TRANSPORTATION RESEARCH RECORD 588

Airport and Air Transport Planning

TRANSPORTATION RESEARCH BOARD

COMMISSION ON SOCIOTECHNICAL SYSTEMS
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1976

Transportation Research Record 588
Price $2.40
Edited for TRB by Marianne Cox Wilburn

subject area
04 air transport

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Library of Congress Cataloging in Publication Data
National Research Council. Transportation Research Board.
Airport and air transport planning.

(Transportation Research Record; 588)
1. Airports–Planning–Addresses, essays, lectures. I. Title. II. Series.
TL725.3.P5N37 1976 387.7'36 76-45466
ISBN 0-309-02554-0

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Forecasting Air Passengers in a Multiairport Region

David Rubin, Maryland Department of Transportation
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Traditional air passenger forecasting has been done for single airport regions generally by estimating a region's share of a national forecast. This method is inadequate in a multiairport region where forecasts must be distributed geographically. In the Washington-Baltimore region, a method similar to that used in ground transportation planning was applied. A share of the market forecast was developed based on a national forecast by using real yield, per capita disposable income, and government purchases as independent variables. Another forecast was completed based on an on-board origin-destination survey and regional socioeconomic data, including population, government employment, nongovernment employment, and per capita income. The 2 forecasts were then adjusted to provide air passenger trip generation by aviation analysis zone. This forecast was then distributed to other U.S. cities based on an analysis of socioeconomic data for Office of Business Economics analysis areas, including manufacturing product and wholesale and retail trade product. The result was forecasts from aviation analysis zone to other U.S. city for use in distribution.

Forecasts of aviation activity are usually done for individual airports. It is unusual for airport service areas to overlap and even more unusual for an overlap to be considered in the forecasting process. This is especially true for major air carrier airports. The forecasting tradition in aviation planning is to rely on national forecasts and local market shares (1). This process is inadequate in a region with competitive air carrier airports. A process similar to ground transportation planning more adequately produces usable forecasts in a multiairport environment.

Forecasts in a multiairport environment must be geographically distributed. The generated air trips have to be split between the airports, and distance from the airport is a major factor in determining airport choice. The other major factor, airline schedules, must also be considered in developing air passenger distributions (2, 3, 4). Even in regions where all airports are operated by the same agency, as a market phenomenon, they compete. The airports in the Baltimore-Washington region are operated by different agencies. The Maryland Department of Transportation operates Baltimore-Washington International (BWI), and the Federal Aviation Administration operates Washington National (DCA) and Dulles International (IAD).

DCA, because it is convenient to downtown Washington, attracts as many planes as can use it. Quotas have been placed on hourly operations, and limits have been placed on types and destinations of aircraft. DCA serves as a connecting hub; about 1.5 million connecting passengers use the airport annually. It also attracts passengers from the entire Baltimore-Washington region, including 4.5 million people who, when asked, would prefer to be at BWI or IAD. DCA has no long-haul flights to such markets as Kansas City, Dallas, Houston, Denver, Las Vegas, Los Angeles, San Francisco, and Seattle. Long-haul traffic is split between BWI and IAD. In most markets, IAD attracts a larger percentage of the long-haul traffic. Frequency and quality of service play a great role in the individual's airport choice because most passengers are not greatly inconvenienced by either airport.

The Maryland Department of Transportation, after acquiring BWI, changed the name of the airport from Friendship International to emphasize that it serves the Baltimore-Washington region. An aggressive promotion of the facility has been started, including advertisement, access service improvements, marketing to the airlines, and development of an aviation system plan for the state. For the first time, the market is being considered in its entirety (5).

To forecast air passenger trips in the Baltimore-Washington region, a 2-pronged approach was used. Macroforecasts were developed based on national forecasts and historic market shares and were distributed to destination cities. At the same time, microforecasts were used in which forecasts were developed for 72 aviation analysis zones based on the relationship between trip generation and socioeconomic factors in the region.

A national macroforecast was developed for the Maryland Aviation System Plan as one tool to be used in reviewing Baltimore-Washington regional participation for its existing and projected share of the 50-state U.S. domestic passenger historical series and forecast. Spe-

Publication of this paper sponsored by Special Committee on Air Transport Activities of the Transportation Research Board.

*Mr. Fagan was with R. Dixon Speas Associates when this research was performed.

cifically, this forecast consists of data reflecting the projected level of revenue passenger-kilometers, passenger originations, and passenger enplanements on domestic trunk and regional carriers. The basic model used for development of this forecast is an equation developed through a Hildreth-Lu multivariate technique.

GENERAL APPROACH FOR MODEL DEVELOPMENT

The least squares fit to a forecast equation with 3 independent variables will be of the form

$$Y(t) = A + BX_1(t) + CX_2(t) + DX_3(t) + e(t) \quad (1)$$

where

A, B, C, D = coefficients to be determined and
e(t) = model estimation term (which, one would hope, is small).

It may turn out that

$$e(t) = f[e(t-1)] \quad (2)$$

which means that the size of the error term is a function of the error at the previous period of time. This is called autocorrelation and is not desirable. A consequence of autocorrelation if the least squares estimation technique is applied is that the various statistical measures (t-test and F-test) conventionally used to indicate the goodness of fit of a model are no longer valid.

An approach to the problem of autocorrelation is the Hildreth-Lu technique. It assumes that the functional relationship between the 2 error terms is of the form

$$e(t) = Ke(t-1) + g(t) \quad (3)$$

where

K = a constant smaller than 1 and
g(t) = estimation error term.

This technique also provides a remedy in the case of first order autocorrelation. The Hildreth-Lu solution makes use of lagged variables, and the equation contains not only the expected independent variables $X_1(t)$, $X_2(t)$, and $X_3(t)$ but also the variables $X_1(t-1)$, $x_2(t-1)$, $X_3(t-1)$, and $Y(t-1)$.

In more specific terms, the Hildreth-Lu technique as used in this analysis contains 3 independent variables: (a) real yield, (b) per capita disposable income, and (c) government purchases of goods and services expressed in constant 1958 dollars. The dependent variable in the model is per capita revenue-passenger-kilometers.

The Hildreth-Lu equation, which is based on a 19-year history from 1955 to 1973, is

$$\begin{aligned}1.6Y(t) = &-170.68 + [0.379\,45 \times X_1(t)] - [0.270\,74 \times X_2(t-1)]\\ &+ [3.2354 \times X_2(t)] - [2.3085 \times X_2(t-1)]\\ &- [29.665 \times X_3(t)] + [21.167 \times X_3(t-1)]\\ &+ [0.713\,51 \times Y(t-1) \times 1.6] \quad (4)\end{aligned}$$

In this equation the coefficient of determination = 0.9606, the Durbin-Watson statistic = 1.5007, and $F(3, 14)$ = 113.91. The t-statistics are as follows:

$X_1(t)$ = 6.8109 per capita disposable personal income,
$X_2(t)$ = 3.5251 government purchases of goods and services, and
$X_3(t)$ = 1.4126 yield.

The Hildreth-Lu equation in the form of equation 4 is the final product of a series of multivariate analyses in which as many as 10 variables were tested. The 3-variable equations are the result of these statistical tests and the desire to select not only a statistically reliable but also a logical model.

After arriving at a forecast of per capita revenue-passenger-kilometers for the forecast period, applying a population forecast of persons 16 years old and older and a trip length projection to obtain a forecast of originating passengers was simple. Application of a projected connection factor then yielded a forecast of passenger enplanements. The projections of both trip length and connection factor were developed by carefully examining past trends and by making projections of these trends through 1995.

Model results in the form of high, median, and low forecasts of originations and enplanements are given in Table 1. Applicable growth rates are given in Table 2. The median and high forecasts have been adopted as reasonable for assessing future traffic levels. The low forecast range is viewed as a pessimistic planning minimum. The high-low forecast ranges relative to U.S. originations and enplanements are shown in Figure 1. (The data in Tables 1 and 2 and Figure 1 are for 50-state scheduled service for air carriers that are on Civil Aeronautics Board certified routes.)

INDUSTRY FORECASTS

Exploring other industry forecasts is often useful in assessing the reasonableness of different forecasts developed at the same time. To this end, we reviewed 4 industry enplanement forecasts and compared them with the results of the aforementioned (Speas) model. Such a calendar year comparison is given in Table 3.

Table 4 gives the relationship of Baltimore-Washington and total U.S. trip originations. From 1960 to 1973, the study area percentage of U.S. trip originations has remained fairly constant except for certain short-term fluctuations in the mid 1960s. Since 1960, the region has experienced an average annual compound rate of growth of about 9 percent. From 1970 to 1973, however, this rate has slowed to approximately 5.3 percent/year. After an extensive review of forecasts for expected population and other Baltimore-Washington regional socioeconomic indicators, a multivariate technique was applied to arrive at estimates of future Baltimore-Washington trip origins as a percentage of total U.S. trip origins. These forecast data are also given in Table 4. Based on the past history of certificated air carrier traffic and regional and national economic trends, the regional percentage of trip originations is expected to show a modest increase. However, the absolute levels of passenger demand (originations) are expected to be substantial as indicated in Table 4.

MICROFORECAST OF REGIONAL AIR CARRIER PASSENGER TRAFFIC

The distribution of forecast air travel passenger originations by planning district relies on analysis of past travel behavior and the socioeconomic environment in which that travel took place. Available data in survey form were used that described the extent to which the public has used available air transport services. As part of the Maryland Aviation System Plan, an on-board survey of passengers was conducted for November 7 to 14, 1973; November 28 to December 13, 1973; and January 9 to 23, 1974. The on-board surveys were conducted on selected flights de-

Table 1. U.S. domestic airline passenger data.

Type of Data	Year	Range	Per Capita Revenue-Passenger-Kilometers	Population ≥16 Years	50-State Revenue-Passenger-Kilometers	Trip Length (km)	Originating Passengers (millions)	Connection Factor	Passenger Enplanements (millions)
Actual	1970		1209.8	142.8	173	1600	108	1.386	149
	1971		1212.2	145.3	176	1628	108	1.401	151
	1972		1322.5	147.7	195	1638	119	1.437	171
	1973		1388.7	150.3	209	1650[a]	126[a]	1.405	177
Forecast	1975	Low	1440	155.3	223	1673	134	1.40	187
		Median	1540	155.3	239	1673	143	1.40	200
		High	1640	155.3	255	1673	152	1.40	213
	1980	Low	1812	167.0	291	1731	175	1.40	245
		Median	1955	167.0	326	1731	189	1.40	264
		High	2098	167.0	350	1731	202	1.40	283
	1985	Low	2256	175.4	396	1793	221	1.40	309
		Median	2467	175.4	433	1793	241	1.40	334
		High	2677	175.4	469	1793	262	1.40	367
	1990	Low	2708	184.4	499	1857	269	1.40	377
		Median	3017	184.4	556	1857	300	1.40	419
		High	3325	184.4	613	1857	330	1.40	462
	1995	Low	3195	194.4	621	1923	323	1.40	452
		Median	3648	194.4	709	1923	369	1.40	516
		High	4101	194.4	797	1923	415	1.40	580

Note: 1 km = 0.6 miles.
[a]Estimated.

Table 2. Growth rate percentages for Table 1 data.

Time Period	Per Capita Revenue-Passenger-Kilometers	Population ≥16 Years	50-State Revenue-Passenger-Kilometers	Trip Length (km)	Originating Passengers (millions)	Connection Factor	Passenger Enplanements (millions)
1970 to 1975	6.3	1.7	8.0	0.9	7.1	0.2	7.3
1975 to 1980	5.1	1.5	6.6	0.7	5.9	–	5.9
1980 to 1985	5.0	1.0	6.0	0.7	5.3	–	5.3
1985 to 1990	4.4	1.0	5.5	0.7	4.8	–	4.8
1990 to 1995	4.2	1.2	5.0	0.7	4.7	0.1	4.7

Note: 1 km = 0.6 miles.

Figure 1. High and low forecasts for U.S. originations and enplanements.

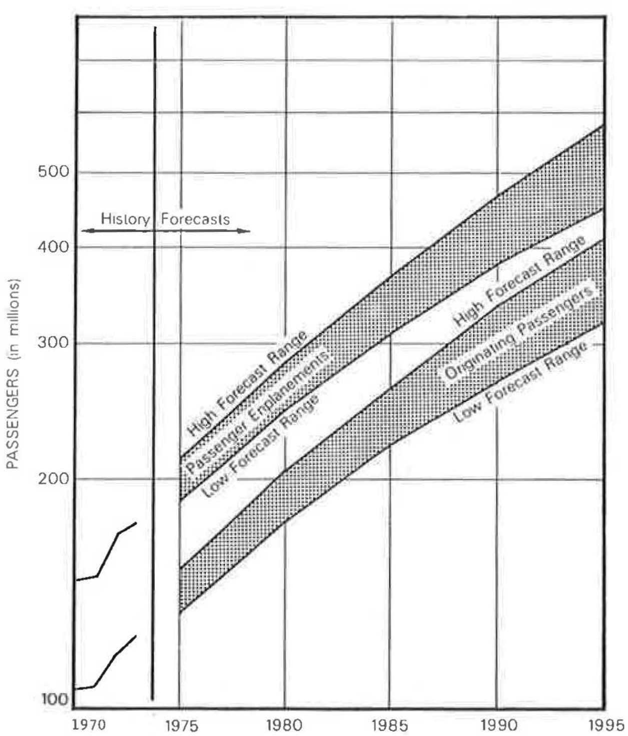

Table 3. 1974 industry forecasts for trunk and regional domestic scheduled service.

	Enplaned Passenger Forecasts (millions)					
					Speas	
Year	ATA	Boeing	General Electric	Lockheed	Median	High
1975	194.3	194.6	224.8	183.8	200.1	213.1
1980	254.6	261.1	275.6	254.7	264.1	283.3
1985	320.8	333.3	319.4	343.2	333.8	366.5
1990	394.5	410.0	–	–	419.4	462.3
1995	479.8	493.7	–	–	516.2	580.4
2000	567.7	579.9	–	–	–	–

Table 4. Relation of Baltimore-Washington and total U.S. trip originations.

Type of Data	Year	Range	United States	Study Area	Percent of United States
Actual	1960		38 868 000	1 755 090	4.52
	1961		40 143 000	1 950 990	4.86
	1962		42 754 000	2 179 970	5.10
	1963		49 047 000	3 165 740	6.45
	1964		55 697 000	2 880 380	5.17
	1965		65 593 000	3 367 420	5.13
	1966		75 069 000	3 791 650	5.05
	1967		88 435 000	4 545 330	5.14
	1968		103 746 000	4 885 130	4.17
	1969		111 697 000	5 317 500	4.76
	1970		107 952 000	5 045 800	4.67
	1971		108 267 000	4 938 820	4.60
	1972		119 267 000	5 385 170	4.52
	1973		127 474 000	5 884 641	4.62
Forecast	1985	Median	241 250 000	11 411 000	4.73
		High	261 790 000	12 383 000	4.73
	1995	Median	368 750 000	17 810 000	4.83
		High	414 580 000	20 024 000	4.83

parting the 3 commercial airports in the Baltimore-Washington region (6). The demand for air passenger service is strongly and directly affected by the socioeconomic environment for air travel as well as by the costs and quality of available transportation services. Nationality, population size, level and mix of employment, and level of per capita income have been found to have a significant impact on the volume of air travel and its rate of growth. Similarly, the transportation variables of time, cost, and frequency are known to have a direct and important influence on passenger traffic development. Consequently, reliable estimates of air travel by planning district require an understanding of the relationships between demand and the factors that influence demand.

By using survey results and a history of the socioeconomic environment in which travel took place, we developed a history of and forecast originations by planning district. For each of the 72 analysis zones, factored originations were segregated by type of trip (government business, nongovernment business, and all other). Three cross-sectional models were then developed to forecast independently the 3 types of trips on a zone basis together with the socioeconomic indicators relevant for each zone. The obtainable and usable variables were government employment, nongovernment employment, population, per capita income, and income product. The results from modeling each of the 3 types of trips for zones 1 through 72 in the aggregate proved to be unsatisfactory. For example, one conclusion in the case of zone-generated government trips was that the travel-generating potential of federal employees is vastly different from that of state employees in both frequency of travel and characteristics of mode of travel. Under the circumstances, therefore, further segregation of the aviation analysis zones into additional regions was found to be more satisfactory for logical and statistical results as well as for providing usable future system planning inputs. The 3 subregions identified were the city of Baltimore (zones 1 to 9), the remainder of the Baltimore metropolitan area (zones 10 to 28), and the Washington metropolitan area (zones 29 to 72).

The equations developed for the microforecast effort are indicative of the 3 subregions and for the 3 types of trips. For example, the equation that was used to generate government-related business trips in a zone of the Baltimore region is

$$\text{Trips from zone (1)} = -633.6 + 0.549\,36 \times \text{government employment (1)} + 0.060\,09 \times \text{population} + 1.1678 \times \text{per capita income} \quad (5)$$

In this equation, the coefficient of correlation = 0.80, the Durbin-Watson statistic = 1.4, and the F value = 4.9.

In general, the equations developed for the Washington area zones tended to be better predictors than those for the Baltimore area zones. After calibration and an add-on adjustment for external zones 73 to 78, the summation of the microforecast modeling effort revealed a slightly higher absolute number of originations for the forecast period than the median and high ranges of the macroforecast modeling effort:

Year	Macroforecast Median	Macroforecast High	Baseline Microforecast
1985	11 411 000	12 383 000	13 594 000
1995	17 810 000	20 024 000	22 094 000

The high range of the macroforecast was selected as being the most reasonable planning range inasmuch as microforecasts often have a tendency to overestimate the true generating potential of an area. This hypothesis proved to be true in this instance because the microforecast model tended to overestimate the base year, 1973, before normalization. Therefore, the microforecast was scaled to the high macroforecast control totals, preserving the zone distribution by type of trip.

OTHER U.S. CITY VERSUS BALTIMORE-WASHINGTON REGIONAL GENERATED DEMAND

The basic external demand unit considered in the regional study of originations was the number of round-trip passengers between the Baltimore-Washington region and another U.S. city. The forecast of city-pair demand was developed first from the region (not zone) to destination because previous studies have found that attempting to develop a forecast of originations from an aviation analysis area by type of trip or trip purpose to a specific external destination is an extremely hazardous exercise. Little reliability can be achieved, and the statistical results are often suspect. Therefore, the zone forecasts by type of trip and the regional forecasts to other U.S. city destination were developed independently.

For all destinations receiving nonstop service in 1971, 1972, or 1973 and any other destinations having an equal or greater number of passengers as any city receiving nonstop service in 1973, the absolute number of inbound plus outbound originations was determined based on the Civil Aeronautics Board 1973 Origination-Destination Ticket Sample. These "qualifying markets" were then grouped to the applicable Office of Business Economics (OBE) analysis area. The distance from the Baltimore-Washington region to each external OBE destination was determined. In addition, the following variables were compared for each external OBE area and the Baltimore-Washington region: per capita income, employment, manufacturing, and wholesale and retail trade. In the initial analysis, grouping markets by unit of distance block was determined to be essential to improvement of the modeling results. For example, the general form of the equation used in forecasting other U.S. markets 1600 or more km (1000 or more miles) from the region was

$$L(1) = -11\,274 + 0.088\,275\,6 \times M(1) + 0.486\,57 \times N(1) - 5.4730 \times P(1)(1.6) \quad (6)$$

where

L = round-trip originations from the region to the OBE external destination,
M = wholesale and retail trade product,
N = manufacturing product, and
P = distance in kilometers.

In this exercise, the coefficient of correlation = 0.995, the Durbin-Watson statistic = 1.6, and the F-value = 301.8. The results of the modeling effort reflect no adjustment for nonstop gateway flows. The results are rank-ordered by unit of distance block classification.

For those markets that did not fulfill the aforementioned criteria to be considered as qualifying markets, a concerted effort was made to redistribute these flows over the qualifying markets. The next step in this procedural analysis was to allocate 1973, 1985, and 1995 traffic levels over all nonstop sectors. All traffic must flow over a nonstop sector because all operations in a mode carry some portion of all traffic to the first nonstop destination. Future nonstop services were hypothesized as feasible when future traffic average daily round-trip flows attained a level of 100 passengers.

The final step was to merge all adjusted city-pair data with the region's aviation analysis zones. Trip purpose for each OBE city was gleaned from the survey. This information, in the form of proportions, was used with the trip-purpose detail developed from the micro forecast.

In the future, the existing trip-purpose proportions of traffic to each other U.S. city as derived from the survey may change. One must keep in mind that the survey, in addition to being a one-time application, is subject to the bias of seasonality. Therefore, although the survey proportions by type of trip for each other U.S. city are recognized as being usable inputs, they are secondary to the primary proportional derivation, the microforecast.

CONCLUSIONS

The forecasts developed were adequate for use in the modeling of air passenger distribution. They appeared reasonable on inspection and intuitively correct. They had their limitations largely because change was being forecast based on a one-time measurement. Time series data were available because a similar survey had been done in 1968, but the status of those data and their incompatibility made time-series analysis a costly and time-consuming process that could not be done within budget and time constraints.

Some of the equations appear counterintuitive. Signs on coefficients are not what would be expected, and relevant factors do not show an expected strong correlation. Part of this problem is a result of the lack of time series. Another is the result of data representing other factors. For example, as population goes up, air travel is expected to go up. Especially in the city of Baltimore, population becomes a surrogate variable for density, and, as density increases, air trips decrease.

This method is applicable in other multiairport environments, including areas in which a second airport is being considered for the future. With greater national application, a better understanding of trip-generation propensity would be developed.

