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Contents

Foreword

The papers in this Record deal with various aspects of the design and operation of airport terminals and landside facilities. Also included is a paper on the planning implications of regional airport closures. All were presented at the 69th Annual Meeting of the Transportation Research Board, Washington, D.C., January 1990.

Martel and Seneviratne report a survey of departing passengers to determine their perceptions of primary indicators of the quality of service offered in the terminal building. The survey results for the circulation elements of the passenger terminal building show that 53 percent of the passengers believe that information is the most important indicator of service quality. For the waiting areas, the most important indicator is the availability of seats, and for the processing elements, it is the waiting time.

Mumayiz describes the major types and characteristics of airport terminal simulation models currently available. He also discusses the advantages of selected approaches to simulation.

Gulewicz and Browne discuss a computer simulation model to evaluate prospective designs of Federal Inspection Service (FIS) facilities and baggage handling systems at the John F. Kennedy International Airport. Using the General Purpose System Simulation (GPSS) language, a model was developed that provided a high degree of detail on transactions of passengers and baggage through FIS and baggage operations. The model provided an estimate of queued passengers and unclaimed baggage by flight in baggage claim. This output, in addition to characteristics of baggage systems under review, was then input to a PC-based spreadsheet to produce statistical information concerning the systems in order to assess their performance. This simulation model provides a new management tool to quickly evaluate operations and assess alternative baggage systems for baggage handling capacity and operational characteristics.

Shen examines the use of Automated People Mover (APM) systems to reduce excessive passenger walking distances in major airport terminals. He describes the effects of eight existing APM systems. The evolution of airport terminal design is also discussed. Two centralized new terminal designs (remote satellites and remote piers) with APM systems to improve airport operations are analyzed, using average travel time for the passengers as the measure of effectiveness. The remote satellite design was found to be better when the percentage of transfer passengers is relatively low, whereas remote piers is a better design when the percentage of transfer passenger is relatively high. The unit terminal design with the APM system was found to be obsolete because its layout is inefficient and difficult for first-time users.

Hanscom addresses the problem of traffic congestion within the Los Angeles International Airport's landside access system and examines the feasibility of an alternative shuttle bus operation to serve 11 hotels in the airport vicinity. The objective was to provide improved utilization and more efficient traffic flow within the airport circulation system. Study results, based on equal passenger loads served by the alternative system, indicated the following benefits: (a) nearly doubled service frequency to area hotels, (b) reduction of airport boarding-passenger wait time, (c) increase in average load factor, and (d) reduction in the overall number of runs and hence generated traffic.

Moog describes the trends of closures of critical general aviation airports in the Philadelphia region since 1980 and projects the continuation of that trend to 2000. Normal growth of general aviation demand is also estimated and assigned to remaining airports. At two intervals in the study, 1988 and 2000, system capacity is compared with demand, and deficiencies are identified. Modifications to public and private capital investment plans are proposed to counteract the loss of capacity in the system and to minimize the negative economic impacts and longer ground access trips resulting from airport closures. Alterations to annual federal and state funding programs and amounts would also be required.

Analysis of Factors Influencing Quality of Service in Passenger Terminal Buildings

NATHALIE MARTEL AND PRIANKA N. SENEVIRATNE

Findings of a personal interview survey of departing passengers conducted to determine the factors influencing the quality of service (QOS) in a passenger terminal building (PTB) are reported. Availability of space is not the most significant factor influencing QOS from the passengers' point of view, and thus, may not be the ideal parameter to use in QOS analysis. The survey results show that the factors influencing QOS differ from one element of the PTB to another. For instance, within the circulation elements 53 percent of the respondents believed that information is the most important factor. Similarly, for the waiting areas the most important factor was the availability of seats and for the processing elements it was the waiting time.

The sudden increase in demand for air travel in the last decade has led to several diverse problems, such as inadequate operational facilities to serve the basic functions. These problems have increased the need to search for satisfactory solutions for the air transportation industry as a whole. Concern here is with a small part of the overall problem: the quality of service (QOS) in a passenger terminal building (PTB). Although the PTB has three principal users—the airline, the airport operator, and the passenger—focus is on the passenger in this paper. Because passengers are the principal source of revenue, it is believed that their needs should be given equal, if not higher, priority than other user needs in the planning and design of PTBs.

Regardless of the configuration, a PTB contains three basic elements: (a) the processing element (involving ticketing, check-in, baggage drop, security, immigration, customs, and baggage claim); (b) the holding element (involving departure concourse, departure lounge, gate lounge, transit lounge, and arrival concourse); and (c) the circulating element (involving drop-off, pick-up, corridors, and airside interface) (*1*). Passengers follow a somewhat typical set of paths through these elements as shown in Figure 1. These paths depend on the different processes and their positions relative to the aircraft and surface modes.

This paper discusses the findings of a personal interview survey of departing passengers conducted to determine the factors influencing QOS in each element in a PTB. QOS is defined as the level of comfort and convenience of the facilities and services that is essential to process passengers in a PTB. The importance of each factor is evaluated according to the manner in which it is perceived by different categories of passengers. It is shown that space is not the most significant factor influencing QOS from the passengers' point of view. Factors such as waiting time and availability of seats are viewed as more important than space.

CURRENT PRACTICE

The widely used PTB planning, design, and evaluation criteria are based primarily on classical theories of pedestrian movement that evolved from studies related to such urban pedestrian facilities as sidewalks and crosswalks. Fruin's concept of levels of service (LOS) appears to underlie the existing tools and techniques (*2*). For example, Hamzawi describes Transport Canada's Airport Traffic Analysis Model (ATAM), which can develop, test, and evaluate design and planning standards on the basis of passenger volumes (*3*). These standards are given in terms of space per person (module), as suggested by Fruin (*2*). Similarly, Davis and Braaksma (*4*) propose LOS for entry corridors on the basis of space. These levels are somewhat different from the values used by Transport Canada, because they consider the effects of baggage and trolleys on maneuverability.

In theory, this appears appropriate because passengers in a terminal building are essentially pedestrians circulating through the various processing points. However, Seneviratne and Morrall (*5*) have found that contrary to the early beliefs, the relationships between space per person and maneuverability do not have the same characteristics as speed-volume or volume-density relationships on highways. Unlike vehicular traffic, pedestrians are able to move under much denser (congested) conditions. Moreover, according to Seneviratne and Morrall (*6*), pedestrians perceive factors other than space to be more essential for circulation.

The deficiencies in the space-based concept have also been recognized by Mori and Tsukaguchi (*7*), who developed a twofold methodology for evaluating LOS. The first phase of this approach is based on pedestrian behavior such as the speed-density-flow relation and the arrival distribution, and the second is based on pedestrian perception of physical characteristics of the facility. Likewise, Mumayiz and Ashford (*8*) attempted to establish a perception response model based on the relation between imposed demand levels and relevant service measures. This model links the passengers' perception of LOS to the time spent in various processes as opposed to the quantity of space available for each person. Ashford (*1*) has argued that because of the continuum linear approximation of the relation between space and LOS, currently used standards do not correspond closely to the LOS perceived by passengers.

An extensive passenger survey conducted by Condom shed some light on the issue of passenger needs and indicated that QOS of PTBs should be assessed in terms of factors other than space (*9*). These factors should represent the overall quality of the transfer between transportation modes expe-

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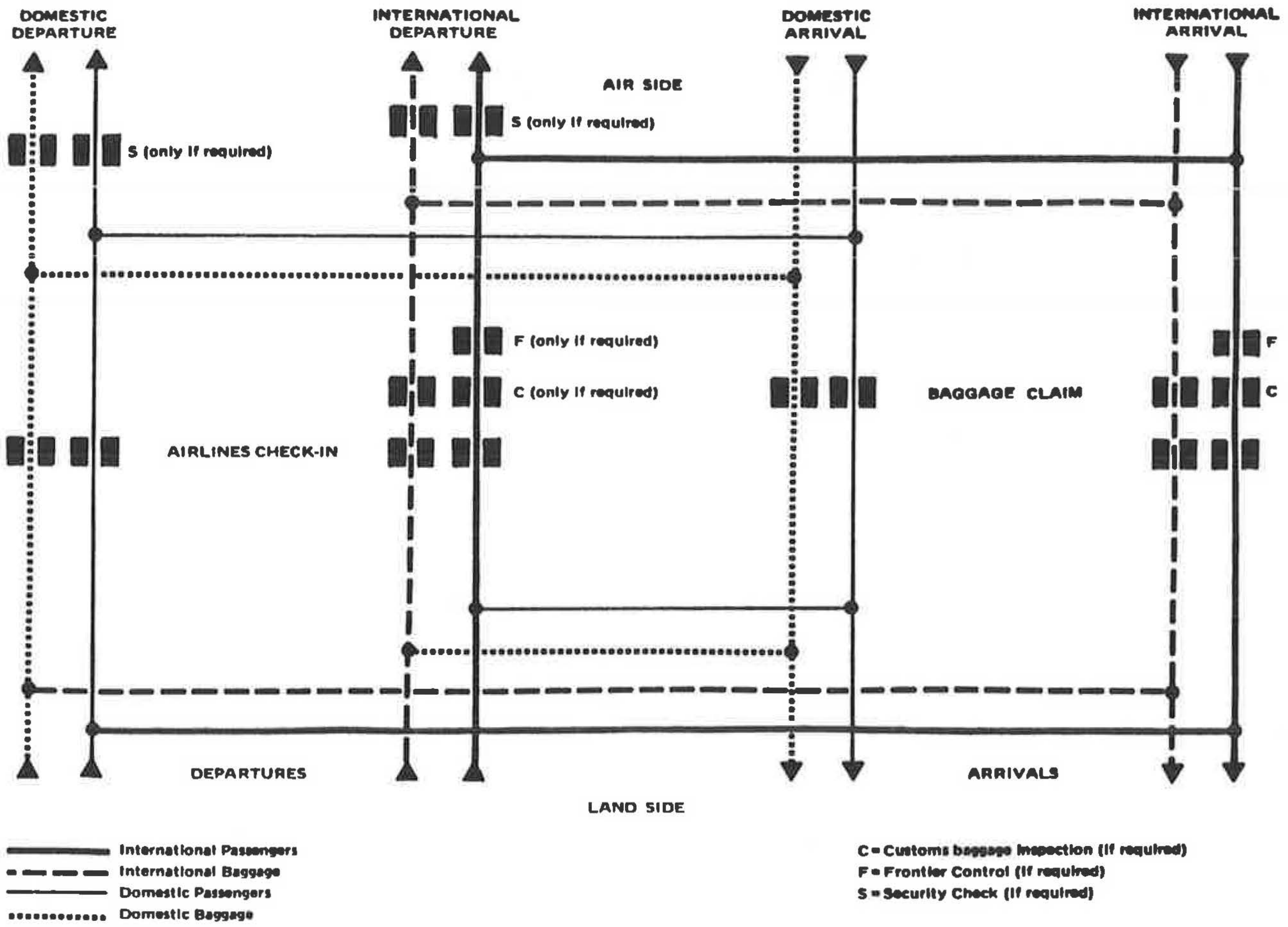

FIGURE 1 Passenger and baggage flow through the PTB.

rienced by passengers. The factors have quantitative components such as walking distance and level changes, waiting time, and availability of space and costs and qualitative components such as courtesy of personnel, information systems, environment, safety, simplicity of procedures, comfort, and convenience. Heathington and Jones have suggested a detailed list of factors (Table 1) that may reflect the user's viewpoint (*10*). Nevertheless, a great deal of subjective judgment or a good understanding of passenger attitudes is needed to identify the most appropriate set of factors from this list to be used subsequently to evaluate QOS in a given PTB.

METHODOLOGY AND DATA COLLECTION

The principal objectives of this study were (a) to perform a disaggregate analysis of QOS at different stages of the flow through the PTB (i.e., in each element); (b) to determine if differences exist among the factors influencing QOS as perceived by passengers when they are classified according to trip purpose, sex, and age; and (c) to determine if factors perceived to influence QOS vary according to the time the passengers spend in the PTB.

The data were collected through personal interviews. To verify the pertinence of the questions, a pilot survey was conducted. From that information, the most relevant set of factors was chosen for detailed study and included in the final questionnaire. Because of time and resource constraints, only the Montreal International Airport at Dorval was studied. Moreover, only departing passengers were considered.

The total number of enplaning and deplaning passengers at Dorval in 1988 was 6,519,000. Of this total, 53 percent flew on domestic flights, 31 percent on transborder flights, 4 percent on charter flights, and 12 percent on regional or local carriers.

The Dorval Airport PTB consists of two pier fingers (one for domestic flights and one for transborder flights) extending linearly from each side of the main area where processing activities take place and where most of the concessions are located.

Pilot Survey

A small sample of 21 passengers was interviewed between 8:00 and 10:30 a.m. on a typical Wednesday. The questions were aimed at obtaining two types of information: (a) mode of arrival at the airport, purpose of trip, frequency of travel by air, and time spent in PTB; and (b) passenger perceptions of the factors influencing QOS for each element of the PTB.

TABLE 1 QUALITY OF SERVICE CHARACTERISTICS (*10*)

Facility	Type of Measure	Originating	Terminating	Connecting	Through	Standby
External walkway	Quantitative	Walking distance Pedestrian assists Pedestrian density Direct flow Lighting Aids for handicapped	Walking distance Pedestrian assists Pedestrian density Direct flow Lighting Aids for handicapped	N. A.	N. A.	Walking distance Pedestrian assists Pedestrian density Direct flow Lighting Aids for handicapped
	Qualitative	Exposure to weather Safety information Systems and signs Pedestrian density Cleanliness Security Environment	Exposure to weather Safety information Systems and signs Pedestrian density Cleanliness Security Environment	N. A.	N. A.	Exposure to weather Safety information Systems and signs Pedestrian density Cleanliness Security Environment
Baggage Check	Quantitative	Processing time Service variability range	N. A.	N. A.	N. A.	N. A.
	Qualitative	Convenience Complexity of procedure Courtesy of personnel Environment	N. A.	N. A.	N. A.	N. A.
Ticketing	Quantitative	Processing time Service variability range Convenience	N. A. N. A.	N. A. N. A.	N. A. N. A.	N. A. N. A.
	Qualitative	Complexity of procedure Courtesy of personnel Environment	N. A.	N. A.	N. A.	N. A.
Internal circulation	Quantitative	Walking distance Pedestrian assists Pedestrian density Direct flow Lighting Aids to handicapped Cost to passenger	Walking distance Pedestrian assists Pedestrian density Direct flow Lighting Aids to handicapped Cost to passenger	Walking distance Pedestrian assists Pedestrian density Direct flow Lighting Aids to handicapped Cost to passenger	Walking distance Pedestrian assists Pedestrian density Direct flow Lighting Aids to handicapped Cost to passenger	Walking distance Pedestrian assists Pedestrian density Direct flow Lighting Aids to handicapped Cost to passenger
	Qualitative	Exposure to weather Safety Information systems and signs Pedestrian density Cleanliness Security Environment	Exposure to weather Safety Information systems and signs Pedestrian density Cleanliness Security Environment	Exposure to weather Safety Information systems and signs Pedestrian density Cleanliness Security Environment	Exposure to weather Safety Information systems and signs Pedestrian density Cleanliness Security Environment	Exposure to weather Safety Information systems and signs Pedestrian density Cleanliness Security Environment
Public waiting	Quantitative	Number of seats Size of area Lighting	Number of seats Size of area Lighting	Number of seats Size of area Lighting	N. A.	Number of seats Size of area Lighting
	Qualitative	Seating arrangements Comfort	Seating arrangements Comfort	Seating arrangements Comfort	N. A.	Seating arrangements Comfort
	Qualitative	Privacy Amenities	Privacy Amenities	Privacy Amenities	N. A.	Privacy Amenities
Security	Quantitative	Processing time Service variability range Location re concessions	N. A.	Processing time Service variability range Location re concessions	N. A.	Processing time Service variability range Location re concessions
	Qualitative	Convenience Complexity of procedure Courtesy of personnel Environment	N. A.	Convenience Complexity of procedure Courtesy of personnel Environment	N. A.	Convenience Complexity of procedure Courtesy of personnel Environment

(*Continued on next page*)

TABLE 1 (*Continued*)

Facility	Type of Measure	Originating	Terminating	Connecting	Through	Standby
Departure lounge	Quantitative	Processing time Service variability range Number of seats Size of area Lighting Location re concessions	N. A.	Processing time Service variability range Number of seats Size of area Lighting Location re concessions	Processing time Service variability range Number of seats Size of area Lighting Location re concessions	Processing time Service variability range Number of seats Size of area Lighting Location re concession
	Qualitative	Convenience Complexity of procedure Courtesy of personnel Environment	N. A.	Convenience Complexity of procedure Courtesy of personnel Environment	Convenience Complexity of procedure Courtesy of personnel Environment	Convenience Complexity of procedure Courtesy of personnel Environment
Boarding means	Quantitative	Walking distance Level Change Aids to handicapped	Walking distance Level Change Aids to handicapped	Walking distance Level Change Aids to handicapped	Walking distance Level Change Aids to handicapped	Walking distance Level Change Aids to handicapped
	Qualitative	Exposure to weather Safety Convenience	Exposure to weather Safety Convenience	Exposure to weather Safety Convenience	Exposure to weather Safety Convenience	Exposure to weather Safety Convenience
Baggage claim	Quantitative	N. A.	Processing time Service variability range Area size Pedestrian density Claim frontage Care of handling Aids to handicapped Proximity to curb	N. A.	N. A.	Processing time Service variability range Area size Pedestrian density Claim frontage Care of handling Aids to handicapped Proximity to curb
	Qualitative	N. A.	Convenience Complexity of procedure Courtesy of personnel Environment Security Availability of sky cap Location re concessions Seating	N. A.	N. A.	Convenience Complexity of procedure Courtesy of personnel Environment Security Availability of sky cap Location re conconcessions Seating
Information services	Quantitative	Consistency Redundancy Legibility Aids to handicapped	Consistency Redundancy Legibility Aids to handicapped	Consistency Redundancy Legibility Aids to handicapped	Consistency Redundancy Legibility Aids to handicapped	Consistency Redundancy Legibility Aids to handicapped
	Qualitative	Understandability	Understandability	Understandability	Understandability	Understandability
Concessions and miscellaneous services	Quantitative	Number and type Location and size Aids to handicapped Conformance with codes	Number and type Location and size Aids to handicapped Conformance with codes	Number and type Location and size Aids to handicapped Conformance with codes	Number and type Location and size Aids to handicapped Conformance with codes	Number and type Location and size Aids to handicapped Conformance with codes
	Qualitative	Services provided Courtesy of personnel Environment Amenities	Services provided Courtesy of personnel Environment Amenities	Services provided Courtesy of personnel Environment Amenities	Services provided Courtesy of personnel Environment Amenities	Services provided Courtesy of personnel Environment Amenities
International	Quantitative	Processing time Service variability range	Processing time Service variability range	Processing time Service variability range	Processing time Service variability range	Processing time Service variability range

(*Continued on next page*)

TABLE 1 (*Continued*)

Facility	Type of Measure	Originating	Terminating	Connecting	Through	Standby
International	Qualitative	Convenience Complexity of procedure Courtesy of personnel Environment	Convenience Complexity of procedure Courtesy of personnel Environment	Convenience Complexity of procedure Courtesy of personnel Environment	N. A.	N. A.

The passengers were requested to rank the factors for each airport element in order of importance (Table 2).

The statistical package MINITAB was used to analyze the results. The analysis was performed in three steps. First, means and standard deviations of the factor rankings were computed for the two types of passengers (i.e., business and leisure). Because the rankings were on an ascending scale starting from 1, the closer the mean was to 1, the more important the factor. Second, factors were ranked according to means. An analysis of variance was then performed to determine if a difference existed between the mean ranks of each factor for the business, leisure, and combined categories. No differences between the rankings of business and leisure travelers in any of the elements were found and therefore subsequent analyses were confined to combined data. Finally, a test of means was performed on the mean ranks of the factors in each element. On the basis of the *t*-values, the following indicators that were not significantly different at the 0.01 level were chosen for the final questionnaire:

- Circulation elements
  - —Walking distance
  - —Visual information
  - —Availability of space
  - —Level changes
- Waiting elements
  - —Availability of seats
  - —Seating comfort
  - —Ease of access to waiting areas
  - —Layout of seats
- Processing elements
  - —Waiting time
  - —Convenience
  - —Availability of space

Detailed Survey

The final survey was conducted at the same airport. Of the 249 passengers interviewed, the responses of 227 passengers were considered for further analysis; the remaining were discarded because of either incompleteness or inappropriateness of answers. These 227 passengers were from 10 domestic and transborder flights and represented 2.53 percent of the estimated enplaning passenger volume of 8,980 for that day. The survey was not conducted at the most representative time because the end of July is the period of construction holidays in Quebec. However, access to restricted areas was permitted during this time only, and parts of the a.m. and p.m. peak periods of a mid-week day were covered.

The final questionnaire consisted of three sections covering each of the primary elements (circulation, waiting, and processing) (Figure 2). Each passenger was asked to identify the factor that he or she believed was the primary determinant of QOS for each element.

The circulation element was defined to include all corridors and paths that the passengers need to use in order to reach their final destination in the PTB. These are, for example, the corridors from the entrance doors to check-in counters, from check-in counters to security checks, from security checks to gates, and so on. The passengers needed to identify one of the following factors as the primary determinant of QOS: (a) walking distance; (b) information, referring to signs (comprehensibility, location or visibility, and visual flight information and auditory information); (c) availability of space for circulation or degree of congestion; and (d) level changes, referring to vertical movements that require passengers to use stairways, escalators, or elevators.

The waiting element consisted of public waiting areas, departure lounges, and concessions. The suggested factors were (a) availability of seats; (b) variety and location of concessions and essential facilities, referring to the ease of access to these concessions and essential facilities and to the number and types of the different concessions; and (c) internal environment, referring to all aesthetics and climate characteristics such as cleanliness, lighting, color schemes of carpets, furniture, air conditioning, and so on.

The processing element consisted of such activities encountered by departing passengers as ticketing, check-in, and security checks. One of the following factors was to be chosen: (a) waiting time, including processing time; (b) convenience, referring to facilities or devices available to facilitate the processing activity such as ergonomic counters, baggage carousels, baggage carts, and so on; and (3) availability of space.

ANALYSIS OF RESPONSES

The responses to the final questionnaire were analyzed using the statistical package SAS. Because there were no rankings, this analysis was mainly tests of proportions.

Basic characteristics of the respondents are given in Table 3 as an overview of the sample. Of the 227 passengers sampled, 68 percent were male and 32 percent were female. A large portion of the males, as opposed to the females, were traveling for business. Forty-seven percent of the passengers were between ages 30 and 49 (which was to be expected,

TABLE 2 AIRPORT ELEMENTS AND CORRESPONDING FACTORS SUGGESTED IN PRELIMINARY SURVEY

Airport elements	Factors
Parking and curbside	(i) direct access (minimum walking distance) (ii) level changes (going up or down) (iii) space available for circulation (iv) more weather protection (v) better visual information (comprehensible) (vi) lighting (vii) aesthetics (beauty, cleanliness)
Check-in	(i) shorter waiting time (ii) convenience (counter space, ease of baggage handling) (iii) space for circulation (iv) aesthetics
Internal circulation	(i) direct access (minimum walking distance) (ii) level changes (going up or down) (iii) more space available for circulation (iv) better visual information (comprehensible) (v) lighting (vi) aesthetics
Public waiting areas	(i) number of seats (ii) good seating arrangements (iii)space available for circulation (iv) lighting (v) comfort (vi) proximity of concessions and amenities (vii) aesthetics
Concessions and amenities	(i) number and type (ii) location (iii) aesthetics (beauty, cleanliness)
Security check	(i) shorter waiting time (ii) space available for circulation (iii) convenience (iv) simplicity of procedure
Departure lounge	(i) number of seats (ii)space available for circulation (iii) ease of access (iv) lighting (v) proximity of concessions and amenities (vi) aesthetics (beauty, cleanliness)
Boarding	(i) level changes (going up or down) (ii) space available for circulation
Information systems	(i) uniformity (ii) utility (iii) legibility

because most business travelers fall in this age category). In fact, even though the range of 30 to 49 is twice the range of other age categories, the proportion of respondents that were in this category was more than twice the proportions in other categories. Most of the passengers in the last category, 60+ years, traveled for leisure. Fifty-four percent of the sampled passengers were traveling for leisure. (At the time of the survey, many people were on vacation, which explains the higher number of leisure travelers. In other periods, for example during the first survey, the opposite was observed.)

