inform persons directly how much their self-interest might be affected by a noise source or a proposed solution alternative. The map distance sequence can give acoustic examples of sounds at specific locations, and the insulation sequence allows adjustment according to personal tastes. In a series of public hearings where citizens were given an opportunity to hear the noise that a controversial project would produce as it would sound from their property, those who were least affected dropped out of the political process. Although there is attrition in any lengthy hearing sequence, it could well be that individualized presentations can accelerate this. It is also possible that, as the differential impacts of alternate policies become better understood, it will be more difficult to create a consensus around particular solutions.

CONCLUSION

The ISIS package, as developed for the FAA, meets its basic objectives of informing people about airport noise and the acoustic consequences of various noise management strategies. It invites a comprehensive approach to airport noise management, and its interactive features permit a decision-making group to experiment with policy alternatives and sample the results.

With its ability to produce understandable, believable, and defensible approximations of sounds as they would be heard at specific locations under specified conditions, ISIS responds to the basic questions that bring people to public hearings about airport noise. It can demonstrate how a particular decision can affect an individual's self-interest. In doing this, it can clarify who in the affected communities will feel the greatest impact from decision alternatives. The features of the system have the potential to exert an important influence on the decision process.

Although experience with the ISIS package in airport management decisions is still quite limited, it is expected that the system's political impact on the decision process will approximate initial experiences. Undoubtedly, the political system will work its own influences on the ISIS package and the presentation scripts. The authors look forward to learning more about how acoustical examples can benefit the decision process.

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