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Interactive Computing Techniques in Airport Master Planning

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Fully implemented interactive computer techniques were employed at Battelle's Columbus Laboratories during each of 2 site-specific airport case studies for the Federal Aviation Administration: Chicago's Midway (1974) and New York's La Guardia (1975). The runway demand forecasts used during these contract studies varied widely by time of day and by season of the year. These time-varying patterns created a need to estimate corresponding aircraft runway delays and aircraft runway queue lengths. These airport airside level-of-service estimates were computed by using a set of simultaneous differential equations derived from classical nonstationary queuing theory. Many quantitative operating variables have to be accounted for during a computer analysis of this type. Depending on the purpose of the analysis, certain categories of variables may be independent input variables in one situation and dependent output variables in another situation. A high degree of computational and operational computer flexibility is therefore required during such an analysis. This paper highlights the interactive computer techniques developed and used during the 2 airport case studies. A typical application is also presented to illustrate the scope and flexibility of these advanced techniques. The paper concludes with a summary of experience gained with the described computer program and the interactive programming techniques employed to significant advantage.

A common element in airport master planning is the estimation of runway capacity requirements that match future air transportation demand forecasts. The Federal Aviation Administration (FAA) developed a 2-part runway capacity advisory circular in the late 1960s to assist transportation planners in this area of airport master planning (1, 2). Many possible runway configurations are treated in these advisory circulars, including a broad range of runway capacity estimates for aggregate categories of aircraft operating conditions.

Many fixed assumptions were used to compute the quoted capacity values. Outdated air traffic control (ATC) procedures also were strong influences. These characteristics limit the usefulness of the advisory circulars during discriminating analyses of alternative air traffic control conditions that may exist in the future. This is especially true for 20-year airport plans that are common in current airport master planning (3).

The FAA was recently confronted with a situation of this kind in which the existing advisory circular capacity methods did not permit an in-depth analysis of the effects of future operating variables on runway delays and aircraft queue lengths. Battelle's Columbus Laboratories was awarded several FAA contracts in 1973 to conduct 2 site-specific airport case studies (4, 5). These studies were part of a series of FAA case studies concerning the feasibility of using underused secondary airports to increase the air transportation system capacity of major metropolitan cities.

The following discussion highlights the runway delay analysis capabilities that were developed and used during the course of these site-specific airport studies. It will be shown that interactive computing techniques were employed to significant advantage throughout the analysis process.

The methods to be described were not submitted to the FAA as new airport master planning standards. However, this site-specific experience has contributed to the FAA's continuing efforts to improve the state of the art in this field. Other contractor studies are currently under way at the FAA to finalize new runway capacity planning standards (6).

PROBLEM DEFINITION

In classical queuing terminology, a runway is a "server" and the aircraft operating from that runway are the "customers". For safety reasons, a given runway can serve only 1 customer at a time. In actual practice, these customers arrive to be served in a somewhat regimented, time-varying pattern throughout the day. In some cases, a given runway is expected to accommodate both arriving and departing customers. Alternatively, a given runway may be devoted exclusively to either arrivals only or departures only. In either event, there are certain times and conditions when 1 or more customers will queue up and incur delays while waiting to be served by a given runway. It should be noted that this definition of delay is not necessarily the same as the deviation of actual arrival

Publication of this paper sponsored by Task Force on Computer Graphics and Interactive Graphics.

time from scheduled arrival time.

The time-varying dynamic characteristics of runway use create the need to estimate aircraft runway delay or queue length of both for different operating conditions. In other words, an airport planner's ability to accurately determine the need for additional runways (more capacity) is greatly improved by the ability to compute the likely impact of growth of aircraft demand on average delay levels. The major analytical problem here is to provide the planner with an efficient computational means for estimating the effects of forecast aircraft demand on runway capacity and runway delay.

EXPANDED RUNWAY CAPACITY DEFINITION

The capacity of an airport runway system can be defined in several different ways. In the absence of a level-of-service criterion (such as average aircraft delay) capacity can be defined rather simply as the maximum number of aircraft that can be processed per unit of time through a given runway system under conditions of continuous aircraft demand. This definition often takes the form of an hourly maximum runway acceptance rate for various operating conditions such as aircraft fleet mix, wind conditions, and weather conditions. The focus of concern is on the physical ability to maintain the maximum possible throughput of aircraft. Delays encountered by aircraft that have to wait to use the available runway capacity are not recognized explicitly under this definition. Alternatively, if concern is expanded to include aircraft that have to wait under continuous demand conditions, an expanded definition of capacity must be used.

The concept of an expanded capacity definition is shown in Figure 1. This characterization can be used to illustrate several important relationships among aircraft demand, capacity, and delay. The first variable of interest is the forecast pattern of daily aircraft demand. This variable must be considered even before the forecast level of daily aircraft operations is treated.

There are several types of demand patterns, and each pattern uniquely defines the relationships shown in Figure 1. The 3 most common patterns encountered at scheduled air carrier airports include

1. Either 1 peak in the morning commuter hours or 1 peak in the late afternoon commuter hours,
2. One peak in the morning commuter hours and 1 peak in the late afternoon commuter hours, and
3. An essentially rectangular pattern between the morning commuter hours and the late afternoon commuter hours.

When the daily aircraft demand pattern is specified for a given airport and time period, the total daily aircraft operations for this condition are required. This is the variable shown as the abscissa in Figure 1.

It is next necessary to estimate the runway system acceptance rate for the previously noted conditions and other variables, such as runway configuration, aircraft fleet mix, weather conditions, and ATC separation standards. A range of possible runway system acceptance rates are illustrated by the family of curves in the upper right-hand portion of Figure 1.

For a given daily aircraft demand pattern, daily aircraft demand level, and runway system acceptance rate, there is but 1 unique value of average daily aircraft delay (that is, ordinate value). For example, given points A and B in Figure 1, a low level of average aircraft delay (point C) can be expected. Alternatively, given points A′ and B′ in Figure 1, a high level of average aircraft delay (point C′) would be expected. It is in this sense that delay can be used to expand the originally stated acceptance rate definition of airport runway system capacity. In actual practice, this requires the deductive selection of an average daily aircraft delay criterion that represents a "satisfactory" level of runway system service. For example, a few minutes of aircraft delay may be considered satisfactory for a given airport (point x in Figure 1). This point then uniquely defines the maximum permissible number of daily aircraft operations (point z in Figure 1) for a given runway system acceptance rate (point y in Figure 1) and a given pattern of daily aircraft operations. Adoption of this expanded runway capacity concept leads to the need for an analysis capability that permits the simultaneous computation of aircraft runway delays and aircraft runway queue lengths for various combinations of future possible operational variables.

REQUIREMENTS FOR ANALYTICAL FLEXIBILITY

Before we proceed with the details of the interactive programming techniques, the reader should recognize that the previously stated concept of runway capacity can be used for analysis purposes in 4 significantly different, optional ways. The major attributes of these 4 analytical options are given in Figure 2.

The basic difference among the options is the category of runway capacity variables treated as dependent, or output, variables as contrasted with the variables that are treated as the independent, or assumed, input variables. A brief definition of each of the 4 categories of variables is necessary for an understanding of the similarities and differences between each analysis option.

The aircraft demand category given in Table 1 is made up of a number of operational attributes that affect the flow of aircraft through the runway system. Quantifiable attributes include such variables as the daily pattern of aircraft arrivals and departures, aircraft approach and takeoff speed, and wake vortex class. The values of these demand variables change slowly with time as airlines modify schedules and acquire new aircraft, and the airport planner must factor these airline trends into his or her demand variable forecasts.

The ATC standards category given in Table 1 consists of various operational variables that air traffic controllers influence through application of FAA-defined flight control procedures. There are 2 basic weather situations in which fundamentally different aircraft separation standards apply. In weather with adverse visibility, instrument flight rules must be employed by the controller to maintain safe aircraft separation distances. In clear weather, visual flight rules may be employed. The FAA continues to improve and automate the electronic aids available to controllers and pilots. These developments periodically permit aircraft separation reductions and thereby increase the maximum throughput rate capability of runways. Airport planners should factor these improvements into their forecasts for future time periods.

The runway configuration category in Table 1 consists of the number and type of runways needed to operate under the various operational conditions described by the previous 2 categories of variables. Runway needs can range from a single runway to a multiple set of dependent or independent parallel or crossing runways depending on the level of airport demand. The airport planner should rely on established FAA standards (advisory circulars) to determine the allowable minimum spacing between multiple runways after their need has been established.

Figure 1. Relation of runway system demand, capacity, and delay.

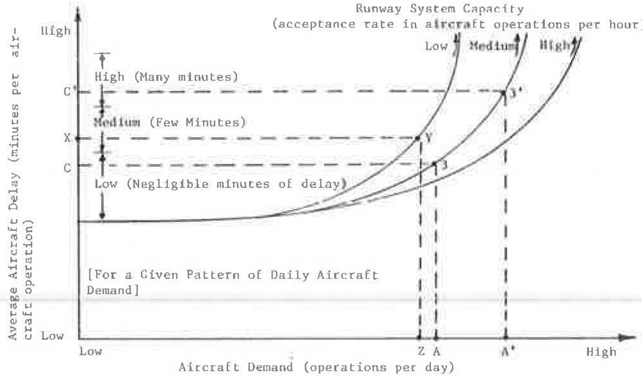

Figure 2. Average delay for current and proposed separation standards.

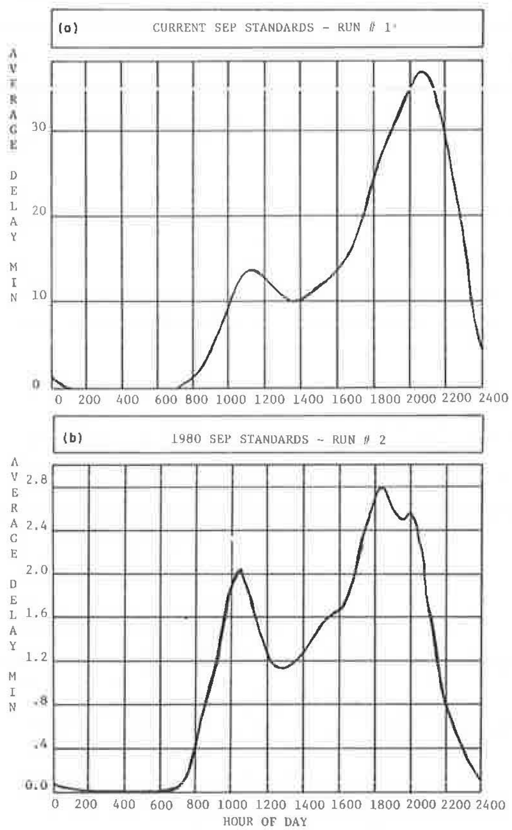

Table 1. Runway capacity analysis options.

Option	Aircraft Demand and Pattern	ATC Standards	Runway Configuration	Average Delay Criterion
1	Independent	Independent	Independent	Dependent
2	Independent	Independent	Dependent	Independent
3	Independent	Dependent	Independent	Independent
4	Dependent	Independent	Independent	Independent

Table 2. Aircraft mix data.

Class	Type	% of Mix	Approach Speed (m/s)	Wake Vortex Class
Jumbo jet	B-747	14	745.9	Heavy
Tri jet	DC10, etc.	29	694.5	Heavy
Long range	B-707-320, etc.	5	694.5	Heavy
Medium range	B-727-200, etc.	12	668.8	Light
Short range	B-737, etc.	40	643.0	Light

Note: 1 m/s = 0.19 knots.

The fourth category of variables given in Table 1 includes 2 interrelated runway performance variables. These variables include aircraft delay and aircraft queue length. These impacts must be computed for any given combination of the preceding variables regardless of the analytical option employed. However, this is a 1-time computation for a given set of assumed independent variables under option 1 whereas a succession of iterative delay and queue length computations may be required to satisfy the analytical requirements of options 2 through 4. For example, under option 2, assume that an average runway delay criterion of 4 min is independently and arbitrarily selected as the maximum average standard for delay. Let it be further assumed that the airport planner is trying to estimate the need for more runways at an existing airport where demand and ATC conditions are specified as independent input variables. A delay computation would first be made to determine whether the existing runways could accommodate the assumed case without exceeding the established 4-min delay standard. One of 3 results could occur. First, analysis might yield a value of, say, 2 min. If this were to happen, the planner would conclude that the forecast case could be accommodated without more runways. Second, the delay result might be very close to 4 min. The planner would again conclude that additional runways would not be needed for the time period of the assumed case. However, the planner would also know that no further aircraft demand growth could be accommodated without exceeding the preestablished 4-min delay standard. Third, the delay computation might yield an answer of 20 min. This outcome clearly leads the planner to conclude that the existing runways cannot simultaneously satisfy the established delay criterion and accommodate the assumed level of demand. It now becomes necessary to iterate the delay computation by successively modifying selected demand variables until a value of 4 min is attained. When this determination has been made, all of the removed demand is then analyzed separately to establish how many additional runways are needed to finally satisfy the 4-min delay standard for all aircraft operations. This phase of the analysis may require a succession of iterations before a combination of variables and runways is found to satisfy the preestablished delay criterion.

This brief discussion highlights the analytical flexibility required during Midway (4) and LaGuardia (5) airports case studies. In essence, the capability was sought to manipulate a large matrix of selectable variables, all of which have a varying degree of effect on aircraft delay or aircraft queue length or both. The manner in which this analytical objective was met through the application of contemporary interactive computing techniques will be described in the remaining sections.

DESIGN OF THE COMPUTER PROGRAM

To be effective, a computer program must satisfy many requirements that may be grouped into 2 general categories called the computational and operational requirements. These 2 sets of requirements, although dependent on each other, are quite different.

The computational requirements for a given problem are usually expressed in the form of a mathematical model that describes the calculations required to determine the solution. Computational requirements are application specific and do not lend themselves to many generalizations.

The operational requirements specify the operating environment within which the computational requirements must be met. These requirements include

1. Manner in which the program is to be used by the analyst,
2. Degree of flexibility desired,
3. Response time required,
4. Form of the input and output, and
5. Degree of interactive user assistance.

In contrast to the computational requirements, a set of operational requirements usually has wide applicability to other similar problems, and much of the programming effort can be used in other similar applications. Transportability of the program may be another operational requirement although it was not a necessity in this case. The program is currently operational on a Control Data 6400 computer. It can be used with either a Tektronix 4012 graphics terminal or a teleprinter. Ninety-five percent of the program is coded in FORTRAN and 5 percent is coded in COMPASS, a Control Data corporation assembly language.

Computational Requirements

In general, the procedure for computing runway delay is to first compute a runway acceptance or service rate (capacity). Using this derived service rate as input with an aircraft demand rate, a queuing model computes the probability that there are 0, 1, 2,... n aircraft in the runway system for each step in time. Given this set of probabilities, the average runway queue length and delay can be computed for each step in time.

The service rate computation is a straightforward operation. The derivation of a deterministic service rate model, however, is based on many variables and can become quite complex (5). Computation of the queuing statistics from the probabilities for a single runway is trivial and for more than 1 runway is only slightly more difficult (6). The most demanding computation is in determining the probability that there are 0, 1, 2,..., n aircraft in the system at a given step in time. This calculation involves the numerical integration of a set of simultaneous first-order differential equations (7) with time-varying coefficients. The coefficients represent the service and demand rates for the runway for a specific step in time. The number of simultaneous differential equations is dependent on the maximum number of aircraft permitted in the runway system. For n aircraft, there is a corresponding set of n + 1 differential equations. The demanding aspect of the computer implementation of this type of queuing model is in making it efficient and cost effective.

A significant improvement in computer time for the program was achieved by varying the number of differential equations in the system instead of maintaining a fixed number throughout the day. An algorithm was designed that permits the program to manage the maximum queue length by tracking the probability that there is an aircraft in the queue corresponding to the maximum permitted length. As this probability reaches a significant value (determined experimentally), the maximum queue length is extended an arbitrary amount (also determined experimentally) thus adding a few more differential equations to the set. The maximum permitted queue length was decreased when the probability decreased below a certain value (determined experimentally).

Operational Requirements

The program had to meet many operational requirements. The more significant ones were to

1. Support an active "person-in-the-loop" iterative solution technique,
2. Be usable by airport planners with little or no experience with interactive programs,
3. Afford a good measure of user protection of the investment in the program learning time yet maintain the flexibility to add new capabilities,
4. Require a minimum of effort to maintain a dialogue with the program, and
5. Display the results in a meaningful manner for end users.

Many of these same requirements are present in most scientific applications that are used by several persons.

The question of whether to implement the program in a batch or interactive computing environment was not a difficult one. Only the interactive environment afforded the degree of user control over the analysis process that was deemed necessary for iterative solutions. The interactive environment, however, is much more demanding in the programming effort required to control and maintain an effective dialogue with the user (8).

Several techniques were used to accommodate airport planners unaccustomed to using computers in an interactive environment. These techniques included use of a simple program-control scheme, reduction of the effort required to communicate with the program, and use of extensive diagnostics.

Two different approaches may be used for program control in an interactive environment. The user-driven control is one in which the user selects the next operation to be performed; the procedure-driven control is one in which the program proceeds automatically to the next predetermined operation. The familiar on-line text editor is an example of a user-driven control scheme that relies on the user to specify which type of text editing operation is to be performed next. The procedure-driven approach first prompts the user for the input required at a given step in the procedure and then performs the programmed operation. Although the user-driven approach is much more flexible, it is more difficult to learn than the procedure-driven approach. The procedure-driven approach was well suited to this application because of the nature of the methodology of the solution technique. Sufficient "backtracking" and override capabilities were built into the program at various points to compensate for limited flexibility.

A minimum of effort in program communication is usually achieved by use of a translator that supports a tailored language. Rather than expend the effort required in development of the translator, we used the standard FORTRAN NAMELIST as an input mechanism for most of the data required by the program. With this input mechanism, the user is presented with a list of variables, of which some, all, or none may be changed for a given computation. This type of input is of the general free field form variable = value in which spaces and decimal points are not important within data fields. NAMELIST input also has the advantage of being transportable to other machines.

To reduce errors and protect the user from selecting illogical choices, we used extensive diagnostics to test for inconsistencies of input variables. One such section applies nearly 50 diagnostic tests to the input data before proceeding to the next request for input. User learning time was protected by freezing the basic program operating concepts with the adoption of an add-only policy. This concept required that no programming changes could be made to dialogue meanings or operating procedures after new versions were released.

Thus, after a long time, the original user would find that the program functioned exactly the same as it had previously.

The output of the program is in the form of tables and plots. The tables are used to summarize the input and output, and the plots provide detail for the queuing statistics as a function of the hour of day. The program is operational on either a teleprinter or a direct-view storage tube and presents either printer plots or line plots, depending on the type of terminal being used.

SAMPLE PROBLEM AND RESULT

This typical application will illustrate how the developed program was used to forecast the impact of improved FAA air traffic control procedures on aircraft delays for a large metropolitan airport. FAA analysts were concerned with improvements in technology for the year 1980 that could permit significant reductions in the minimum airspace separation distances between aircraft. The described interactive program was used with data for the existing (1973) situation at the airport from a recently published FAA report (9) and then was exercised to determine maximum aircraft delay and aircraft queue length levels. A second run immediately followed in which only the forecasted improvements in the separations standards were changed.

Runway configuration was as follows:

1. Two parallel and independent runways,
2. Takeoffs and landings interleaved 1:1, and
3. High-speed [23.15 m/s (45 knots)] turnoffs.

Aircraft demand daily pattern was for Friday, May 4, 1973; the peak-hour demand was 142 operations. Instrument flight rules longitudinal separation standards (9, p. A-17) were as follows:

Leading Aircraft Wake Vortex Class	Run 1, 1973 ATC (km/h)	Run 2, 1980 ATC (km/h)
Heavy	9.3	5.5
Light	5.5	3.7

Aircraft mix data are given in Table 2. A complete definition of the input data used is available elsewhere (9). The interactive computer dialogue required to enter the input data is not shown in this paper in the interest of brevity. To indicate the degree of effort required, however, a total of 20 values were entered to obtain the first run and 2 values were changed for the second run. Selected output for the 2 computations is shown in Figure 2 and indicates that, for the same demand rate, the peak aircraft delay can be expected to improve significantly from 37 min to only 2.8 min. The major impact of reducing the assumed aircraft approach separation distances is largely a significant improvement in the maximum runway acceptance rate (aircraft operations per hour). For these 2 cases, the rate improved from 127 to 170 operations/h.

SUMMARY AND CONCLUSIONS

The computer program described in this paper originally took approximately 4 person-months to develop and has been used over a period of 2 years at Battelle's Columbus Laboratories to perform various airport analyses during 4 U.S. Department of Transportation contracts. The program has undergone 9 modifications since initial development, but the result of the add-only policy has been to increase the capabilities of the program such that the first version remains a subset of the current version.

It is difficult to quantify the time savings and efficiency gained by having an on-line computer analysis capability that is always ready for transportation analysts deeply involved in a wide variety of studies. The results have been gratifying. The program has been used by several analysts with no prior interactive computing experience after a minimum of learning time. The ability of these analysts to use the program without having to rely on an experienced programmer speaks well of the operational efficiency designed into the program.