It is clear from Figure 3a–c that the most important perceived factors are (a) information in the circulation element (53 percent of passengers), (b) seat availability in the waiting element (44 percent of passengers), and (c) waiting time in the processing element (60 percent of passengers). However, the relative importance of factors within an element differs from one element to another. For example, in the circulation element, 53 percent of the passengers perceive information to be the most significant and 38 percent believe that walking distance is the most significant. Availability of space is clearly

1) At what time did you arrive at the airport? (1-4)

2) What is the purpose of your trip? (5)

Business 1
Leisure 2

3) Is this your first trip by air? (6)

Yes 1
No 2

4) If no, how frequently do you fly? (7)

Between 1 and 8 times/year................1
9 times or more/year........................2

5) At what time does your flight depart? _______ (8-11)

6) What is your flight number? _______ (12-15)

7) At which gate do you board? _______ (16-17)

PART "A" : CIRCULATION

This section refers to all places where you circulate, i.e. from entrance doors to check-in counter, from check-in counter to security check, from security check to gate, etc...

8) Which of the following factors do you feel is **most** important? (18)

Walking distance ....1 Go to no.9
Information (signs, visual, auditive) .....2 Go to no.10
Space for circulation ....3 Go to no.13
Level changes ....4 Go to no.15

9) a) Was the distance you walked, between entrance doors and check-in counter (19)

Good? 1
Acceptable? 2
Too long? 3

b) Was the distance you walked, between check-in counter and security check (20)

Good? 1
Acceptable? 2
Too long? 3

PART "B": WAITING AREAS

This section refers to waiting areas, departure lounges and concessions (restaurants, bars, boutiques, etc.).

17) Which of the following factors do you feel is **most** important? (37)

Availability of seats ....1 Go to no.18
Variety and location of concessions (restaurants, bars,cafés,boutiques,etc) and of essential services (washrooms, water fountains, etc.) .....2 Go to no.19
Internal environment (aesthetics, climate, etc) ....3 Go to no.22

PART "C": PROCESSING POINTS

This section refers to processing activities (check-in and security check).

23) Which of the following factors do you feel is **most** important? (46)

Waiting time ....1 Go to no.24
Convenience (handling baggage, etc) ..2 Go to no.26
Availability of space ....3 Go to no.27

PART "D": GENERAL INFORMATION

29) In which category of age do you belong? (56)

Less than 20 1
20 to 29 2
30 to 49.....................................3
50 to 59.....................................4
60 or more..................................5

30) Sex? (57)

Female 1
Male 2

FIGURE 2 Final questionnaire.

TABLE 3 CHARACTERISTICS OF PASSENGER SAMPLE

TOTAL SAMPLE : 227 Passengers.	
SEX :	FEMALE: 32% MALE : 68%
AGE :	LESS THAN 20: 5% 20 to 29 : 17% 30 to 49 : 47% 50 to 59 : 15% 60 AND OVER : 16%
PURPOSE OF TRIP :	BUSINESS : 46% LEISURE : 54%

not as significant as expected because only 6 percent perceive it as the most important, and level changes came last with only 3 percent of passengers perceiving it as most important. On the other hand, passengers in the waiting element appear to have different priorities, and the proportions for each of the three factors do not differ as much as they do in circulation. For instance, 44 percent perceived seat availability as the most important, 34 percent of the passengers chose the variety and location of concessions, and 22 percent chose internal environment.

Information is probably regarded by many as the most significant factor because it directly affects other factors. For example, passengers can minimize walking distance and level changes if the appropriate information is available at the appropriate place to aid them in reaching their destinations. Also, when information systems are well managed and well utilized, obscurity and time lost in searching are minimized. A certain confidence then develops in a passengers' mind and helps them better appreciate the airport facilities and procedures. Availability of seats appears to be a logical factor that influences QOS, when passengers are in the waiting element, whether the department lounge or public waiting area, because people need to occupy themselves until boarding time. This need to be occupied and pass time is perhaps why accessibility to concessions is perceived as important by an equally large percentage (31 percent) of respondents.

The factors perceived as determinants of QOS in the processing element appear completely different from those in other sections. The 60 percent who feel that waiting time is the most important is twice the proportion of those who chose convenience (31 percent) and almost seven times the proportion of those who chose availability of space (9 percent). Once again, space is of little significance.

STATISTICAL COMPARISON OF FACTORS

To determine if there is a significant difference in the passengers' perception of the most important factors (QOS variables), X^2 test was performed on the proportions. This enabled 95 percent confidence that, for example, the share of passengers who believed that information was the most important factor for circulation (see Figure 3a) is significantly different from the share of passengers who identified walking distance as the most important factor. Similar differences existed between the number of votes received by the most important factor in the waiting element and the number of votes received by the most important factor in the processing element, as seen in Figures 3 b and c.

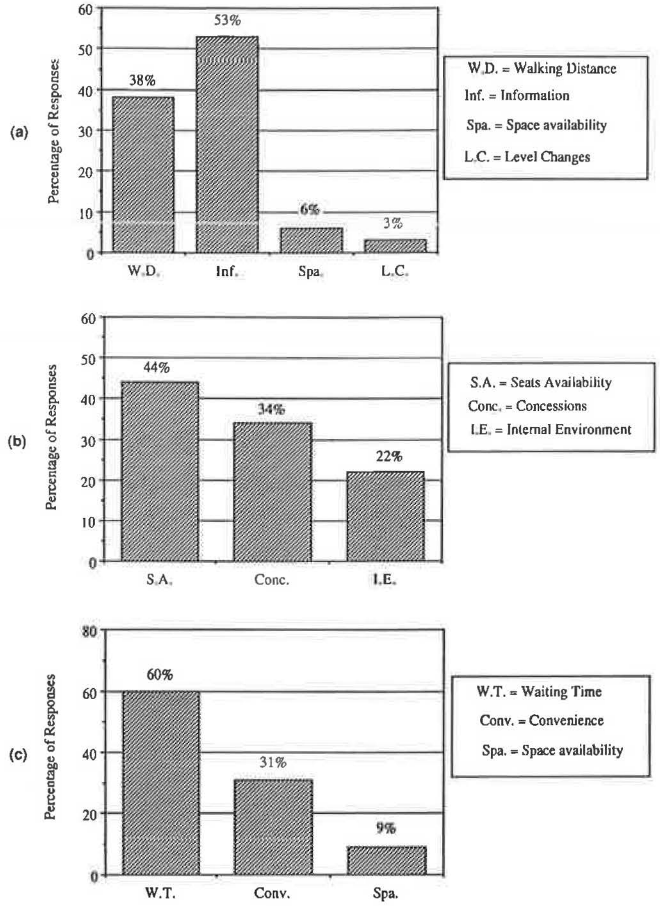

FIGURE 3 Passenger perception of variables in elements. (a) Circulation, (b) waiting areas, and (c) processing.

There was also a significant difference at the 5 percent level between the business and leisure travelers' perception of the most important factor within each element of the PTB. For example, it is evident from Figure 4 that waiting time is the most important factor at processing for both groups of passengers. However, there is a significant difference in the proportions of the two groups who rated this factor in the same way. In other words, the difference between the proportion of business travelers (70 percent) and leisure travelers (50 percent) who identified waiting time as the most important factor was significantly different. One can also see from Figure 4 that, for circulation, the percentage of business travelers who identified walking distance as the most important factor is greater than the percentage of leisure travelers; it is the reverse in the case of information.

These differences appear to reflect differences in the value of time for the two groups as well as differences in familiarity with the airport (i.e., business travelers, who are more frequent travelers, are less likely to need information than leisure

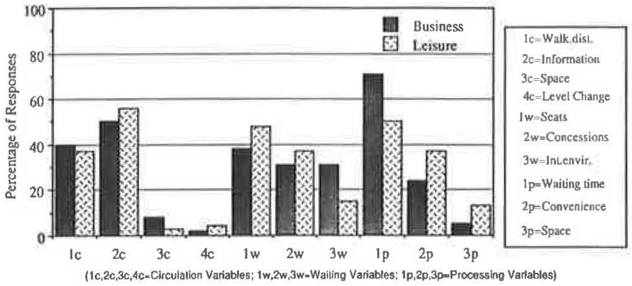

FIGURE 4 Comparison of variables by trip purpose.

travelers, who fly less frequently). However, the differences are not statistically significant in all cases.

Significant differences also exist between the perceptions of males and females. Although both males and females consider walking distance and information significantly more important than space and level changes, a significant difference exists between the proportions of the sexes identifying walking distance and information as most important (see Figure 5). There is also a difference in the proportions of the sexes who identify the same factor as most important. For instance, the percentage of males who are concerned with waiting time at processing is significantly larger than the percentage of females. On the contrary, the percentage of females identifying convenience as the most important factor is much greater than that of males.

When the different age categories shown in Figure 6 were considered, it was found that there are significant differences in the proportions that identified walking distance as being most important for circulation. The differences are also significant in the case of information. These differences demonstrate the relative importance of walking distance for the different age categories. Nearly 55 percent of the 60+ years group believed walking distance to be the most important factor. In the waiting element, one can find the same degree of age differences in the proportions that identified availability of seats as the most important factor. The majority (over 65 percent) of the older passengers thought that seats were most important, but they were hardly concerned about the internal environment as compared with concern about the internal environment expressed by other age categories. As for the processing element, age categories 20–29 and 30–49 were mainly concerned about waiting time. The proportions of these two categories that found convenience and space to be most important are significantly less than for waiting time, whereas the 60+ years category is indifferent among their choices.

The amount of time spent in the PTB by business and leisure travelers is presented in Figure 7. Over 60 percent of the business travelers spent between 30 and 90 min in the PTB before the flight. On the average the leisure travelers spent approximately 30 min more than the business travelers. Note, however, that regardless of the time spent, there is no difference in the perception of the different factors between business and leisure travelers (Figure 8).

CONCLUSION

There are many factors to be considered other than space or time when it comes to evaluating QOS from the passengers' point of view. This limited study has also demonstrated that QOS is a complex concept that is inappropriate to evaluate with one indicator. The factors influencing QOS differ

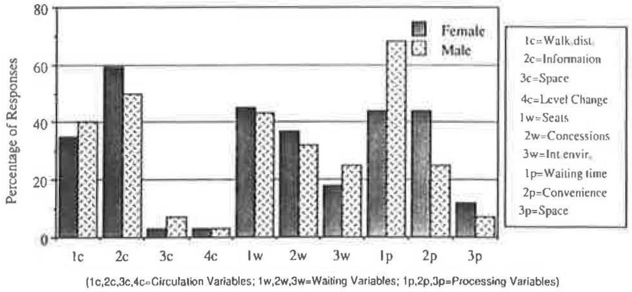

FIGURE 5 Comparison of variables by sex.

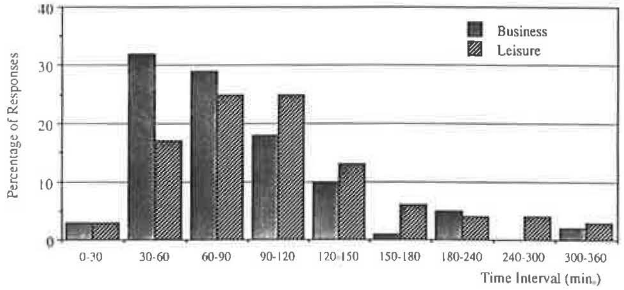

FIGURE 7 Time spent in PTB.

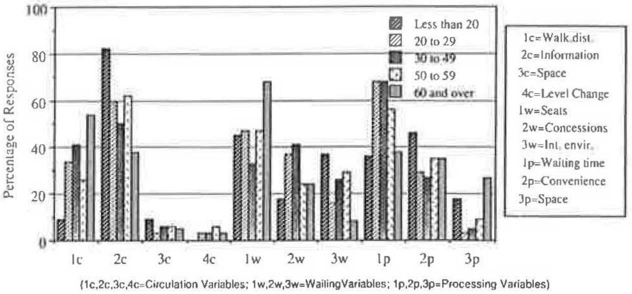

FIGURE 6 Comparison of variables by age groups.

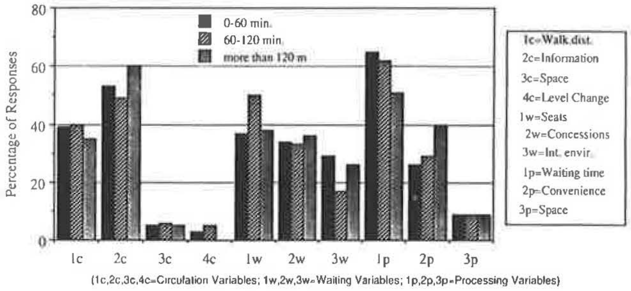

FIGURE 8 Comparison of variables by time spent in PTB.

depending on the element of the PTB that one is considering. Thus, changing passenger needs should be considered in planning and designing PTBs.

The optimal set of evaluation factors for a particular facility can only be determined by interviewing passengers. For instance, the factors identified in this study may not be the optimal set to evaluate another site. This study can be considered a pilot study to determine the bases for evaluating QOS in PTBs. However, the problem of finding a compromise design that could account for the concerns of different age categories, business or leisure travelers, and males and females still remains unsolved. Moreover, incorporating such qualitative aspects as information and internal environmental quality into the designs and developing a yardstick for measuring them could be an extremely difficult process. Even if this dilemma could be resolved, the process of developing design standards that could satisfy the needs of other PTB users will be an uphill task.

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Overview of Airport Terminal Simulation Models

SALEH A. MUMAYIZ

Airport terminal simulation models developed in academia, industry, and government are surveyed. An overview is presented of modeling and simulation including definitions, conceptual approaches to modeling, and types of simulation techniques and simulation languages used for airport landside simulation. Desirable technical properties of airport terminal simulation systems are discussed. Three simulation approaches considered most suitable to model airport terminals are reviewed and their use is discussed in detail.

Airports are currently facing many problems of varying complexity and importance. Although most of these problems are not new, the long-term neglect and lack of action to find valid solutions have exacerbated the current situation of aviation and airport systems. Major problems include inadequate capacity and deterioration of quality of service, difficulties of financial planning and funding of new major airport development, political and environmental considerations that affect airport development and other specific issues related to planning, design, and operation of airports. For airport terminals in particular, airport congestion, severe capacity shortages in the competitive deregulated environment, and airport security are major problems facing airport planners, designers, and managers (*1*). The status of airports is becoming a major concern, not only to airport operators who are struggling to accommodate passenger loads for which the designers did not plan, but also to federal, state, and local government officials, the airline industry, local communities, and the public at large.

Airport planners and managers need effective tools to assess the effects of these problems on airports. Techniques currently used for planning, design, and management of airport landside facilities appear inadequate to provide appropriate solutions. Nomographs, empirical data, and rule-of-thumb approaches are overly simplistic, based mostly on gross and generalized assumptions, and unlikely to achieve effective solutions to complex problems in such a dynamic environment as the airport terminal (*2*).

This paper reviews modeling and simulation from a transportation systems vantage point, presents an overview of the development of airport terminal simulations reported in the technical literature, and concludes with a discussion of state-of-the-art simulation and the future of simulation techniques in airport planning, design, and operation.

MODELS AND SIMULATION

It is important to differentiate between modeling and simulation. Models are generally thought of as an idealized representation of reality, as some subject of inquiry that may be already in existence, or as a conceived idea awaiting execution (*3,4*). Because models are abstractions of an assumed real-world system that can identify pertinent relationships, models are used rather than the real system primarily because manipulating the real-world system would be costly or impossible. In most instances, models are constructed to be simpler than the real-world system because complex systems are difficult to implement and control.

To optimize the accuracy of the simplest possible model, the elements of the model are examined to determine their degree of representation of the real system. Finding the right variables and the correct relationships among them is the essence of good modeling. Although a large number of variables may be required to predict a phenomenon of the real system with perfect accuracy, only a small number of variables usually account for most of the real system. This rule is widely recognized and accepted in modeling—especially in regression. Nonetheless, the reliability of information obtained from a model eventually depends on the validity of the model in representing the assumed real-world system.

Simulation is one type of model. Iconic (physical), analogue, symbolic (abstract), and heuristic are other types of models. Simulations are models that use mathematical-logical representations of the real-world system to convert system descriptions, or input parameters, into output that describes some features of the system. Operations research scientists hold various interpretations of simulation. Taha (*4*) regards simulation as behavioral imitation of the real-world system over time and seeks to replicate real-world behavior by studying interactions among its components. Shannon (*5*) interprets simulation as a process of designing a model of real-world systems and conducting experiments to either understand the behavior of the system or evaluate various strategies to operate the system. Pritsker (*6*) considers simulation models as laboratory versions of systems on which experiments can be conducted as a first step in the design, analysis, and assessment of the performance of real-world systems. Inferences can then be drawn about the real system without the need to physically build, disturb, or destroy it.

Functional types of simulation models are

- Analytic queueing models—probabilistic models that use mathematical expressions derived from queueing theory;
- Accounting models—time-based and deterministic in nature that use predefined rules to describe the state of the system; and
- Time-dependent models—event-based and stochastic in nature that use dynamic equations with mathematical-logical

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representations or Monte Carlo methods for fast-time reproduction of the state of the system.

In developing a simulation model, the first step should be to select a conceptual framework to describe the system to be modeled. Essentially, this involves defining a "world view" within which the real-world system's functional relationships are perceived and described (*6*). If a general-purpose computer language is used (e.g., FORTRAN), then defining the world view and organizing the system description are the modeler's responsibility. On the other hand, if a simulation language or package is used, then the world view is implicit in the simulation language.

Simulation basically employs one of two world views: discrete or continuous. In discrete-event simulation, the system can be described by changes of its state that occur at discrete times (event times); between these times, the state of the system remains unchanged. In continuous-event simulation, the behavior of the system is characterized by equations for a set of state variables whose dynamic behavior simulates the real-world system (the state of the system is represented by dependent variables that change continuously over time).

Discrete-event simulation is normally used for an airport terminal system because no set of equations can be derived to define the characteristics of the airport terminal and describe the nature of the systems operation.

Discrete-event simulation can be of three general types depending on the specific features of simulation. These are event-oriented, activity-oriented, and process-oriented simulations. Objects or basic units within the boundaries of a discrete system are called "entities." Each entity has various characteristics called "attributes." Attributes are characteristics common to those groups of entities that engage in different kinds of "activities" (sometimes called "transactions"). A "process" is a time-ordered sequence of events that may encompass several activities. The relation among an event, an activity, and a process is graphically presented in Figure 1. This representation of simulation is adhered to throughout this paper.

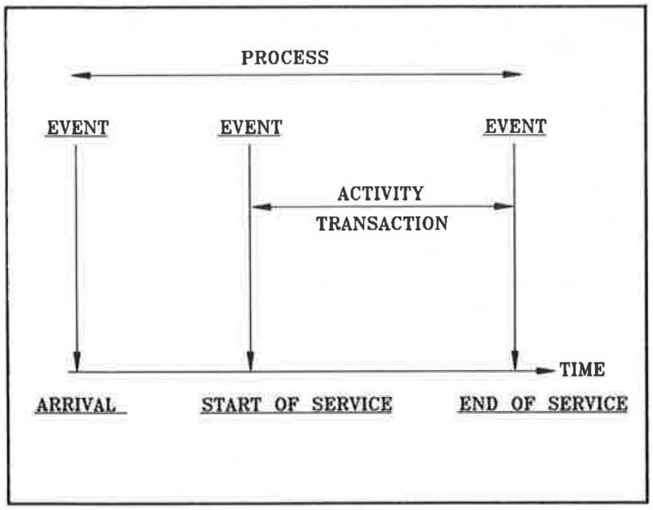

FIGURE 1 Conceptual diagram of service.

A simulation system, whether a language or computer package, could be one of these three general types, could be an object-oriented simulation, or could be a hybrid simulation. A brief description of each follows.

Event-Oriented Simulation

A system is modeled by defining changes occurring at event times and by determining events that can change the state of the system, and then by developing the logic associated with each event type. Simulation is run by executing the logic associated with each event in a time-ordered sequence. This category of simulation languages includes SIMSCRIPT, a FORTRAN-based language that uses English-like statements (*7*), and GASP, a language that uses a general-purpose computer language (e.g., FORTRAN or PL/I) structured as a conceptual framework with a short main program and supporting routines that are coded by the user in the same general-purpose language to provide event logic and perform different executive functions (*8*).

Activity-Oriented Simulation

Models are built by describing activities engaged in by entities of the real world and prescribing conditions that cause each activity to start or end. These conditions must be scanned continuously to ensure that each activity is accounted for. This orientation results in a rather cumbersome structure with inefficient computer handling. ECSL (*9*) is an example of this category; it is used mainly for industrial process control.

Process-Oriented Simulation

The real-world system is modeled by defining the flow of entities through the system on the basis of sequences of events that occur in a predefined pattern, the logic of which can be generalized and used in single statements. Because event logic is implicit and automatically contained in corresponding statements, process-oriented simulations combine features of both event- and activity-oriented approaches. This contributes to the simplicity and the relative ease of use of this approach. GPSS, Q-GERT, SIMPL/I, and SIMULA are process-oriented simulation languages. The most widely used is GPSS, a FORTRAN-based package in which a model is constructed by combining a set of standard "blocks" that maps the logical structure, or network, of the simulated real-world system. Each block is a short subroutine or GPSS macro that performs a particular function on entities and is represented graphically by a standard stylized figure and by a statement containing all parameters (attributes) of the function (*10*). Q-GERT employs an activity-on-branch network representation, in which entities flow through the network model defined by its nodes and branches that refer to processing time or delay (*11*).

Object-Oriented Simulation

Model development consists of a highly modular approach used mostly in artificial intelligence (AI) and expert systems to provide simple, unifying programming and prevents extensive intertwined subroutine coding (*12*). The basic entities in object-oriented simulation are objects with attributes that have values, or object-attribute-value (OAV) triplets. Each object has rules and procedures associated with the OAV triplets. These objects have the capability to "communicate" with each other through "messages"; upon arrival of messages, OAV and rules and procedures process these messages and carry out their effects. This approach is believed to have great potential in simulation because it can considerably reduce the amount of programming and coding required for real-system representation.

Hybrid Simulation

Hybrid simulation systems incorporate the advantageous characteristics of the alternative simulation approaches in a unified modeling framework. SLAM, Simulation Language for Alternative Modeling, is a hybrid system that can operate in the discrete-event, network, and continuous-event simulation modes. These modes can also operate in the same model. SLAM adopts GPSS's block-statement approach, GASP's discrete-event simulation approach, and Q-GERT's philosophy of graphical representation of networks (*6*). SLAM is a FORTRAN-based package containing various subprograms, functions, and capabilities that support model development in the alternative modes. In SLAM's network mode, statement blocks call FORTRAN subprograms that model generic activities and transactions, and this can specify organizational structures for simulation model building.

DESIRED PROPERTIES OF SIMULATION

To build and run simulation models efficiently, the simulation system should possess certain minimum requirements for built-in capabilities and facilities (*13*). They are

1. Flexible methods of describing state changes during an event;
2. Techniques for scheduling events to occur relative to the independent variable time, or upon satisfaction of a set of logical relations of state variables;
3. Extended data structures such as lists and trees and capabilities for easily manipulating these structures;
4. Built-in capabilities for generating random variables and random functions (because many discrete models are stochastic processes);
5. General arithmetic capabilities and methods for gathering statistics and controlling experiments in the system;
6. Interfacing capabilities with other segments of the computer system (e.g., FORTRAN library and standard statistical packages); and
7. Debugging features.

Additional desirable capabilities that are becoming popular in simulation systems are

1. Graphics capabilities to display output of statistical analysis of experiments;
2. Real-time animated graphics of the simulated system, showing entities entering the system and going through different processes and components of the system before leaving the system;
3. A programming and editing capability to facilitate entering and manipulating data structures, programming, and coding; and
4. A "help" function to provide brief useful information on various features of the simulation system while it is in use.

AIRPORT LANDSIDE SIMULATION

As mentioned earlier, simulation is increasingly becoming an essential tool for planning, design, and management of airport landside facilities. Landside-related research started in the late 1960s to investigate the problem of severe congestion and delay in airport terminals resulting from the substantial growth in air travel and the introduction of wide-bodied jets. Researchers in airport landside considered using simulation because of its convenience, reliability, and efficiency in analysis, and its capability in describing detailed activities in a manageable fashion (*14*). Airport organizations worldwide credited simulation as the most promising method of analysis, because it can efficiently cope with the time-varying nature of demand and the stochastic nature of the air travel system (*15*).

Characteristics of simulation can vary depending on their features, specific approach in modeling particular situations, and the objective of using simulation in analysis in airport planning. Basic properties of simulation could be static versus dynamic, analytic versus numeric, deterministic versus stochastic, discrete versus continuous, or interactive versus closed. Low (*16*) treats simulation as a technique for developing artificial historic (synthesized) data for situations described by the airport planner.