The range of the program has been from studies of small general aviation airports to studies of large metropolitan airports. In some cases, the problem was to estimate future runway capacity requirements for a given forecast of aircraft demand. In another situation, the problem was to estimate the maximum level of demand permitted by a given level of capacity. In each case, a given maximum runway delay criterion was used to define a desirable level of passenger service. The most comprehensive study performed to date involved a determination of the impact of the FAA's upgraded third generation (UG3RD) air traffic control system on future runway delay levels at the 30 largest U.S. domestic hub airports. This study was part of a larger FAA program directed toward the costs and benefits of implementing various UG3RD component systems. The range of these applications illustrates the flexibility that has been designed into the existing program. Modifications and extensions from the original program version can be easily made to suit the priorities of the particular study. This evolutionary growth capability has maximized the original programming investment and has permitted the development of new capabilities to suit the needs of particular sponsors.

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Staging Runway Expansion by Dynamic Programming for Washington National and Dulles International Airports

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A time-staging decision for a long-range runway expansion program has been developed by adapting the dynamic programming methodology to economic optimization for a given planning horizon. Specifically, major efforts are made to bring the model into a highly useful form and to further tie the theoretical concept to the working reality by testing the model on real-world examples. Washington National Airport and Dulles International Airport were selected as test cases. The results showed that National could best be served by adding a fourth runway and that Dulles already has too large a runway capacity for its air traffic demand. Viewed in a multiairport perspective for the Washington, D.C., metropolitan region, the possibility of improving both airport operations by shifting some portion of National's demand to Dulles was indicated. A thorough evaluation of the methodology and its applicability revealed that the developed model should be capable of greatly benefiting the planning of airport runway operations.

The relatively new mode of air travel has grown steadily to the point at which it is now indispensible in the public's mind. Its maximum range has grown as quickly as the development of airport facilities and the furthering of air technology have allowed. Today, air traffic congestion at the major airports is considered to be the most critical problem of air transportation. Because of the complicated mixture of authority and interest inherent in the airport organization, including governments, commercial carriers, and the general public, planning of the airport for relief of traffic congestion can become a highly difficult process. As with most transportation facilities, airport planning is an attempt to best meet the needs of demand with a limited financial resource.

The problem facing the airport planner is assessing the operating and maintenance costs incurred by the current facilities and attempting to balance the costs of improving these facilities. The basic objective is to minimize the overall costs to 3 sectors: airport operator, aircraft owner, and aircraft passenger. Both aircraft operators and passengers bear costs incurred by delay of arrival or departure of airplanes. The air passenger typically values his or her time more highly than the passenger on other major modes, reflecting the perceivable benefit that air travel holds in the form of reduced travel time. When delays are excessive, this cost plays a far more significant role and leads to a drop in demands due to dissatisfaction with air service. The operator, faced with fuel, wage, and maintenance cost increments due to terminal delay, is sensitive to the value of time. All 3 segments of this airport problem must live with the time value of money itself, which is expressed economically as land value, growth rates, and interest rates. These, then, are the cost factors directly associated with runway planning.

For reducing air traffic delay costs, a runway configuration expansion is an appropriate consideration. A total analysis of the interactions of the cost factors previously described obviously should be carefully made. But, because of the complexity of runway planning and the amount of money involved, the tools of analysis that are available to the planner are insufficient.

The objective of this study was to introduce a factual and practical guideline relating to the timely development of runway configuration. This guideline was developed as a time-staging decision model that accounts for all cost factors that should be properly involved in deciding on improvements. Furthermore, the emphasis was on bringing the developed model into a highly useful form. With much of the conceptual groundwork apparently complete, tying the theoretical concept of the model to the working reality of today's planning situations was vital.

PREVIOUS WORK ON METHODOLOGICAL DEVELOPMENT

An investigation was initiated to determine how to best schedule runway configuration improvements for planning and design purposes (1, 2). A brief review of this previous study is necessary to indicate the theoretical framework on which the current study was based.

As indicated, the costs involved in runway configuration decisions include many factors relevant to airport users, both passengers and aircraft owners, as well as

Publication of this paper sponsored by Special Committee on Air Transport Activities of the Transportation Research Board.

to aircraft operators. These costs are of 2 types. The first is capital costs, which are those directly related to configuration and include land acquisition costs, land preparation costs, facility construction costs, and salvage values. The other type of cost is annual or cash flow costs, which include those costs connected with the use of a given configuration over a period of time and encompass items such as runway maintenance, aircraft delay costs, and passenger delay costs. The time value of money, interest, is a substantial cost in the scope of a long-range planning period, and will affect the optimal timing of a runway improvement. The incorporation of time cost of money necessitated a means of comparing funds on an equivalent basis.

The solution technique selected for analyzing this cost problem was dynamic programming. By putting all costs throughout the planning period on a present worth cost (PWC) basis, we derived 2 major types of costs. One is the cost of maintaining operations on a given configuration for an additional year, and the other is the cost of making the transition from one configuration to another. These 2 types of cost correspond directly to the change-of-stage and change-of-state quantifiers in dynamic programming formulation. They establish a latticed network of possible economic decisions through which the optimal path (or course of actions) can be found by the dynamic programming method. The optimal solution is that which yields the least costly path through the latticed network.

A concern with the practicality of using such a model for real analysis dealt with the difficulty in quantifying some of the necessary parameters, such as interest and growth rates, over a long planning period. Deviations from assumed values could alter the optimal expansion plan. To handle this difficulty, the program was designed with a built-in sensitivity analysis capability. Results can be produced in a single run for a large range of combinations of parameter estimates, allowing the programmer to check the sensitivity of the solution to changes in estimated parameters. Deviations in cost estimates, although affecting the total costs of alternatives, did little to alter the relative ranking of alternatives. The complex web of cost interactions necessitated a stage improvement model, rather than a rule of thumb, for proper decisions by planners. In addition, the planning program as developed was tested on a number of hypothetical runway configuration planning problems that were fabricated to illustrate not only the versatility and workability of the decision model but also the utility and applicability of the entire package in an actual planning situation. For the problem as formulated, the dynamic programming approach was suitably efficient for computation.

The computer program that has been developed for analyzing the runway expansion problem by using the described time-staging decision model has 3 major functional stages as shown in Figure 1. The first stage in execution is the use of data concerning operations level and flight delay to determine a functional relationship between these 2 variables. Data and analysis, by means of polynomial regression techniques, are necessary for each alternative configuration.

After the delay model has been constructed, its results are combined with the second half of the data deck. This group of cards defines the economic characteristics inherent in the runway configuration alternatives and the airport in general. This information is used by the second program stage, which calculates the component costs related to aircraft and passenger delay, construction maintenance, land costs, and salvage factors. It also performs the dynamic programming search for the least costly expansion program.

The final functional stage is the arrangement and printing of the results in such a form that they are ready aids to the decision-making process. Emphasis is placed on visually descriptive output forms and on completeness of possible output.

The program is capable of handling an economic analysis with a planning horizon of up to 20 years and up to 10 alternative configurations. The 10 alternatives, including the current or base configuration, must be ranked in order of increasing capacity or efficiency.

Within the above framework, the program can accommodate many cost parameter variations in the sensitivity analysis. The limits as written are as follows: 5 land value growth rates, 5 construction costs, 5 estimates of operations growth rates, and 6 interest rates. In addition, 3 salvage value determinations are built into the analysis. Although this number can be easily expanded, it should be remembered that the previously mentioned limits would allow for examination of 2250 different parameter combinations in 1 analysis.

Further documentation of the previous work is available elsewhere (1, 3).

APPLICATION TO WASHINGTON, D.C., AREA AIRPORTS

To check and to demonstrate the utility of the developed model, we selected 2 existing major airports, Washington National Airport and Dulles International Airport, both of which serve the Washington, D.C., region, for this study. A number of considerations were involved in the selection of these airports. They are both major air terminals. Their designs and operations contrast sufficiently to demonstrate the versatility of the computer model, yet the airports, though contrasting, serve the same area, which allows for an investigation of the use of the model in analyzing a multiairport situation. Furthermore, the gathering of data on alternative configurations and other economic factors, though not a simple process, was facilitated by selecting these airports because of their proximity, close cooperation, and the fact that a single agency, Metropolitan Washington Airport Service (MWAS), a division of the Federal Aviation Agency, operates the 2 airports. Both historical and predictive data covering the period from 1964 to 1983 were collected for both Dulles and National airports.

The difficulties involved in data collection for this study tend to reveal how innovative this form of analysis technique is in the airport planning field. Data collection involved personal contacts with many offices of federal and local government. In addition, a questionnaire was designed and sent to MWAS.

Two basic types of data were necessary—those related to the determination of capacity and delay and those related specifically to the various economic cost factors required as program input. Portions of the data body had to be estimated and thus may not be as accurate as the remainder. The sensitivity analysis feature of the program proved highly valuable in confirming the reliability of the results based on these estimates by establishing the stability of the solutions.

Capacity and Delay Data

Of prime importance in calculating delay costs is the preliminary analysis necessary to ascertain the operating characteristics of all the proposed configurations. To accomplish this objective, we used the Airport Capacity Handbook (4). A wind rose showing the percentage of time that the wind blows in a particular direction and at a particular velocity was used to develop runway use patterns. MWAS was able to supply the National wind rose. That for Dulles was obtained from the Data Processing Division of the U.S. Air Force Weather Service.

After obtaining data on exit locations and types from airport master plans and knowing runway use and aircraft mix at each airport, we could determine average runway occupancy times. An additional factor involved was the amount of time that operations were under instrument flight rules (IFR) and visual flight rules (VFR) because this affects the aircraft mix. Occupancy times could then be transformed into configuration capacities from which delays at certain operation levels could be calculated. As shown by the data given in Table 1 (5), the operations levels selected cover the years 1964 to 1983, which spans historical and projected demand.

Economic Data

After the magnitude of delay is known, the cost of that delay can be found by using appropriate unit cost factors for aircraft operation and passenger time values. Aircraft delay costs were obtained from 2 sources, the Civil Aeronautics Board (CAB) (6) and Airborne Instruments Laboratories (4). The costs were used in conjunction with the aircraft mix data for National and Dulles airports to establish weighted average costs for both airports.

The valuation of passenger travel time is a complex area of study. Values for an hour of a passenger's time range over a wide spectrum. Most are based on a relationship to the wage rate of the passenger. Although travel time values ranged from \$5.78/h (21) to \$14.00/h (7), more typical estimates include \$7.28/h (8) and \$8.09/h (9) for coach passengers and \$11.97/h (9) for first-class passengers. The Warshow study (7) uses a weighting formula of 1.5 times the wage to determine the value of business travel time, and uses 0.5 as a factor for personal travel. By applying this formula to the average value of \$5.78/h mentioned above, we obtained a weighted value of \$7.88/h for use in this study. Average passenger loads for aircraft were derived from the MWAS questionnaire results.

Because current land values were not available, estimates had to be obtained from the Real Estate Assessor's offices of Arlington and Fairfax Counties. For National Airport, these values were \$151 to \$161/m^2 (\$14 to \$15/ft^2). For Dulles Airport, they were \$11/m^2 (\$1/ft^2). The 1963 land value for Dulles Airport was obtained from MWAS based on the acquisition cost and was \$1.78/m^2 (\$0.16/ft^2). The approximate rates of growth in land value were 26 percent for Dulles Airport and 5.5 percent for National Airport based on the county estimates.

Construction costs for Dulles Airport came from MWAS information. The total cost of the 3 Dulles runways and their taxiways was \$20.7 million, or approximately \$8.29 million per single runway. For National Airport, no actual costs were available; therefore, estimates of \$30 to \$36/m^2 (\$25 to \$30/yd^2), obtained from the firm of Howard, Needles, Tammen and Bergendoff of Alexandria, Virginia, were used. The higher figure accounts for heavier jet aircraft.

Setup costs are those 1-time costs associated with construction, such as machinery transfer. They essentially include all nonadditive costs if 2 or more improvements are built simultaneously. The estimate used for setup costs was 10 percent of the overall construction costs. Maintenance costs were derived from the operating budgets for the 2 airports in their current state.

The final cost consideration is the time value of money as expressed by the interest rate. Rates selected for use included 10 percent based on the prime interest rate, 8 percent based on local government bonds, and 6 percent based on local bank rates. Sensitivity analysis was performed around these figures.

ANALYSIS OF WASHINGTON NATIONAL AIRPORT

A time-staging decision model was first used to analyze potential improvements to the runway configuration of National Airport. The existing configuration for National Airport was considered the null case. The basic alternatives that were investigated are shown in Figure 2. Table 2 details the physical plant costs involved for each alternative. Delay data figures are given in Table 3.

As has been previously discussed, the improvement configurations fall into 2 possible expansion series. The first involves upgrading the current layout by means of high-speed exits and addition of a fourth runway. The other program of improvement (the remaining 3 alternatives) relies on developing an additional land area for new runway construction. The result of this program would be a parallel duplication of the current configuration of National Airport.

An evaluation of the entire 20-year period from 1964 through 1983 was conducted to study the long-range evaluation of the model. This 20-year plan could be compared with the preferences indicated by 2 consecutive 10-year runs, one from the planning viewpoint of 1964 and the other from the planning viewpoint of 1974. The 20-year analysis results revealed that the cost of upgrading the existing runways by adding high-speed exits would not be entirely counterbalanced by reduced delay costs. As currently operated, Washington National Airport is crowded, yet it is an efficiently run system. The additional efficiency possible through a high-speed exit improvement program is not that significant. However, a combination of high-speed exit improvements and the addition of a dual runway in 1964 would have significantly aided the overall cost incurred by operation. Table 4 gives the 20-year analysis results for Washington National Airport. The modification factors for the data in Table 4 are as follows:

1. Interest rate of 8 percent,
2. Operation growth of 0 percent,
3. Land value growth of 5.5 percent,
4. Construction factor of 1.00, and
5. Salvage factor of 1.00.

As shown by the data, the savings over the 20-year period would have accumulated to about \$33 million in present worth terms for 1964. The increased construction and maintenance costs would be offset by reduced delay costs totaling \$45.5 million. On the other hand, continued expansion by using the series of alternatives that build a duplicate runway system next to the null system would seem to be a poor plan. Although delay would be dropped to extremely low levels, the land cost is prohibitive and would nearly double the total 20-year cost of operation. The dual runway would need no additional land for construction, but these alternatives would require a large outlay. Note further that the land and construction costs do not include glide path clearance costs, or the necessary cost of redesigning the terminal and parking facilities.

The stability of these results is very high. The same results were achieved by both 10-year analyses as well as the 20-year analysis. This indicates that such an expansion has been worthy of consideration for some time, and should continue to be attractive. In other words, a marked reduction in total operating cost would be realized if the dual runway had been implemented at any time since 1964. The earlier the construction had taken place, the greater the overall savings would have been for the full planning period.

Subjecting these results to the sensitivity analysis produced no change in the relative ranking of preference among the alternatives. Naturally, the actual dollar costs involved for all alternatives varied as parameter values were changed, yet the dual runway option remained a clear-cut best choice. Several factors help to account for the obvious superiority of this alternative. Most important of these is the decision by MWAS to set an upper limit on the number of operations handled at Washington National Airport. This ceiling has been set at 342,700 operations/year. In terms of demand estimates, this means a steady demand, not a growing one, throughout most of the second decade of the study. Therefore, there is little necessity for planning for major expansion of the airport, and the results from the earlier years indicate that the dual runway would be beneficial even at a lower level of operation. This, in combination with the very high land cost involved with the expansion series of configurations, gives a competitive edge to the lower cost, limited-growth alternative that the dual runway configuration represents. It is a question of building one runway on the current land or buying new land and building only one runway on the new land. The dual runway is less expensive and is effective enough for the policy-limited demand on National Airport facilities.

Another policy already in effect in Washington, D.C., makes the dual runway more appealing. This policy directs all operations involving large superjets to Dulles Airport, thereby allowing the close-distance parallel runway scheme to be more effective in practice at Washington National.

ANALYSIS OF DULLES INTERNATIONAL AIRPORT

An analysis framework with 3 planning periods, identical in form to that for Washington National Airport, was applied to Dulles International Airport. In this case, though, the current configuration was not designated as the null alternative. Examination of the level of operations that Dulles Airport has had to handle showed them to be well below the practical capacity of the currently existing configuration.

Because of the low use of Dulles Airport runways, it was decided to use only a portion of the existing layout as the null configuration. The 2 near, intersecting runways were selected. Dulles Airport was designed and built on an extremely large tract of land partly acquired with future expansion in mind but mainly bought for purposes of a noise buffer and to control commercial development in the near vicinity of the airport. It was assumed, therefore, that all of the land that was actually acquired would also have been acquired had only the hypothetical 2-runway configuration been built originally. This expanse of available land also led to the assumption that no land acquisition would be needed to add the fourth runway used in the design of the alternatives.

The 3 alternatives are shown in Figure 3. The physical costs are given in Table 5. The second alternative is the actual current configuration. Table 6 gives the data for delay and operation calculations that have been estimated for these Dulles Airport alternatives.

The 3 alternatives examined develop directly from the original design of the airport, which left a definite pattern to follow in planning future expansion. Considering the assumptions previously made here that lead to a constant land cost independent of the number of runways, one might expect that the planning situation at Dulles Airport would lean heavily toward favoring expansion. There are only the increased maintenance costs to offset the benefits of delay reduction, and these benefits have been shown to be considerable at times.

In the Dulles Airport case, though, there is a more immediate factor involved that prevents the bias toward expansion from taking effect. This is simply that, because of the historically low use of Dulles facilities, the delays are already minimal. Although the costs of expansion are low, any improvement in service would be marginal enough not to justify the expansion.

The studies using all 3 planning periods yielded the same results. The best choice economically proved to be the hypothetical null case with only 2 runways. The 3-runway existing configuration was roughly 12 percent more costly overall, and the 4-runway expansion alternative was about equally more expensive compared with the 3-runway scheme. Table 7 gives this well-defined cost separation over the entire 20-year planning period. The modification factors for the data in Table 7 are as follows:

1. Interest rate of 8 percent,
2. Operations growth of 0 percent,
3. Land value growth of 26 percent,
4. Construction factor of 1.00, and
5. Salvage factor of 1.00.

For the null alternative, the combined aircraft and passenger delay costs are roughly equal to the maintenance cost; for the larger alternatives, maintenance costs climb well above delay costs. Although this is a strong indication of overbuilding, it should be recalled that the analysis does not include an evaluation of other planning factors that went into the Dulles design. It considers only runway-configuration-related costs. Presumably, what was gained in the actual design of Dulles offset the increased operation cost.

As with the Washington National Airport analysis, the stability of the solution is high. Large variations in the values of several variable factors would be necessary to alter the ranking results of the program. From an economic viewpoint, there is strong indication that the third runway is not required, and that no further expansion beyond the current 3 runways should be necessary at Dulles International for many years to come.

MULTIAIRPORT CONSIDERATIONS

In a growing number of situations, a number of airport facilities are clustered to serve a large city or, more likely, an entire region. In this context, planning each facility independently of the others or using them in this way is not necessarily the best methodology. In Washington, D.C., MWAS directs all international flights and all jumbo jets to Dulles International Airport. Through demand manipulations such as this, the operations at any individual airport can be greatly altered. The question naturally arises about how the demand should be allocated for best results overall; therefore, multiairport planning considerations become necessary without choice.

The Washington, D.C., example seems ideally suited for such an investigation based on the results of analysis of the 2 individual airports. Demand is already being manipulated between Dulles and National; it would be desirable to study the implications of this process in

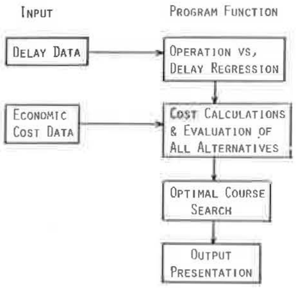

Figure 1. Functional organization of computer program.

Table 1. Operation levels of Washington National and Dulles International airports.

Type of Data	Year	National Airport	Dulles Airport	Type of Data	Year	National Airport	Dulles Airport
Historical	1964	290 640	131 726	Projected	1974	330 400	189 900
	1965	308 972	156 488		1975	335 400	194 700
	1966	319 711	172 930		1976	340 600	199 800
	1967	318 072	193 688		1977	342 700	206 400
	1968	341 399	220 818		1978	342 700	216 300
	1969	341 500	217 114		1979	342 700	226 200
	1970	333 548	204 910		1980	342 700	237 300
	1971	317 731	190 237		1981	342 700	247 900
	1972	321 300	190 800		1982	342 700	261 200
	1973	325 300	185 500		1983	342 700	277 400

Figure 2. Alternative runway configurations for Washington National Airport.

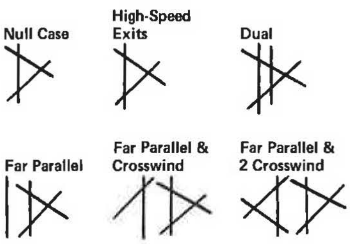

Table 2. Cost components for alternative runway configurations for Washington National Airport.

Runway Configuration	Costs (millions of $) Additional Land	Construction for Addition	Duplicative Setup	Annual Maintenance
Null case	231.710	0	0	1.538
High-speed exits	0	2.927	0	1.698
Dual	0	3.550	0.355	2.268
Far parallel	343.46	15.578	1.558	2.351
Far parallel and crosswind	0	9.494	0.949	2.847
Far parallel and 2 crosswind	0	9.494	0.949	3.942

Table 3. Delay versus operation data for alternative runway configurations for Washington National Airport.

Operations	Delay (h) Null Case	High-Speed Exits	Dual Runway	Far Parallel	Far Parallel and Crosswind	Far Parallel and 2 Crosswind
290 000	7 400 000	7 250 000	4 166 000	2 456 000	2 280 000	1 981 000
300 000	9 028 000	8 839 000	5 315 000	2 592 000	2 528 000	2 128 000
310 000	10 791 000	10 632 000	6 464 000	2 826 000	2 745 000	2 286 000
320 000	13 358 000	13 018 000	7 815 000	3 082 000	2 947 000	2 453 000
330 000	15 947 000	15 815 000	9 471 000	3 393 000	3 222 000	2 631 000
340 000	18 583 000	18 226 000	10 846 000	3 681 000	3 476 000	2 814 000
350 000	21 695 000	21 254 000	12 451 000	4 058 000	3 804 000	2 995 000

Table 4. Twenty-year analysis results for Washington National Airport.

Alternative	Costs (millions of $) Passenger Delay	Aircraft Delay	Maintenance	Construction	Land	Total
Null case	37.075[a]	73.261	15.103	0.000	214.545	339.984
High-speed exit runway	36.447	72.020	16.671	2.710	214.545	342.393
Dual runway with high-speed runway[b]	21.737	42.954	22.271	5.673	214.545	307.180

[a]Present worth. [b]Optimal runway configuration.

Figure 3. Alternative runway configurations for Dulles International Airport.

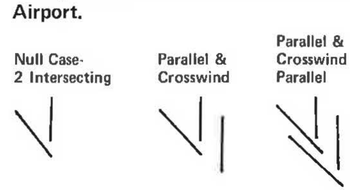

Table 5. Cost components for alternative runway configurations for Dulles International Airport.

Runway Configuration	Costs (millions of $) Additional Land	Construction for Addition	Duplicative Setup	Annual Maintenance
Null case, 2 intersecting	57.830	14.490	0	1.096
Parallel and crosswind	0	8.280	2.070	1.683
Parallel and crosswind parallel	0	8.280	2.070	2.193

detail. Also 2 prominent points emerge from the individual studies. Washington National Airport is overcrowded and expensive to operate and would be even if the dual runway were added. Dulles International is underused and would be even if only 2 of the 3 current runways had been built.

The complementarity of these results is obvious. Attention was focused on the consequences of diverting air traffic from National to Dulles by using the mechanism of a lowered operations level ceiling at National Airport. Data for the 1974-1983 planning period were used for this analysis to show what could be done now. Figure 4 shows the current projection for division of operations between the 2 Washington airports. The annual number of operations at National levels off at the estimated value for 1977, which is 42,700 operations. Analyses were run that shifted enough flights to Dulles International in subsequent years to reduce the National Airport demand load to 90, 80, and 70 percent of the original projected level. If the reduction of delay at National is significantly larger than the additional delay at Dulles, then a net benefit should result.

The results bear out the expectations of overall reduced costs. If we use the current 3-runway configurations, the total cost (excluding land cost) in present worth terms for 1974 drops from the original $126.31 million to $91.79 million for an operation cutback to 90 percent and $77.66 million for an operation cutback to 80 percent. If no additional runways are built, then there is a potential of saving about $35 million to $50 million over the next 10 years.

Adding the dual runway at National Airport lowers the original cost total (excluding land cost) of $98.54 million to $79.47 million with a 10 percent demand shift and to $65.46 million with a 20 percent shift. Again, large savings, even in discounted terms of present worth, are possible. The results for a 30 percent demand transfer from National gave spurious delay figures because of the extremely low delay levels.

It should be reemphasized that these savings accrue to aircraft operators and passengers, not to the airport operators themselves, who must fund the runway construction at National. Benefits to be derived by the operators directly would include only such things as reduced operational problems and so on, although the service provided would appear to improve dramatically.

The aircraft operators clearly benefit from reduced delay. Aircraft operating cost totals are given in Table 8

Table 6. Delay versus operation data for alternative runway configurations for Dulles International Airport.

	Delay (h)		
Operations	Null Case	Parallel and Crosswind	Parallel and Crosswind Parallel
75 000	187 000	105 000	104 000
100 000	337 000	189 000	182 000
150 000	787 000	432 000	424 000
200 000	1 512 000	788 000	761 000
250 000	2 742 000	1 281 000	1 213 000
300 000	5 845 000	2 019 000	1 810 000
350 000	12 839 000	3 080 000	2 723 000
400 000	24 349 000	4 667 000	3 646 000
450 000	46 318 000	6 885 000	5 057 000
500 000	82 657 000	9 734 000	7 010 000

Table 7. Twenty-year analysis results for Dulles International Airport.

	Costs (millions of $)					
Alternative	Passenger Delay	Aircraft Delay	Maintenance	Construction	Land	Total
Null case[b]	3.776[a]	6.468	10.765	0.000	53.550	74.559
Parallel and crosswind runway	1.977	3.386	16.524	7.667	53.550	83.104
Parallel and crosswind parallel runway	1.927	3.300	21.531	13.417	53.550	93.725

[a]Present worth. [b]Optimal runway configuration.

Figure 4. Demand split of the 2 study airports.

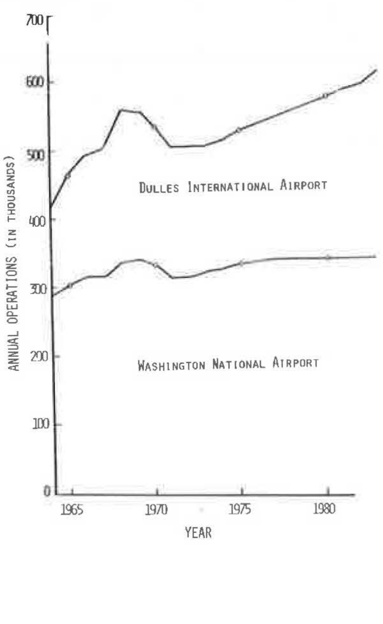

Table 8. Combined airport operation costs, 1974-1983.

	Costs (millions of $)		
Configurations	Passenger Delay	Aircraft Delay	Total Excluding Land
Current			
Current demand split	35.757	64.271	126.310
10% demand split	21.209	41.300	91.791
20% demand split	16.549	31.888	77.656
Current National and 2-runway Dulles			
Current demand split	34.461	67.190	119.331
10% demand split	24.366	46.708	88.774
20% demand split	22.546	42.160	82.386
Dual National and Current Dulles			
Current demand split	19.872	38.810	98.536
10% demand split	13.517	26.101	79.472
20% demand split	8.898	16.770	65.459

for the courses of action just discussed. Savings are substantial for this segment of the airport population. Passengers, on the other hand, may find it hard to accept the notion that landing at Dulles is more convenient than landing at National, which is closer to central Washington. After assuming the number of trips to the center of the District of Columbia made from these airports, one can calculate the additional costs of these transfer passengers. Each 10 percent shift represents roughly 1 million passengers. For that subgroup of passengers who have Washington as a final destination, the additional costs caused by landing at distant Dulles must be considered to fully investigate the economics involved. These costs include the added time necessary to reach downtown Washington (or whatever destination) and the added fare involved for such a trip compared with a similar trip from National. The increased number of passengers making this trip from Dulles could warrant consideration of a provision of mass transit. That is,

$$S = T_o - T_n + P(G) \quad (1)$$

where

S = potential savings,
T_o = original total operation cost,
T_n = new total operation cost,
P = number of passengers transferred, and
G = ground transport cost (including delay) per passenger.

Obviously, such a broad scope is beyond the problem outlined for this research, but it demonstrates how the time-staging decision model for runway configurations can be used in conjunction with a larger scale analysis by yielding cost information for the configuration subsystem.

CONCLUSIONS

The suggested approach to the configuration expansion planning is a computerized analysis that is capable of greatly benefiting the planning and design phases of airport runway operation. The program is designed to provide to those involved with improvement decisions and policies the body of tangible information needed to carefully evaluate the consequences of potential configurations to be applied to future air travel needs. An effort has been made to keep all aspects of the developed methodology, including data requirements and analytic sophistication, at a reasonable level to facilitate use in actual practice. The solution method is capable of handling most planning cases that may arise and can be adapted to handle other cases beyond this majority through careful input technique and problem structuring.

Several conclusions can be drawn based on the result of this study.

1. The economic costs (land cost, construction cost, maintenance cost, delay costs, and salvage value) reflect the major component costs (to airport operators and users) that are directly related to runway configuration.
2. The data requirements of the economic analysis are not unreasonable for a long-range planning effort. The data items are ones that should rightfully be considered in a comprehensive plan, yet they are currently difficult to obtain.
3. Development of the computer program as a planning aid with built-in comparative analysis and sensitivity analysis has proved much more valuable than a program that only mathematically optimizes.
4. For Washington National Airport, the addition of a dual fourth runway is indicated as desirable at any time between 1964 and 1983, the bounds of the planning period examined. Addition of high-speed exits alone was shown to be uneconomical in terms of reducing delay.
5. For Dulles International Airport, the analysis results indicate that 2, rather than the current 3, runways are capable of efficiently accommodating projected demands through 1983. This is true even though no additional land cost was involved for adding the third runway.
6. Preliminary investigations of the combined airport costs reveal potentially sizable savings through control of demand split between the 2 Washington, D.C., airports. These cost reductions, which would aid the aircraft operators and passengers, would occur both with and without addition of the dual runway at National Airport.
7. Throughout the case example runs, the stability of the solutions was high, which indicates clear-cut distinctions of all alternatives in terms of economic costs and operating characteristics.

ACKNOWLEDGMENTS

We are indebted to the U.S. National Aeronautics and Space Administration, particularly the Flight Instrument Division, for its assistance in this study. The research was carried out under a NASA grant. Special thanks go to David R. Gibson for his help in collecting data on the study airports.

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Passenger Behavior and Design of Airport Terminals

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The main deficiency in current terminal design methodology relates to the lack of empirically based information regarding passenger behavior and passenger requirements in airport terminals. This is exacerbated by the fact that airport planners do not have an adequate model of passenger behavior. This paper describes a research program that has attempted to alleviate these problems. The basis of the research has been the development of a design procedure and rationale capable of explicitly catering to the requirements of all terminal users. This approach will enable the airport planner to define levels of service to suit both the extent of passenger flow and the operational characteristics of the terminal. The central theme of the design methodology was the development of a set of linked analytical queuing models that can act as a framework for interpreting the processing activities of terminal users. This approach was complemented by an extensive survey of passenger behavior at an airport terminal. The survey was designed to both validate the modeling approach and test some general hypotheses about how various passenger groups spend their time in airport terminals. The latter aspect is dealt with in a discussion of some of the design implications of observed passenger behavior.

The level of demand for medium- and long-distance air transport has been known for some time to be dependent on a number of factors, including the cost, comfort, safety, and convenience of the service being provided. Air travel is recognized as the most expensive of all intercity modes of travel. A consequence of this is that traffic is attracted by offering a premium service in terms of speed, comfort, and convenience. However, it is evident that, within the air transport system, the airport terminal has become a major impedance to the rapid and comfortable processing of passengers from origin to destination. During the past 20 years, the airport terminal has had to reduce its level of passenger service in 3 distinct areas: access to and from the airport, the period spent within the terminal and its immediate environs, and the time spent within the aircraft both in ground delays and in the "stack."

The discussion here relates to the second, and possibly most significant, problem area, the time spent by the passenger within the airport terminal. The implications of observed airport terminal passenger behavior are considered for the overall terminal design procedures that have been adopted for airport planning. The research described is based on observations at a medium-sized regional airport; the applications are thus limited to the function of this type of airport with yearly passenger movements between 200 000 and 2 million. The relevance of the work to the larger metropolitan airports such as John F. Kennedy, Heathrow, and O'Hare has not been explicitly considered. The problems discussed here are unlikely to be of relevance to small airports where the elements of congestion are unlikely to occur over long periods.

The problem with current airport terminals is that the passenger is subject to delays and procedures that, together with increasing congestion of the airway system, have produced a marked deterioration in the overall level of service in air travel. For example, many passenger terminals are subject to crowding in peak hours and passengers have to endure long waiting times. This problem has been exacerbated by the fact that many terminals have been designed to cut down aircraft movement times to minimize aircraft operation costs. The result is a further increase in passenger waiting times and special difficulties for those passengers transferring between flights. Another facet of the problem is the apparent inability of airport designers to cope adequately with secular and short-term variations of passenger demand (1, 2). Airport authorities are familiar with the problem of the rapid obsolescence of terminal buildings (3, 4). The British Airports Authority, for example, recognizes that terminals may be subject to major alterations at intervals as frequent as 5 years and major restructuring and rebuilding at intervals of 15 years. Compared with the economic life of other transport infrastructure and the physical life of the component structures, the renovation and renewal periods of airport terminals would appear inordinately short. The same problem is apparent for short-term design forecasts, as current terminal designs seem to be inflexible with respect to hourly, daily, and seasonal variations in passenger flow (3). Some of these problems have been tackled by airport designers who have considered strategies such

Publication of this paper sponsored by Special Committee on Air Transport Activities of the Transportation Research Board.

as mobile lounges as temporary terminal building expansions or remote gate boarding areas for services where terminal facilities can be deemphasized (3, 5).

Many of these problems are considered to be related to the use of inflexible and inappropriate terminal design procedures and criteria. A review of current terminal design methodology (1) has indicated that the inappropriateness results from the lack of an explicit consideration of passenger behavior and requirements (2, 6). Without such information it is difficult for the airport planner to define levels of terminal service to suit both the extent of passenger flow and the operation characteristics of the terminal.

A research approach to the problems of terminal design is proposed that is based on an empirical study of the macroscopic behavior of passengers at terminals. The research, which has been multidisciplinary in nature, has had several aspects; 3 in particular are relevant to the arguments put forward in this paper.

1. A survey was carried out at a British regional airport to determine the parameters of passenger behavior and requirements while in the airport terminal (7).
2. A stochastic model was developed that described in broad terms the pattern of passenger behavior as a series of linked queuing models. The model was calibrated against survey data (8).
3. An overall rationale and procedure were developed for terminal design based on an explicit model of passenger behavior that can ensure that an adequate level of service is maintained for the premium travel mode (1, 9).

SURVEY DESIGN AND ORGANIZATION

Survey Scope

Passenger behavior in airport terminals can be classified in terms of processing, throughput, circulation, and auxiliary times. This classification, together with the data requirements of the airport modeling procedure that has been developed, formed the basis for a definition of the required survey information.

Processing Times

At various points in the terminal, servers are required to process passengers on an individual basis (customs, immigration, and check-in). Representative distributions were required for the various processing characteristics of these facilities, such as arrival rate, processing time, and variation in queue length.

Throughput Times

In other parts of the terminal, the method of processing passengers is not characterized by the server-passenger relationship. These are mainly holding areas or areas where passengers serve themselves (departure lounge and baggage reclaim). Again, distributions for the time spent by passengers in these facilities, or throughput times, are required.

Circulation and Auxiliary Times

A considerable amount of time is spent by passengers in most airports passing from one facility to the next or using nonessential facilities such as banks, shops, and restaurants. These times were not specifically measured in the current series of surveys.

As will be discussed in the next section, the total time in the terminal is also of importance for the model validation. Two measures of this time were defined for the purposes of the survey.

1. Total terminal time for enplaning passengers is defined as the time lapse between entering the terminal and the scheduled departure time of the flight. For deplaning international passengers, it is the time lapse between the actual time of arrival of the aircraft at the pier and passenger exit from customs.
2. Terminal occupancy time is a composite measure of the time spent in the main body of the terminal. For enplaning passengers, it is the time lapse between arrival at check-in and exit from the departure lounge. For deplaning international passengers, it is the time lapse between arrival at immigration control and exit from customs.

Description of Methods Used

The problems of airport survey organization choice of data collection methods and sampling procedures have been discussed elsewhere (7). For the surveys described in this paper, 3 main data collection techniques were evolved.

Card System

The main characteristic of the card system was that it involved passengers only to the extent of their being agents for the timing of their own movements within the terminal. The practical basis for this survey procedure was that each passenger involved carried a specially designed time-check card through the terminal. Passengers were asked to hand the card to members of the survey team at one or more chosen locations, or check points, so that a time could be recorded. This technique was used for the recording and estimation of throughput times such as the time spent in the departure lounge or baggage reclaim and for the estimation of circulation times and terminal occupancy. The cards were dispensed to passengers at the start of the process in which they were examined with the aid of a brief initial interview.

Direct Observation

A separate technique was evolved for the collection of processing time data at individual facilities such as immigration control. This involved the use of team members as observers at these facilities to record arrival rates, service times, and variation in queue length. The behavior of passengers was sampled either as a total record of discrete events (in the case of processing times) or at intervals (queue length was sampled at minute intervals).

Time-Lapse Cinecamera

For the survey of the check-in facility, it was decided to collect the passenger processing information by a time-lapse cinecamera. Apart from its unobtrusiveness, the main advantage of this approach was that no potential information was wasted; the required level of data could be subsequently extracted from the film within the degree of accuracy of the time lapse.

Survey Organization

The surveys of airport terminal processing were carried out at the International Airport at Manchester, England, during 1974. Most of the data obtained related to weekday conditions; large samples of passengers were involved for both international and scheduled and charter domestic flights. For the card system surveys some individual data on reasons for travel and previous experience of the airport terminal process were collected. The overall survey was subdivided into 7 separate parts; a summary of these surveys, including information on the technique used and the data required, is given in Table 1.

SURVEY RESULTS

It is not possible to give a comprehensive description of the survey results (7) in the context of the present paper. Here, certain aspects of the information obtained are selected to demonstrate, first, the relevance of the research approach and, second, the importance to terminal planning and design of obtaining some basic information on the behavior of terminal users.

Terminal Occupancy Time

The survey provided some interesting information in relation to the established differences between the arriving (deplaning) and departing (enplaning) passenger processing systems. The terminal occupancy time for international enplaning passengers averaged 55 min (Figure 1). The equivalent measure for international deplaning passengers was 8 min (Figure 2). Thus the deplaning passengers spent on average a seventh of the time that enplaning passengers spent in the main body of the terminal.

On the surface, this large difference between the 2 groups of passengers seems to be of little consequence; after a passenger is in the terminal, he or she will require approximately the same amount of space for equivalent facilities no matter how long he or she spends in the terminal. However, if the length of stay is such that other flights arrive or depart during this interval, then there could be competition among passengers from different flights for the available space. Thus, the combination of flight schedule and terminal occupancy is the important design factor. The deplaning passengers arrived at immigration control over an approximate 4-min period; thus only rarely were there more than 2 or 3 flights occupying the arrival facilities and processes such as baggage reclaim and immigration. For enplaning passengers, however, there will often be 7 or 8 flights during the average occupancy times, and considerable interaction among passengers from different flights and competition for terminal facilities are likely to result.

The difference between enplaning and deplaning passengers of 15 min for average terminal occupancy was less marked for domestic passengers than for international passengers. Although the average for international enplaning passengers was 55 min, there was a wide variation according to type of flight. The average terminal occupancy of charter passengers was 62 min, for example, compared to 48 min for scheduled passengers. There was a similar degree of difference between charter and scheduled deplaning passengers (5.5 and 8 min respectively).

Total Terminal Time

Some interesting observations can be made in relation to differences of various groups of enplaning passengers with respect to how long before their scheduled time of departure (STD) they arrive at the terminal check-in. Intercontinental scheduled passengers arrived at check-in 83 min, on average, before STD; European scheduled passengers arrived 66 min before STD (Figure 3). As one might expect, international charter and scheduled passengers had average total terminal times of 84 and 71 min respectively (Figure 4). If one examines the tail end of the distribution of times for arrival at the terminal before STD, one can see that all international scheduled passengers had arrived by some 20 min before their latest reporting time (LRT) and that the latest European scheduled passengers were only 5 min before LRT. This difference could be explained by the greater number of business passengers on European scheduled flights; one presumes that time is more valuable to those on business than to those traveling purely for pleasure.

Distribution of Time in Terminal

Apart from being designed to examine the total amount of time spent in the main body of the terminal, the survey was designed to investigate the manner in which passengers divided that time among various processes, auxiliary facilities, and the time spent waiting at or moving between the various facilities. Some of the results that were obtained are given in Tables 2 and 3.

If one considers international enplaning passengers, the first feature of interest is the small amount of time in which the passenger is actually being processed. For scheduled passengers, for example, only 3.5 min or 8 percent of terminal occupancy is required for actual processing. If the time spent queuing at these various processes is included, this still increases the proportion of service time to only 13 percent. Comparing this with international deplaning passengers shows that their stay in the terminal is not only shorter but busier; only 20 percent of terminal occupancy is required for activities other than processing. The longer service times obtained for charter passengers probably reflect the generally larger load factors for these flights. For each of the individual facilities described in Tables 2 and 3, a set of empirical distributions were obtained to characterize the processing system. As has already been mentioned, this characterization involved the derivation of distributions for queue length, arrival rate, and service times. The obtained distributions for most facilities confirmed the stochastic nature of processing at airport terminals. Figures 5 and 6 show typical distributions obtained; they describe the arrival rate and service time for international scheduled passengers at the Manchester check-in facility.

Terminal User Survey

Apart from obtaining time distributions, the survey also considered the proportion of different groups of terminal users (Table 4). It is interesting to note that 40 percent of terminal users were nonpassengers (people were interviewed as they entered the main terminal building). Of the 60 percent who were passengers, only a few were deplaning passengers (2 percent) using the main body of the terminal.

MODEL OF PASSENGER BEHAVIOR

The information obtained in the airport surveys was used primarily for the development of a stochastic modeling procedure for the passenger processing system. The basis of the modeling methodology is a series of linked analytical queuing models embedded in a matrix of walking time estimates. This approach allows the estimation of both distributional and average terminal processing times. Thus the model is a planning tool that can identify the major focal points of delay within the terminal process. It can also be used to evaluate the efficiency of alternative functional rearrangements or technological innovations.