Simulation is the preferred tool for airport capacity assessment. As shown in Figure 2, the central step in the process of landside capacity assessment, planning, and management is capacity and level-of-service evaluation (Steps 7 and 8) (*2*). In Steps 5 and 6, data on demand characteristics, operating conditions, and community factors are collected. Essentially, these steps will determine the level of detail of the simulation model as the analysis tool. In Steps 7 and 8 capacity and levels of service of the different components are evaluated, compared with the service volumes generated throughout operation. A balance should be struck between simplicity, speed, and ease of use of the model on the one hand and accuracy with more detailed representation of the facilities and services of interest, greater need for data, and cost on the other (*3*). Different functional levels of simulation can be defined by the purpose of the simulation, characteristics of the model, degree of simulation sophistication and detail in representing the real-world system and level of precision anticipated (*17*), and as follows:

- *LEVEL I*: The simplest and most basic level that considers only fixed peak-demand patterns at each part of the airport (e.g., design peak hour). Time variation and the stochastic element of the system are not taken into consideration.
- *LEVEL II*: Only time variation in average demand, not its stochastic nature, is explicitly considered. Such models do

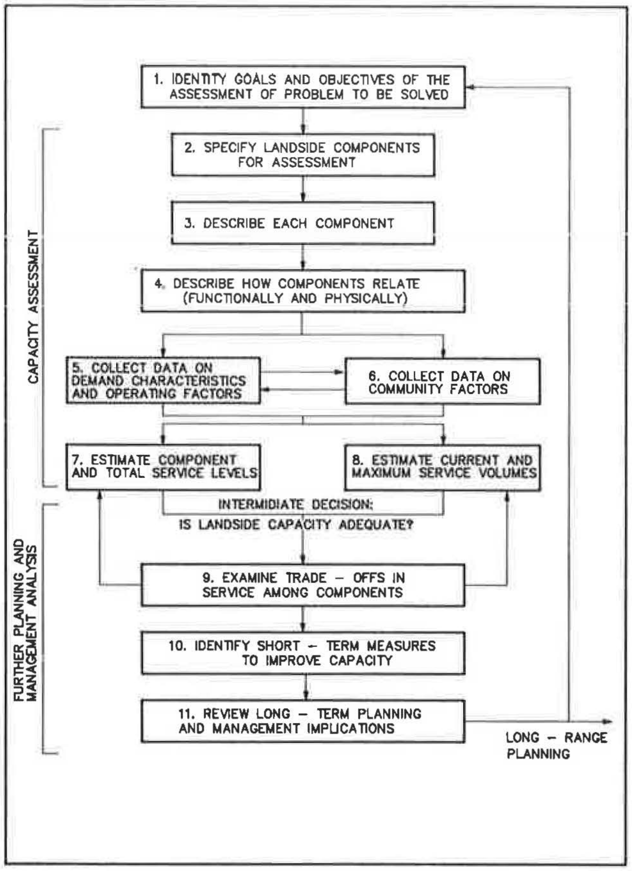

FIGURE 2 Landside capacity assessment, management, and planning (*2*).

not follow queueing theory, in which congestion and delays are incurred only when average demand rate at a particular time exceeds the maximum service rate (e.g., accounting-type models).

- *LEVEL III*: Probabilistic aspects of demand and the stochastic nature of service are explicitly considered. However, for this modeling level, assumptions of steady-state queueing analysis hold (e.g., queueing theory-based models).
- *LEVEL IV*: Demand arrival and service rates are both probabilistic and explicit functions of time. Calculations involve a high degree of mathematical complexity and can prove to be impractical for computer simulation (i.e., time-varying probabilistic queueing).

Typical of modeling, there is a trade-off between accuracy and cost-effectiveness. Although airport landside capacity can be measured only in terms of an airport's individual functional components, the analyses of individual components' capacities may fail to recognize important functional linkages within the airport landside (*3*).

It is convenient to group the airport terminal simulation models surveyed by the environment in which they were developed. Models are categorized as those developed by academia, industry, and government.

Academia-Developed Simulation

Universities pioneered research on airport congestion, initiating simulation approaches to solve this problem. The Massachusetts Institute of Technology (MIT) first drew attention to future problems facing air transportation in a workshop convened in 1967 (*17*). Other U.S. universities followed suit, mainly the Universities of California, Berkeley, and Texas at Austin.

At MIT, Odoni simulated processing facilities of the terminal using analytical queueing models, which were later used to model passenger delay in airports under steady-state queueing conditions (*18*). As part of the MIT research a simulation model of the terminal building (*19*) was developed as well as an approach to evaluate alternative terminal designs (*20*).

At Berkeley, Horonjeff (*21*) was the leader in modeling airport terminal facilities using deterministic queueing models. Work done at Berkeley included modeling of gate utilization (*22–25*), baggage claim facilities (*26,27*), movement in piers (*28*), processing of departing passengers (*29,30*), arriving passengers (*31*), passenger enplaning and deplaning (*32*), check-in counters (*33*), security (*34*), and departure lounges (*35*). This work, however, did not culminate in a complete and integral airport terminal simulation model.

At Austin, federally sponsored research analyzed terminal operations and evaluated systems' capacity (*36*). Airport access (*37*) and passenger flows in terminals (*38*) were modeled, and a simulation model (ACAP) was developed (*39,40*). ACAP is a Level II FORTRAN-based, accounting-type model. Its structure is composed of a main program and component modules that simulate individual facilities. The peculiar aspect of ACAP is that the modules' deterministic models are actually regression models derived from survey data collected in the airports studied. In essence, these models draw their predictive power only from the survey data from which they were derived. Hence, these models could not replicate operational conditions except where and when survey data hold. To overcome this shortcoming, the regression-derived, logic-core modules of ACAP were replaced by Monte Carlo models to simulate passenger processing on the basis of average service times of negative exponential distributions (*41*). This modification transformed ACAP from a Level II to Level III model. Unfortunately, the modified ACAP was not used in a practical application.

AIRSIM was developed in Florida. It is a GASP-based, event-oriented simulation model that dealt with flows of individual passengers and baggage according to flight schedules. The model was tested at the Miami International Airport (*42*).

Outside the United States, airport simulation studies were done in universities in the United Kingdom, Canada, Australia, Germany, and Denmark. At the University of Strathclyde, Scotland, a terminal simulation model (AIR-Q) was developed (*43,44*). Research conducted at the Loughborough University of Technology included analyzing behavior of passenger processing in airports (*45*), processing and service time distributions (*46*), and simulating individual terminal facilities using SLAM (*42*).

At Monash University, Australia, international terminal operations were simulated using GPSS and FORTRAN (*47*). In Denmark, Rallis (*48*) studied terminal operations, and a simulation model was established for quantitative evaluation of basic alternative design strategies for terminal extensions of Copenhagen/Kastrup Airport (*49*). In Germany at the University of Dortmund, Baron developed a simulation model for terminal operations at Dusseldorf Airport (*50,51*). In Canada, airport modeling research was conducted at the Universities of Toronto (*52*) and Waterloo and at Carlton University (*53*) where the airport terminal building was modeled using PERT as sequences of essential functions to process passengers in airports (*54,55*).

Industry-Developed Simulations

Several consulting firms have established their own airport simulation models that are used in planning, design, and management of airport terminals inside and outside the United States. However, because these models are essentially proprietary, little has been published on their properties and features.

TAMS Consultants, Inc. developed a simulation model for the planning and design of Maiquetia International Airport, Caracas, Venezuela (TAMS, unpublished data, 1972)—a Level III, GPSS-based, time-oriented queueing landside simulation model. A previous version of this terminal simulation model was used to design the Greater Pittsburgh Airport (*16*). A model for gate selection and occupancy, as part of a comprehensive airfield simulation model, was developed and used for the planning and design of Dallas-Fort Worth Regional Airport (P. Sih, unpublished data, 1973).

Bechtel developed a similar model (Level III, GPSS-based, time-oriented queueing) capable of simulating terminals of up to 50 gates (B. Metais, unpublished data, 1974). The FAA later acquired this model and expanded and embellished it as ALSIM (*15*), as described later. A modified version of the Bechtel model was used to plan the international airports in Saudi Arabia. This model was demonstrated to the author in 1985. It is used at the International Airports Project in Jeddah, Saudi Arabia. The model is an interactive, GPSS-based model with FORTRAN subprograms.

Battelle (*56*) developed a Level II, FORTRAN-based, deterministic, accounting-type airport landside model that has fixed service times. This model is similar in its characteristics to ACAP.

Peat Marwick Mitchell & Company developed a time-based simulation model, which has been applied in assessing operations at several U.S. airports (*2*).

Another proprietary airport terminal simulation model, ATSIM, was developed by Aviation Simulations International (*2*). ATSIM has been used in the planning of Denver Stapleton International Airport.

Government-Developed Simulations

Government agencies actively support research and development of airport simulation models. In the United States, FAA's policy has been to sponsor research in this area. In Canada and the United Kingdom, similar organizations developed airport simulation models.

Some of the FAA-sponsored airport simulation models were ACAP (discussed earlier), the Airport Landside Model developed by H. H. Aerospace (*17*) (a Level III model that uses the analytical queueing approach of MIT), and ALSIM, which was acquired from Bechtel Corporation and was subsequently upgraded by the U.S. Department of Transportation Transportation Systems Center (*15*). ALSIM's properties and features are described in more detail in the next section.

The Port Authority of New York and New Jersey developed a simulation model to evaluate expansion plans for international arrivals at John F. Kennedy International Airport (*57*). It is GPSS based and uses the time-oriented queueing model approach.

The Canadian Air Transportation Administration developed the Calgary Model, a GPSS-based simulation using time-oriented queueing models (Canadian Air Transportation Administration, unpublished data, 1973). Recently, Transport Canada developed a terminal simulation model composed of three interactive modules for gate assignment (*58*), ground transportation, and passenger and baggage terminal flow. It has several attractive features, including graphics capability, good editing capabilities, and flight schedule simulator. The modules employ deterministic multichannel queueing models using FORTRAN IV with Monte Carlo sampling technique (*59*). This model will be discussed in detail in the next section.

The British Airport Authority (BAA) has developed an airport simulation model for gates and individual processing facilities in-house. General properties and features of this model are not known because nothing has been published about it. The author saw a demonstration of this model in 1982 at BAA's main offices in Gatwick. One attractive feature is the real-time animated graphics screen display that simulates passenger flow and processing. Passengers, shown as "blocks" with different colors identifying their attributes, move through the terminal. Predefined attributes determine exactly where each block will go and what processes are to be performed on it. This feature is similar to the one adopted in the TEXAS Model for modeling intersection traffic. This model considers the interaction among individually characterized driver-vehicle units as they operate in a predefined intersection environment. It provides real-time animated graphics simulation of the intersection together with all simulated data output and statistical analysis of the data (*64*).

DESCRIPTION OF SELECTED SIMULATION APPROACHES

The airport terminal can be modeled on two scales—macroscopic, as one integral system from groundside to airside; or microscopic, where individual facilities are considered separately (*41*). Each approach has its merits and shortcomings, and it is up to the airport planner to decide which scale to use. The microscopic view may fail to recognize the importance of functional interactions between individual facilities. On the other hand, adopting the macroscopic view may prove to be extremely laborious and costly because it is so data intensive. Of the airport terminal simulations it surveyed, TRB's Special Report on airport landside capacity (*2*) considered three simulation approaches. They are FAA's ALSIM, the Canadian Airport Planning Models, and SLAM.

Airport Landside Simulation Model (ALSIM)

ALSIM (*15,65*) is a macroscopic, probabilistic, discrete-event, fast-time computer simulation model capable of producing flow and congestion parameters and statistics on simulated facilities. The structure consists of main and auxiliary programs (written in GPSS-V, which creates transactions representing passenger and visitor processing and directs them through the model blocks that describe the simulated system), FORTRAN-based supporting subprograms (to provide flight schedule, airport configuration data, matrix manipulation, and assignment of facilities to GPSS-created transactions), and IBM/370 assembly language subprograms to provide linkages between GPSS-V and FORTRAN subprograms. (See Figure 3.)

Model input is grouped into four major categories: flight schedule, passenger characteristics, airport geometry, and facility information. (See Table 1.) The first two describe demand and the last two represent service characteristics of the system. ALSIM produces a statistical report for each facility encountered in a simulation. The report includes total number of persons served, maximum and average number of servers (agents) busy, occupancy, and flow of persons through the system. ALSIM assumptions are as follows:

- Passenger and visitor processing facilities are similar and independent of airport type,
- Random functions govern transfer flight selection and baggage delivery times,
- Service time distributions are independent of time and server workload,
- Single queue lines are used to represent multiserver queues at each facility,
- People proceed directly from one facility to another,
- Exogenous flight schedule provides the time-varying demand, and
- Arrival rates and operations of facilities are determined by the model itself.

Operationally, ALSIM can simulate a 100-gate airport during a busy 5-hr period involving 20,000 passengers on 165 flights. Such a simulation requires about 7 min of CPU time on an IBM/370 mainframe computer (with GPSS-V and FORTRAN IV compilers) and takes 570K bytes of core capacity.

Canadian Airport Planning Models

Transport Canada has developed a set of airport planning simulation models to assist planners and designers in assessing demand, capacity, and levels of service in airport terminal

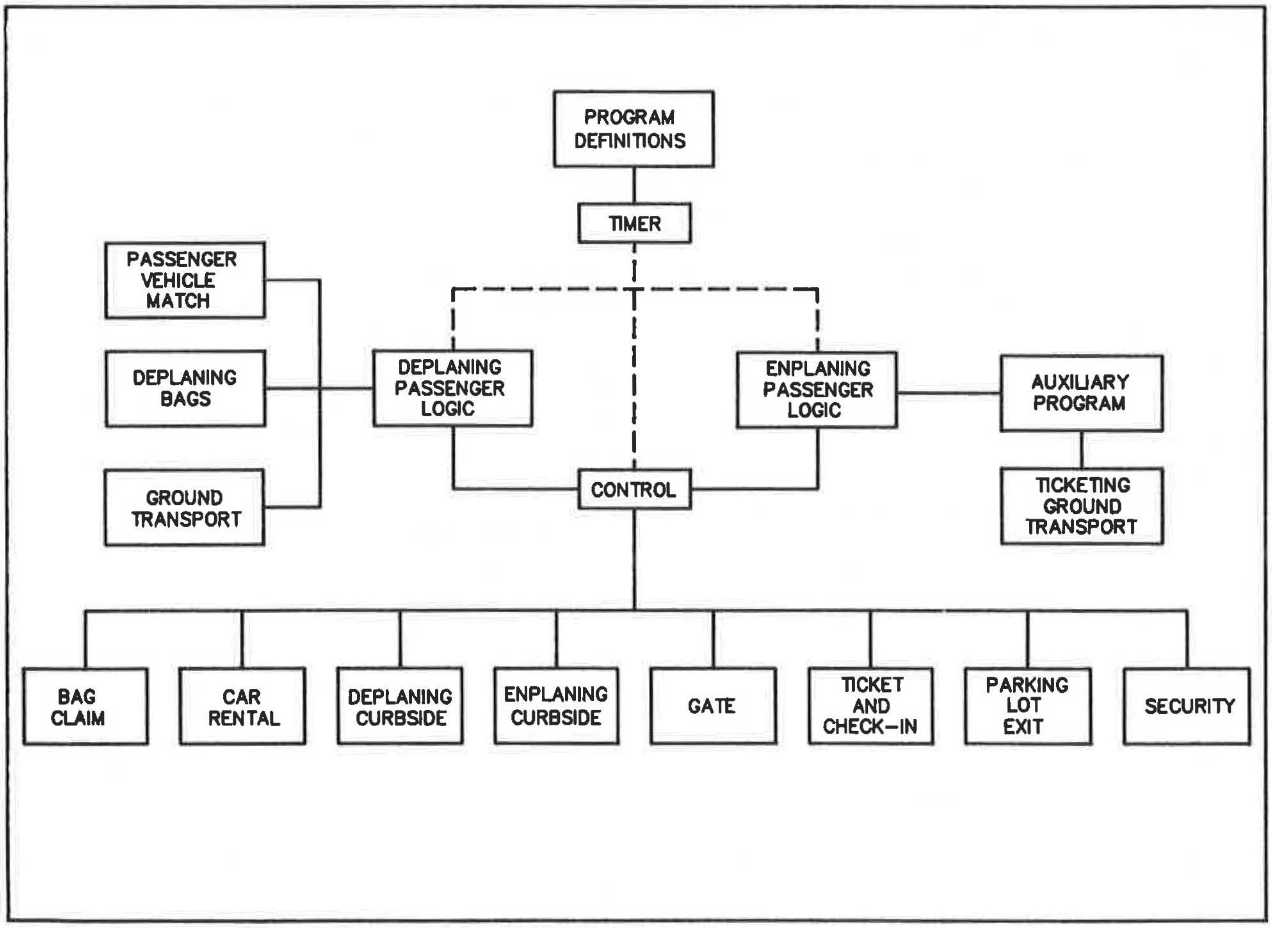

FIGURE 3 **Airport landside simulation model program structure (*15*).**

TABLE 1 ALSIM INPUT DATA (*15*)

1. FLIGHT SCHEDULE CHARACTERISTICS

- Flight Number
- Airline
- Arrival / Departure Time
- Aircraft Type
- Domestic / International / Commuter
- Total Passengers
- Transferring Passengers
- Bag Claim Facility Identification Number

2. PASSENGER CHARACTERISTICS

- Percent Preticketed
- Percent Using Express Check-in
- Passenger Routing on Landside
- Ground Transportation Modal Choice
- Passenger Group Size
- Well-Wishers Per Group
- Greeters Per Group
- Originating Passenger Times of Arrival Distribution Prior to Flight
- Arrival Distribution Greeters
- Arrival Distribution of Vehicles Meeting Passengers
- Distribution of Number of Bags Per Passenger
- Car Rental Agency Selection Distribution
- Percent of Well-Wishers or Greeters Proceeding to Gate
- Percent of Greeters Proceeding Inside Terminal

3. AIRPORT GEOMETRY CHARACTERISTICS

- Point Number
- X-Y Coordinates
- Facility Type at Point
- Facility Number Within Type

4. FACILITY INFORMATION

- Service Time Distributions
- Car/Taxi Loading and Unloading Times
- Number of Servers or Size of Facility
- Baggage Transport Times to Claim Area

and groundside facilities (Transport Canada, unpublished data, 1988). These models are interactive, interrelated, and mutually compatible separate models that run on an IBM-AT compatible microcomputer. They are structured in front and end segments programmed in BASIC/PASCAL and a middle segment, the simulator model, programmed in FORTRAN IV. These three models are the gate assignment model, air terminal passenger flow simulation model, and ground transportation simulation model.

Gate Assignment Model

This model is a deterministic multichannel queueing model, operating in 5-min intervals (*58*; G. Singh, unpublished data, 1988). Gates are assigned to flights in the schedule according to the assignment strategy specified by the user. Each flight is assigned in the order that they appear in the flight schedule. Required input consists of the flight schedule (up to 300 flights) created by a computer editor and the airport description. The airport description input includes aircraft class by seating capacity, carrier preference (up to 30 carriers), gates (up to 100), service times in minutes of aircraft arriving at and departing from gates, gate conflict (up to 50) defining any intergate restrictions caused by aircraft or gate size incompatibility, and time equal to the aircraft push-out maneuvering time.

Simulation output includes a listing of the two-way passenger flow through each gate, a Gantt Chart assigning aircraft to gates, statistics on gate utilization and aircraft and passenger delays, and a step chart plotting the cumulative number of aircraft on gate in each 5-min interval over the simulation period or time span of the schedule.

Air Terminal Passenger Flow Model

The air terminal passenger flow model is an interactive event-oriented stochastic simulation model that simulates flow of passengers along predefined paths from curb to aircraft and vice versa (Transport Canada, unpublished data, 1988; F. Mangano, unpublished data, 1988). The model consists of three interactive segments: the airport terminal description data entry and edit module, the simulator module, and the statistics report generation module. Special data files are created using the data entry and editor module. Data required as input include the following:

1. Identification of carriers, sectors, terminal users, aircraft types, passenger types, and baggage claim;
2. Description of layout of air terminal building by identifying gates, links, processing facilities, separators and meeting areas, baggage dispensers, waiting, and holding rooms;
3. Arrival distribution tables;
4. Processing rate distributions;
5. Sequential lists of node numbers identifying paths used in the terminal;
6. Ratio tables of visitors to passengers by hour of day and by sector; and
7. Flight schedule that includes 17 different attributes for each flight.

The program processes terminal users through the building according to the information provided by the airport terminal description entry module. The simulation module is then activated. Each element of a flow path representing a part of the terminal building (node) is acted upon, assigned a next event time, and moved sequentially through its designated flow path. Each transaction is associated with 19 attributes that are used in the logical control of the transactions when simulation progresses as described by the airport description file. When a transaction enters a baggage area, a probabilistic match is performed based on passenger arrival rates, baggage arrival rates, and bag-to-passenger ratio. The statistical report generation module then accesses the output files created by the simulation module to print the output data specified by this module. Simulation output includes the following:

1. Cumulative number of users entered and exited, present count in facility, maximum accumulation of users, and time of maximum accumulation for each facility;
2. Summary of baggage device assignment statistics;

3. Queue statistics for each processor including total and maximum user queue time, number of users in queue, frequency distribution of queue times, and flight causing maximum congestion; and
4. Summary of delay statistics for each flight.

Ground Transportation Model

The ground transportation model is an interactive program developed to simulate the flow of vehicular traffic along access and egress road systems of the airport (Transport Canada, unpublished data, 1988; G. Singh, unpublished data, 1988). Movement of traffic on roads, parking lots, and curbs is simulated through a description of the road network, vehicular flow patterns and paths, and behavioral characteristics of the vehicles on the road system. The simulation approach applies the survey statistics and flow path information to each flight in the schedule, employee schedule, visitor schedule, and cargo schedule. Vehicle transactions are created as they move through the road link system. At each part of the system, transactions are acted upon, assigned a next event time, and moved through their prespecified paths. Statistics are gathered whenever a vehicle enters or exits an element in the road network.

Required data input consists of

1. Road link system and associated transit times;
2. Vehicular and user flow along the road link system;
3. Time distribution relating vehicle creation to flight arrival and departure times;
4. Visitor-to-passenger ratios, modal split, average vehicle occupancy by mode, curb processing distribution, and mass transit schedule and demand parameters;
5. Aircraft flight schedule; and
6. Arrival and departure schedules for employees, visitors, and cargo.

The model's output can provide information on any combination of the eight attributes (current node, next node, path, transportation mode, trip purpose, user type, sector, and flight number). Output statistics include time-interval occupancy counts for each link in the simulated network. Output includes the following information on each link: time, total number of vehicles entering and exiting the time interval (broken down into passenger, visitor, employee, and cargo vehicles and private cars, taxis, rental cars, and mass transit), present vehicle count at end of interval, and maximum vehicle count for time interval and time of its occurrence.

Alternative Simulation Method for Individual Facilities

SLAM was used to simulate individual processing facilities of the airport terminal (*41*). This is a microscopic approach to simulating terminal facilities in which input requirements are minimal. Each facility is modeled by writing a short program consisting of SLAM network-mode statements that best describe the operation of the facility. The major input is number of channels (servers), processing rate of each, service discipline, and arrival distribution of demand. A user function USERF(I) (*7*) was used to simulate an aggregate stochastic arrival distribution on 20-min intervals, closely representing the arrival distribution for the facility actually observed (*41*). This SLAM function simulates any pattern of arrival distribution, an essential requirement that provides accurate simulation of operation and a realistic performance model. Using a randomly sampled arrival rate from a standard probability density function would have been erroneous and unrealistic.

As an example, the following model in SLAM network-mode statements was used to simulate the departure official controls (security and passport checks) (*41*):

```
NETWORK;
  CREATE,USERF(1);
  ASSIGN,ATRIB(1)=TNOW;
  ASSIGN,XX(2)=XX(2)+1;
  COLCT,XX(2),PAX ARRIVING;
SECK QUEUE(1);
  ACT/2,EXPON(0.15,2),,PASP;
PASP COLCT,INT(1),TIME IN SECURITY,20/0/0.75;
  ASSIGN,ATRIB(2)=TNOW;
  QUEUE(2);
  ACT/3,EXPON(0.12,3),,EXIT;
EXIT COLCT,INT(2),TIME IN PASSPORT,20/0/0.5;
  TERM;
  ENDNETWORK;
INIT,0,250;
MONTR,SUMRY,0,20;
FIN;
```

All major input describing the operation at this facility is represented as parameters to SLAM statements in this example. For instance, CREATE USERF(1) will assign a prespecified (user-defined) arrival rate corresponding to the observed rate at the particular simulation time (TNOW). COLCT will record total number of arrivals in the time interval (20 min) to the first facility, security check (SECK). This arrival will be assigned to the security process queue [QUEUE(1)], where the security check takes place if the queue is empty. The statement ACT/2,EXPON(0.15,2),,PASP will perform a security check (ACTivity 2) for a time duration whose value is randomly selected from a negative exponential distribution with an average rate of 0.15 min per transaction before directing the entity (passenger) to the next facility, the passport check (PASP). The simulation time (TNOW) is changed to the current time after completion of security check. The entity (passenger) is now ready for passport check (ACTivity 3), which commences immediately if the queue [QUEUE(2)] is empty. The processing time for passport checks is randomly sampled from a negative exponential distribution with an average rate of 0.12 min per transaction, after which the entity EXITs. The statements (TERM) and (ENDNETWORK) mark the end of the model and termination of simulation, and the statement (MONTR) produces a summary report on all operations between initializing and terminating the simulation (in this case 250 min). This example is modeled using the SLAM network mode. SLAM's discrete-event mode could have been used as well. A user-written, FORTRAN program would replace the SLAM network statements.

Standard SLAM output includes statistics on processing operations at a facility at any desired time or time interval.

Statistics for the example are collected for TIME IN SECURITY and TIME IN PASSPORT. Such statistics as maxima, minima, averages, variation of queue length, queue time, server utilization, and number of entities in each facility can be gathered.

SLAM can also be used for the macroscopic simulation approach. Of course, the programming involved will be much more detailed with a more complex modeling structure than the example. The macroscopic approach was used to establish the performance models for individual facilities at varying service volumes and demand levels (*41*). Separate FORTRAN segments will be needed to relate various parts of the model and provide the means to input arrival distributions at the system boundaries.

SUMMARY

Airport terminal simulation models developed in academia, industry, and government were reviewed. An overview of modeling and simulation was presented. Definitions, terminology, conceptual approaches to modeling, types of simulation, and simulation languages used to model airport terminal systems were reviewed and discussed. To evaluate different simulation systems and set selection criteria, desirable technical properties of simulation systems were presented. Three simulation approaches to model the airport terminal were presented in detail and implementations of these approaches were discussed.

General conclusions are as follows:

1. Airport landside simulation is an effective tool that airport planners and managers can use to provide synthesized data to help plan individual facilities and the relationship between all facilities that compose the landside. The efficiency and reliability of landside simulation for planning and operational analysis depend on the particular application. Although it is ideally suited for planning purposes, namely, capacity and performance analyses of new or existing facilities, simulation may be less efficient for operational analysis of the system. This is because of extreme variations in system attributes caused by the probabilistic nature of system operations and the need to provide quantified level-of-service criteria for all components of the landside.

2. Airport landside simulations are data intensive and, depending on the specific features of the simulation and scale of application, generally require relatively high computer capabilities. However, most of the recently developed simulation systems can be operated on standard advanced technology microcomputers.

3. Desirable features for landside simulation include the ability to use standard microcomputers, flexible programming methods for simulating state changes and system representation, efficient programming and editing capabilities to facilitate manipulation of the data structures, and graphics capabilities to display output of statistical analyses and real-time animated graphics of the simulated system.

4. Airport landside simulation has advanced in stages over the past two decades using conventional computer simulation techniques to their maximum capabilities and either general purpose languages (e.g., FORTRAN) or simulation languages (e.g., GPSS). A different approach is apparently needed in the future to enhance the efficiency and reliability of simulation. Such enhancements include more efficient and flexible programming logic and structure, modular and interactive simulation, better real-world animation capabilities and graphics display, and more manageable data structure editing capabilities. It is believed that object-oriented programming has good potential for facilitating enhancements to airport landside simulations in the coming years.

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Designing an Improved International Passenger Processing Facility: A Computer Simulation Analysis Approach

VICTOR GULEWICZ AND JIM BROWNE

During the past 20 years, the management engineering and analysis group of the Port Authority of New York and New Jersey has periodically performed design and operational evaluations of the international passenger processing system facilities at the John F. Kennedy International Airport. The most recent effort included the development and validation of a computer simulation model of the Federal Immigration and Naturalization and Customs Services and the baggage processing operations. This model was developed to perform operational analyses of planned improvements to the federal inspection facilities. The simulation was initially used to evaluate the expected operational performance of two alternative baggage system expansion plans. The model development, initial model application, and results are described in this paper.

The Port Authority of New York and New Jersey is a public agency responsible for promoting and facilitating trade, commerce, and transportation in the New York–New Jersey region. It is a self-supporting bistate agency that finances it activities through bonds paid off by its own revenues. It has about $6 billion invested in existing transportation (tunnels and bridges, airports, bus and marine terminals, rapid transit, etc.) and trade and commerce facilities (World Trade Center, industrial parks, etc.). An equal amount of capital expenditures is currently being spent for new facilities and improvements of existing ones.

The three major New York metropolitan airports are operated by the Port Authority under long-term leases from local governments, and the authority is responsible for such common-use facilities as runways and taxiways, heating, ventilating and air conditioning plant and equipment, roadways, and security, among other things. The Port Authority plans an approximately $3 billion package of expansions and improvements for John F. Kennedy International Airport (JFK), which will include new roadways, a new transportation center, a hotel, and passenger and baggage distribution systems that will serve some 45 million passengers a year by the turn of the century. More than 30 million air travelers currently use JFK annually. The goal is that it will remain competitive and meet air transport needs in the year 2000 and beyond. The International Arrivals Building (IAB) is a common-use facility that handles about 50 international air carriers and their passengers. The Port Authority is responsible for the planning, design, operation, and maintenance of this facility. Both the Port Authority and the airlines using the common federal inspection services (immigration, customs, and agricultural processing) at the IAB are, of course, concerned about the levels of service provided during the interim period from now until the end of the 1990s when the airport redevelopment program is completed.

MODEL DEVELOPMENT

Objectives and Scope

JFK staff requested the Port Authority to develop a simulation model of the federal inspection services and baggage claim processes. Upon development and validation, the model would be used to evaluate alternative plans, facilities and equipment, and operations in terms of their expected service levels and adequacy to handle future projected demand. It was agreed that the full federal inspection system from "blocking" (arrival at gate) of the aircraft through immigration processing, baggage delivery and pick up, and customs inspection should be modeled because these operations are integral to the system. Desired evaluative data included estimates of flows, queues, and space requirements for each process as well as the expected elapsed times for different categories of passenger from block time to clearing of customs. The initial application, described later, was to evaluate alternative plans to replace existing baggage claim devices, because some extended delays were occurring during peak periods.

Study Duration and Approach

Model development was designed to be completed in 4 months, including model structuring, data collection to obtain processing rates, programming in General Purpose System Simulation (GPSS), validation testing, and reporting on the evaluations. An appropriate model was needed to complete the initial application within 6 months. Primary reasons for choosing GPSS for personal computers was to maintain independence and reduce coordination requirements and possible delays in a mainframe environment. Also, the GPSS "gather" command facilitates increased accuracy in analyzing baggage claim operations by keeping track of individual passenger and bag movements. The simulation assigns each bag to the associated passenger, randomly mixes bags, and models the matching process at the baggage belt so that each passenger leaves the area only when all of his or her bags have arrived. This pro-

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vides the potential for greater accuracy than treating baggage claim as a fixed processing-rate activity or estimating the number of passenger-bag matches by formula.

Model Assumptions and Inputs

The development of a simulation model of the federal inspection and baggage claim process was important to international airlines to ensure competitiveness and service levels while maintaining reasonable costs at the IAB. Therefore, the management engineering and analysis study team and the Port Authority manager who requested the study met on a number of occasions with the Kennedy International Airport Tenants Association (KIATA), a group representing airline needs and viewpoints, to obtain concurrence on its plans and objectives and to develop a set of assumptions on which the model would be based. Thus, the basic assumptions and methodology were agreed upon before programming the model began. The major concepts and relationships used in the simulation are described in the next section. Input data on flow rates, passenger walking times, baggage delivery and unloading rates, and so on, were obtained by direct observation and data collection. Projected airline schedules and citizen and visitor passenger loadings were available from a previous forecasting study. For the initial application of the model these inputs and assumptions were reviewed and modified as necessary (e.g., level and time frame for passenger demand and arrival) to satisfy the specific requirements of the analysis.

Model Structure

The conceptual basis of the simulation model is that the passenger and baggage flows in the model will predict flows in the actual operation; thus the flowchart mirrors the operation that occurs at the airport. Figure 1 is a simplified flowchart of the operation and of the model for each aircraft arrival. Of course, the simulation has its "internal clock" and keeps track of all planes, passengers, and baggage in the system. This flowchart describes the sequence of operations for each plane arrival.

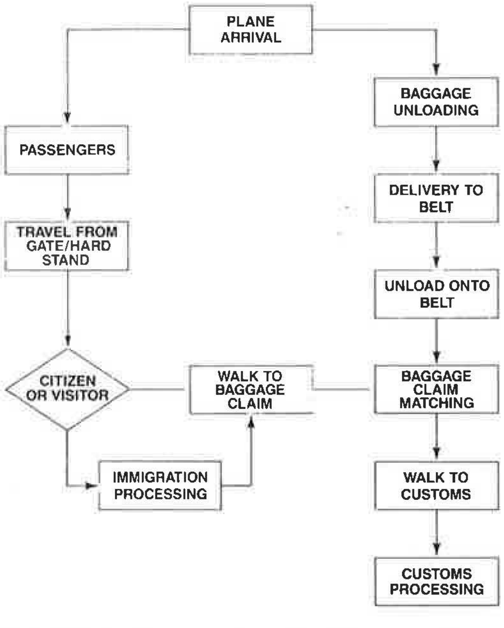


FIGURE 1 Conceptual model of the operation.

When the simulation reaches the arrival time of the plane, the program stores key data including the block time; the citizen-to-visitor ratio; location of plane arrival at a wing, finger, or remote gate; and the number of passengers and bags. Passenger "transactions" are generated; these are the units that are tracked as they progress through the remainder of the simulation logic over the time being simulated. The model also generates and randomly mixes the apropriate number of bags, each carrying a special code (parameter value) to identify the passenger to whom it belongs.

On the basis of the blocking location (wing, finger, or remote gate) of the flight, passengers are assigned walk times to immigration processing (for those from outside the United States) or to baggage claim (for citizens). Immigration processing rates are based on direct observations of immigration outflows for different numbers of booths in operation. Similarly, times required for delivery of bags to assigned baggage belts and unloading rates for the transfer of bags from delivery cart to belt are based on actual rates observed for specified unloading crew sizes. The passenger-bag matching process at baggage claim is modeled so that a passenger does not leave until all associated bags are available on the belt and claimed. Observations showed that once the passenger and associated bag or bags were available, the bag or bags were claimed within one revolution of the baggage belt. This time is incorporated into the travel to customs for each passenger.

The modeling of the customs operation allows for the designation of three different processing rates—one for "red" booths (for passenger with goods to declare), one for "green" booths (for other passengers), and an expedited processing rate for cases in which total queues exceed a certain level—and "rovers" (additional moving inspectors) are introduced to speed processing.

Output Information

Because the simulation tracks each passenger and bag through the process, there is great flexibility in the types of output that can be obtained to meet a user's needs. Examples of typical output information are described. For each major processing area (immigration, baggage claim, customs), the simulation routinely summarizes waiting time and queue-length data. Queues at each of these operations are typically provided at 5-min (or shorter, if needed) intervals so that the performance of the component parts of the federal inspection process can be tracked through the peak period and interrelationships identified. For example, in baggage claim, this would include both the number of passengers and the number of bags so that estimates of required belt capacities and floor space can be calculated. Delays in unloading bags due to unavailability of belts are also accumulated, if desired. The elapsed times to or between each of the key points in the operation (immigration, baggage claim, and customs) are routinely provided. A wide variety of specialized outputs can be obtained by making minor modifications to the program.

Validation

In addition to cooperative development of assumptions with facility and airline staff and establishment of processing rates and other operational data on the basis of on-site observations to ensure realism and accuracy in the model, an extensive validation test and analysis were performed. On a peak day, two data teams visited the IAB and simultaneously collected operational data. One team obtained input and processing-rate data—plane arrivals, passenger loads, crew sizes, baggage unloading rates, and so on; the other obtained data on flows and service levels—passenger flows out of baggage claim, queue length at 5-min intervals, and so on. The input data were run through the simulation to obtain simulated results at each step in the process for each time period for comparison with the actual observed results. Whenever significant differences occurred, the data were analyzed in detail to determine whether the differences resulted from unpredictable fluctuations (e.g., in citizen-to-visitor ratio or in customs inspection processing rate) or whether they indicated an area in which changes in the model could improve the correspondence between actual and predicted results. This led to a number of model enhancements (e.g., the specification of wing or finger arrivals rather than simply a building gate as opposed to a remote gate arrival).

In sample validation results (Figure 2) as well as all other numerical results in this paper, reasonable but hypothetical values are used because of the sensitivity of the data (in particular the various processing rates for federal inspections). In the authors' opinions, this does not detract from the value of the comparative analyses that were performed and reported here. The remainder of this paper will describe the initial application of the model. Further applications at both JFK and Newark International Airports were subsequently requested.

MODEL APPLICATION

The Federal Inspection Services (FIS) hall is in the IAB, one of nine separate terminals at JFK. International air travelers arriving on foreign-flag carriers are processed through federal immigration and customs inspections at this facility. As noted earlier, following passenger arrival the federal inspection process includes immigration inspection, baggage claim, and customs inspection.

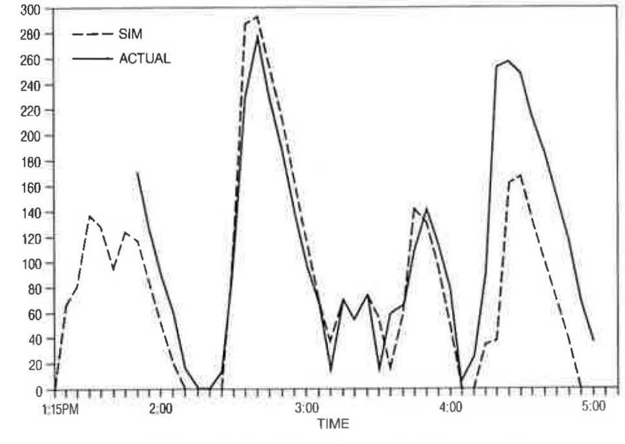


FIGURE 2 FIS model validation—total immigration queue, simulated versus actual.

The ability to efficiently process significant numbers of passengers at the baggage claim is critical to providing an efficient overall federal inspection process. This ability has been compromised for some time because of the unreliability and limited baggage processing capabilities of the existing claim devices, which were installed in 1965. These devices do not have sufficient capacity to handle baggage being generated by the predominately wide-body aircraft that now characterize arrivals at the IAB. As a result, bags sometimes must be removed from the devices and stored on the floor to permit subsequent flight arrival processing. Because of downtime and lack of adequate storage capacity, passenger processing times have exceeded desired service standards on occasion. Consequently, arriving international passengers sometimes experience congestion and delay at the baggage claim area. Also, there was concern that desired standards be achieved with the expected increases in passenger volume projected through the 1990s. This concern resulted in a decision to replace the existing claim devices.

Following a review of several design concepts, two alternative baggage system designs were selected for further evaluation of expected service level. The systems were characterized generally as being either "in-ceiling" or "at-grade." Both systems would include eight baggage claim devices, four each in the east and west wings of the IAB. The systems additionally would be continuous-loop flat-plate devices that have interlocking movable plates (covered by a rugged material) that are supported and guided and travel along a framed structure. The systems differed in how the desired baggage storage capacity and the required number of devices within the existing confines of the hall would be achieved. The in-ceiling system would use available unused space and loop above the hall; the at-grade system would employ devices with snakelike configurations using available space on the airside apron adjacent to the hall (Figures 3 and 4). Each system would consist of high-capacity claim devices capable of holding baggage generated from a fully loaded, wide-body aircraft (e.g., 747).

Simulation Modeling Approach

The evaluations of expected service levels for 1990 and 1995 (chosen to evaluate the projected short- and long-term performance of the proposed baggage systems) were done using the GPSS computer simulation model developed for the FIS

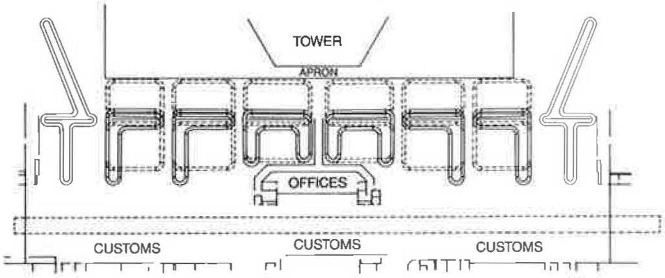


FIGURE 3 Proposed new baggage system—in-ceiling device.

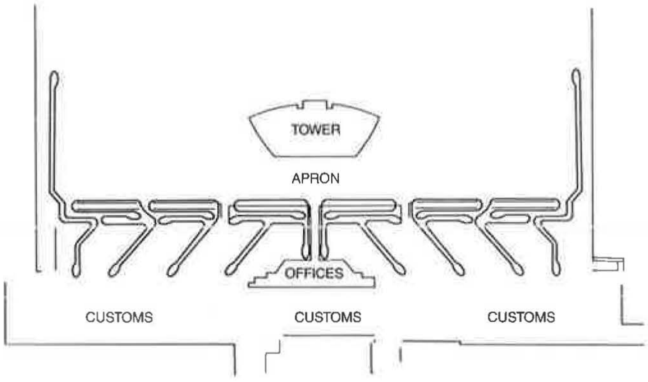


FIGURE 4 Proposed new baggage system—at-grade device.

processes and baggage claim operation. Structuring the simulation model to evaluate the performance of the proposed baggage systems required a modeling approach that incorporated the applicable components of the FIS and baggage claim operations. Specifically, the simulation included the flow and processing of arriving passengers from the plane block through primary immigration inspection or citizen bypass (at immigration) to baggage claim. Similarly, baggage flow from the plane block to the claim device, including dolly train processing and loading onto the claim devices, was simulated (Figure 5). A key element was modeling the matching of passengers and bags, which determines the time spent in the baggage claim area.

Modeling assumptions and input parameters that were broadly discussed earlier were developed for this particular application of the model. The simulation was then run, using summer peak-period passenger demand estimates for 1990 and 1995. This provided information (output at simulated 5-min intervals) for a peak 4-hr period of flight arrivals, which included the number of queued passengers and unclaimed baggage by flight in baggage claim (selected indexes of system performance).

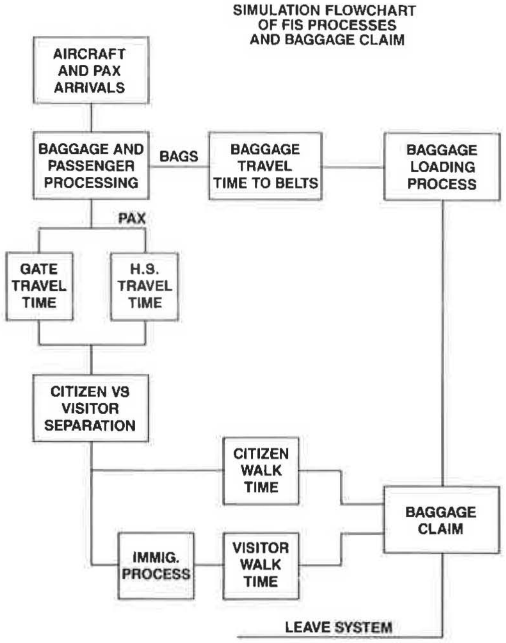


FIGURE 5 Simulation flowchart of FIS processes and baggage claim.

Model Assumptions and Inputs

Passenger Demand

To establish base demand, actual aircraft and passenger arrival information for 26 summer Friday and weekend days in 1987 (which approximated peak conditions) was reviewed. This information was entered into a PC-based spreadsheet to identify the rolling peak hour of demand for each day (e.g., 2:10 to 3:09 p.m.). The average (3,505 passengers) of these peak rolling hours was recommended for use as a base demand volume.

To simulate the processing of passengers through the FIS operation, information relating to actual aircraft arrival times, passenger loadings for a peak period, including a peak rolling hour, was selected from data on the 26 days surveyed. The day chosen was July 3, 1987, with a peak rolling hour volume of 3,468, which approximated the average demand for the 26 days surveyed. Demand was documented for a 4-hr period, which was necessary to "load" the simulation to report results for the peak 3 hr period (2:00 to 5:00 p.m.).

To establish future year demand estimates, growth factors for 1990 and 1995 were documented. These factors were applied to the chosen base passenger loadings to establish the future demand estimates for 1990 and 1995 (Table 1).

The number of citizens and visitors by flight was established by applying a 40:60 percentage split (used by aviation staff for planning purposes at JFK), respectively, to the 1990 and 1995 forecast passenger loadings.

Passenger Travel Time from Plane to Immigration

Travel times for hardstand and gate locations were based on available information and data collected at the IAB (see Table 2).

Visitor Processing

Visitor processing, through primary immigration inspection, assumed full staffing of booths. Also, it was agreed that the modeling of visitor processing through immigration inspection would be based on the current practice of preclearance at the airport of origin for Aer Lingus, Air India, and El Al flights (expected to have this status by 1990). Visitors on these flights therefore did not require primary immigration inspection at JFK. The primary immigration inspection rate used was based on past data collection and discussions with the Immigration and Naturalization Services.

Citizen Walk Time to Baggage Claim

Citizens bypass primary immigration inspection and proceed directly to the baggage claim area. Citizen walk time from

TABLE 1 FUTURE YEARS' PEAK PERIOD DEMAND ESTIMATES

				PASSENGERS		
FLIGHT	**TIME**	**WING**	**BLOCK LOC**	**1987**	**1990**	**1995**
FF33	1305	EAST	HS	476	533	643
SR110	1305	EAST	F	322	361	435
VA800	1315	EAST	W	47	53	63
SF4116	1325	WEST	HS	469	525	633
EI103	1350	EAST	W	330	370	446
SK903	1405	WEST	F	211	236	285
DF3306	1425	EAST	HS	359	402	485
AZ610	1435	WEST	F	353	395	477
NW43	1435	EAST	HS	283	317	382
SK911	1440	WEST	F	225	252	304
PK715	1440	WEST	W	304	340	410
KL645	1450	EAST	F	373	418	504
LH410	1455	EAST	W	77	86	104
SR100	1455	WEST	W	331	371	447
AF077	1500	WEST	W	318	356	429
BB692	1510	WEST	HS	345	386	466
NW37	1510	EAST	HS	127	142	171
IB951	1515	EAST	F	373	418	504
BR267	1525	WEST	F	242	271	327
LH408	1540	EAST	W	214	240	289
AY105	1545	WEST	HS	224	251	302
MS985	1555	EAST	HS	385	431	520
NW18	1600	EAST	HS	329	363	444
LH404	1605	EAST	W	312	349	421
SK901	1610	WEST	W	220	246	297
EI105	1625	EAST	F	246	276	332
AI109	1635	WEST	F	385	431	520
OA411	1640	WEST	HS	195	218	263
KL641	1650	EAST	W	382	428	516

Hypothetical Data

TABLE 2 PASSENGER ARRIVAL DISTRIBUTIONS

LOCATION	**ELASPED TIME BLOCK TO PASSENGER ARRIVAL AT IMMIGRATION**	**NUMBER OR PERCENT OF ARRIVING PASSENGERS**
Hardstand[1]	20 minutes	first passenger
Hardstand	25 minutes	66% of flight
Hardstand	30 minutes	100% of flight
Gate/Wing[2]	10 minutes	first passenger
Gate/Wing	15 minutes	75% of flight
Gate/Wing	20 minutes	100% of flight
Gate/Finger[2]	5 minutes	first passenger
Gate/Finger	10 minutes	75% of flight
Gate/Finger	20 minutes	100% of flight

[1] Hardstands are remote locations from the IAB where planes block

[2] Wing or Finger denote different gate locations at the IAB where planes block

the beginning of the bypass in the immigration area to baggage claim was measured at 2 min and was used as the basis for simulating this movement.

Baggage Processing

The modeling of baggage processing encompassed the movement of bags for each arriving flight, from plane blocked at a building or remote gate to loading onto claim devices. The assumptions and inputs used for simulating these activities included the following:

- The number of bags by flight was 1.5 bags/passenger (consistent with current planning assumptions).
- Dolly train travel time, from plane block to the claim device area for the first consist, was measured at average values of 15 min for flights arriving at building gates and 20 min for remote gates. From the data collected, baggage loading from the dolly trains to belts for each flight was observed to be a continuous operation, with no delays occurring between loadings from the dolly transports.
- A staffing level of 12 handlers/wing (east and west) in the load area was assumed on the basis of discussions with JFK operations staff and observations made. A loading rate of 6 bags/min/handler was used (consistent with observations and current planning assumptions). This figure represented an average processing rate, with allowance for handler fatigue.

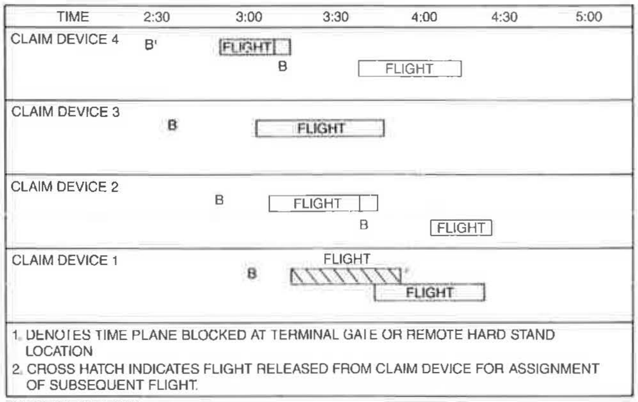
Baggage Claim

It was assumed that passengers claim baggage individually and that all pieces must be claimed before the passenger can depart from the claim area. Passengers were randomly assigned a processing time for seeking, claiming, and loading baggage onto a cart from a time distribution ranging from 3.5 to 6.5 min. This time distribution was based on the observation that passengers claim baggage before a second full revolution of their baggage on the claim device occurs and that passenger seek time includes their movement from the baggage area entrance to a specific claim device and time required to locate and select their baggage.