Processing Models

Figure 7 shows the deplaning processing system typical of most medium-sized regional airports. The nodes represent the processing centers, and the links represent the proportion of total passenger flow. There are 3 main problems in modeling such a network:

1. Maintenance of mathematical tractability when linking queuing models,
2. Parallel processing of flows in the system, and
3. Interaction of passenger and baggage flows.

The solution of all these problems required simplifying assumptions that were tested in the field (the section on model validation). Table 5 gives a summary of the primary modeling assumptions by using Kendall's queuing notation (10). Each facility queuing model embodies a

Table 1. Summary of Manchester Airport survey.

Survey	Period	Technique	Information	Passengers
Departures process	5 h, Friday morning	Card system, random sample	Landside terminal time, departure lounge time	207
Immigration arrivals	3 h, Friday afternoon	Observation, total sample	Arrival rate, queue length, service time	109
Immigration departures	5 h, Wednesday morning	Observation, total sample	Arrival rate, queue length, service time	154
Check-in departures	5 h, Tuesday morning	Time lapse, total sample	Arrival rate, queue length, service time	89
Domestic arrivals, baggage	4 h, Thursday afternoon	Card system, random sample	Baggage or no baggage, baggage reclaim time	76
International arrivals, customs	4 h, Thursday afternoon	Card system, random sample	Customs time, red or green channel	112
Terminal user	5 h, Thursday morning 3 h, Friday afternoon	Interviews, time sample	Reasons for using terminal	222
International arrivals	4 h, Friday afternoon	Card system, random sample	Landside terminal time, baggage reclaim time	94

Figure 1. Terminal occupancy times for domestic and international enplaning passengers.

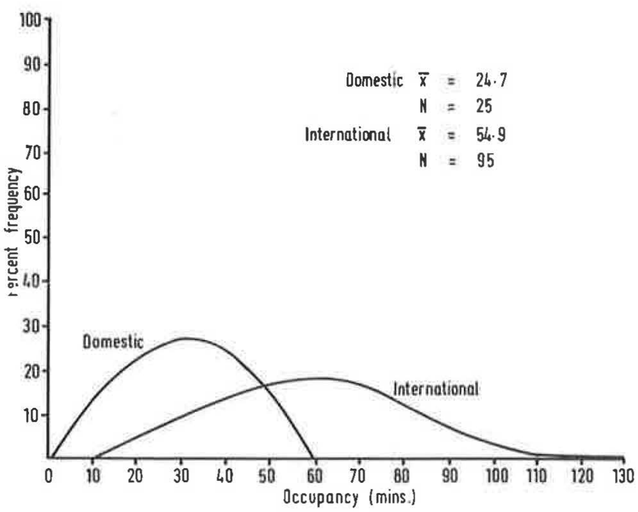


Figure 2. Terminal occupancy times for domestic and international deplaning passengers.

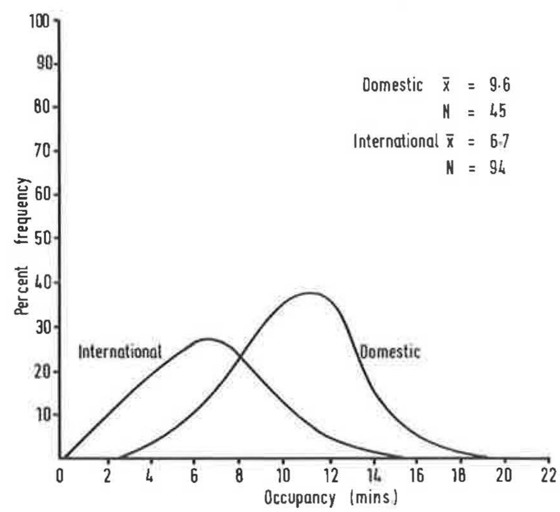


Figure 3. Arrival time at check-in before STD for intercontinental and European scheduled passengers.

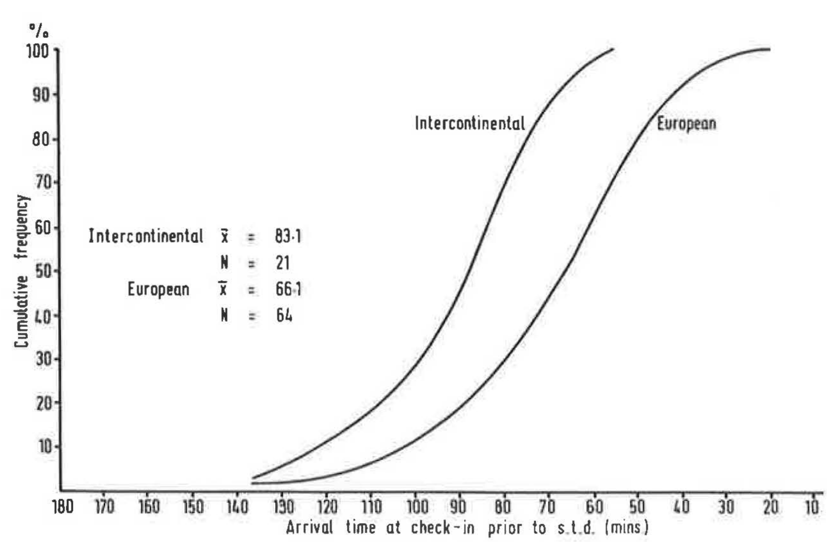


Figure 4. Arrival time at check-in before STD for international charter and scheduled passengers.

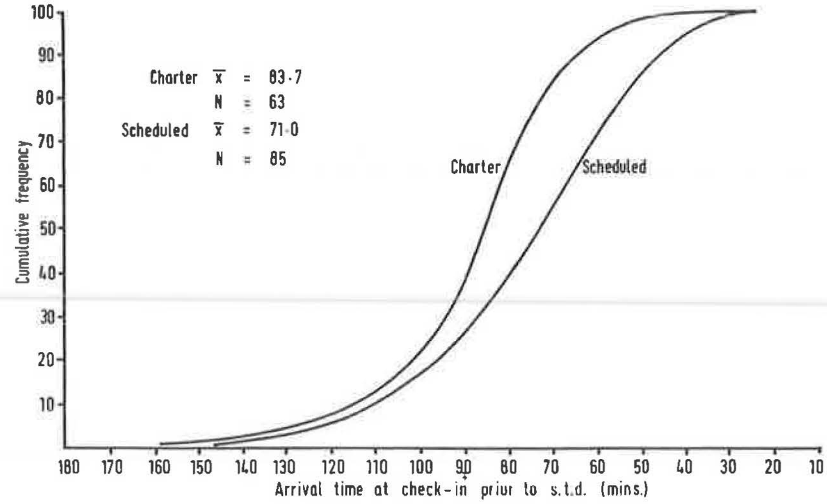


Table 2. Average time spent by enplaning passengers in terminal facilities.

Type of Flight	Check-In						Passport Control						Departure Lounge		Circulation and Holding Areas		Total Minutes
	Waiting		Being Served		Total		Waiting		Being Served		Total						
	Minutes	%	Minutes	%	Minutes	%	Minutes	%	Minutes	%	Minutes	%	Minutes	%	Minutes	%	
International scheduled	2.1	4	3.3	7	5.4	11	0.6	1	0.2	1	0.8	2	23.9	49	18.3	39	48.4
International charter	7.6	12	1.3	2	8.9	14	0.6	1	0.2	1	0.8	2	19.2	31	32.8	53	61.7
Domestic scheduled	2.1	9	3.3	4	5.4	22									19.3	75	24.7

Table 3. Average time spent by deplaning passengers in terminal facilities.

Type of Flight	Immigration Control						Baggage Reclaim		Customs		Circulation and Holding Areas		Total Minutes
	Waiting		Being Served		Total								
	Minutes	%	Minutes	%	Minutes	%	Minutes	%	Minutes	%	Minutes	%	
International scheduled	1.2	18	0.3	5	1.5	23	2.7	42	1.0	15	1.3	20	6.5
International charter	1.0	10	0.1	1	1.1	11	5.0	52	1.3	14	2.2	23	9.6
Domestic scheduled							5.5	57			4.1	43	9.6

Figure 5. Poisson distribution fitted to the observed arrival distribution of scheduled passengers at check-in.

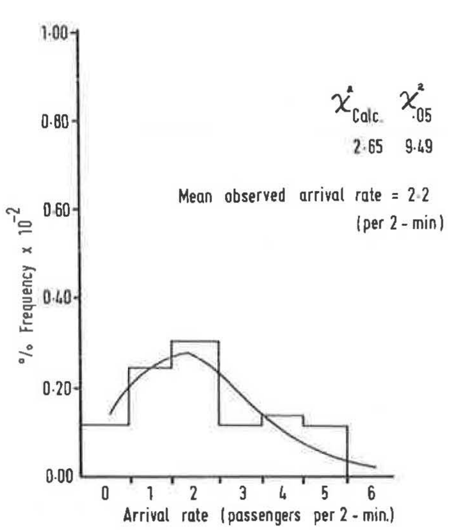
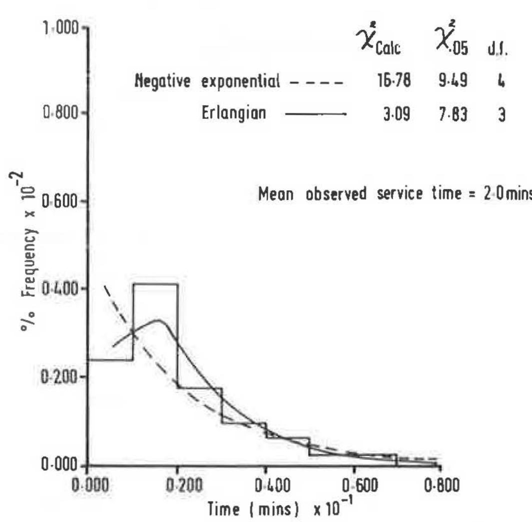


Figure 6. Erlang (a = 2) and negative exponential distributions fitted to the observed service time distribution of international passengers at check-in.



Poisson input or arrivals process M, a negative exponential service distribution M, an appropriate number of servers C, and a universal first-come, first-served queuing discipline FCFS. The aim of such a distributional characterization is to encapsulate the essential stochastic nature of passenger behavior by measuring not only the average activity but also the variation about that average.

There are, however, other good analytical reasons for these modeling assumptions. From the work of Burke (11) and Reich (12), we know that, under certain capacity assumptions, the steady state output of a queuing system with a Poisson input rate and exponential service times will be Poisson at the same rate. Thus, if we assume that the effect of the spatial separation of processing centers on queuing times in a serial process is negligible, then the initial Poisson process is propagated (13). Thus it follows that averages for the serial process are simply the sum of the "averages" of its centers. Clearly this principle has direct application to the network of 4 serial processes in Figure 7. A similar argument can be used for the summation of individual center waiting time distributions. From the work of Nelson (14), the order of the centers in a serial process can be transposed without affecting the resulting service and waiting time distributions. Thus the network shown in Figure 7 can be transformed to the network shown in Figure 8. The average queuing time for the network can be shown to be equal to the weighted contributions from the centers making up each route. That is,

$$\overline{WQ}_{1234567} = pr \times \sum_{1,4,7,2,5} \overline{WQ}_j + ps \times \sum_{1,4,7,2,6} \overline{WQ}_j + qr \times \sum_{1,4,7,3,5} WQ_j + qs \times \sum_{1,4,7,3,6} \overline{WQ}_j \quad (1)$$

where

$\overline{WQ}_{1234567}$ = average queuing time in the network,
p, q, r, and s = passenger split-flow proportions as shown in Figures 7 and 8, and
WQ_j = average queuing time at center j in the network.

Similarly, with an FCFS queuing discipline, the network queuing time distribution (that is, the probability of waiting in the queue longer than τ) is given by

$$\text{Prob (delay} > \tau)_{1234567} = pr \times \text{prob (delay} > \tau)_{14725} + ps \times \text{prob (delay} > \tau)_{14726} + qr \times \text{prob (delay} > \tau)_{14735} + qs \times \text{prob (delay} > \tau)_{14736} \quad (2)$$

A final problem is related to the modeling of baggage reclaim. This facility combines 2 inputs, passenger and baggage flows, to provide 1 output. This problem was overcome by thinking of the time passengers wait for their baggage as their service; this can be done by using in Kendall's notation an $M/M/\infty$: FCFS infinite channel queuing model. Here the number of servers is always equal to the number of passengers because passengers serve themselves.

The problems associated with the enplaning flow are similar to those of the deplaning flow and were solved by using similar devices. Table 6 gives a summary of the models used.

Model Validation

It must be recognized that the use of analytical queuing theory represents an approximation by obtaining operational solutions with models that deductively are often inaccurate but are rapid and simple to use. Thus, when testing the assumptions underlying such models, the planner need not be too critical in his or her expectations.

The completed validation studies (7, 8) have shown that the assumptions of Poisson arrival and negative exponential service times are reasonable. Figures 5 and 6 show the sort of agreement achieved between the observed and theoretical distributions. Although the theoretical distributions do not fit the measured data exactly, they do not differ from them sufficiently to warrant the use of a more complex modeling procedure. A possible extension to the queuing models that retains a fair degree of computational simplicity is the use of erlang distributions to represent passenger service times. Such distributions fit the skewed empirical distribution more exactly (Figure 6), but their use destroys the linking theme of the queuing system model. Thus they are only recommended as an adjunct to the modeling process, if planning emphasis must be switched from an overall view to the design of individual facilities.

DESIGN IMPLICATIONS OF PASSENGER BEHAVIOR

It is evident that the information elicited in the survey of passenger behavior has important implications for the planning and design of terminals. Some of these implications have been dealt with in detail elsewhere (7, 8, 9); in this section, 2 particular points have been selected to demonstrate, it is hoped, the relevance of the research approach to airport planning. The first point relates to ticketing requirements at terminals; the second relates to the need for a more flexible terminal design based on a sound knowledge of passenger behavior.

Design Solutions to Ticketing Congestion at Terminals

The problems related to ticketing and checking in passengers at the terminal have received a considerable amount of attention from airport planners in the last decade in both Europe and the United States. The reason for this attention is the recognition of check-in as perhaps the major point of congestion in the terminal. The survey at Manchester has shown that a large number of passengers arrive at the terminal well in advance of their LRT, which means that, in the departures process, there is considerable competition between passengers on different flights for use of the various facilities. Those passengers who arrive at the terminal particularly early are typically holiday passengers on charter flights; most of them are using the terminal for the first time and are probably apprehensive of the processing system at the terminal. There has also probably been some uncertainty in their access mode. Whatever the reason is, the result is the same—long queues, excessive waiting times, and congestion.

Currently, a number of solutions are being tried at airports in the United States and Europe:

1. Adaptations of conventional check-in systems at central terminals,
2. Gate check-in,
3. Satellite terminals,
4. Automation in check-in and ticketing, and
5. Car park check-in.

Perhaps the point that was really highlighted at Manchester was that different passenger groups (split in

Table 4. Terminal users survey.

User Category	September 11, 1974, 7:40 a.m. to 12:45 p.m. Number	%	September 12, 1974, 2:30 p.m. to 5:00 p.m. Number	%	Both Days Combined Number	%
Enplaning passengers	62	54	60	61	122	59
Deplaning passengers	3	3	1	1	4	2
Senders	11	10	14	12	25	11
Greeters	7	6	20	18	27	12
Temporary staff	6	6	3	3	9	4
Permanent staff	7	6	1	1	8	4
Terminal facility users	10	10	5	4	15	7
Spectators	3	3	0	—	3	1
Total	109		104		213	

Figure 7. Double split network of queuing processes.

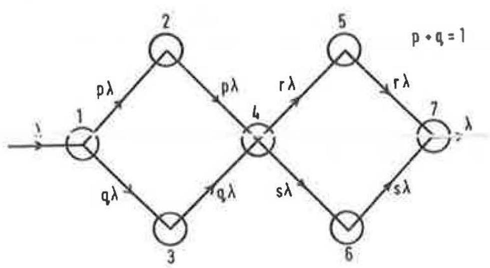


Figure 8. Rearranged network.

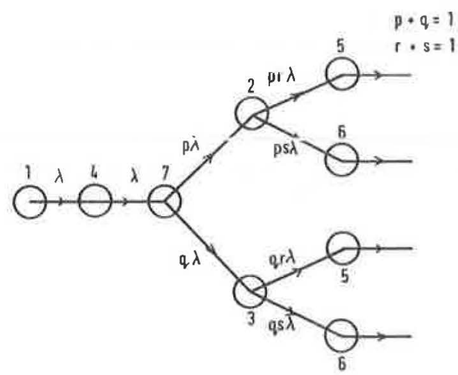


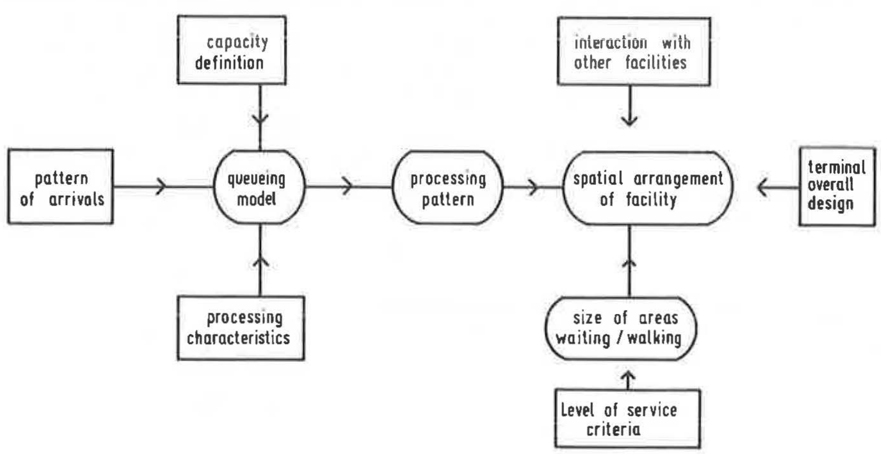
Table 5. Network of models describing arriving passenger processing system.

Node	Description	Model to be Used
1	Disembarkation	Dummy node
2	Immigration, U.K.	M/M/1
3	Immigration, non-U.K.	M/M/C
4	Baggage reclaim	M/M/∞
5	Customs, red	M/M/C
6	Customs, green	M/M/C or M/M/∞
7	Leaving terminal	Dummy node

Table 6. Network of models describing departing passenger processing system.

Node	Description	Model to be Used
1	Entering terminal	Dummy node
2	Check-in	M/M/C
3	Passport control	M/M/C
4	Departure lounge	M/M/∞
5	Embarkation	M/M/1

Figure 9. Individual facility design process.



terms of either journey purpose or type of flight) exhibit different behaviors and consequently have different requirements. For example, the business passenger who has considerable flying experience will probably time his or her check-in for the last possible minute. The inexperienced charter passenger, on the other hand, might regard the time in the terminal as part of the holiday and plan to shop or eat before flying. This difference in behavioral requirements is reflected in travel agent practice; when the charter passenger books his or her holiday, for example, the agent will recommend that he or she arrive at the airport well in advance of the airline-determined LRT. The important implication is that a mixed strategy would seem appropriate for the type of airport investigated in this research; perhaps gate check-in could be available for the business passenger and conventional check-in could be available for charter passengers.

Flexibility in Terminal Design

It would appear to be a mistake to employ constraining technological solutions to problems of passenger flow when experience has shown that flexibility and adaptability make for economic and comfortable terminals (3). A feature of modern terminal designs is that the aircraft has assumed primacy in the terminal layout and particular importance is attached to the terminal-apron interface. To achieve this, the landside access system is funneled either above or below ground and sophisticated people movers are used between the main terminal and the gate positions. In the long term, such arrangements are likely to suffer from the effects of inflexible building design, which is typical of older terminals. In some cases the problems associated with such terminal designs are already apparent. Satellite lounges, for example, are devoid of the usual facilities associated with passenger waiting areas. Thus they are inconvenient and particularly unappreciated when there are aircraft delays. In other cases, those passengers whose patterns of terminal use differ from the norm imposed by the design can suffer considerable inconvenience; this is especially true where passenger movement systems have been designed for 1-way operation.

CONCLUSIONS: DEVELOPMENT OF TERMINAL DESIGN METHODOLOGY

A recent consumer survey (15) of the quality of service at British airports has stated:

> This summer, 20 million passengers will struggle through British airports for reasons of business or holiday pleasure. All of them face up to two hours waiting for the plane to take off and for baggage to arrive after landing. Some will face much longer delays.

In general, the problems have resulted from the large increase in the demand for air travel. Specifically they have resulted from the inadequate provision for peak passenger flows (1). These peak flows have resulted primarily from the massive developments in holiday charter flights, although an important contributory factor has been the introduction of larger aircraft. Various design solutions have been proposed, but an examination of recent airport terminal procedures (1, 2, 4) reveals that there is an apparent emphasis on the problems of handling aircraft at the expense of passenger requirements. Within the terminal itself there is a tendency to rely on technological innovations, such as people movers, baggage carousels, and computer ticketing, to solve passenger flow problems that do not appear to be completely understood. The main deficiency in current terminal design methodology appears to be a lack of knowledge regarding passenger behavior and requirements in terminals, combined with a lack of an adequate planning model of that behavior.

An important part of the research program involved a number of more general aims that were pursued concurrently with the practical studies of passenger behavior in airport terminals. A primary aim was the identification of a design procedure and rationale capable of explicitly catering to the requirements of terminal users and facility operators. The basis and rationale of this design approach, namely the airport survey and the calibration of an overall system flow model, have already been discussed. The next stage was the development of an overall procedure that could serve as a design framework capable of incorporating design criteria and methods that will retain for the air mode its reputation for premium level of service.