Approach for Evaluating Alternative Baggage Claim Systems

Output from the simulation model on the number of passengers and bags in the baggage claim area by flight by 5-min interval was used as input for the Lotus 1-2-3 spreadsheet for each system, year (1990 and 1995), and east or west wing of the IAB. The spreadsheet also included the characteristics of each baggage system under review (e.g., number of devices and maximum baggage storage). The information contained in the spreadsheet and the operating procedures in the claim area, which were documented by discussions with baggage operations staff, were used for making flight assignments by claim device (Figure 6) and subsequently for evaluating the performance of each system. The criteria used for making the assignments are as follows:

1. Flights arriving at each wing (east or west) are assigned to a claim device on a first-come, first-served basis, and
2. When all devices in a wing are in use, the device serving the flight with the minimum number of bags left to be claimed is chosen for the assignment of the next arriving flight. This practice causes bags for the flight being served to be removed from the claim device and placed on the floor.



1. DENOTES TIME PLANE BLOCKED AT TERMINAL GATE OR REMOTE HARD STAND LOCATION
2. CROSS HATCH INDICATES FLIGHT RELEASED FROM CLAIM DEVICE FOR ASSIGNMENT OF SUBSEQUENT FLIGHT.

HYPOTHETICAL DATA

FIGURE 6 Proposed new baggage systems—example of flight assignments by claim device, year 1995, east wing.

For each of the systems under review, information concerning the maximum number of bags that could be stored on the claim devices and the area available for passengers or passengers and bags around the devices was developed and input into the spreadsheet as constants for evaluative purposes. Then, given the flight-to-claim device assignments, number of bags in claim areas by device, and the storage characteristics for each of the proposed systems, formulas were employed within the spreadsheet logic to generate (at 5-min intervals) the number of bags on a device versus on the floor by claim device. Similarly, using this information and the number of passengers in the claim area by device, the percentage of floor area in use around each claim device was derived. The numerical results for these two measures of device performance were then translated graphically for each of the alternative systems by year (1990 and 1995) and by east and west wing of the IAB.

Results and Recommendations

On the basis of design and installation considerations, either the in-ceiling or at-grade system was identified as being an acceptable alternative for replacement of the existing baggage claim system. For this reason, a comparative evaluation of the systems' operational performance was considered a critical ingredient to the decision-making process. As mentioned previously, the criteria used to evaluate system performance in years 1990 and 1995 included

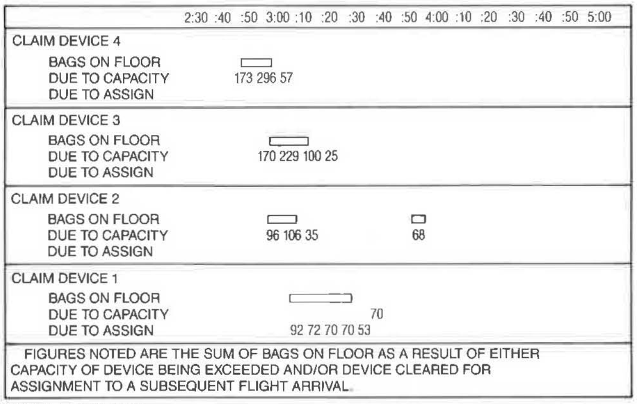
1. The number of bags removed from a claim device and placed on the floor because the bag storage capacity of the device was exceeded or because the device had to be cleared

for assignment so that a subsequent flight arrival could be assigned; and

2. The percentage of dedicated floor space around each claim device used for the storage of bags removed from a device and passengers waiting to claim baggage.

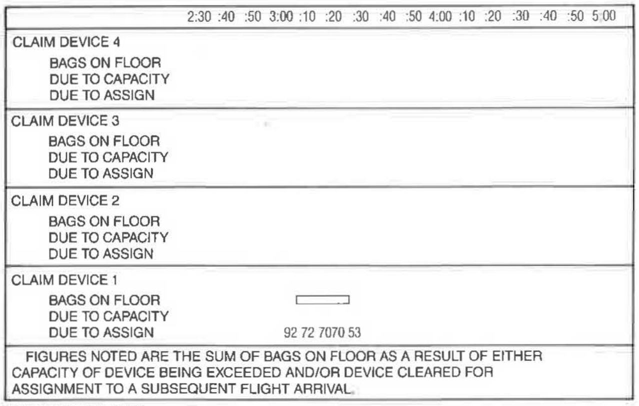
Although the in-ceiling system had only moderately lower practical operational capacity, it showed a significantly lower level of performance when compared with the at-grade system. For the in-ceiling system, large volumes of bags would be required to be placed on the floor, with the situation worsening markedly from 1990 to 1995 (Figures 7–14). This was largely because the storage capacity of the devices was exceeded and not a result of bag placement on the floor to clear devices for flight assignment. Also, the increase in passenger demand levels projected for 1995 would generate higher numbers of bags and therefore exacerbate situations exceeding storage capacity.

Generally, significantly less floor space was used by the at-grade alternative when compared with the in-ceiling proposal (Figures 15–22). Interestingly, for 1995, there was a noticeable decrease in service level (floor space criterion) for the in-ceiling system, although for the at-grade system, projected



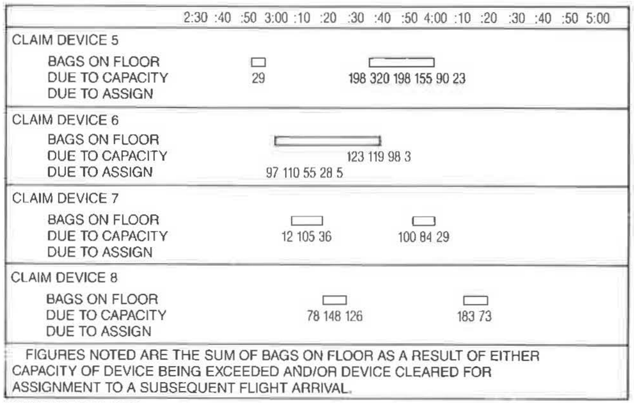
HYPOTHETICAL DATA

FIGURE 7 **Proposed new in-ceiling baggage system—year 1990, bags on floor—east wing.**



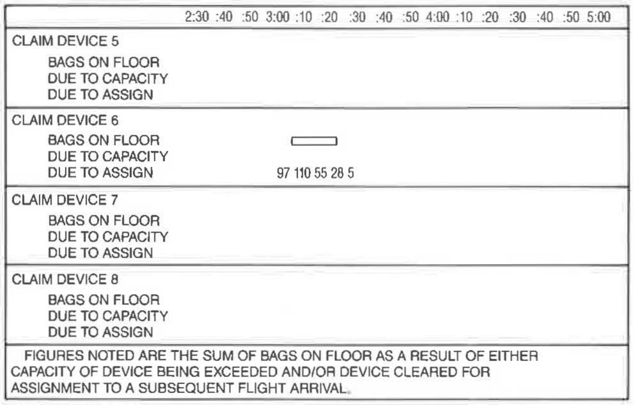
HYPOTHETICAL DATA

FIGURE 8 **Proposed new at-grade baggage system—year 1990, bags on floor-east wing.**



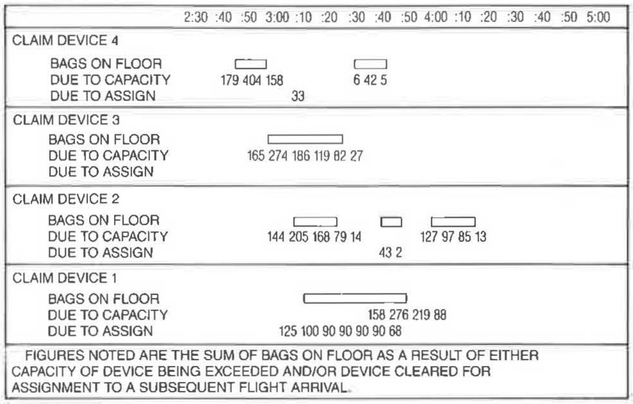
HYPOTHETICAL DATA

FIGURE 9 **Proposed new in-ceiling baggage system—year 1990, bags on floor—west wing.**



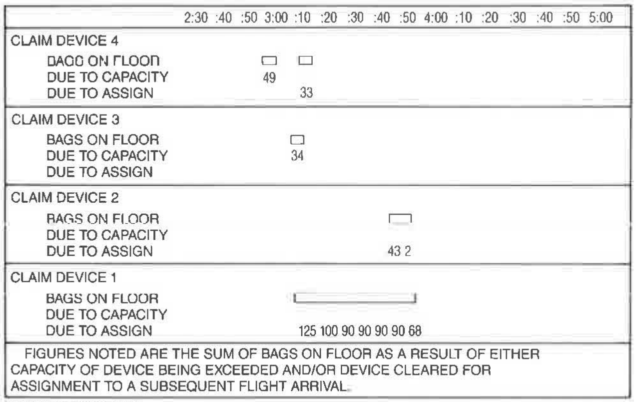
HYPOTHETICAL DATA

FIGURE 10 **Proposed new at-grade baggage system—year 1990, bags on floor—west wing.**



HYPOTHETICAL DATA

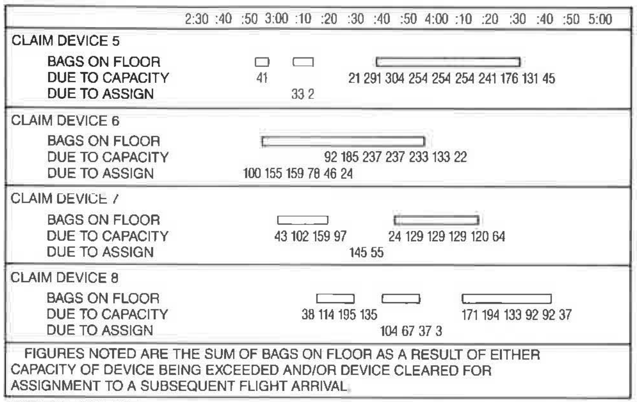
FIGURE 11 **Proposed new in-ceiling baggage system—year 1995, bags on floor—east wing.**



FIGURES NOTED ARE THE SUM OF BAGS ON FLOOR AS A RESULT OF EITHER CAPACITY OF DEVICE BEING EXCEEDED AND/OR DEVICE CLEARED FOR ASSIGNMENT TO A SUBSEQUENT FLIGHT ARRIVAL.

HYPOTHETICAL DATA

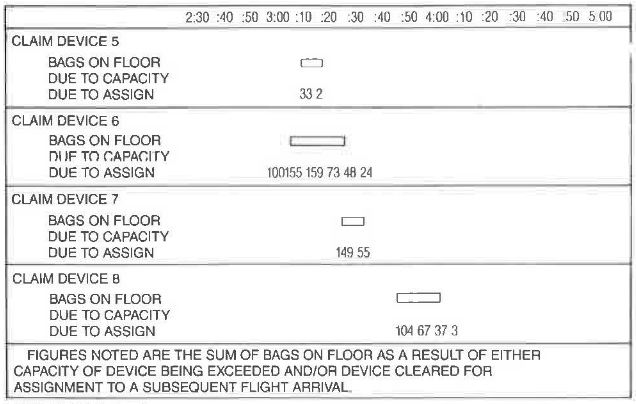
FIGURE 12 **Proposed new at-grade baggage system—year 1995, bags on floor—east wing.**



FIGURES NOTED ARE THE SUM OF BAGS ON FLOOR AS A RESULT OF EITHER CAPACITY OF DEVICE BEING EXCEEDED AND/OR DEVICE CLEARED FOR ASSIGNMENT TO A SUBSEQUENT FLIGHT ARRIVAL.

HYPOTHETICAL DATA

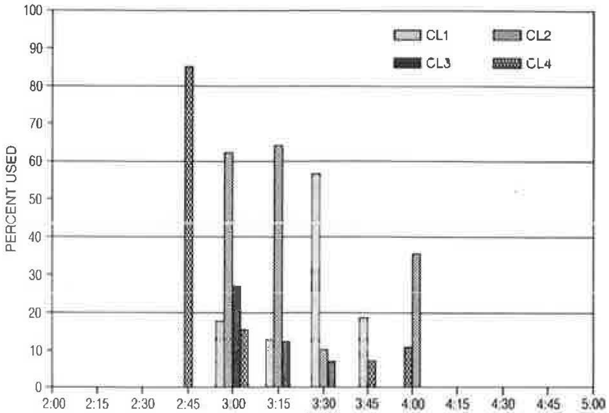
FIGURE 13 **Proposed new in-ceiling baggage system—year 1995, bags on floor—west wing.**



FIGURES NOTED ARE THE SUM OF BAGS ON FLOOR AS A RESULT OF EITHER CAPACITY OF DEVICE BEING EXCEEDED AND/OR DEVICE CLEARED FOR ASSIGNMENT TO A SUBSEQUENT FLIGHT ARRIVAL.

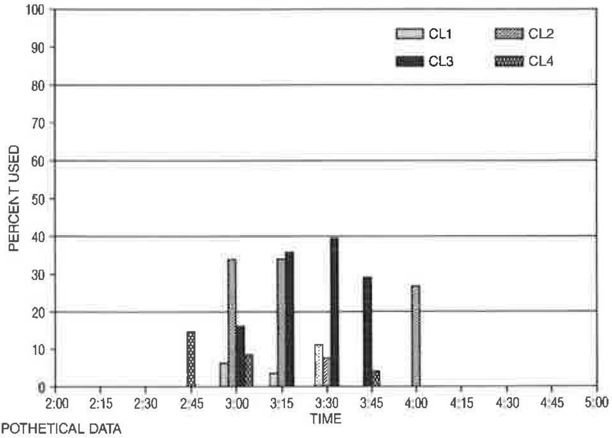
HYPOTHETICAL DATA

FIGURE 14 **Proposed new at-grade baggage system—year 1995, bags on floor—west wing.**



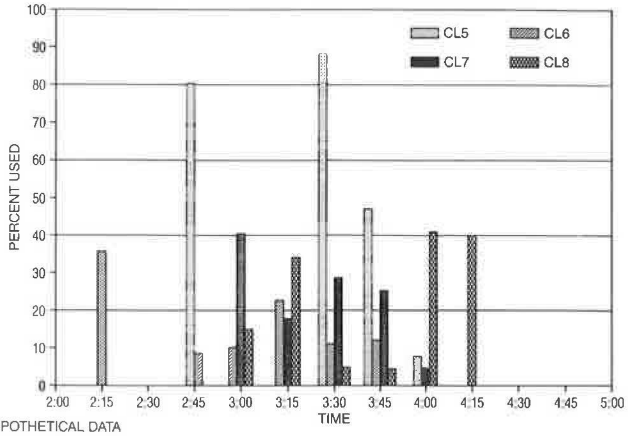
HYPOTHETICAL DATA

FIGURE 15 **Proposed new in-ceiling baggage system—1990 percent of floor space utilized—east wing.**



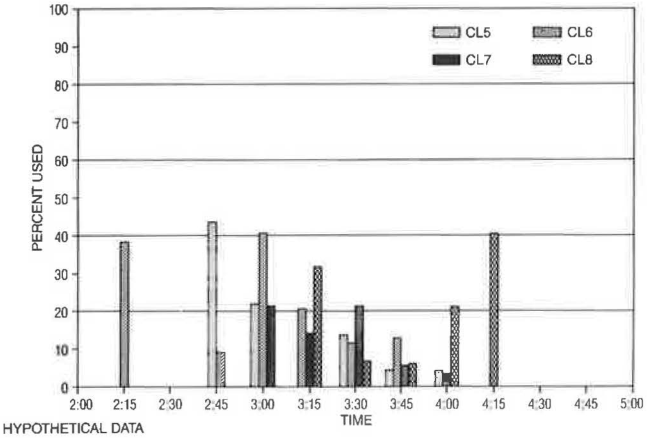
HYPOTHETICAL DATA

FIGURE 16 **Proposed new at-grade baggage system—1990 percent of floor space utilized—east wing.**



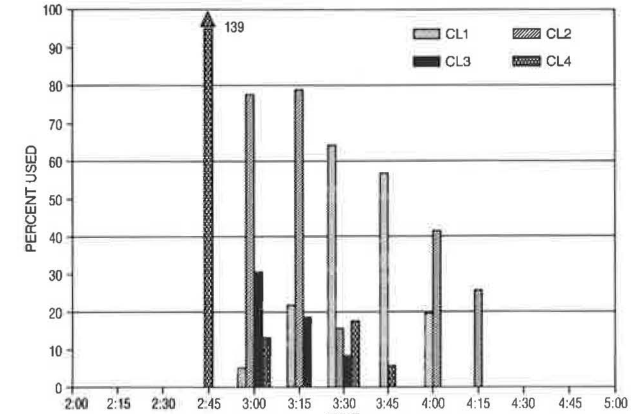
HYPOTHETICAL DATA

FIGURE 17 **Proposed new in-ceiling baggage system—1990 percent of floor space utilized—west wing.**



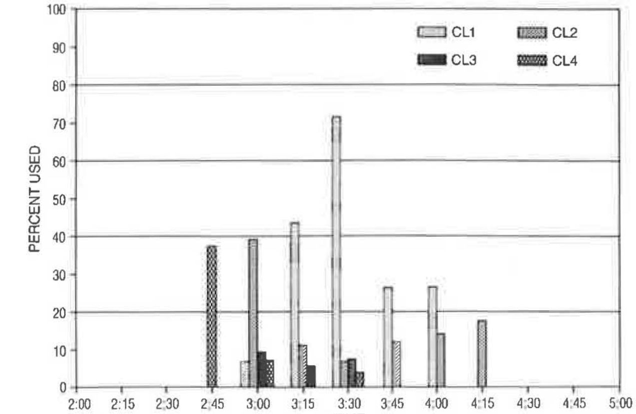
HYPOTHETICAL DATA

FIGURE 18 Proposed new at-grade baggage system—1990 percent of floor space utilized—west wing.



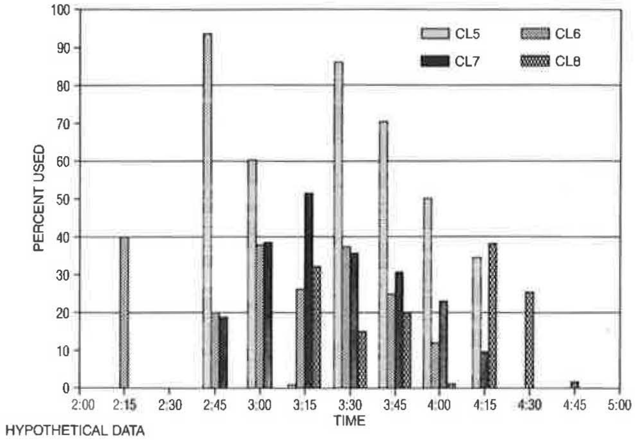
HYPOTHETICAL DATA

FIGURE 19 Proposed new in-ceiling baggage system—1995 percent of floor space utilized—east wing.



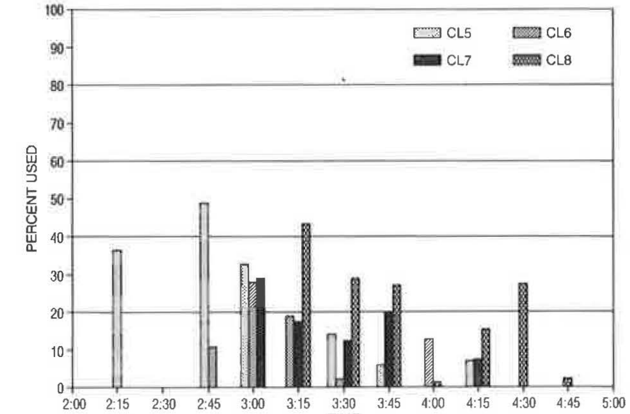
HYPOTHETICAL DATA

FIGURE 20 Proposed new at-grade baggage system—1995 percent of floor space utilized—east wing.



HYPOTHETICAL DATA

FIGURE 21 Proposed new in-ceiling baggage system—1995 percent of floor space utilized—west wing.



HYPOTHETICAL DATA

FIGURE 22 Proposed new at-grade baggage system—1995 percent of floor space utilized—west wing.

service levels for 1990 were generally maintained through 1995, despite the higher expected demand level.

Hence, because of higher service levels projected for the at-grade system, it was preferred operationally and was recommended to replace the existing system. The system, which was also found to be less costly than the other alternative, was being installed at the time of this writing.

SUMMARY

This project developed and validated a computer-based simulation model that could be used for various analyses relating to the Federal Immigration and Naturalization and Customs Inspection Services system facilities. The initial application of the model led to selecting a new baggage claim system, largely on the basis of its operational attributes, which were shown through the model to improve service levels for international air travelers through the 1990s.

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

Airport Terminal Designs with Automated People Movers

L. David Shen

Existing terminal designs generally require excessive passenger walking distances at the nation's major airports. Airport terminal designs with automated people mover (APM) systems to eliminate this problem are discussed. Data are presented describing the effects of eight existing APM systems on terminal designs and operations. Minimum and maximum walking distances at 18 airport terminals with and without APM systems are presented. The evolution of airport terminal design is also discussed. Two new centralized terminal designs with APM systems to improve airport operations, remote satellites and remote piers, are analyzed. The average passenger travel time was the measure of effectiveness for the analysis. Six prototype designs serving 10 to 30 million annual passengers each are used. The effects of using different percentages of transfer passengers on average travel time and terminal design are also analyzed. Remote satellite design is found to be better when the percentage of transfer passengers is lower but the remote pier is a better design when the percentage of transfer passengers is higher. However, unit terminal design with the APM system is found to be obsolete because its layout is inefficient and difficult for the first-time user.

The function of an airport terminal is to effect the transfer of passengers and goods from surface transportation to air transportation quickly with a minimum of confusion and discomfort. Most airport terminals in the United States were designed during the 1950s and 1960s when air transportation was undergoing rapid growth. However, because of increasing concern over environmental issues, not one major airport has been built in the United States since the Dallas-Fort Worth International Airport opened in 1974. In the meantime, the Airline Deregulation Act of 1978 has produced a tremendous increase in air travel. The number of passengers increased 63 percent between 1978 and 1987, from 275 to 447 million passengers. The trend is expected to continue well into the next century.

In 1987 the 16 most active airports accounted for half of the enplanements in the United States (*1*). As airport terminals grew to accommodate increasing passenger traffic, excessive passenger walking distances have been created at the nation's major airports. Passengers must move from terminals to aircraft, within the terminals themselves, or between terminals that can be miles apart. Delays and complications at these old terminals cause missed connections and passenger irritation, and result in poor airline equipment use. New terminal design with speedy and comfortable ground transportation, on the other hand, pleases passengers and boosts airline and airport revenues by minimizing aircraft ground time. It is clear that old terminal design concepts, widely used 20 or 30 years ago, are no longer effective in these rapidly changing times.

An innovative Automated People Mover (APM) system has recently gained popularity in airport terminal design to solve this ground transportation problem. With APM, new airport terminal design and existing terminal modifications that were impossible 20 years ago have become common. Unfortunately, few studies have researched this new system's impact on airport terminal design. An application of two airport terminal designs with APMs to improve airport operations and efficiency is presented in this paper. It is believed that these designs will be useful for major airport expansions and new airport construction.

TERMINAL DESIGN CONCEPTS

The design of an airport terminal depends on the nature of air traffic to be accommodated at the airport. The design concept chosen is a function of a number of factors, including the size and nature of traffic demand, the number of participating airlines, the traffic split between international and domestic, the number of scheduled and charter flights, the available physical site, the principal access modes, and the type of financing (*2,3*). There are two different design concepts that describe the way passenger terminal facilities are physically arranged for passenger processing. "Centralized" means that all the elements in the passenger processing sequence are located as much as possible in one area. An example of a centralized concept is the pier design. "Decentralized," on the other hand, means that passenger processing facilities are arranged in smaller modular units and repeated in one or more buildings. An example of a decentralized concept is the unit terminal design in New York's John F. Kennedy International Airport. This unit terminal design is heavily decentralized and duplication of facilities is common.

Designs Before APM

Before the introduction of an airport APM system in 1971, five passenger terminal designs, each with varying degrees of centralization, were commonly used (*4–6*). These designs are shown in Figure 1 and are discussed in the following paragraphs.

Linear

The linear design is a centralized terminal design with simple open apron or linear arrangement (Figure 1a). Because this

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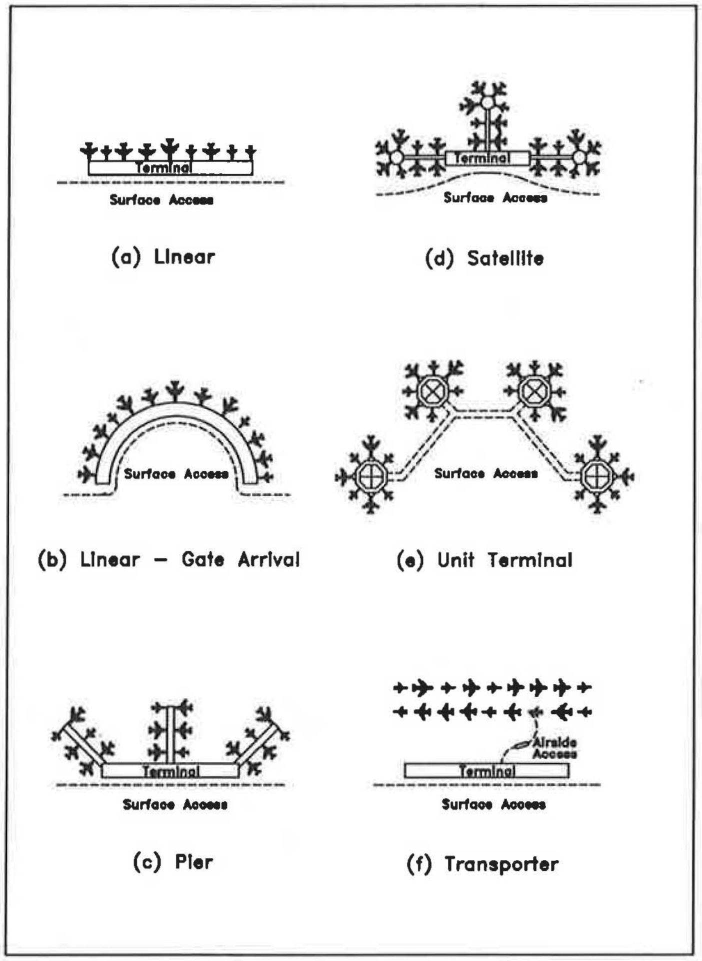


FIGURE 1 Typical airport terminal designs before APM systems.

type of arrangement has a small length of airside interface in relation to the size of the terminal, it is frequently used for low-volume airports such as Greenville-Spartanburg Airport in South Carolina where the number of gates required does not necessitate an inconvenient, long terminal. An extension of the linear design is the gate arrival design (Figure 1b). The terminal is arranged in a circular fashion so that the traveler can park at a point opposite his departure gate to minimize walking distance. However, if more than one circular unit is used in the design, it becomes a decentralized processing design. This design can cause severe problems for interlining passengers. An example of this design is the Kansas City Airport.

Pier

The pier design is a centralized processing design. It is probably the most common system found at airports (Figure 1c). With central passenger processing, the facilities may not have sufficient perimeter to accommodate the corresponding number of aircraft gate positions. Therefore, a pier is added to the building to increase the perimeter without increasing the total floor area substantially. This design is capable of providing high passenger-processing capacity without excessive land requirements. This design is economical to build; however, excessive passenger walking distances are frequently required. Miami International Airport is an example of pier terminal design.

Satellite

The satellite design is a modification of the basic pier concept. Aircraft are parked around a rotunda at the end rather than along the side of the finger (Figure 1d). The satellite design represents a move toward decentralization in the pier design and easily permits assembly of passengers as well as ticketing activities near the aircraft gates. Excessive passenger walking distance is a major problem for this design. San Francisco International Airport is an example of a combination pier and satellite design.

Unit Terminal

The unit terminal design uses two or more separate, self-contained buildings. Each houses a single airline or group of airlines, and each has direct access to ground transportation (Figure 1e). New York's John F. Kennedy International Airport is an example of the unit terminal design. This design is usually justified at high-volume airports where walking distance is excessive for originating passengers with pier or satellite design. However, this design can create serious problems for interlining passengers. Therefore, unit terminals should not be used if a significant number of passengers at the airport are connecting passengers.

Transporter

The transporter design uses a mobile conveyance system such as a bus or mobile lounge to take passengers to and from aircraft (Figure 1f). This design can reduce walking distance significantly. However, it can also increase passenger processing time and create traffic problems on the aprons. Many studies indicate that transporters are best used for peak-period loads as supplements either to gate arrival or to pier terminal designs (*7,8*). The Dulles International Airport in Washington, D.C., is an example of a transporter design.

Design Problems

An airport commonly uses more than one design configuration in its passenger terminal layout to accommodate increased passenger volume and reduce passenger walking distance. Figure 2 shows the evolution of airport terminal design in the United States (*9*). Terminal designs at 27 major airports in the United States before APM was adopted are given in Table 1 (*4*). It is clear that the pier terminal design dominates at major airports, probably because this design generally provides good service to all passengers and expansion can be accomplished efficiently and flexibly. Because of their centralized design, pier terminals simplify airport security control. Basic terminal designs before APM was adopted are evaluated in Table 2.

Walking distance within airport terminals is an important measure of the level of service provided to passengers. Most authorities agree that terminal walking distance of 600 ft is an ideal maximum and that any distance greater than 1,200 to 1,300 ft must be considered unacceptable. The number of boarding gates and the walking distances to the nearest and farthest gates for the originating passengers are not strongly correlated. (This assumes that originating passengers exit limousines at the terminal entrance, go directly to ticket counters, then go to the airline gate.) However, for interline passengers, a high correlation coefficient does exist between maximum walking distances and number of boarding gates as shown in Figure 3 (*10*).

Table 3 shows typical ranges of walking distance at airports with different terminal design configurations. For interline passengers, the figures reflect debarkation at the remote end of the farthest concourse with a walk directly to a gate at the remote end of the most distant concourse without a stop at a ticket counter. It is clear that as the number of gates increases, excessive walking distances may be required for both the originating passengers and interline passengers at the airports.

Designs with APM Systems

The APM system is an automated, electric-powered vehicle operating in single- or multicar trains on steel or concrete guideways. It can carry from 1,000 to 16,000 passengers per hour with headways as short as 60 sec, offering convenience comparable with that of modern elevators. Ride quality is among the best of any transit system in the world. APM vehicles travel at speeds up to 35 mph, yet accelerate and decelerate smoothly and swiftly. They stop and start automatically and can operate in a demand mode during off-peak hours to minimize energy used (*11,12*).

After Tampa International Airport installed an APM system in 1971, similar systems were built at airports in Seattle (1973), Dallas (1974), Atlanta (1980), Miami (1980), Houston (1981), Orlando (1981), and Las Vegas (1985) (*13,14*). In addition, ground was broken for the new APM system at Chicago O'Hare International Airport on September 10, 1987, and is expected to open in late 1991 or early 1992 (*15*). The Pittsburgh Airport's new midfield terminal, made possible by adding an APM system to its design, is scheduled for completion in 1992 (*16*). The $2.2 billion expansion program for New York's Kennedy Airport, announced in 1986, also includes a new APM system (*17*). Many additional applications at the nation's other major airports are currently being studied.

An APM system can be incorporated in any existing airport terminal design during airport expansion or modification to reduce the long, tiring, time-consuming trek from the parked car to the boarding gate. The maximum walking distances at the airport terminals designed with APM systems are generally less than 1,300 ft. This is acceptable to most airport authorities. Table 4 shows the typical ranges of walking distances at airports designed with APM systems. These systems were installed during expansion or modification in Seattle, Miami, Houston, and Las Vegas and generally involved the construction of one or more new remote satellites. The APM system is used to connect the satellite or satellites with the main terminal. In Seattle and Houston, all airport facilities are connected by the APM; in Miami and Las Vegas, only the new remote satellite is connected to the main terminal with the APM.

New airport passenger terminal designs with APM systems generally favor the centralized design concept because the concept uses airport resources more efficiently. Examples of such designs are the remote piers in Atlanta and the remote satellites in Orlando. In addition, the trend toward increasing airport security for passenger and luggage processing also favors the centralized designs of remote piers and remote satellites. The only exception is the Dallas-Fort Worth International Airport, which is basically a decentralized design conceptualized in the late 1960s. When a new airport passenger terminal complex is designed from scratch with APM, three passenger terminal designs are generally used. These designs are shown in Figure 4 and evaluated in Table 5 (*18*).

Remote Satellites

The remote satellites design has a central terminal and several remote satellites, which are connected by an APM shuttle train either above or below the apron (Figure 4a). This design usually takes full advantage of the APM system by having all ticket purchase, baggage check and reclaim facilities, and other primary passenger services only in the main terminal area. Only the holding lounges and supplementary check-in facil-

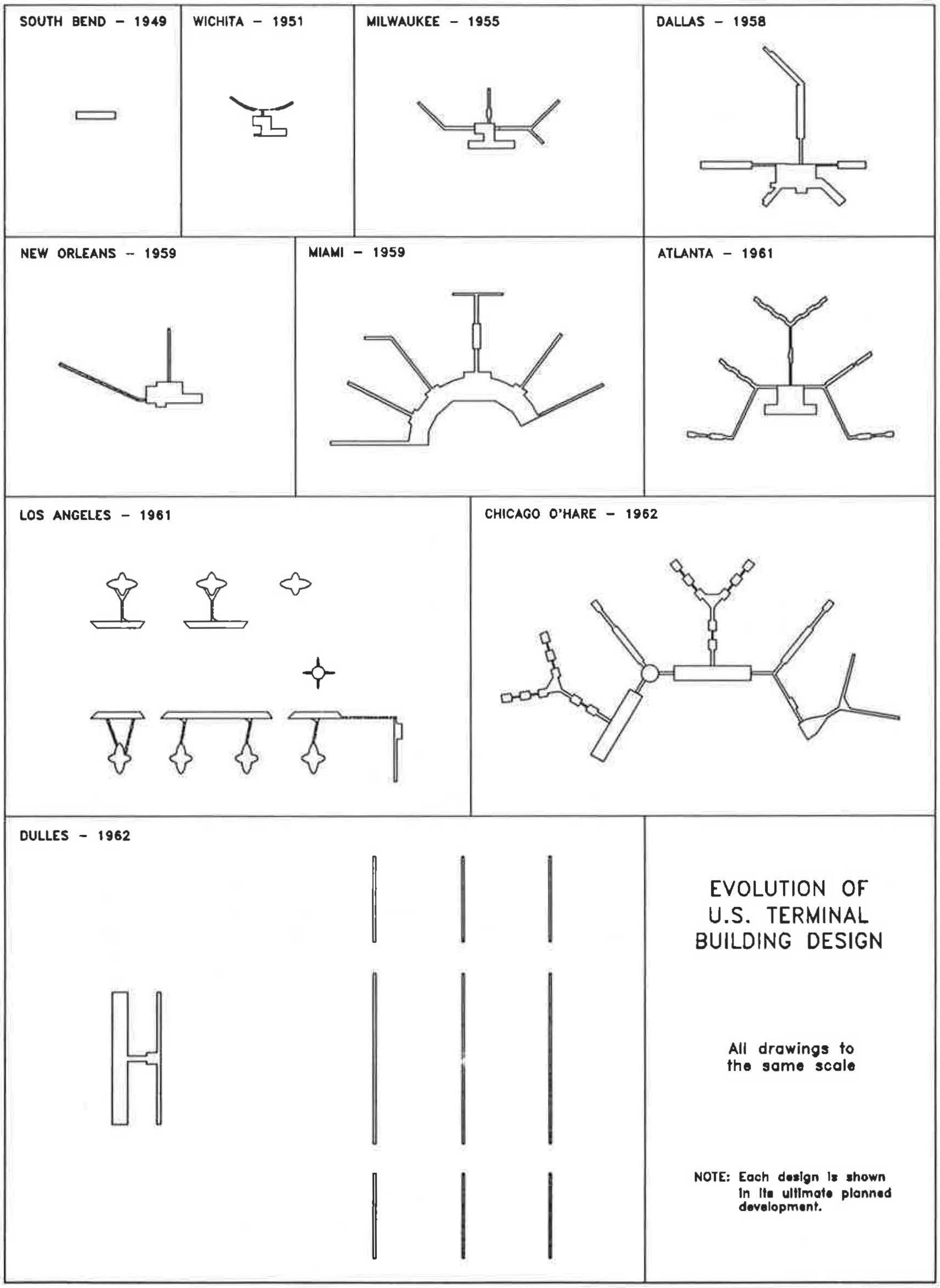


FIGURE 2 Evolution of airport terminal design in the United States (*9*).

TABLE 1 TERMINAL DESIGNS AT SELECTED MAJOR AIRPORTS BEFORE ADOPTION OF APM

Airport Name	Terminal Design Linear	Pier	Satellite	Transporter
Atlanta Hartsfield		X		X
Boston Logan	X	X		
Chicago O'Hare	X	X		
Cleveland Hopkins		X		
Denver Stapleton	X	X		
Detroit Wayne	X	X		
Honolulu	X	X		
Houston Hobby	X	X		
Kansas City	X			
Las Vegas McCarran		X		
Los Angeles			X	
Miami		X		
Palm Beach	X			
Minneapolis-St. Paul	X	X		
New Orleans Moisant		X		
Newark		X		
New York Kennedy	X	X	X	
New York La Guardia	X	X		
Philadelphia		X		
Phoenix Sky Harbor	X			
Greater Pittsburgh	X	X		
St. Louis		X		
San Francisco		X		
San Juan		X		
Baltimore-Washington	X	X		
Washington National	X	X		
Washington Dulles				X

TABLE 2 EVALUATION OF BASIC TERMINAL DESIGNS

Terminal Design	Level of Service	Economy of Design	Flexibility	Security Control
Linear	Good	Poor	Very Good	Fair
Gate Arrival	Good	Poor	Very Good	Poor
Pier	Good	Very Good	Very Good	Good
Satellite	Fair	Good	Good	Good
Unit Terminal	Fair	Poor	Good	Poor
Transporter	Good	Good	Very Good	Fair

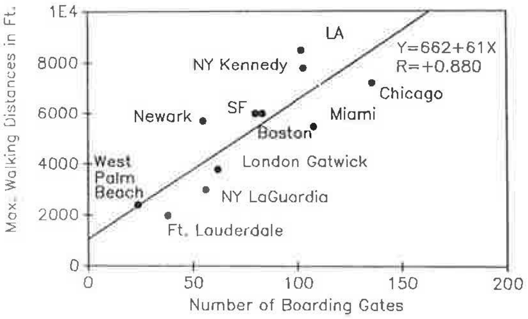


FIGURE 3 Plot of maximum interline walking distances versus the number of boarding gates (1988 data).

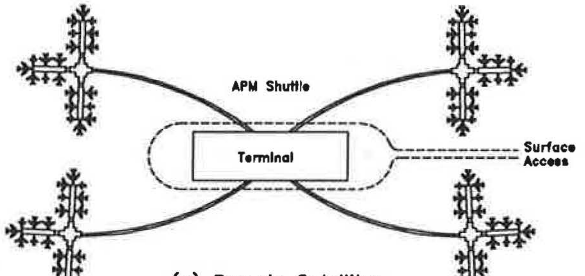
ities for passengers not carrying baggage are located in the satellites. Tampa and Orlando international airports are examples of the remote satellite design. The design of one focal point (the main terminal) with several remote satellites is simple and "user-friendly," especially for the first-time user. In addition, the design is extremely flexible and can be expanded without difficulty. Remote satellites generally have the shortest passenger walking distance. However, this design is inefficient for very high-volume airports (annual passengers more than 40 million). Only the top four airports in the world currently have this much passenger volume. Therefore, with rapid growth in demand for air travel the use of the remote satellite design should gain wide popularity at the world's major airports in the future.

TABLE 3 TYPICAL WALKING DISTANCES AT AIRPORTS BEFORE APM

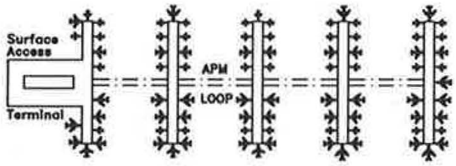
		Originating Passengers		Inter-Line Passengers
Terminal Design	Typical No. of Gates	Minimum Walking Distance-Nearest Gate (ft.)	Maximum Walking Distance-Farthest Gate (ft.)	Estimated Maximum Walking Distance (ft.)
Linear	5-20	200	700	600-2,000
Pier	16-136	500	1,500	1,500-7,500
Satellite	18-102	210	1,700	2,500-9,000
Unit	30-104	200	1,000	2,000-8,000
Transporter	40-50	160	1,000	1,000-1,300

TABLE 4 TYPICAL WALKING DISTANCES AT AIRPORTS WITH APM SYSTEMS

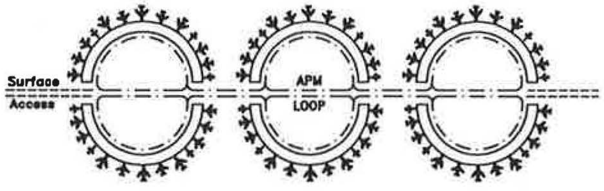
		Originating Passengers		Inter-Line Passengers
Terminal Design	Typical No. of Gates	Minimum Walking Distances	Maximum Walking Distances	Max. Walking Distances
Remote Satellites	48-69	300	700	700
Remote Pier	142	400	1,300	2,000
Unit Terminal	101	300	700	1,200



(a) Remote Satellites



(b) Remote Piers



(c) Unit Terminal

FIGURE 4 Typical airport terminal designs with APM systems.

TABLE 5 EVALUATION OF TERMINAL DESIGNS WITH APM SYSTEMS

Terminal Design	Level of Service	Economy of Design	Flexibility	Security Control
Remote Satellites	Excellent	Good	Very Good	Excellent
Remote Piers	Excellent	Very Good	Very Good	Excellent
Unit Terminal	Good	Poor	Good	Poor

Remote Piers

The remote piers design is a new design completely based on the proven effectiveness of APM. Remote piers (concourses) are linked with a central terminal via APMs under the apron (Figure 4b). The terminal complex is located in the middle of the airfield between parallel runway systems. This facilitates aircraft movement between gates and runways, makes for short taxiing time, and alleviates congestion. This design allows efficient use of airport land: one of the highest volume airports in the world—Atlanta's Hartsfield International Airport—was built on an area of less than 3,800 acres using this design. Parallel alignment of the piers ensures efficient use of apron space. One thousand ft of apron separates the twin parallel piers so that two widebody jets can taxi between them at the same time, even as two other widebodies are parked at their gates (*9*). This design is ideal for high-volume airports, especially where there is a significant amount of domestic transfer and interlining. The proposed new Denver International Airport will use this design.

One major problem with remote piers is that extremely long piers may result in longer-than-desirable walking distances for transferring passengers. This is the case in Atlanta where the maximum walking distance for interline passengers—2,000 ft—is the same as the length of one remote pier. This problem can be overcome by using a design with a greater number of shorter piers.

Unit Terminal

The unit terminal design (Figure 4c) is the same as the previous unit terminal design before APM was adopted. The only difference is that the APM system is built into the terminal design to connect different unit buildings, therefore providing a high level of interline ground connection service. Dallas-Fort Worth International Airport is an example of this design. This design is not efficient in land use and requires an extraordinary amount of APM guideways to make it work. In addition, the design lacks a single focal point for transfer passengers and is too complex for the first-time user. Subsequently, no new airport has adopted this design since Dallas-Fort Worth Airport opened in 1974.

COST OF AIRPORT APM SYSTEMS

The capital cost per single-track mile of APM construction in 1980 dollars for the eight existing airport APM systems in the United States is shown in Table 6 (*13,19*). The cost varies from airport to airport depending on the specific features involved and the systems used. Underground guideway construction is generally more expensive than that for an elevated guideway. A more accurate estimate of the true cost of the system should take the number of passengers it carries into consideration. Table 7 shows the capital cost per single-track mile per first-year annual passenger in 1980 dollars for the eight airport APMs (*10*). Except for Miami and Houston, the capital cost per mile per first-year annual passenger varies from $1.77 to $4.35 in U.S. dollars. The relatively high capital cost per passenger for Miami was because of its extremely high construction cost; the high cost for Houston was caused by low ridership.

Airport APM systems are extremely reliable, as indicated by the operational statistics shown in Table 8 (*10*). In addition, the operating and maintenance cost per passenger ride is relatively low. As of June 1987, most than 770 million airport passengers have used the systems at the eight airports, with an average system availability of 99.7 percent. Even when failures have occurred, delays until the system has been returned to normal operation have averaged less than 6 min (*11*). This performance translates into satisfaction for passengers, higher equipment utilization for airlines, and greater efficiency for the entire airport complex.

TABLE 6 COST OF EXISTING APM SYSTEMS IN 1980 DOLLARS

Airport	APM System Length	Capital Cost	Cost per Mile
Tampa	4 double shuttle, 1000 ft. each	$19.6 M	$12.9 M
Seattle	2 loops/1 shuttle, 8900 ft. all	$47.3 M	$28.1 M
Dallas	1 pinched loop, 13 miles all	$83.4 M	$ 6.4 M
Atlanta	1 pinched loop, 1 mile each	$69.7 M	$35.0 M
Miami	1 double shuttle, 1300 ft.	$13.4 M	$27.2 M
Houston	1 pinched loop, 7500 ft. all	$21.6 M	$15.2 M
Orlando	2 double shuttle, 1900 ft. each	$25.5 M	$17.7 M
Las Vegas	1 double shuttle, 1200 ft.	$ 7.0 M	$15.4 M

*Cost is in millions (M).

TABLE 7 COST SUMMARY BASED ON FIRST-YEAR PASSENGERS CARRIED

Airport (Code)	1987 U.S. Rank	APM Year Opened	Estimated First Year Passengers	Cost Per Mile Per Passenger	Operating Cost Perr Passenger
Tampa (TPA)		1971	4.13 M	$3.13	$0.06
Seattle (SEA)	21	1973	7.17 M	$3.91	$0.08
Dallas (DFW)	4	1974	2.45 M	$2.62	$0.28
Atlanta (ATL)	2	1980	39.37 M	$1.77	$0.11
Miami (MIA)	9	1980	3.60 M	$7.56	$0.09
Houston (IAH)	19	1981	1.88 M	$8.09	$0.09
Orlando (OIA)	20	1981	6.89 M	$2.57	$0.10
Las Vegas (LAS)		1985	3.54 M	$4.35	N/A

TABLE 8 OPERATIONAL STATISTICS OF AIRPORT APMs

Airport	System Coverage	Estimated Passengers Carried (as of 6/87)	System Availability (in percent)	No. of Cars
Tampa	Entire airport	177,320,000	99.9	8
Seattle	Entire airport	164,030,000	99.8	24
Dallas	Entire airport	75,450,000	99.0	52
Atlanta	Entire airport	253,000,000	99.8	24
Miami	Int'l terminal only	19,197,000	99.8	6
Houston	Entire airport	12,000,000	99.6	21
Orlando	Entire airport	59,000,000	99.9	8
Las Vegas	New terminal only	11,000,000	99.9	2

At present, only 5 of the top 20 airports in the United States have operational APM systems. For the remaining 15 major airports, two APMs are under construction (Chicago and Pittsburgh); three are under design (New York JFK, Newark, and Denver); and five are being proposed or studied (Los Angeles, San Francisco, Newark, New York LaGuardia, and Boston) (*10*,*14*). More airport terminal designs with APM systems certainly can be expected in the future.

APPLICATIONS

On the basis of terminal design experiences at eight existing airports, it is possible to identify two terminal designs with APM systems that are suitable for future applications—remote satellites and remote piers. Unit terminal design is not suitable because its layout is inefficient and difficult for first-time users. Six prototype designs serving 10 to 30 million annual passengers were used for analysis. The number of boarding gates required at most airports varies within 3 to 5 gates per 1 million annual passengers (*5*). Four gates per 1 million annual passengers were used in this analysis. The six prototype designs are (a) remote piers, 40 gates, and 10 million annual passengers; (b) remote satellites, 40 gates, and 10 million annual passengers; (c) remote piers, 80 gates, and 20 million annual passengers; (d) remote satellites, 80 gates, and 20 million annual passengers; (e) remote piers, 120 gates, and 30 million annual passengers; and (f) remote satellites, 120 gates, and 30 million annual passengers. Designs similar to Figure 4a and 4b, which are intended to be generally representative of major existing or future airports, were used.

Distance between satellites and the terminal was assumed to be 1,000 ft. Distance between piers was assumed to be 1,100 ft. Average travel speed of APM systems was assumed to be 20 mph. Average walking speed of passengers was assumed to be 4 ft per sec. Three different percentages of transfer passengers (10, 35, and 65 percent) were used in the analysis. The measure of effectiveness was average passenger travel time. Selecting this criterion appeared to be a reasonable way to balance the needs of transfers with those of originating and terminating passengers. In addition, average travel time accounts for different APM length requirements for different terminal designs. Average travel time was calculated as follows. Travel times between each gate and the terminal entrance, and between all gates, were multiplied by the anticipated number of passengers taking that path. These products were summed and then divided by the total number of passengers. Traffic was assumed to occur during peak hours. The APM system headway was assumed to be 2 min. The average travel time for the six prototype designs under different transfer passenger scenarios is shown in Table 9.