Figure 9 shows the conceptualized design procedure. It is based upon the rational interaction of elements within the complex organizational and planning structure of airports. The aim of this particular conceptualization is the production of a functional design for a facility; this is achieved primarily by the explicit examination of the behavioral implications of each stage in the design process.

The flow chart in Figure 9 is composed of 2 types of elements. Inputs are shown as rectangular boxes, and the processes for producing the facility design are shown as oval boxes. The prime inputs are the pattern of arrivals, capacity definition, and processing characteristics, which together constitute the queuing or waiting characterization. The input described as level-of-service criteria is associated with the attitudes and the requirements of passengers (15, 16) and involves both subjective and objective measures of passenger response to the terminal processing system. The other 2 inputs are primarily interactive; that is, they show the interrelationship with the function of other facilities and the implications and constraints imposed by a consideration of the overall terminal design philosophy (3, 6). The prime division of terminal design concepts relates to the use of modular or central philosophies, but other considerations would be the relationship between domestic and international passenger flows or the security provisions in the terminal (1, 3).

The balanced design of airport terminals is thus necessarily interactive and also interdisciplinary. The often competing requirements of passenger comfort, operator convenience, and, of course, cost must be considered in relation to the particular problems of the airport user, the airlines, and the operator. The design philosophy described in this paper has, itself, derived from an interdisciplinary research program involving the skills and philosophies of industrial design, ergonomics, operations research, and transport planning; this is described in detail elsewhere (1, 9). It is sufficient to note here that overall design procedures have been evolved that emphasize flexibility and level of service to passengers in the provision of facilities, space, and structures at both the airport planning and terminal design phase.

ACKNOWLEDGMENTS

We wish to express our appreciation of the practical help and interest shown by the airport authorities at Manchester, where the passenger surveys were completed. The research program was supported by the Science Research Council.

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Time-Stamping: A New Way to Survey Pedestrian Traffic in Airport Terminals

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The author has developed a new method for collecting pedestrian traffic flow data in airport terminals. The method was developed for the Airport Facilities Branch of the Canada Ministry of Transport. The problem was to find a better way of conducting terminals surveys. Traditional interview surveys and time and motion studies yield only fragmented bits of information. A total systems approach was required. The method consists of handing a card to each person as he or she enters the terminal either at the gate or at the door. The person is asked to carry the card during his or her stay in the terminal. At various check points the card is time-stamped. When the person leaves the terminal, the card is collected. The result is a complete trace of his or her movements in the terminal. A pilot study to test this technique was conducted at the Winnipeg International Airport on August 1 and 2, 1975. The survey was successful: 10 055 cards were carried successfully through the terminal for 2 days, 96 cards were discarded and recovered, and about 150 cards were unaccounted for, which is a 98 percent return. The result is a complete travel pattern for each person. The data are so comprehensive that they will yield volumes, flow rates, occupancies, queuing length, service times, delays, levels of service, velocities, densities, flow patterns, conflicts, processing line balance, space use, and total travel effort.

In the summer of 1974, the Airport Facilities Branch of the Canada Ministry of Transport initiated a program to conduct effectiveness evaluation studies of major airport terminal buildings in Canada. I was retained by the Canada Ministry of Transport to develop the overall methodology. Part of this methodology was directed at the pedestrian traffic flow subsystem of the terminal. The terms of reference for the pedestrian flow system specified that the methodology

identify, assess and quantify:

1. Problem areas in major terminal buildings;
2. The operational capacity, level of service, and traffic pattern of major terminal buildings;
3. Relationship between traffic volumes, capacities, and net costs;
4. Data for a comparative analysis of terminal concepts leading to policies and standards;
5. A data base for the calibration of simulation models.

Publication of this paper sponsored by Committee on Pedestrians.

Furthermore, 1 constraint was imposed. The new methodology was not to use questionnaires of any kind to collect data. Traditional surveying techniques, such as questionnaires and time and motion studies, yield only fragmented pieces of information. A total systems approach was required.

The purpose of this paper is to report on a new type of terminal survey—time-stamping—that was developed to meet the objectives and constraints set out in the terms of reference. Essentially the technique involves "tagging" each pedestrian and tracing his or her movements through the terminal. The method was successfully tested in a pilot study at the Winnipeg International Airport on August 1 and 2, 1975.

PEDESTRIAN FLOW SYSTEM

The pedestrian flow system can be viewed at 3 levels of detail: small, intermediate, and large.

Components (Small Level)

At the small level, there are 3 basic components: reservoirs, processors, and links. Reservoirs are terminal elements where people are collected and detained for a period of time. A reservoir is a static component of the terminal, generally a waiting area with either ordered or bulk queuing. Examples of reservoirs are public waiting areas, washrooms, coffee shops, restaurants, bars, bookstores, and newsstands.

Processors are special types of reservoirs that house mandatory activities related to processing passengers for their flights. A processor consists of a service facility plus queuing space. Examples of processors are curbsides, ticket counters, check-in counters, holding rooms, aircraft, customs inspection, and baggage-claim areas. Examples of service facilities are desks, carousels, and magnetometers.

A link is a terminal component that connects reservoirs and processors to other reservoirs and processors. It is a transportation facility where people move or are moved. It is a dynamic component of the terminal system. Examples of links are corridors, aisles, moving sidewalks, loading bridges, mobile lounges, stairs, escalators, and elevators.

Processing Lines (Intermediate Level)

A processing line is a linear sequence of reservoirs, processors, and links associated with the enplaning or deplaning function of each flight. Processing lines can be classified by flight sector (e.g., domestic, transborder, and international).

Flow System (Large Level)

The pedestrian flow system is made up of a set of interconnected processing lines. Grouping the processing lines into 2 major subsystems—enplaning and deplaning—is convenient. The enplaning subsystem handles originating and outbound connecting flows. Enplaning activities normally take place on the departure floor of the terminal building. The deplaning subsystem handles terminating and inbound connecting flows. Deplaning activities normally take place on the arrivals floor of the terminal.

REQUIRED DATA

The minimum data required for analysis of the reservoirs, processors, links, processing lines, and flow system are given in the following outline:

1. Reservoirs
   a. Geometry (shape and area)
   b. Loads (number of people)
   c. Waiting time (min)
   d. Population mix (passengers, visitors, greeters, well-wishers)
2. Processors
   a. Geometry (shape)
   b. Mode of operation (first in, first out)
   c. Processing time (min)
   d. Volumes (persons/min)
   e. Loads (number of people)
3. Links
   a. Geometry (shape and area)
   b. Volumes (persons/min/m)
   c. Speeds (feet/min)
   d. Densities (persons/m^2)
4. Processing Lines
   a. Sequence of reservoirs, processors, and links (geometric configuration)
   b. Processing times (min)
   c. Volumes (passengers/h)
   d. Flights (flight numbers)
5. Flow System
   a. Layout of terminal building (walking distance matrix)
   b. Origin-destination trip table (flow matrix)
   c. Desired line pattern

TERMINAL SURVEY TECHNIQUES

It was clear from the nature of the data required that some kind of survey had to be conducted in the terminal building. In the past few years, numerous surveys of various types have been conducted in air terminals around the world. The purpose of these surveys has been as diverse as their techniques. This section offers a brief overview of various pedestrian survey techniques that have been used in airport terminals.

Manual Observation Techniques

Manual observation relies on survey personnel to make head counts and time readings either manually or with mechanical devices. The method is best suited for analysis of components. It has been widely used in airport planning. Recent examples are the surveys at the Ottawa International Airport (1), at the Toronto International Airport (2), and at Washington National and Dulles International Airports (3).

Photographic Techniques

The photographic technique is essentially a deferred observation technique. The activity at a component is either filmed by movie camera or taped by television camera for analysis later at the office. A method using videotape analysis has been used by the Ground Transportation Section of the Airports Facilities Branch of the Canada Ministry of Transport to evaluate the road access at Dorval, Toronto, and Vancouver Airports. I have done experimental work using time-lapse photography and videotaping for the Vancouver and Ottawa terminals. It appears to be a valuable technique as a supplement to or a check on other techniques.

Mail-Back Questionnaires

The third type of data collection technique is the self-administered mail-back questionnaire. Respondents are given a questionnaire to be filled out and mailed back to the survey office. This technique is suitable when respondents have little time or will not be able to answer certain questions until they have left the airport. The success of this technique is highly dependent on the use of a simple, readily understandable questionnaire (4). This technique has been used by the Toronto Area Airports Project Team at Toronto International Airport (Malton) (5).

Collected Questionnaires

In the fourth technique, self-administered questionnaires are handed to the respondents to be completed by themselves. The questionnaires are collected after some reasonable time period by survey personnel. For this technique to be applied successfully, the respondents must be captive and not be pressed for time. The questionnaire should be simple, in the sense that questions can be easily understood by respondents. It is also important that the respondent know the answers to questions rather than have to guess or estimate in responding. For example, inbound air passengers may not know which of the available ground services they will use, how many persons are going to meet them at the airport, or how long it will take to reach their ultimate destinations (4).

Interviewing Technique

In the personal interviewing technique, surveyors ask questions directly of respondents and record the answers on prepared forms. The use of this technique requires that the respondent not be pressed for time or that only a few questions be asked. Personal interviewing is most suitable when certain aspects of the questionnaire might not be fully understood by respondents or when the line of questioning is dependent on the response to specific questions. This survey technique is often used to determine characteristics of the terminal population. Personal interviewing is generally employed only when activities to be surveyed are concentrated at a small number of points, activity levels are low, and the desired sample size is small (4). This technique has been widely used by the Canada Ministry of Transport. For example, it was used by the Toronto Area Airports Project team (5) and by the New Montreal International Airport Project Office at Dorval (6).

Tailing Technique

The tailing technique involves following a small sample of people as they travel through the terminal. The sample can be selected by using a random number table. The surveyor fills in a questionnaire as he or she follows the traveler around. Thus, in addition to recording the traveler's travel pattern, the surveyor is also able to note certain other characteristics such as sex of the traveler, party size, number of bags carried, flight number, physical handicaps, and queuing behavior. This technique was recently used in Britain in a survey of Heathrow Airport (7).

Tag Technique

The tag technique involves "tagging" the traveler and tracing his or her movements through the terminal. The tagging can be accomplished by having the pedestrian carry a card and having the time entered at various checkpoints in the terminal building. The card is collected when the pedestrian leaves the terminal either by gate or by door. A limited survey of this kind was conducted in West Germany by Baron and Henning (8).

NEW TIME-STAMPING SURVEY TECHNIQUE

An analysis of the advantages and disadvantages of the various survey techniques in light of the required data showed the tag technique to be the most suitable method. In the time-stamping survey technique each pedestrian—passenger and visitor alike—is handed a card when he or she enters the terminal either at the gate or at the doors at the curb. The pedestrian is asked to have the card time-stamped at various checkpoints in the terminal. The time stamps are coded by checkpoint. The card is collected from the pedestrian when he or she leaves the terminal either by gate or by door. When aggregated over a day, the result is a complete travel pattern of pedestrians.

Advantages

The technique yields a maximum of quantitative data. A complete travel pattern (complete origin-destination table) of all pedestrians can be obtained. The method permits analysis at 3 levels of detail: (a) component level, (b) subsystem level, and (c) total system level. The resulting data are versatile, and useful for evaluation, simulation, and standards. The technique minimizes passenger contacts; no questions are asked. A 100 percent sample/day is theoretically possible, and excellent results at a low cost per sample are yielded. The method is flexible; it can be used in terminals of any size. The survey can be done quickly (within 2 or 3 days). Some pedestrian characteristics (e.g., what the sex of the person is, whether the person is a visitor or a passenger, and whether the person has baggage) can be determined.

Disadvantages

The survey can be expensive in terms of total cost because of the large number of surveyors and equipment required in a major terminal building. The placement of a large number of surveyors in a terminal may be a hindrance to normal traffic flow. The method produces a minimum of qualitative data.

Checkpoints

A checkpoint is an entrance and exit at a reservoir, processor, or link. Here the cards are time-stamped, thereby recording the time in and the time out for each person. Checkpoints are identified, coded, and recorded on the floor plans of the terminal building. The following is a list of typical facilities where checkpoints should be located: doors; stairs, escalators, and elevators; general waiting areas; special waiting areas; ticket counters; check-in counters; baggage claim areas; U.S. preclearance areas; security clearance areas; holding rooms; gate positions; immigration check areas; customs check areas; and amenity areas such as restaurants, coffee shops, bars, rent-a-car counters, gift shops, duty-free shops, flight insurance counters, post offices, banks, barbershops, and VIP lounges.

Equipment

The success of the time-stamp technique depends on 2 pieces of equipment, a time stamp and a card.

Time Stamp

Each surveyor must have a time stamp. These stamps should be lightweight, portable, and compact. The stamps should show the time of day to the nearest minute, a.m. and p.m., and the code for the checkpoint. An ink pad should be available and fastened to a clip board. Figure 1 shows a typical time stamp.

Card

Each person entering the terminal either at the door or at the gate is handed a card and instructed to carry the card wherever he or she travels in the terminal. The card is time-stamped by a surveyor at each checkpoint. It is collected when the pedestrian leaves the terminal building. The card should be of attractive design, look "official," and be of convenient size (e.g., the size of an airline ticket). Figure 1 also shows a typical card. (The message on the card is printed in French on the reverse side.)

WINNIPEG TERMINAL PILOT STUDY

Need for Pilot Study

The proposed time-stamping survey was new and untried. To my knowledge, no such survey had ever been done before in Canada or the United States; therefore, a pilot study was required to test the technique. The objectives of the pilot study were

1. To test public acceptance of the new technique (Would people carry the cards through the terminal? What would their reaction be?),
2. To test the surveyor's acceptance of the technique (Would survey personnel be able to cope with large volumes of traffic? Would they be comfortable?),
3. To test the equipment of the survey (Would the time stamps work? Were the cards designed correctly?),
4. To test the logistics of implementing the survey (Can the survey be started and stopped with ease? Is the work schedule adequate?),
5. To test the impact of the new survey technique on the terminal's operation (Will it alter flow patterns? Will it delay passengers? Will it impede airline operations?), and

6. To provide useful data to a planning team.

Winnipeg—An Ideal Site

An appropriate terminal had to be found in which to conduct the pilot study. The terminal had to be relatively small to keep the cost down and to keep the survey under control. It also had to have a representative sample of air traffic (domestic, transborder, and international). The terminal at the Winnipeg International Airport fitted these selection criteria well. Furthermore, it offered an additional benefit. Traditional surveys were planned for the terminal for 2 weeks beginning July 21, 1975. These surveys were to be conducted by the Winnipeg Area Airports System Study team (WAASS) as the first phase of a 2-year study to formulate a plan of long-range development for airports in the Winnipeg area. Here was a unique opportunity to conduct the pilot study. An agreement was reached with the WAASS team by which they would add 2 days to their normal survey schedule to accommodate the pilot study. The WAASS team also agreed to provide the necessary personnel, include the pilot study in their extensive public relations program, and secure cooperation from the various airlines concerned. In return, the Airport Facilities Branch in Ottawa agreed to purchase the time stamps and provide the WAASS team with the results of the survey.

Figure 1. Time stamp.

Terminal Layout

To keep the pilot study within manageable proportions, only the north end of the terminal was surveyed. The Winnipeg terminal is of symmetrical design; the north end is a mirror image of the south end. The south end of the terminal is exclusively for Air Canada, and the north end accommodates all other airlines. This division in effect creates a self-contained miniterminal.

Forty checkpoints were identified and coded in the north end of the terminal. Table 1 gives the codes of the checkpoints, and Figures 2 and 3 show the layout of the north end of the terminal. Openings in the rope barricades dividing the terminal were treated as entrances to and exits from the miniterminal. Thus, if a passenger walked from the CP Air counter to the Air Canada counter, he or she effectively exited the miniterminal and surrendered the time card. If the passenger returned, he or she would be given a new card and would be treated as a new person. Therefore, the cards really represent person trips, rather than persons. Because some of the 40 checkpoints required 2 surveyors, 50 time stamps were required to conduct the pilot study.

Personnel and Equipment

Fifty people were needed to conduct the survey because, as was just mentioned, some of the 40 checkpoints required 2 surveyors. Only 1 shift would be operated per day (11:00 a.m. to 8:00 p.m.) to keep costs down. The surveyors were supplied by a private company in the temporary help and project staffing industry. This company also provided 3 supervisors. Each surveyor was equipped with a time stamp, an ink pad, and a clipboard that was rigged with a harness. The harness was necessary to free the surveyor's hands to accept the card, ink the stamp, and stamp the card. The strange looking outfit had an added advantage in that it made the surveyors clearly identifiable. An examination of the airline schedules for the north end of the terminal suggested that 15 000 cards would be required for the 2 days.

Table 1. Codes of checkpoints in north end of terminal.

Code	Checkpoint	Code	Checkpoint
1	In and out door 1	21	Out Northwest check-in desk
2	In and out door 2	22	In U.S. preclearance facility
3	In and out door 3	23	Out U.S. preclearance facility
4	In and out barrier at south stairs	24	In immigration queue (PIL)
5	Up and down north stairs	25	Out immigration desks (PIL)
6	In and out gate 1A	26	Out baggage claim (customs)
7	In and out barrier at information counter	27	In customs queue (secondary)
8	In and out barrier at cafeteria	28	Out customs hall
9	In and out gate 1	29	In and out waiting area
10	In and out gate 2	30	In and out duty-free store
11	In and out gate 5	31	In security check
12	In baggage claim area	32	Out security check
13	Out baggage claim area	33	In hold room 1 queue
14	In CP Air queue at check-in counter	34	Out hold room 1 desk
15	Out CP Air check-in desk	35	In hold room 2 queue
16	In Transair queue at check-in counter	36	Out hold room 2 desk
17	Out Transair check-in desk	37	In hold room 5 queue
18	In Frontier queue at check-in counter	38	Out hold room 5 desk
19	Out Frontier check-in desk	39	In and out greeter and well-wisher area
20	In Northwest queue at check-in counter	40	Out corridor

Figure 2. Checkpoints in north end of terminal, first floor and basement.

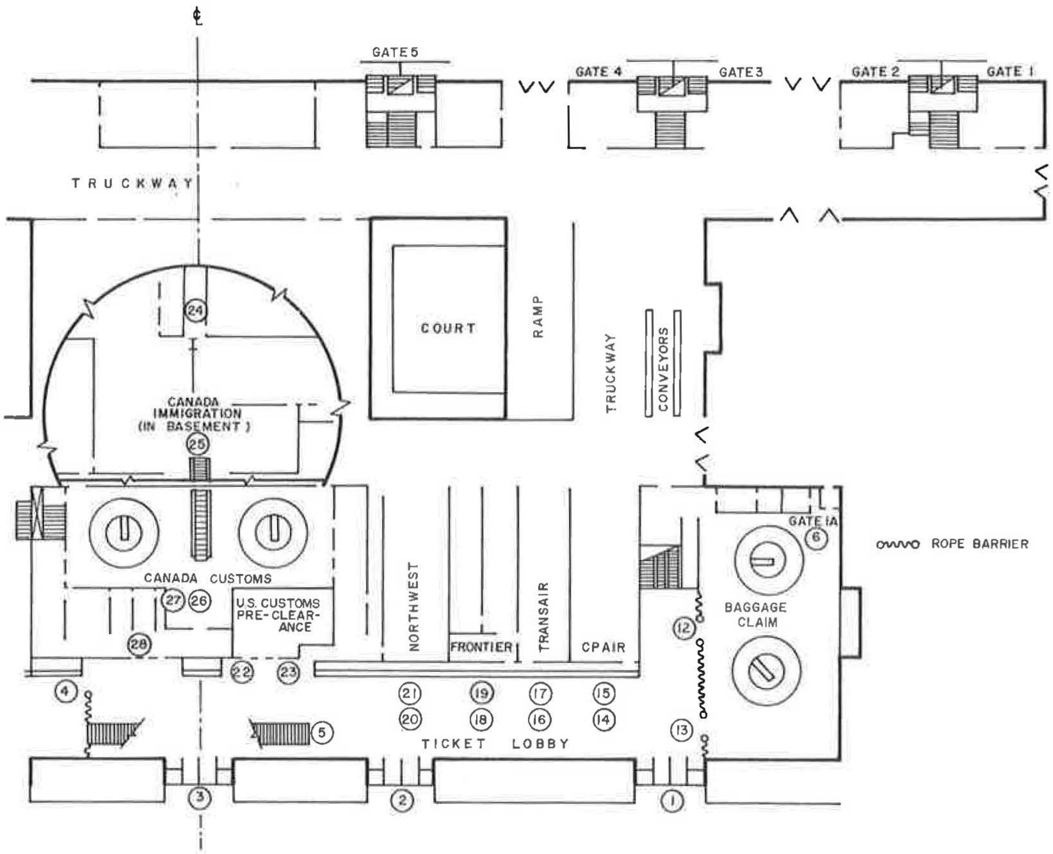

Figure 3. Checkpoints in north end of terminal, second floor.