Using annual passenger level and the airport functional nature as defined by the relative proportions of transfer passengers, Figure 5 can guide planners and designers of future airport terminals. In addition to average travel time, the final passenger terminal design will depend upon the amount of

TABLE 9 AVERAGE TRAVEL TIME FOR SIX PROTOTYPE DESIGNS

	Average Travel Time in Seconds		
	Annual Passengers		
Terminal Design	10 Million	20 Million	30 Million
	10 Percent Transfer Passengers		
Remote Piers	250	295	335
Remote Satellites	260	280	280
	35 Percent Transfer Passengers		
Remote Piers	250	300	335
Remote Satellites	280	300	305
	65 Percent Transfer Passengers		
Remote Piers	245	295	335
Remote Satellites	305	300	335

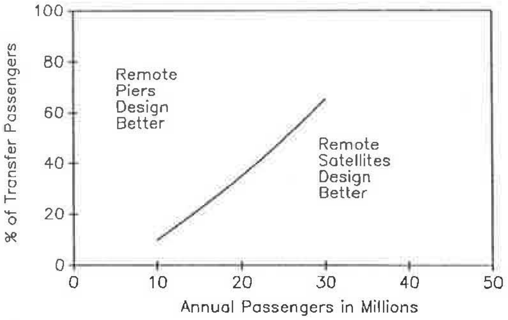


FIGURE 5 Dominant situations for remote pier and remote satellite designs.

land available, the operational effectiveness, the expansion adaptability, and the economic effectiveness of the specific design.

SUMMARY AND CONCLUSIONS

The main points that emerge from this paper are as follows:

1. Existing terminal designs at the nation's major airports generally require excessive passenger walking distances.
2. Delays and complications created by excessive walking distances at major airport terminals cause missed connections and irritation for passengers, and result in poor equipment utilization for airlines.
3. Airport APM systems eliminate one of the most aggravating facets of modern travel—the long, tiring, time-consuming trek from the parked car to the boarding gate.
4. Two new terminal designs with APM systems can be used to solve these problems—remote satellites and remote piers.
5. The remote satellite design is found to be better when the percentage of transfer passengers is low and land availability is not a problem.
6. The remote pier design is found to be better when the percentage of transfer passengers is high and land availability is a problem.
7. The unit terminal design with APM systems is found to be obsolete because it is inefficient and difficult for first-time users.

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Feasibility of an Alternative Shuttle Bus System To Reduce Curbside Traffic Congestion at the Los Angeles International Airport

FRED R. HANSCOM

The problem of traffic congestion within the Los Angeles International Airport's internal landside-access system was addressed. The study examined the feasibility of an alternative shuttle bus operation to serve 11 hotels near the airport. Improved utilization of shuttle vehicles (e.g., improving current service frequency, increasing load factors, and reducing overall fleet size) was expected to produce more efficient traffic flow within the airport's circulation system. Peak-hour observations of hotel courtesy van operations revealed arrivals of one van every 44 sec, but specific destinations were served on an average of only one van per 12 min. The inefficiency of the current system was characterized by an observed average peak-hour load factor of 0.26. An alternative pooled van system was developed using several criteria. Study results indicated that (a) service frequency nearly doubled to hotels in the airport vicinity, (b) airport boarding-passenger wait time was reduced from an average of 11.8 to 6.0 min, (c) average load factor was increased from .26 to .41 and provided comfortable service that allowed for peaking demand fluctuations, and (d) overall number of runs (hence generated traffic) was reduced by 35 percent.

Airport operations are significantly affected by the functioning of the landside ground access system. The importance of ground access is its potential to influence passenger choice, not only decisions among airports but also selection of travel mode.

A case study, which addressed crowded curbside-access conditions at the Los Angeles International Airport (LAX) and assessed the feasibility of an alternative shuttlebus system serving some airport-related industries, is reported in this paper. The project aimed at reducing ground-access traffic congestion through improved utilization of hotel courtesy vans. This approach is directly applicable to other public transportation systems serving airports.

Literature was reviewed to place the ground-access problem in an appropriate perspective. Although the curbside congestion problem is documented in the literature, suggested solutions (e.g., to segregate ground traffic, to modify air schedules) are costly, and these would tend to move the problem rather than eliminate it. Thus, the need for a low-cost solution aimed at reducing traffic generated in the airport's vicinity is evident.

Observations were conducted of shuttlebus operations during a peak period at LAX. These data led to the development of an alternative system, designed to provide equivalent or improved service, while reducing access congestion through improved efficiency. The new system would reduce curbside passenger wait time, provide more frequent service, and operate with a 35 percent reduction of total fleet size.

LITERATURE REVIEW

Initial project activity was to conduct an extensive review of relevant background literature. An automated search of the following five data bases was performed: TRIS, NTIS, Engineering Index, Aerospace Database, and Prompt. The automated search yielded 175 items consisting of journal articles, research reports, and textbook citations. Although both U.S. and foreign items were listed, the majority of relevant work had been conducted in the United States. Of the 175 abstracts, many were not relevant to project objectives and hence were discarded.

The importance of proper ground-access planning was stressed in the publications. Airport access had been identified by some airport authorities as a potential threat to the growth of aviation (*1*). As a determinant of air passengers' choice of airport, ground accessibility plays a more significant role than air carrier level of service (*2*). Airport access systems have been defined in four categories as follows: (a) distribution within airports, (b) circulation within airport complexes and environs, (c) access to the airport complex from remote points, and (d) regional high-speed systems (*3*).

Access to airports from adjoining urban areas was addressed in the majority of papers, and its impact on overall demand for air transportation was stressed. Numerous models have been applied to predict airport access demand; typical of these is Skinner's (*2*) application of the logit model to passenger airport choice decisions.

A 1970 *Highway Research Record* contains a series of papers describing access to six major airports (i.e., Boston, Cleveland, London, Kansas City, Philadelphia, and Tokyo) (*4*). Yet, with the exception of Logan Airport's people-mover, no information on internal airport circulation was provided.

Although few items in the literature addressed internal landside access circulation, most of these pertained to operations at LAX. An economic incentive to reduce internal traffic congestion that was documented is low-rate off-airport

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Transportation Research Corporation, 2710 Ridge Road, Haymarket, Va., 22069.

parking with free tram service to terminal buildings (*5*). Additionally, the Schoenfeld work touted the Fly-Away bus, which offered free parking in Van Nuys.

The circulation system within LAX includes reversible flow facilities, a metered parking lot, and illuminated tram stops (*6*); possible future improvements include an intra-airport tracked air vehicle access system (*7*). Innovative intra-airport circulation facilities at other locations include systems at Tampa and Seattle-Tacoma, Houston's underground transit system, and the AIRTRANS system at Dallas-Fort Worth (*8*).

An early examination of curbside space usage applied computer simulations of vehicle arrivals and dwell times to generate design requirements (*9*). More recent work cites causes of curbside congestion as follows (*10*):

1. Imbalances between the available capacity on the airside sector and the landside areas;
2. Surges due to the arrival or departure of passengers to and from high-capacity aircraft;
3. Uneven distribution of passenger loads along the curbs, due to the parking patterns of individual airlines;
4. Activity concentrations on terminal doors, curbside and baggage check-in locations, resulting in imbalances in available space and demand;
5. Lack of strict enforcement of parking duration restrictions along the curb, resulting in vehicles remaining at the curbs for longer periods than desirable; and,
6. Perceived difficulties in recirculating from the curb back to parking, from parking to curb or, when unable to find a curb space, back again to the curb.

The paper by Mandle et al. also developed level-of-service criteria for curbside operations and suggested strategies for operational improvements. However, improvement strategies included steps that were expensive (i.e., traffic segregation) or impractical (i.e., modification of airline schedules to reduce peak period demand).

An ameliorative strategy not cited in the literature is to charge a fee for vehicle use of circulation roads; this approach has recently been implemented at LAX. Another uncited operational improvement, implemented at Washington, D.C.'s National Airport, is the "Alexandria Express"—pooled service to a number of local hotels.

Critically inadequate curb frontage at John F. Kennedy Airport warranted extensive study and construction of a new internal circulation roadway (*11*). The high cost of this construction project included the loss of parking spaces.

Finally, the importance of recognizing and improving curbside operations is noted in a definitive Institute of Transportation Engineers statement of problems and solutions pertaining to airport access and circulation systems (*12*):

> The future will see little deviation from the highway as the primary form of ground access to airports. . . . Innovative airport access development will be concentrated on providing unique and ingenious intra-airport systems to interface with ground access to avoid choking curbside traffic.

BACKGROUND

The criticality of ground access to airports was demonstrated as posing a potential threat to the growth of aviation (*1*). Relatively little has yet been accomplished to ameliorate the problem of curbside congestion. Moreover, studies documenting causes of this problem have ignored trip-generation factors that affect airport internal ground-access circulation.

A major source of curbside congestion, which adversely affects the overall level of service of the ground-access system, is traffic generated by businesses in direct service of the airport. Shuttle buses offering regional transportation and courtesy vans operated by motel and rental car agencies are typical of this traffic. Because of frequent service redundancies (e.g., overlapping routes) and high exclusive exposure to potential customers (e.g., attempting to solicit business and ridership), these vehicles frequently operate at very low load factors. The result is congestion consisting of underused vehicles that greatly impedes traffic flow in the airport system. Figure 1 shows the current congestion situation at LAX.

A workable solution to this problem is to impose regulation that reduces congestion in the ground-access roadway system. A program recently implemented at LAX that charges commercial vans an access fee is a step in the right direction. However, an essential requirement for solving the congestion problem is increasing service vehicle utilization (e.g., higher passenger occupancy) as a means of maintaining service standards desired by airport-related industries.

PROJECT OBJECTIVE

The objective of this project was to examine the feasibility of an alternative shuttle bus system to reduce traffic congestion

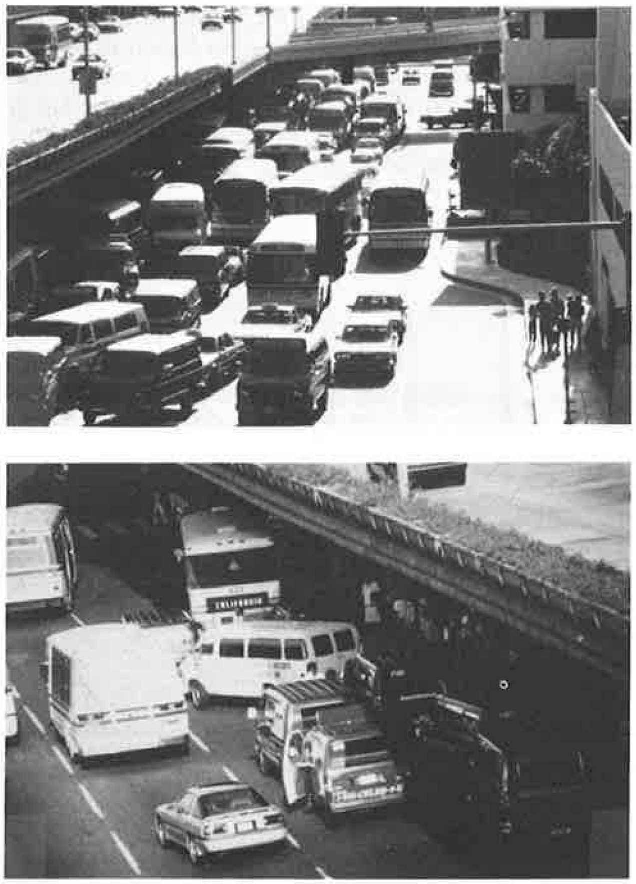


FIGURE 1 Sunday afternoon peak at LAX. *Top*: Internal access congestion on lower level. *Bottom*: Delayed van departure resulting from congestion.

within the LAX landside internal access system. The targeted congestion reduction was to be achieved by increasing shuttle bus efficiency by improving services, increasing load factors, and reducing overall fleet size.

PROJECT SCOPE

Although a variety of vehicles operate in the LAX ground-access system roadway, project resources precluded observations of all vehicle classes. Service vehicles amenable to study included car rental agency courtesy buses, local shuttle buses (e.g., serving fringe-area parking, nearby communities, and etc.), and hotel-motel vans. Although this study was limited to hotel courtesy vans, the methodology is applicable to other vehicle classes operating within the airport ground-access roadway system.

STUDY METHODOLOGY

Observations were conducted on hotel courtesy van operations on the lower (deplaning) level at LAX. The terminal access circulation pattern at LAX is shown in Figure 2.

Manually recorded measures were vehicle arrival time, hotel destination, and load factor (visual estimation of passenger occupancy as a percentage of available capacity) on a vehicle-by-vehicle basis. Figure 3 is a sample data collection form (headway observations are those for specific hotels). Operations were observed for about 4 hr, from 6:00 to 10:00 p.m. on Sunday. This observation period represented peak-period conditions. Selection of the observation point, Terminal 7, ensured that observed load factors represented actual loading upon departure from the airport.

The analysis involved calculating average headways and passenger loading for vans serving specific hotels in the LAX vicinity. These data were combined over specific routes, whereby each van served a maximum of three destinations. This alternative routing scheme offered greater efficiency than the observed practice (each van serving a single destination).

Operational criteria were established for designating the alterative routing system. These requirements specified improved service in concert with an overall reduction in generated traffic volume. Following development of the alternative bus system, benefits were assessed and its feasibility was evaluated.

CURRENT HOTEL COURTESY VAN OPERATIONS

During the nearly 4-hr study period, 311 courtesy vans were observed; 253 of these served 11 hotels in LAX's immediate vicinity. Figure 4 is a map (not to scale) showing the location of each hotel in relation to the airport property. Also shown are hotel groupings suggested for service by individual pooled vans designated in the alternative shuttle bus system.

Table 1 summarizes operations, giving the number of observed runs for each hotel, average headways, and load factors. Hotel destinations are ordered with the most distant at the top. The four groups shown are those designated in the pooled (alternative) shuttle bus system. An interesting trend is evident from these data. Average headways decrease for each hotel group; the closer the group is to the airport, the shorter the average headway. It is not surprising that more frequent shuttle service was observed for hotels closer to the airport. Also, as expected, the number of observed runs is approximately proportional to the size of the hotel.

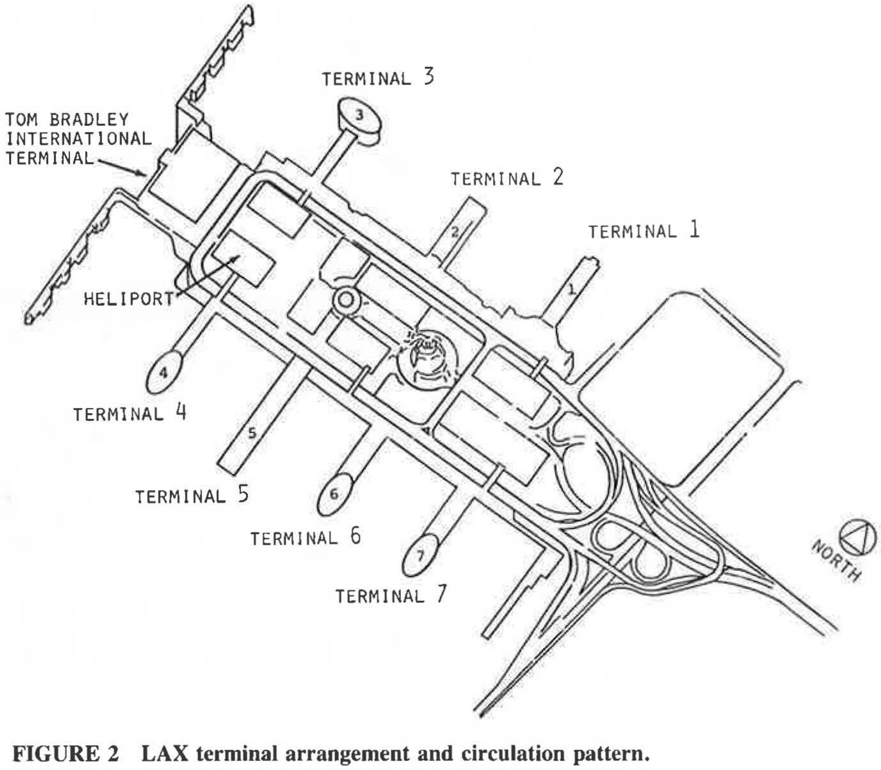
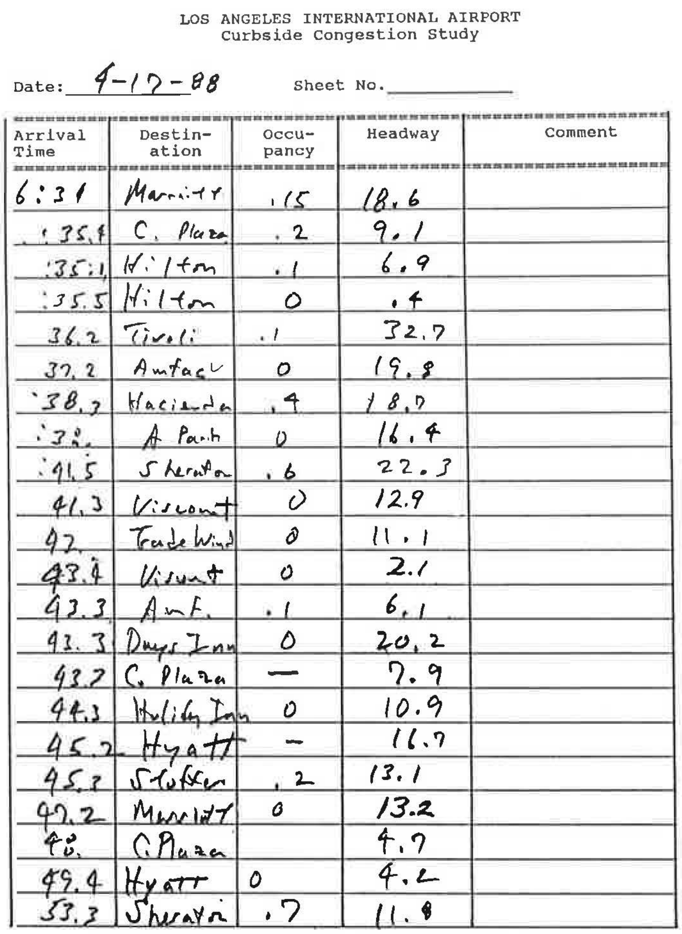


FIGURE 2 LAX terminal arrangement and circulation pattern.



LOS ANGELES INTERNATIONAL AIRPORT
Curbside Congestion Study

Date: 4-17-88 Sheet No. ____________

Arrival Time	Destination	Occupancy	Headway	Comment
6:31	Marriott	.15	18.6	
:35.4	C. Plaza	.2	9.1	
:35.1	Hilton	.1	6.9	
:35.5	Hilton	0	.4	
36.2	Tivoli	.1	32.7	
37.2	Amfac	0	19.8	
38.7	Hacienda	.4	18.7	
:39.	A Park	0	16.4	
:41.5	Sheraton	.6	22.3	
41.3	Viscount	0	12.9	
42.	Trade Wind	0	11.1	
43.4	Viscount	0	2.1	
43.3	Amf.	.1	6.1	
43.3	Days Inn	0	20.2	
43.7	C. Plaza	—	7.9	
44.3	Holiday Inn	0	10.9	
45.2	Hyatt	–	16.7	
45.3	Stouffer	.2	13.1	
47.2	Marriott	0	13.2	
48.	C Plaza		4.7	
49.4	Hyatt	0	4.2	
53.3	Sheraton	.7	11.8	

FIGURE 3 Sample data collection form.

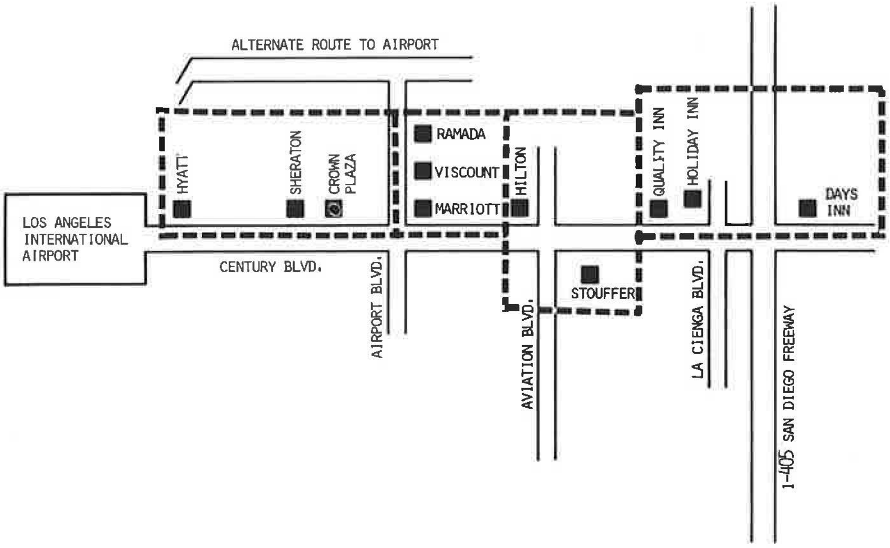


FIGURE 4 Hotels near LAX and designated groupings for alternative courtesy van system.

TABLE 1 HOTEL COURTESY VAN OPERATIONS, HEADWAYS, AND LOAD FACTORS BY DESTINATION

Group	Destination	Number of Runs	Average Headway (Minutes)	Average Load Factor
1	Days Inn	10	23.0	.19
	Holiday Inn	19	12.1	.21
	Quality Inn	8	28.8	.28
			21.3	.23
2	Stouffer Inn	20	11.5	.26
	Hilton	29	12.1	.21
			11.8	.24
3	Marriott	26	8.8	.48
	Viscount	17	13.5	.47
	Ramada Inn	24	9.6	.16
			10.6	.37
4	Crown Plaza	30	7.7	.30
	Sheraton	24	9.6	.30
	Hyatt	29	7.9	.20*
			8.4	.27

* Hyatt load factor estimated on partial sample; tinted van windows obscured observations.

The average observed headway for courtesy vans serving all local hotels (including some not shown in Table 1) was one van every 44.4 sec; however, the average wait time for any one LAX area hotel was 11.8 min. The average load factor was .26 (i.e., vans were loaded only to 26 percent of their capacity, on average) on the basis of 240 observations. This final statistic points out that if a bus system provided service to hotels with 100 percent efficiency, nearly three-fourths of the hotel courtesy van traffic could be eliminated.

DEVELOPMENT OF ALTERNATIVE BUS SYSTEM

Planning criteria for the alternative bus system was developed and applied as follows:

1. *Political considerations*—For the pooled system to work, it must be acceptable to participating hotels and businesses. Priority should thus be given to (a) exposure to arriving passengers, and (b) maintenance of high service frequency.
2. *Maximum number of hotels per pool*—In order to provide suitable exposure (e.g., advertisement logos on van), a maximum of three hotels would be served by one van.
3. *Service frequency*—In order for the system to be accepted, service improvement over the existing system is required. Thus, runs between the airport and hotel groups are provided at twice the current frequency.
4. *Total fleet size reduction*—In order to ease congestion, the improved service must be accompanied by a substantial reduction in fleet size. The service level just specified can be met by a 35 percent reduction in overall number of runs.

Operational characteristics for the new system are presented in Table 2.

The first developmental step involved designating service frequencies (operational headways) for each motel grouping. Taking one-half of the current operating value and rounding, the following headways would be applied: Group 1, 10 min; Group 2, 6 min; Group 3, 5 min; and Group 4, 4 min. Because 5 min is a reasonable minimum, and to avoid favoring Group 4, 5 min was assigned to both Groups 3 and 4. Therefore, the average wait time for arriving passengers, based on current demand, is reduced from 11.8 min for current operations to 6 min for the alternative system operations.

Projected load factors presented in Table 2 were computed assuming the same passenger loading for each hotel grouping. These load factors were slightly higher than the currently observed load factors, therefore characterizing a more efficient system. Projected loading, however, would still allow for passenger comfort and accommodate load fluctuations because of peaking.

A substantial benefit of the new system is the 35 percent overall reduction in the number of runs required for the designated service level. For example, for the observed 230-min operation, 37 runs were generated by Group 1 hotels. By using the alternative pooled operation, the number would be reduced to 23—a 38 percent reduction in required runs. At the same time, average headways for Group 1 hotels would be reduced from 21.3 to 10 min.

Four routes would be designated for the hotel groupings. Airport-return passengers would be taken to their terminals on the upper level. The van would then pass all terminals on the lower level for pick-ups to the hotels within each group.

TABLE 2 OPERATIONAL CHARACTERISTICS OF ALTERNATIVE HOTEL VAN SYSTEM

Group	Participating Hotel	New Headway (Minutes)	Projected Load Factor	Benefit (Reduced Runs)
1	Days Inn Holiday Inn Quality Inn	10	.32	38%
2	Stoffer Inn Hilton	6	.24	22%
3	Marriott Viscount Ramada Inn	5	.52	31%
4	Crown Plaza Sheraton Hyatt	5	.48	45%

A number of operational features are desirable to render this shuttle bus system acceptable to participating hotels. A demand-response feature is suggested to facilitate airport returns. Each van would be equipped with either a two-way radio or beeper device to flag an airport return. This feature would eliminate the unattractive necessity of stopping at all hotels within the group on the run to the airport. Because most vans are currently equipped with two-way radios, this demand-response feature would not entail an additional expense.

SUMMARY OF RESULTS

Peak-hour observations of 311 hotel courtesy van operations revealed arrivals of one van every 44.4 sec, yet specific destinations were served on an average of only one van per 11.8 min. The inefficiency of the current system was characterized by an observed average peak-hour load factor of .26 (26 percent utilization of available passenger-carrying capacity).

A suggested alternative pooled van system was developed to serve groupings of two or three hotels each. This system provides service twice as frequently and operates with a substantially reduced fleet size.

Study results, based on equal passenger loads, indicated benefits of the alternative system as follows:

1. Service frequency is nearly doubled to hotels in the airport vicinity.
2. Airport boarding-passenger wait time is reduced from an average of 11.8 to 6.0 min.
3. Average load factor is increased from .26 to .41. This level still provides comfortable service and allows for peaking demand fluctuations.
4. The overall number of runs (hence generated traffic) is reduced by 35 percent.

FUTURE STUDY REQUIREMENTS

The development of an alternative ground transportation system to reduce curbside congestion must consider elements in addition to local hotel courtesy vans treated in this paper. However, the approach used here is applicable to other vehicle classes, including charter-party carriers and passenger-stage corporation vehicles.

Data on courtesy van operations reported in this paper address peak-hour conditions. Additional study is required for schedule and routing modifications applicable to off-peak conditions.

CONCLUSION

Airport area hotel courtesy vans are but one traffic component contributing to the curbside congestion problem within the LAX ground-access system. Yet this study has analytically demonstrated the effectiveness of improved vehicle utilization and systematic scheduling to reduce overall traffic while increasing service frequency.

A significant lesson can be learned by contrasting the approach applied in this study to curbside congestion reduction strategies suggested in the literature. Two approaches (air schedule modifications and traffic separation) pose practical and financial problems. The alternative solution of more efficient vehicle utilization is not only easier to implement from the airport landside operations standpoint, but also offers additional cost-saving benefits to local bus system operations.

ACKNOWLEDGMENT

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Planning Implications of Regional Airport Closures

ROGER P. MOOG

Trends in the Philadelphia region of closing critical general aviation airports since 1980 are described in this paper. The continuation of this trend is projected to the year 2000. Diversion of based aircraft and operations are assigned to remaining airports through the study period. Normal growth of general aviation demand is also estimated and assigned to remaining airports. System capacity is compared with demand in 1988 and 2000 and deficiencies are identified. Modifications to public and private capital investment plans are proposed to counteract the loss of system capacity and to minimize the negative economic impacts and longer ground access trips resulting from airport closures. Alterations to annual federal and state funding programs and amounts, especially regarding privately owned airports in the National Plan of Integrated Airport Systems, are required. Airspace conflicts near remaining airports are also anticipated and will necessitate further study.

The Delaware Valley Regional Planning Commission (DVRPC), acting as the regional planning agency for the 12-county, four-state area surrounding Philadelphia, adopted the Regional Airport System Plan (RASP) in 1982. RASP identifies critical public use airports and heliports necessary to serve the region's mobility and economic development to the year 2000 (*1*). The region is a 6,000-mi^2 area including Philadelphia; Bucks, Chester, Delaware, and Montgomery counties in Pennsylvania; Mercer, Burlington, Camden, Gloucester, and Salem counties in New Jersey; New Castle County, Delaware; and Cecil County, Maryland. The plan provides the direct local system input to FAA for its annual funding decisions concerning federal Airport Improvement Program grants to improve safety and capacity at all public use aviation facilities. In fiscal year 1988 FAA grants to regional airports totaled more than $25 million.

In 1982 RASP contained 42 facilities distributed geographically throughout the region to ensure reasonable travel time access from ground origins and to ground destinations. These facilities included 3 commercial airports (all publicly owned), 13 reliever airports (3 publicly owned and 10 privately owned), 14 general aviation airports (2 publicly owned and 12 privately owned), 3 seaplane bases, and 9 heliports or sites.

Between 1982 and 1988 many private factors and market forces changed the regional airport system as well as the expected demand for aviation facilities to the year 2000. Certain airports had been closed or sold for nonaviation development by their private owners. Markets for heliports and seaplane bases had not materialized. Drastic increases in commercial airline traffic at the Philadelphia International Airport (PHL) had caused the suburban reliever and general aviation airports to take a more significant role in maintaining safety through air traffic control and airspace separation. Private and public investment in some airports enhanced their capacity, but lack of capital facilities investment in critical local markets caused other airports to languish. In response to these events, DVRPC, in fall 1988, amended RASP to include only 35 facilities, reflecting a 25 percent reduction in the number of noncommercial airports originally in the system.

DVRPC and the regional aviation community believe that without modification of funding levels and recipient eligibility procedures, the trend of closing private airports will continue to the year 2000. Additional strain on those airports remaining open will be created; a negative impact on regional economic development, mobility, and airspace related delays and safety will result as well. As development extends outward from Philadelphia to distant suburbs, land prices rise and the resulting increased value of airport real estate pushes private owners to liquidate. Between 1982 and 1988 the RASP system had experienced a significant loss of general aviation capacity resulting in shifts of storage and operations demand to other available airports. These shifts have yet to result in demand exceeding capacity at any system facility. However, many airports now approach full usage. Further closures, which are probable between now and 2000, will have more deleterious effects on the overall system capability to provide mobility and support economic development in the region.

STUDY OBJECTIVE

Shifts in demand for airport facilities will be evaluated in two stages; first, storage and tangential operation demand shifts resulting from airport closures between 1982 and 1988, the time of RASP amendment, will be examined. A "worst-case" scenario of additional airport closures from 1988 to 2000 will then be projected, on the basis of assumptions to be defined, and the cumulative shift of demand will be calculated to 2000. With this year 2000 restructured demand scenario, storage and operating capacity deficiencies at remaining facilities will be identified. Potential airspace conflicts of concentrated demand may become apparent among groupings of airports in the suburbs. The possibility of major shifts of demand back to commercial airports can be determined. This information will allow regional officials to better determine the direction of multiyear airport capital programming and provide corroboration for developmental decisions at individual RASP airports.

Delaware Valley Regional Planning Commission, The Bourse Building, 21 South 5th St., Philadelphia, Pa. 19106.

BACKGROUND DATA AND ASSUMPTIONS

Base System

Table 1 lists the noncommercial airports contained in the 1982 adopted RASP. Data describing demand at these facilities include the number of based aircraft, which was estimated by site visits during 1985 and 1986 or from the RASP plan document. Annual operations levels at each airport are listed. These data were estimated by the DVRPC counting program or from the RASP document for those airports that closed before 1988. Also estimated is the available additional storage capacity at each airport (*2*). Airports closed by 1988, the first phase of demand shift, have zero additional capacity. Current general aviation system storage capacity is estimated as the sum of the existing regional fleet—2,285 aircraft plus 1,313 extra storage spots at airports open in 1988, or 3,598.

Sequence of System Reduction

Table 2 summarizes the stages of reduction of the airport system, from its original capacity before the RASP amendments of 1988 to the amended post-1988 system (which has lost several airports) to the worst-case system of airports remaining in 2000. Over six years, from 1982 to 1988, the number of system general aviation airports decreased from 30 to 23. This total further reduces to 12 in the 12 years to 2000, amounting to more than a 50 percent reduction in the number of airports from the original RASP number.

The post-1988 system reflects actual changes to the airport facilities but the 2000 worst-case system is an extrapolation of trends that have formed since 1982. Only publicly owned airports and those privately owned airports that receive public funds are retained in the year 2000 system, because they are the only airports with a high degree of certainty of continued operation.

This study excludes heliports because no capacity crisis exists or is anticipated because of the low level of regional helicopter operations. Also, given the small area required for a heliport, compared with fixed wing aircraft, maintaining existing or locating new sites is much less difficult for heliports than for airports.

Other Factors Influencing Diversion

Several other factors affect diversion of general aviation demand in the region. Although closing of airports is the most dramatic and quantifiable factor, other factors include diversion of general aviation traffic from PHL as commercial operations increase and diversion of general aviation traffic from the terminal control area (TCA) resulting from revised operating rules, Mode C-transponder equipment requirements, and extension of the radius and floor of the TCA.

Since deregulation of the airline industry in 1978, line haul and commuter and commercial operations at PHL have grown to approximately 420,000 per year, a 50 percent increase over prederegulation levels. Some nonitinerant general aviation traffic may have shifted from PHL to suburban airports to avoid commercial traffic or TCA regulation around PHL. Because the based aircraft numbers used in this study represent field observations at general aviation airports from 1985 to 1987, it is assumed that any diversion of based aircraft is represented in the based aircraft numbers for the system noncommercial airports.

Likewise, the effect of the TCA equipment and dimension changes on aircraft owners' choice of basing location cannot be measured at this time. These rule changes are not completely enforced yet, but when fully implemented, certain air traffic control exceptions or corridors for general aviation airports in the TCA are being contemplated by PHL ATC. If airport-specific exemptions occur, pressure on aircraft owners to move to less restrictive operating locations may not be significant, so no predictable diversion will be estimated for this analysis.

Airport Storage Versus Operations Capacity

The Federal Aviation Administration establishes annual operations capacities for general aviation airports on the basis of runway configuration, existence of crosswind runway, mix of aircraft, and taxiway configurations (*3*). Airports in this study have annual capacities in the range of 150,000 to 230,000 operations. Only Northeast Philadelphia, Wilmington, and Mercer County airports, which are considered later in the study, have current operation volumes in this range. Consequently, only storage capacity, which is based on available hangars and tie down storage space, will be considered when assigning diversions to remaining airports. However, by the year 2000, additional operating capacity improvements and storage improvements may be needed to accommodate regional aggregate operating demand.

Potential Airspace Conflicts

As demand concentrates at fewer airports through the three phases of the study, volumes of operations at these airports will go up as potential conflicts from neighboring airports in some locations go down. Those airports continuing to operate will probably be fully equipped with visual NAVAIDS and precision instrument approach systems for visual flight rules and instrument flight rules operations. Currently, it does not appear that airspace conflicts will deter the diversion of aircraft to study airports.

Growth Trends in Regional General Aviation Fleet, 1982 to 2000

RASP's 1982 growth projections of based aircraft, from which operations projections follow, varied by airport from 1.5 to 5 percent per year for the 18-year period. Typically, New Jersey airports averaged higher growth rates while Pennsylvania airports averaged slightly lower rates, reflecting the more mature nature of development on the Pennsylvania side of the region.

Actual growth in general aviation activity has not been as significant as assumed in 1980. Although business-related operations are increasing in the suburbs with the influx of

TABLE 1 STUDY INVENTORY RASP AIRPORTS (1982)

1982 Airport/County	Based Aircraft	Available Storage Capacity (Aircraft)	Operations Per Year
BUCKS			
Buehl	65	50	12,500
Quakertown	40	40	22,600
Doylestown	105	60	32,700
Pennridge	55	105	34,600
3-M	60	0	18,000
Warrington	65	0	20,000
Vansant	30	0	10,000
	420	255	150,400
MONTGOMERY			
Turner	120	0	43,900
Willow Grove	-	-	-
Wings	80	65	40,100
Pottstown-Limerick	70	40	28,500
Pottstown Municipal	70	0	35,000
Perkiomen Valley	90	60	26,100
	430	165	173,600
CHESTER			
Shannon	50	30	37,000
Brandywine	80	40	18,100
Chester County	100	100	30,500
Oxford	20	0	8,000
New Garden	95	65	26,600
	345	235	120,200
PHILADELPHIA/NE Philadelphia	250	50	190,000
MERCER/Trenton-Robbinsville	150	75	68,900
BURLINGTON			
Red Lion	70	57	35,800
Burlington County	60	150	16,900
Flying W	100	49	50,000
	230	247	102,700
CAMDEN/Camden/Burlington	70	0	35,000
GLOUCESTER			
Bridgeport	60	0	23,000
Cross Keys	120	80	68,200
	180	80	91,200
SALEM			
Oldmans	45	85	20,000
Salem County	25	50	10,000
	70	135	30,000
NEW CASTLE/Summit	120	25	40,400
CECIL/Cecil County	20	47	7,500
	2,285	1,313	1,009,900

TABLE 2 PHASES OF SYSTEM CAPACITY REDUCTION

Pre-1988 Regional Airport System	Post 1988 System	Year 2000 Worst Case System
BUCKS COUNTY		
Buehl	Buehl	Quakertown
Doylestown	Quakertown	Doylestown
Pennridge	Doylestown	Pennridge
3-M	Pennridge	
Warrington	Vansant	
Vansant		
MONTGOMERY COUNTY		
Turner	Wings	Wings
Willow Grove NAS	Pottstown-Limerick	Pottstown Municipal
Wings	Pottstown Municipal	Pottstown Limerick
Pottstown Limerick	Perkiomen Valley	
Pottstown Municipal		
Perkiomen Valley		
CHESTER COUNTY		
Shannon	Shannon	Brandywine
Brandywine	Brandywine	Chester County
Chester County	Chester County	New Garden
Oxford	New Garden	
New Garden		
PHILADELPHIA		
NE Philadelphia	NE Philadelphia	NE Philadelphia
MERCER COUNTY		
Trenton-Robbinsville	Trenton-Robbinsville	
BURLINGTON COUNTY		
Burlington County	So. Jersey Regional	So. Jersey Regional
Red Lion	Red Lion	
Flying W	Flying W	
CAMDEN COUNTY		
Camden-Burlington		
GLOUCESTER COUNTY		
Bridgeport	Cross Keys	
Cross Keys		
NEW CASTLE		
Summitt	Summitt	Summitt
CECIL COUNTY		
Cecil County	Cecil County	

TABLE 2 (*continued*)

Pre 1988 Regional Airport System	Post 1988 System	Year 2000 Worst Case System
SALEM COUNTY		
Oldmans	**Oldmans**	
Salem	**Salem**	
Total Facilities: 30	**Total Facilities: 23**	**Total Facilities: 12**

new regional employment, recreational flying has not increased, partially because of the effects of insurance cost increases on aircraft cost and flight school operations. Because based aircraft and operations data are current and based on field observations, not original RASP estimates, this study will use a conservative 2 percent growth rate from 1989 to 2000 to reflect the regional growth of demand and any diversion from commercial airports (*4*,*5*). Assuming a level of annual operations per based aircraft equal to the average at each airport now, this rate of increase, even with significant diversion, would not exceed the operating capacity of the general aviation airports.

AVIATION DEMAND ASSIGNMENT PROCESS

In this section of the analysis the 1988 amended RASP system and the 2000 worst-case system are assigned aircraft storage demand shifted from airports that have closed. Total airport demand assignments are cumulative to 2000, when projected regional demand is assigned to remaining airports without regard to existing capacity to establish capacity deficits.

Table 3 lists the operating airports according to the RASP as amended in 1988. Current levels of based aircraft and available storage capacity are presented. Demand in based aircraft from airports that have left the system from 1982 to 1988 is then assigned to the amended system. Airports that have closed include Warrington, Turner, 3M, Oxford, Bridgeport, and Camden-Burlington. Demand was shifted by assigning aircraft to the nearest operating airports within concentric rings around the closed facilities. This assumes that the airplane owners are distributed randomly around the airport. In one case, Bridgeport, demand was assigned to the only two nearby airports, 6 and 14 mi away. In the case of Turner, demand was shifted to the five closest airports within a 6- to 18-mi band around the airport. In all cases, new demand at the remaining airports did not exceed available storage capacity. Assignment of demand is identified in the third column of Table 3 by its placement in the row of the recipient airport. The letter next to the assigned aircraft represents the airport of origin of that demand. The revised 1988 demand for based aircraft at the recipient airport is in the fourth column.

Table 4 describes the year 2000 worst-case system and the demand diversion from airports closing from 1989 to 2000 under the study assumptions. Airports assumed to close include Vansant, Buehl, Trenton-Robbinsville, Perkiomen Valley, Shannon, Cecil County, Flying W, Red Lion, Oldmans, Salem, and Cross Keys. Wings and Pennridge, private airports that have not to date received federal grants, have been retained in the year 2000 system because of the significant private investment in Pennridge and the growing scheduled commercial service at Wings. These airports ultimately might be sold to nonaviation interests, further eroding the system.

Mercer County and Wilmington airports have been added, although they are commercial service facilities, because the commercial traffic is light enough to permit general aviation use if their locations warrant general aviation assignment (Table 4). The first three columns identify year 2000 based aircraft and available aircraft storage capacity. These levels were derived by increasing the based aircraft levels of the amended plan as presented in the last column of Table 3 by 2 percent per year. Available capacity is adjusted downward as a result. The "1989–2000 shift" column indicates reassigned demand from closed airports (identified with initials after the reassigned volume). Based aircraft growth at airports proposed to close (and therefore the total aircraft per airport reassigned) was inflated at the same rate but only for 6 instead of 12 years to reflect the average end date of operation, which was 1994. "Total Demand" indicates total year 2000 general aviation demand at the remaining airports. The last column lists the aircraft storage deficit by airport, which could also be interpreted as a measure of additional capacity needed.

FINDINGS AND CONCLUSIONS

After review of the 1988 and 2000 demand scenarios, several findings can be cited that have ramifications on the direction of airport system development in the Delaware Valley for the next 12 years.

1988 Amended RASP

Shifts of storage demand between 1982 and 1988 have increased based aircraft at 16 of 23 operating airports (Table 3). However, none of these airports has exceeded its storage capacity. Enough airports remain in the system so that owners or pilots do not have to travel far from their original base to find an alternative location for their aircraft. Consequently, no significant travel time loss or negative economic impact to users has resulted from the closure of the six airports between 1982 and 1988. Also, operating capacity at each of the amended system airports, conservatively estimated at 150,000 opera-

TABLE 3 1988 DEMAND MODIFICATIONS AT OPERATING SYSTEM AIRPORTS

	Based Aircraft -	Available Space	1982-1988 Shift	Total Demand
BUCKS				
Buehl	65	50	+20 W+10 M	95
Quakertown	40	40	+20 T	60
Doylestown	105	60	+20 W+30 T	155
Pennridge	55	105	+15 W+20 T	90
VanSant	30	0		30
	295	255		430
MONTGOMERY				
Perkiomen Valley	90	60	+10 W+20 T	120
Wings	80	65	+30 T	110
Pottstown-Limerick	70	40		70
Pottstown Municipal	70	0		70
	310	165		370
CHESTER				
Chester County	100	100		100
Brandywine	80	40	+5 O	85
Shannon	50	30		50
New Garden	95	65	+10 O	105
	325	235		340
PHILADELPHIA/NE	250	50	+30 M	280
BURLINGTON				
Burlington County	60	150	+20 B/C	80
Red Lion	70	57	+20 B/C	90
Flying W	100	40	+15 B/C	115
	230	247		285
GLOUCESTER/Cross Keys	120	80	+20 B + 15 B/C	155
SALEM COUNTY				
Oldmans	45	85	+40 B	85
Salem County	25	50		25
	70	135		110
MERCER/ Trenton Robbinsville	150	75	+20 M	170
NEW CASTLE/Summitt	120	25		120
CECIL/Cecil County	20	46	+55 O	25
				2285

tions per year, has not been exceeded as of 1989. (At the airports of greatest increase of based craft, previous operating volumes were well below 50 percent of operating capacity.) Because per vehicle usage per year has generally remained constant and the number of aircraft has increased, at most by 45 percent, no operating capacity problems are expected.

Year 2000 Worst-Case RASP Storage Capacity

Demand for storage of aircraft is based on 1988 based aircraft at each site, and has increased by 2000 (Table 4). These non-shift related increases have taken 4 of 12 airports to or beyond their storage capacity limits. When shifted storage demand from the 11 airports that are suggested to close is reassigned to the remaining facilities, severe storage capacity deficiencies appear in 9 of 12 general aviation airports. In this scenario, Mercer County and Wilmington, both underutilized commercial airports, have been used to absorb diverted general aviation demand because of their critical locations and public ownership stability. Specifically by area, Chester County airport storage capacity is predicted to be adequate to 2000, although Montgomery County airports may experience modest storage capacity shortages. In Bucks, County, Doylestown Airport will have a severe capacity shortfall and Northeast Philadelphia Airport, which was assigned diverted traffic from Bucks and Burlington counties, will also experience a serious general aviation storage deficiency. Over 200 based aircraft

TABLE 4 YEAR 2000 DEMAND MODIFICATIONS AT OPERATING SYSTEM AIRPORTS

	Year 2000 Based -	Available Capacity	1989-2000 Shift	Total Demand	Yr. 2000 Deficit
BUCKS COUNTY					
Quakertown	**76**	**4**	**+10 V**	**86**	**6**
Doylestown	**195**	**-30**	**+35 B+14 V+25 TR**	**269**	**104**
Pennridge	**113**	**47**	**+10 V**	**123**	**-**
MONTGOMERY COUNTY					
Pottstown Municipal	**88**	**-18**	**+20 PV**	**88**	**38**
Pottstown-Limerick	**88**	**22**	**+58 PV**	**146**	**36**
Wings	**138**	**2**	**+57 PV**	**195**	**55**
CHESTER COUNTY					
Chester County	**126**	**74**	**+28 Sh**	**154**	**-**
Brandywine	**100**	**20**	**+27 Sh**	**127**	**7**
New Garden	**119**	**41**	**+14 CC**	**133**	**-**
PHILADELPHIA/NE	**352**	**-52**	**+35 B+51 RL+40 FW +60 CK**	**538**	**238**
BURLINGTON COUNTY					
South Jersey Regional	**100**	**50**	**+60 RL+60 FW+25 TR +65 CK**	**310**	**160**
NEW CASTLE COUNTY					
Summit	**151**	**- 1**	**+30 OM**	**181**	**31**
MERCER COUNTY*					
Mercer			**+37 B+30 FW+142 TR**	**209**	**209**
WILMINGTON*					
Greater Wilmington			**+66 OM+14 CC+28 S +50 CK**	**158**	**158**
				2717	**1042**

*Commercial Service Airport

from Bucks and Burlington counties and Trenton-Robbinsville were assigned to Mercer County Airport, greatly increasing storage demand at that airport. South Jersey and New Castle County airports will experience moderate capacity deficiencies assuming that Wilmington can accommodate 158 general aviation aircraft within its commercial operations.

Significant capital investment to the year 2000 may be needed at Doylestown, Philadelphia Northeast, South Jersey Regional, Mercer, and Wilmington to acquire land and provide storage aprons and hangars for the expected additional aircraft. Extraordinary regional allocations from the Aviation Trust Fund may be necessary annually to the year 2000 in order to accomplish the necessary expansions of remaining airports.

Year 2000 Operating Capacity

Based aircraft at remaining nontowered general aviation airports have increased drastically, resulting in additional operations. South Jersey Regional and Doylestown have experienced the largest increases; however, total operations at these airports based on aircraft utilization ratios from actual counts and field observations are not expected to exceed operating capacities, assuming normal runway, taxiway, and facility investments. However, in the cases of Northeast Philadelphia, Wilmington, and Mercer County, all of which are FAA towered airports with 1989 operations levels of 190,000 per year, additional assigned aircraft plus internal based airport growth is 286,209, and 158 aircraft, respectively, above 1988 levels. This increase in traffic may exceed operations capacity at Northeast Philadelphia and Mercer County. Air traffic control impacts on commercial operations may occur. Additional capacity investment in runways, taxiways, and aprons would be necessary.

Year 2000 Economic Impacts

Of the total regional general aviation fleet estimated at 2,717 aircraft in 2000, 1,091 or 40 percent will have to relocate their bases under the assumptions in this study, sometimes at distances up to 20 mi from the original location. Given the restricted choices of general aviation base locations (14 in 2000 versus 23 in 1988) and the presumed increased travel times associated with getting to and from these airports, significant wasted time and cost will occur. This may discourage business activity in the region and have negative economic impact. The magnitude of this impact could be estimated with further study.

Airspace Conflicts and Other Impacts—Year 2000 RASP

The potential increase of general aviation operations at Northeast Philadelphia, Mercer County, and Wilmington, coupled with commercial and military usage at these airports, could result in increased complications and responsibilities for air traffic control. The consolidation of general aviation traffic at Doylestown, South Jersey Regional, Chester County, and Wings, especially with precision instrument approaches, suggests traffic control, noise, and ground access complications. These questions must be resolved through future study at the system or master plan level as part of qualifying these airports for additional FAA and state grants to respond to future shifts in general aviation demand.

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