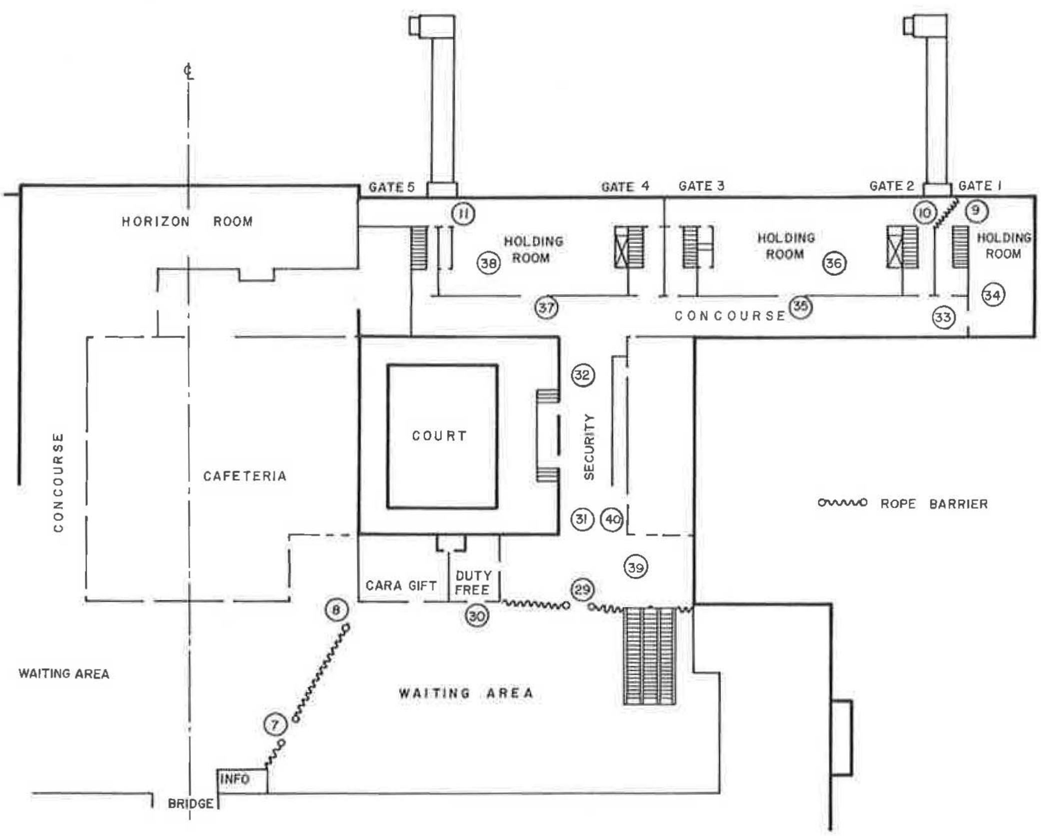

Table 2. Airline schedule during time-stamp survey.

Airline	Arrival Flight Number	Arrival Time	Departure Flight Number	Departure Time
Northwest	505	12:20 p.m.	736	1:10 p.m.
	735	1:17 p.m.	382	2:15 p.m.
	215	3:24 p.m.	474	5:00 p.m.
North Central	571	12:40 p.m.	574	1:15 p.m.
Frontier	94	3:30 p.m.	99	4:10 p.m.
Trans Air	710[a]	12 noon	332[b]	1:05 p.m.
	106	12:10 p.m.	753[a]	1:05 p.m.
	743	12:15 p.m.	738[b]	1:30 p.m.
	726	12:35 p.m.	740[a]	1:30 p.m.
	754[a]	3:45 p.m.	703[b]	2:05 p.m.
	331[b]	4:45 p.m.	731[a]	2:05 p.m.
	704[b]	5:05 p.m.	744[b]	4:40 p.m.
			757[b]	5:45 p.m.
CP Air	72	12:15 p.m.	72	12:35 p.m.
	86	1:25 p.m.	86	1:45 p.m.
	73	3:50 p.m.	73	4:10 p.m.
	385[a]	4:20 p.m.	385[a]	5:30 p.m.
	70	6:05 p.m.	70	6:25 p.m.
	386[b]	6:30 p.m.	386[b]	7:30 p.m.
	87	7:35 p.m.	87	7:55 p.m.

[a]Saturday. [b]Friday.

Sample Size

On Friday, August 1, 1975, the survey ran from 11:30 a.m. to 8:30 p.m. This time span covered 34 scheduled flights and 3 charter flights. On Saturday, August 2, 1975, the survey ran from 11:00 a.m. to 6:30 p.m. During this time span, 30 scheduled flights and 2 charter flights were surveyed. A total of 69 flights of 7 airlines were surveyed. Table 2 gives the airline schedule during the time-stamp survey.

Training

On July 21, 1975, the surveyors were introduced to the new survey technique along with the traditional surveying methods. A review session was held for an hour on the morning of August 1, 1975. Equipment was issued at that time and the surveyors practiced stamping. At 11:30 a.m., the survey personnel moved into their positions in the terminal.

Performing the Survey

The surveyors were sent out in 2 groups. Those who manned the internal checkpoints of the terminal were sent out first so that they would be in position when the public started coming through with cards. Those assigned to cover the entrances and exits were sent in about 10 min after the first group. During the first 2 h, there were some difficulties as the surveyors learned their task. After that, the survey ran very smoothly. Five supervisors equipped with walkie-talkies coordinated the survey. A half hour before closing the survey, the surveyors at the entrances and exits were instructed to collect cards and not hand out any more. This step permitted most pedestrians with cards to leave the terminal and have their cards collected. Lunch breaks were scheduled between 2:00 p.m. and 3:00 p.m., the period that was the least busy. Coffee breaks were taken when feasible.

Videotaping

Nineteen and a half hours of videotape were produced before, during, and after the time-stamping survey for 3 reasons:

1. To have a check on the validity of the data,
2. To record the survey technique, and
3. To permit an analysis of the impact of the survey on terminal operations.

The taping was done by 2 television cameras that were mounted at the same place each day. All major activities were taped including activities at entrance doors, check-in counters, stairways, security checks, hold rooms, and baggage claim areas.

PILOT STUDY RESULTS

Public Acceptance

The survey technique was a tremendous success. In 2 days, 10 055 cards were carried by the public through the terminal. During and after the survey, the terminal was searched for discarded cards; 52 cards were found in the north end of the terminal, and another 44 cards that somehow escaped the surveyors at the barricades were found in the south end of the terminal. About 150 cards were unaccounted for, which means a 98 percent return. From surveyors' notes and recollections and videotape analysis, an estimated 150 people refused to carry cards. Another 300 people were estimated to have been inadvertently missed in the survey. Thus the sample size was 94.4 percent.

Surveyors' Acceptance

In general, the surveyors accepted the technique well. There were some poor starts initially, but these were quickly corrected. A more thorough training program would have eliminated a lot of start-up problems. Some of the surveyors complained of standing, and chairs were provided where feasible. No difficulties were encountered in keeping up with the volumes of traffic. Heavily loaded areas, such as doors and gates, had more than 1 surveyor. In future surveys, survey personnel should be issues airline schedules so that they can prepare themselves for peak periods.

Equipment

The time stamps caused some difficulties. Occasionally, a clock would stop ticking. When that happened the surveyor would record the time by hand until the clock could be started or repaired by a supervisor. Another problem with the clocks was synchronization. Most of the clocks lost 2 to 3 min over a day. This problem was minimized by the supervisors who checked each clock every hour. Another synchronization problem occurred between clockface and stamp imprint. Play in the gears and hands caused some time stamps to be out 2 min. The resulting data are not as precise as was anticipated. A problem with the clarity of the imprint on some cards was also detected, but, as the surveyors gained experience, this difficulty righted itself. Some surveyors found that the size of the grid on the card was too small for the stamp and that the stamping process was messy. The cards themselves appeared to function well. They were the correct size and weight. Not one card was mutilated in any way.

Logistics

No great difficulties were encountered in actually running the survey. The start-up and shut-down procedure worked well. The biggest problem was in scheduling lunch and coffee breaks for 50 surveyors. In future surveys, extra personnel should be available to act as relief when required. The nurse provided by the temporary services company looked after the welfare of the surveyors and appeared to be good for morale.

Impact on Terminal

Except for a couple of isolated incidences, the time-stamping survey appeared to have had little impact on terminal operation. One incident occurred at checkpoint 39 near the top of the escalator (Figure 3). Some 200 passengers of a charter flight came up the escalator en masse. The 2 surveyors at the checkpoint attempted to handle the volume but, because queuing space was very small at the top of the escalator, a dangerous situation developed. The time-stamping was suspended for a few minutes at the checkpoint until the backlog cleared. On Saturday, that checkpoint was eliminated.

During the peak period, a second bottleneck occurred at checkpoint 8 on the second floor (Figure 3). This checkpoint was on the main corridor between the 2 halves of the terminal. The problem was quickly corrected by adding a second surveyor to the checkpoint. No comments were made about the rope barricades that divided the terminal. These barriers did not appear to influence traffic flow patterns very much. An in-depth analysis is planned of the videotapes to see whether pedestrian traffic flow patterns changed. After the survey, I interviewed several agencies to learn whether they had been inconvenienced in any way. Canadian immigration and customs personnel said that the survey had had no impact on their operation. Similarly, agents for Northwest, Transair, and CP Air stated that the survey had not bothered them at all. And the agents at the security check position declared that the survey had had no effect on their operation.

Before the implementation of the pilot study, many people had expressed concern over the impact of so many surveyors in the terminal building. This concern was unfounded. From a vantage point above the first floor, I had difficulty in spotting the surveyors among the hundreds of passengers and friends. They were well dispersed throughout the terminal. Most passengers encountered only 6 to 8 surveyors in their path of travel.

Data Collected

The ultimate test of the success of any survey is the quantity and quality of data collected. The data were processed by computer, and the results were verified by comparing the computer printout with videotape head counts. The results were excellent. From the data, accumulations (loads), average occupancy times, and population mix for reservoirs were extracted; processing times, rates of flow, average waiting times, and queue sizes for processors were obtained; and volumes, speeds, and densities in the links were derived. Processing times and volumes by flight numbers also were produced, and a complete flow matrix and a desire line pattern for the north half of the terminal were generated. This vast amount of data can now be used to analyze the terminal for capacities, levels of service, bottlenecks, and adequacy of layout. A complete description of the results is available elsewhere (9).

Survey Cost

In terms of total cost, the pilot study was fairly expensive primarily because of the initial capital cost of the time stamps and personnel costs. The following tabulation gives an itemization of the costs in dollars:

Item	Cost
50 time stamps	3750
50 surveyors	5000
15 000 cards	300
Total	9050

If we look at the survey in terms of cost per sample, then the time-stamping technique is much cheaper than other surveys. For example, the cost per sample for the time-stamp survey was 90 cents ($9050 ÷ 10 055). The cost per sample for the traditional surveys at Winnipeg International Airport was $1.12 ($45 000 ÷ 40 000). Furthermore, if other time-stamp surveys were to be done, the capital cost of the time stamps would decrease. Also a great deal more quantitative information can be extracted from the time-stamp survey than from other types of surveys.

CONCLUSIONS AND RECOMMENDATIONS

The time-stamp survey technique was a success. We derived 6 conclusions and recommendations.

1. Public acceptance of the time-stamp survey technique was excellent. People cooperated to the fullest in carrying their cards and presenting them for stamping. Therefore, other terminals should be surveyed by using the new technique. Also the survey should be well advertised before the date of the survey.
2. The pilot study demonstrated that ordinary people with little training can do a good job with this type of survey. However, for better and quicker results, a more detailed training program should be instituted. One day should be set aside for training, and practice on the floor should be closely supervised.
3. The equipment worked satisfactorily. But there is room for improvement in the time stamps. The time stamps were not designed for this study. Therefore, a research and development program should be instituted to design a better time stamp. Ideally, the stamp should leave a digital imprint and be self-inking, accurate, nonwinding, and lightweight.
4. No great problems were encountered in the logistics of the survey. Some difficulty was experienced in scheduling lunch, coffee, and rest breaks. Therefore, adequate spare personnel should be available for future surveys.
5. The impact of the survey on the terminal operations appeared negligible. No significant delays were experienced by passengers; no complaints were received; and no detrimental effects were observed.
6. In the light of the magnitude of the data and the large number of ways of manipulating them, a computer should be used to process the data.

ACKNOWLEDGMENTS

Appreciation is accorded to H. J. Bell, Project Manager, Winnipeg Area Airports Systems Study, Winnipeg Ministry of Transport, for his faith in the new technique and for providing the opportunity to test it.

Thanks are also due to G. Y. Sebastyan, Director, Airport Facilities Branch, Ottawa Ministry of Transport, for his cooperation on this project and for his constructive criticisms of this paper.

This project was entirely financed by the Ministry of Transport. Financial support for the production of this paper was derived from a grant from the National Research Council of Canada.

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Abridgment

Analysis of Economic Impact Associated With Development of an Airport-Industrial Complex

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Availability of air transport is a significant factor in the growth and prosperity of communities. The airport has become vital to business and industry by providing air access for companies that must meet the demands of expanding, competitive markets. Communities also benefit from the local expenditures of airport-related businesses for supplies, materials, equipment, and contracting services. These expenditures represent significant direct contributions to the business activity of communities served by the airport and, of course, have a multiplier effect on the communities' economies.

Wages and salaries paid by airport business activities provide the purchase prices of local goods and services while generating tax revenues. Local payrolls alone are not the only measures of the economic benefit of an airport to the community, however. Indirectly, employee expenditures also have a multiplier effect and generate successive waves of additional employment and purchases that are substantial, although more difficult to measure.

The importance of the development of a regional airport to the local and regional economy was recognized by the Louisville and Jefferson County Air Board as it planned for future aviation requirements. As part of the site evaluation process, both the financial and economic aspects of proposed airport sites were analyzed. The methodology used in financial planning was reported in a previous paper (1). This paper describes the development of the economic impact analysis that formed part of the site evaluation process.

DIRECT EMPLOYMENT

Three major sources of direct employment associated with the airport-industrial complex development were identified: airport employment, industrial and commercial employment, and construction employment. Air board staff forecasts of enplanements were used to derive airport employment. The current employment level at Standiford Field (the existing Louisville-Jefferson County airport) is 1.8 employees/1000 enplanements. This relationship was used to derive employment projections from enplanement forecasts.

Planning for the new airport included proposed air board development of approximately 15 320.5 hm^2 (6200 acres) of land covered by the 115 composite noise rating (CNR) noise contour. (A CNR of 115 encompasses an area within which individual reactions to airport noise would likely include repeated, vigorous complaints. Concerted group action might be expected. Typically only commercial, industrial, and certain nonspectator outdoor recreational activities should be placed within this area.) The area would be developed for whatever commercial and industrial uses are compatible with airport operations. Such land uses would benefit from the high accessibility and superior utility service associated with the airport core; at the same time, they would be a buffer between the intense activity of the airport and the surrounding area.

A 1971 study of industrial land requirements of the 94-county area surrounding Louisville projected a need for 30 319.7 hm^2 (12 270 acres) during the 20-year period 1971 to 1990. A 1972 report to the Louisville and Jefferson County Riverport Authority showed a demand within the Louisville Standard Metropolitan Statistical Area (SMSA) (Jefferson County, Kentucky; Floyd and Clark counties, Indiana) of 8623.9 industrial hm^2 (3490 industrial acres) during the period 1970 to 2000. However, neither of these studies attempted to estimate how much additional industrial land requirement would result from construction of a major new airport. Therefore, these projections should serve as lower limits on industrial growth in the region. For this study, a land absorption rate of 247.1 hm^2/year (207.5 industrial hm^2/year and 39.5 commercial hm^2/year) [100 acres/year (84 industrial acres/year and 16 commercial acres/year)] was selected. This was consistent with experience at Bluegrass Park, a local commercial-industrial development and well within the projections of the previous studies. Manufacturing employment densities developed for the Economic Development Administration of the U.S. Department of Commerce in 1966 were used

Publication of this paper sponsored by Committee on Social, Economic, and Environmental Factors of Transportation.

with these land absorption rates to project commercial and industrial development in the airport area. Average employment density for new plants was 2 employees/hm^2 (6 employees/acre) and for commercial operations 3 employees/hm^2 (7 employees/acre).

Airport construction costs were estimated as outlined in the paper mentioned earlier (1). Based on U.S. Department of Commerce figures, an investment cost of $15 000/job station was used for the commercial-industrial development. Construction employment was then estimated to be 25 percent of the total combined airport-commercial-industrial construction investment.

DEVELOPMENT OF AN ECONOMIC BASE EMPLOYMENT MULTIPLIER

Determination of overall economic impact of new industries on a region must account not only for their direct effect but also for their indirect or induced effect. Income received by the new industries will enter the local economy in the form of wages and salaries and purchase of services, materials, and equipment from local firms. Thus these expenditures become income to other local citizens and industries who, in turn, spend a portion of it on the purchase of goods and services in the region. As the process continues, local income increases in a continuing but diminishing chain. Payroll associated with this induced employment, as well as required additional job site investment, generates additional income and sales tax revenue for the region.

The phenomenon of the income and employment change series following initial injection of new employment is known as the multiplier effect. This term covers both direct and indirect effects of new economic activity and is, in this case, expressed in terms of employment. The multiplier for this study was devised by the location-quotient method, which develops a relationship between total employment and export employment within a region. (The location quotient of any area is the ratio of the proportion of employees in industry I in the area to the proportion of employees in industry I in a benchmark economy, such as the state or nation.) The ratio of change in total employment to change in export employment is the economic base employment multiplier; its value is 2.171. Thus total employment in the region will increase by 2.171 times the initial direct employment increase; induced employment will be 1.171 times direct industrial employment. The derivation of this economic base employment multiplier was based on employment data obtained in 31 standard industrial classifications (SICs) for the period 1961 to 1970. To determine total induced employment, we applied this economic base multiplier to the direct airport employment and to the industrial and commercial employment resulting from the development of the airport complex. This yields a somewhat conservative estimate in that construction employment is considered as transient rather than as adding to the economic base.

COMPUTER MODEL

A computerized model (programmed in an interactive time-share mode) was developed to perform the complex calculations involved in determining the economic impact of a new or expanded airport on the region and the state. The economic model determines the impact of alternative projects on investment, employment, payroll, and taxes.

Inputs to Model

The economic impact computer model requires 2 major annualized data inputs (uninflated): construction costs and enplanements. The major control parameters are:

1. Number of years to be analyzed,
2. Year construction begins,
3. Year operation begins,
4. Year land disposal begins,
5. Industrial land absorption rate,
6. Commercial land absorption rate,
7. Inflation rate for construction costs,
8. Inflation rate for wages,
9. Multiplier applied to capital costs, and
10. Multiplier applied to enplanements.

Outputs From Model

By using the inputs just mentioned, the program develops an economic impact summary for years of construction, years of operation, and all years. The outputs are

1. Direct investments (airport, commercial, industrial);
2. Direct payroll (airport, industrial, commercial, construction);
3. Induced expenditures (payroll, investment); and
4. Tax yields (state income, state sales, state tax on investment).

ANALYSIS

For each alternative, the computer model was run under 3 sets of conditions: pessimistic, likely, and optimistic. Total direct wages were determined in accordance with data obtained from the Kentucky Employment Service. The wage rate applied to the induced employment was conservatively estimated to be the average of the industrial and commercial rates, or approximately $9000/year. Total income and sales tax yields were computed from state and federal tax returns. An average family size of 3.2 was used, and the state income tax was based on linear interpolation. A sales tax rate of 5 percent was applied to a quarter of the direct and indirect investment.

LOCAL TAX IMPACT

The final portion of this analysis concerned determining the effect of the airport-industrial development on local tax revenues. To obtain the increase in the residential tax base resulting from such development, the participation ratio method (employment divided by population) was used to derive total population growth anticipated with development. It was assumed that the airport would generate a socioeconomic structure similar to the Louisville SMSA [a participation ratio of 0.39 has been forecast for this SMSA (2)]. Direct and indirect employment totals were obtained from the economic impact computer model; total projected population increases were obtained by applying the participation ratio to the employment data. Within the Jefferson County area the average number of persons per dwelling is 2.96. Applying this with data on the ratio of urban to suburban dwellings to the population projection yielded the number of urban and suburban dwellings projected to be associated with the airport-industrial development. Assessed values were based on existing residential property valuations in the Louisville-Jefferson County area for urban and suburban dwellings.

Industrial and commercial investment (excluding the tax exempt airport) was obtained directly from the computer model. This was added to the projected increase in the residential tax base to obtain the total tax base to be expected from the airport-industrial complex development. Current tax rates were applied to this base to determine total local tax revenues (school plus local services) to be expected from the development. Local tax revenue expected without the complex development was estimated similarly by using population projections developed by the Kentucky Program Development Office. A comparison was then made of tax revenues with and without the airport-industrial complex. This analysis indicated that total local tax revenues per person with the airport development would be 162 percent greater than could be expected without the development and that, by 1995, local educational revenue per pupil would be 105 percent greater than would have been obtained without the development.

These analyses support the contention that both the region and local community benefit economically from development of air carrier facilities.

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Scheduling Analysis Model of Rural Commuter Air Service

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The analysis and evaluation of a regional air transport system for urban areas of 10 000 to 50 000 people and for large metropolitan areas have quantitative and qualitative differences. Airport facilities within an intrastate air system often serve as catalysts of community development. The analysis of alternatives, therefore, is different from conventional major air system evaluation. The objective of this paper is the formation of a scheduling analysis model for air commuter systems in rural regions. The optimal transportation alternative will be selected in light of costs, subsidies, and travel demand. The format of this scheduling analysis model incorporates a Markovian decision theory approach. This analysis technique employs the formulation of the system state space, state transition probabilities, and state reward matrices. The alternatives studied reflect differences in service patterns and scheduling frequency. A test case example involving the Idaho intrastate air transportation system was used.

The objective of the example problem presented in this paper is to develop and demonstrate a scheduling analysis model for an air commuter system for rural regions. Its financial feasibility is related to optimal employment of scheduling alternatives in light of subsidies for commuter systems and to the travel demand characteristics of a sparsely populated rural region (1).

The regional case deals with commuter airports in communities or urbanized areas of 10 000 to 50 000 people oriented to interstate travel. Urban areas of this size have quantitative and qualitative life-style differences from larger metropolitan areas (2), and the airports and their impacts are significant in linking each of the communities as functional places in the rural region (3, 4). The air transportation system often serves as a catalyst for the community in attracting components of a strong economic base (business, industry, and tourism) and provides a basis to connect centers of government and finance with remote or isolated areas, allowing the entire region to operate in an integrated and functional manner.

Publication of this paper sponsored by Special Committee on Air Transport Activities of the Transportation Research Board.

PROBLEM INPUTS

The case study region selected for the example problem is the Idaho rural commuter air transportation system. The current system is shown in Figure 1 (5); a further breakdown of the Idaho air transportation demand areas is shown in Figure 2. This system has been discussed in detail in previous research documents (6).

ANALYSIS APPROACH

The analysis and evaluation of an air transportation system such as that described can be undertaken by a Markovian decision theory approach that involves the formulation of a state space, state transition probabilities, and reward matrices for the system under study. The system can be considered as occupying a specific state when the system is exclusively described by the values of the state variables delineating that state. The state transitions can then be viewed as a change in the value of these variables from one set describing a state to those of another set. In this example, the variable considered was a person trip and the states were the specific origin and destination points within the rural commuter study region. These state transitions can be indexed by time; that is, the system can be considered to make a state change (a new person trip demand) after some time increment t. As a result, the suitability of employing this statistical decision theory for this discrete time process turns on the development of the probabilistic nature of these state transitions. These transition probabilities were developed from current passenger demand volumes.

Associated with the state transitions are rewards that accrue to the system for such transitions. These rewards are a summation of costs and revenues for the service provided that are peculiar to the service and scheduling alternatives considered. The optimal alternative for the long-term system operation is determined by using the policy iteration method. This method employs a 2-step iterative technique: the value-determination operation (calculation of the relative values to the system of occupying any state for each alternative) and the policy improvement routine (selection of the alternative that maximizes the reward to the system for each state).

Figure 1. Existing air service.

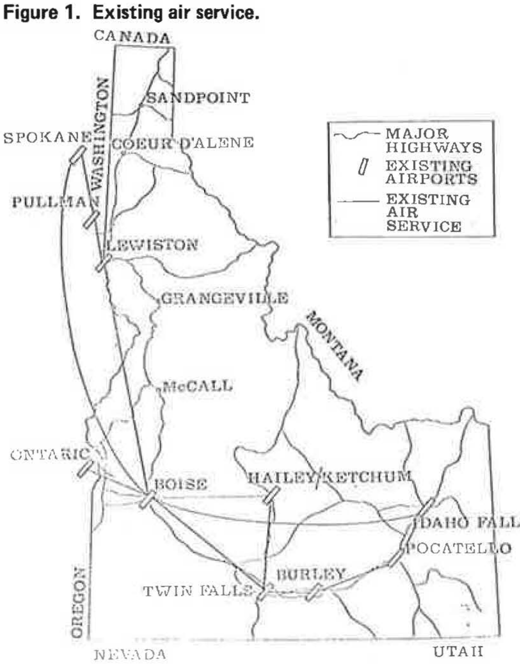

Figure 2. Demand areas.

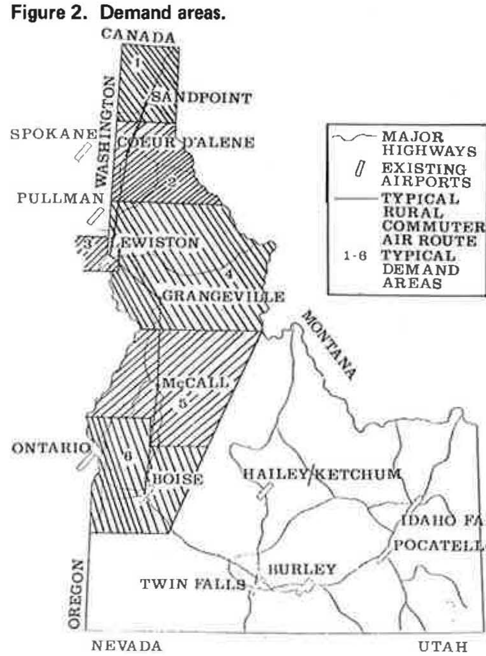

Table 1. Daily 2-way person trips by air mode in the commuter region.

	Person Trips					
Airport	Sandpoint	Coeur D'Alene	Lewiston	Grangeville	McCall	Boise
Sandpoint	—	7	7	15	4	9
Coeur D'Alene	7	—	16	35	7	17
Lewiston	7	16	—	19	10	19
Grangeville	15	35	19	—	17	27
McCall	4	7	10	17	—	48
Boise	9	17	19	27	48	—

Table 2. Remote region air travel demand.

Site	State	Estimated Daily Enplanements	Site	State	Estimated Daily Enplanements
Sandpoint hub	1		Grangeville hub	4	
Bonners Ferry	7	2	Orofino	16	4
Priest River	8	2	Pierce	17	1
Clark Fork	9	0.5	Kamiah	18	1
Coeur D'Alene hub	2		McCall hub	5	
St. Maries	10	2	Riggins	19	0.5
Avery	11	0.5	Council	20	1
Kellogg	12	4	Cambridge	21	0.5
Lewiston hub	3		Cascade	22	1
Potlatch	13	1	Boise hub	6	
Elk River	14	0.5	Caldwell	23	8
Craigmont	15	1	Emmett	24	2
			Weiser	25	3

Figure 3. State space transitions.

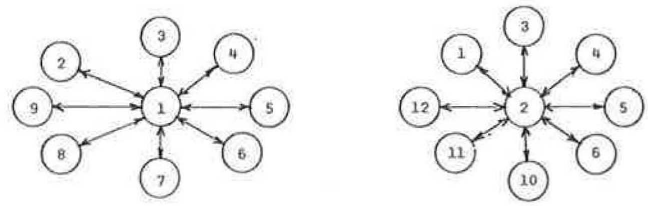

Table 3. Single-step transition probabilities.

State	1	2	3	4	5	6	7	8	9	...
1	0.135	0.118	0.118	0.255	0.068	0.153	0.068	0.068	0.017	...
2	0.074									
3	0.075									
4	0.102									
5	0.056									
6	0.042									
7	1.0									
8	1.0									
9	1.0									
⋮	⋮	...	...	...	...	...	...	...	...	

The basic underlying concepts of Markovian decision theory are detailed by Howard (7, 8).

The decision algorithm developed in this paper makes use of Howard's policy iteration method for the determination of the steady-state probabilities method and yields an optimal scheduling alternative for commuter operation for the current travel demand status of the region. The formulation of the state space, associated transition and steady-state probabilities, alternatives, reward matrices, and iteration results will now be discussed in detail.

FORMATION OF STATE SPACE

The formulation of the system state space involved a review of the north-south travel corridor in Idaho and the classification of air transportation into 2 categories. In the first category, the commuter airports located in Sandpoint, Coeur D'Alene, Lewiston, Grangeville, McCall, and Boise were selected as candidate interstate commuter airports as shown in Figure 2. In the second category selected for analysis, airports were in a remote region and had a sufficient air travel demand and air service in various cities was 32.2 to 96.6 km (20 to 60 miles) from the commuter hubs. These remote region air service airport locations include the cities of Caldwell, Emmett, Weiser, Cambridge, Cascade, Council, Riggins, Kamiah, Pierce, Orofino, Craigmont, Elk River, Potlatch, Saint Maries, Avery, Kellogg, Clark Fork, Priest River, and Bonners Ferry.

The selection criteria were based on the availability of travel demand data for further analysis; the common criterion was that all sites enveloped only 1 competing mode of transportation—a state highway within the study region shown in Figure 2. The travel patterns assumed a 50-50 directional split. Such projected rural commuter air travel is given in Table 1. Table 2 gives the estimated daily enplanements for the remote region service areas. The transition state space (9) can be schematically represented for state 1 as shown in Figure 3. State 1 represents Sandpoint; states 2 through 6 (commuter hubs) refer to Coeur D'Alene, Lewiston, Grangeville, McCall, and Boise respectively. States 7 through 9 represent Bonners Ferry, Priest River, and Clark Fork respectively and constitute the remote region serviced by the airport in Sandpoint. By a similar delineation, a state space sample is developed, numbered, and shown schematically in Figure 3 for state 2 also. This process can be repeated for each state of the rural commuter air service region that represents a terminal location. In effect, the Idaho air transportation system can be modeled as a multiple Markov chain. A traveler in the system may move from a location in a remote region only to the corresponding commuter hub, thus incurring a transition in location state. The sequence of successive state transitions is viewed from the perspective of a passenger within the system selecting a destination j given his or her origin at some state i. The transition probabilities are therefore $P(T_{ij}) = P_{ij}$ where $P(T_{ij})$ = probability of a trip with a destination being state j given the fact that the passenger is now originating in state i. The values of the probabilities P_{ij} reflect the volume of trips from locational state i to locational state j relative to the total number of trips from state i to all states j within the system. Mathematically,

$$P(T_{ij}) = \frac{T_{ij}}{\sum_{j=1}^{m} T_{ij}} \qquad (1)$$

where

$P(T_{ij})$ = probability of a trip from state i to state j,
T_{ij} = total number of trips from state i to state j, and
m = number of destination states from i.

Typical transition probabilities are given in Table 3.

SCHEDULING AND OPERATION ALTERNATIVES

The formulation of the alternatives reflects options in alteration of service patterns and operations given the demand levels of the system (10, 11). Alternative 1 includes 8 round trips/day between Boise and Coeur D'Alene. Four of these trips per day will continue to Sandpoint. In the remote service region, service would be on a demand-responsive basis. Alternative 2 constitutes the same commuter hub service but with a different pattern in the remote service region. Table 4 gives this pattern. Alternative 3 has 8 round-trip flights/day from Boise to Sandpoint and a demand-responsive service to the remote region. Alternative 4 has 8 round-trip flights also but with the scheduled remote region service given in Table 4 for alternative 2. Demand-responsive service here means service for passengers at the requested location within a period of time that fits into the air commuter's overlying basic schedule for hub operation.

DEVELOPMENT OF REWARD MATRICES

The reward matrices for the system state transitions reflect the air fares, direct and indirect operating costs, and potential of available subsidies from any source (12). The air fares were calculated as a function of stage length as shown in Figure 4, and a sample is given in Table 5. Direct operating costs reflect crew pay, purchase cost of aircraft, insurance, fuel, and maintenance costs. Indirect operating costs were calculated as a function of stage length as shown in Figure 5. The total of these costs for the various transportation scheduling alternatives was used, and sample values are given in Tables 6 through 9. These calculations assume an interest rate of 12 percent and project life of 20 years in calculating annual cash flows (13), and a value of time of \$10.00/h in determining time penalties for different service patterns. The r_{ij}^k value is the monetary reward per enplanement accruing to the system operation for the passenger trip from state i to state j while the commuter

Table 4. Pattern of service for remote regions, alternative 2.

Hub	Remote Service Region	Type of Service
1. Sandpoint	7. Bonners Ferry	Morning, evening
	8. Priest River	Morning, evening
	9. Clark Fork	Demand responsive
2. Coeur D'Alene	10. St. Maries	Morning, evening
	11. Avery	Demand responsive
	12. Kellogg	Morning, noon, evening
3. Lewiston	13. Potlatch	Demand responsive
	14. Elk River	Demand responsive
	15. Craigmont	Demand responsive
4. Grangeville	16. Orofino	Morning, noon, evening
	17. Pierce	Morning
	18. Kamiah	Morning
5. McCall	19. Riggins	Demand responsive
	20. Council	Demand responsive
	21. Cambridge	Demand responsive
	22. Cascade	Demand responsive
6. Boise	23. Caldwell	4 flights daily
	24. Emmett	Morning, evening
	25. Weiser	Morning, noon, evening

Figure 4. Air taxi fares, including taxes.

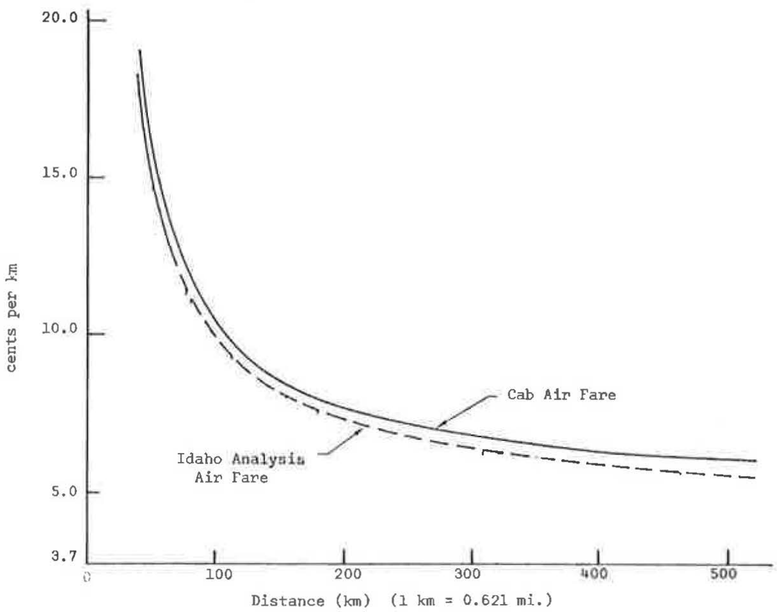

Table 5. Actual 1-way air fares.

State	1	2	3	4	5	6	7	8	9	...
1	0	8.95	17.85	21.00	26.70	34.50	8.35	6.00	6.60	...
2	8.95									⋮
3	17.85									⋮
4	21.00									⋮
5	26.70									⋮
6	34.50									⋮
7	8.35									⋮
8	6.00									⋮
9	6.60									⋮
⋮	⋮	...	...	...	...	...	...	...	...	⋮

Figure 5. Indirect operating costs.

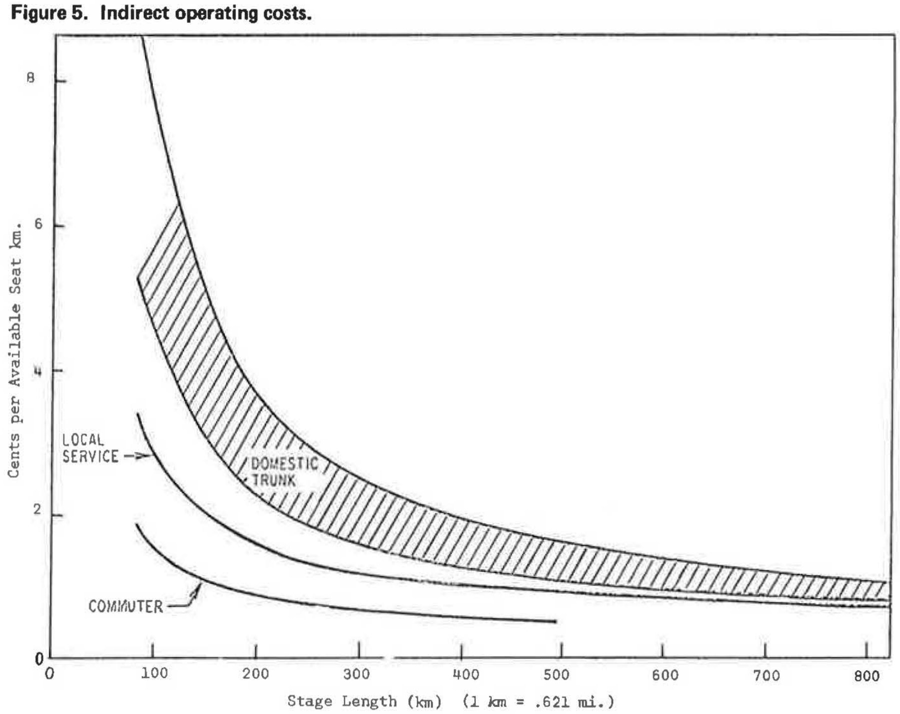

Table 6. Reward matrix, alternative 1.

State	1	2	3	4	5	6	7	8	9	...
1	0	2.22	9.69	11.68	15.95	22.49	-1.94	-2.75	-2.41	...
2	2.37									⋮
3	9.80									⋮
4	11.87									⋮
5	16.37									⋮
6	22.68									⋮
7	-2.14									⋮
8	-2.95									⋮
9	-11.56									⋮
⋮	⋮	...	...	...	...	...	...	...	...	⋮

Table 7. Reward matrix, alternative 2.

State	1	2	3	4	5	6	7	8	9	...
1	0	2.22	9.69	11.68	15.95	22.47	-11.62	-12.55	-12.19	...
2	2.37									⋮
3	9.80									⋮
4	11.87									⋮
5	16.37									⋮
6	22.68									⋮
7	-11.82									⋮
8	-12.75									⋮
9	-21.34									⋮
⋮	⋮	...	...	...	...	...	...	...	...	⋮

Table 8. Reward matrix, alternative 3.

State	1	2	3	4	5	6	7	8	9	...
1	0	-1.54	6.03	8.02	12.28	18.82	-1.94	-2.75	-2.41	...
2	-1.29									⋮
3	6.14									⋮
4	8.20									⋮
5	12.41									⋮
6	19.02									⋮
7	-2.14									⋮
8	-2.95									⋮
9	-11.56									⋮
⋮	⋮	...	...	...	...	...	...	...	...	⋮

Table 9. Reward matrix, alternative 4.

State	1	2	3	4	5	6	7	8	9	...
1	0	-1.54	6.03	8.02	12.28	18.82	-11.62	-12.55	-12.19	...
2	-1.29									⋮
3	6.14									⋮
4	8.20									⋮
5	12.41									⋮
6	19.02									⋮
7	-11.82									⋮
8	-12.75									⋮
9	-21.34									⋮
⋮	⋮	...	...	...	...	...	...	...	...	⋮

Table 10. Steady-state probabilities.

State	π_i	State	π_i	State	π_i
1	0.0688	10	0.0053	18	0.0027
2	0.1594	11	0.0014	19	0.0015
3	0.1196	12	0.0104	20	0.0028
4	0.2104	13	0.0025	21	0.0015
5	0.1228	14	0.0013	22	0.0028
6	0.2259	15	0.0025	23	0.0171
7	0.0047	16	0.0116	24	0.0043
8	0.0047	17	0.0027	25	0.0121
9	0.0012				

Table 11. Long-term system gain with subsidy.

Subsidy Level (¢)	Gain ($/enplanement)			
	Alternative 1	Alternative 2	Alternative 3	Alternative 4
0	-5.0820	-5.5347	-4.8353	-5.2599
10	-3.3296	-3.6262	-2.9756	-3.3814
20	-1.5811	-1.7220	-1.1625	-1.5021
26.3	—	—	0	—
28.0	—	—	—	0
28.6	0	—	—	—
29.0	—	0	—	—

system is employing scheduling alternative k.

ANALYSIS

Markovian decision analysis is an iterative solution process based on an efficient algorithmic investigation of long-term gains to the system under study. The solution is arrived at by the policy iteration method outlined by Howard (7, 8), which yields an optimal alternative for each state of the system. The compendium of these state-specific optimal alternatives is termed the policy vector. In this specific example, however, each state is a location of origin or destination, and a transition from i to j denotes a completed person trip from location i to location j. As such, solution requires the specification of an alternative that maximizes the gain to the system over the long-term demand characteristics of the entire set of locations. This gain g is defined as

$$g^{k*} = \max_{k} \sum_{i=1}^{N} \pi_i(Q_i^k) \quad (2)$$

where π_i is the vector of steady-state probabilities (Table 10). g is computed as demonstrated by Howard. This is the long-term average fraction of total system person trip origins that emanate from location i at any time t. Q_i^k is the expected immediate reward as denoted by Howard (7, 8). This long-term gain g can be operationally defined as the reward to the system operation in dollars per enplanement.

CONCLUSIONS

The values of g for the various alternatives are as follows:

Alternative	Gain	Alternative	Gain
1	-5.0820	3	-4.8353
2	-5.5347	4	-5.2599

In terms of the system description and problem inputs herein, the system obtains a loss over all scheduling alternatives reviewed. In light of this, rather than review and develop other alternatives, the research team decided to investigate the subsidy issue by applying a sensitivity analysis to the losses over a range of subsidies in terms of lump-sum percentage of total capital and operating cost required to be subsidized to yield a break-even point in operations. This subsidy may come from any source such as an additional statewide sales tax, a federal subsidy, or local community support.

As can be seen by the data given in Table 11, alternative 3 requires the minimum subsidy level for operation with 26 percent of its system costs being assignable to subsidy sources. This is the scheduling alternative with 8 round trips/day from Boise to Sandpoint and a demand-responsive service in the remote region.

It should again be noted that the advantage of using a technique such as that described here lies in the capability to perform meaningful sensitivity analysis. In this case, the subsidy required was tested against different alternatives. In another option, the algorithm could have been employed to detail other radically different scheduling or curtailment of service alternatives to test the resulting system gain. The issues of subsidy and curtailment of service and resultant regional impact have certain philosophical overtones and must be dealt with by the corresponding governing and regulating agencies from the federal to the state and local levels. Options that are open to consideration and review include scheduling and service patterns and subsidies.

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