3. Entry of a new airport to replace service provided by an existing airport.

Detailed procedures were formulated for developing the index numbers and for comparing the index numbers of the three cases above.

The resulting entry indexes range from large positive numbers to negative numbers. In general, the larger the positive index is, the more desirable the airport is. An airport with a negative index is undesirable. Exceptions to these rules exist, however. For proper interpretation of test results, these indexes should be fully understood.

The results of the improvement model are improvement indexes ranging from zero to large positive numbers. An absolute significance is not attached to these indexes, but rather a relative significance relates projects to each other. The decision maker makes the final decision of which projects are feasible and which are not.

MODEL RESULTS AND DECISION MAKING

The models result in rankings of airports and improvement projects that reflect the relative desirability to the user and the community of the airports or projects. These rankings, however, must be used in a subjective manner; the final decision of whether an airport should enter the system or a project should be undertaken rests with the decision maker. The rating indexes do not determine which projects are feasible or which airports should enter the system, but provide an indication to the decision maker of how the entities being analyzed relate to one another. These ratings must be viewed in conjunction with the budgets for improvement projects and new airports to arrive at a final plan.

These models represent an incremental, yet substantial, improvement over previous subjective methods of determining aviation system plans. In our models, many factors normally considered subjectively have been quantified and incorporated into theoretically sound and workable cost-effectiveness formulations.

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Dynamic Modeling of Airport Activity

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This paper discusses problems encountered in modeling airport activity and particularly emphasizes forward planning and policy making. It is concerned with the relations among airlines, airports, and users (passengers and freight). Three simple models of activity are indicated, dealing successively with capacity, investment, and pricing. A basic need is creating a workable typology of airports in which attributes other than size may be considered. A second requirement is considering the importance of fluctuations in airport output. We used multivariate analysis of data for the leading British airports in the period 1968 to 1972 to develop a successful typology, which is essentially applicable to other national airport systems. It stresses the differences between scheduled and nonscheduled activity. Correlations among definitive output variables are used as input to principal components and factor analysis to derive the typology. Output is then disaggregated by the use of a corrected moving mean to give seasonal and trend components. These are used for analyzing growth and growth variability and for studying the stability over time of seasonal variations. In addition, we note positive links between nonscheduled activity and output variability. The implications for planning are demonstrated, in particular the close association among nonscheduled activity, variability, and predictability. The variable associations also indicate possible investment scenarios for the airport manager and the airport modeler.

This paper considers a number of problems associated with building a fundamental dynamic system model of airport activity. At first sight, such activities as movements, passenger throughput, and financial turnover might appear to vary solely as a function of airport size. We examine this possibility, which would permit size variables to provide the basic structure of a simple system model, and also examine whether there is a valid alternative methodology for developing an activity-based system model. Moreover, we examine the amount of variability in the activity measures chosen for study, showing that the amounts are of significance for the forward planning of activity levels by airport management.

Although airports vary considerably in their size and scale of operation, they all fill the same operational function—providing a landing place for aircraft where users (both passenger and freight) can interchange to, from, and within the air mode. The basis of building an airport model is really one of synthesizing a typical airport, which is feasible only if airports are found to lie along some common operational continuum. An operational definition would constrain the analyst to consider airport output, making this appear as the continuum of greatest relevance. The question is, Are airports operationally similar, varying only in size? Were this so, other variations in the system might be expected to be of only minor importance. In fact, we discovered that the idea of the continuum is not strictly valid, that airports do appear to have structural differences in activity patterns based on function.

BASIC FORMS OF A DYNAMIC AIRPORT MODEL

In a dynamic model, output should be distinguished from demand. Demand is controlled not only by the internal variables of transport supply, but also by sociopolitical factors that act externally to the airport system. Output, however, can be considered to be determined internally at the interface between flight demand and flight provision. Forecasts of future demand activity are thus concerned with the prediction of internal and external variables, but the actual operation of the system can be considered to be determined by the balance of supply of flights and price.

We considered the development of an autonomous provision model in work not covered by this discussion (1), but the problems of modeling what is often ad hoc behavior have constrained considerations to an endogenous model (2), an approach previously used by Ellison and Stafford (3). The idea of considering the dynamic provision or supply model as a lagged demand model offers a number of procedural advantages. Clearly, parallels exist between the structure of such a model and the actual behavior of airline route managers (1, 4). In particular, emphasis is placed upon information feedback.

Management usually monitors activity by considering costs and revenues, which may be shown as functions of output (5). Therefore, basic models can be conceived that specifically exclude any consideration of external costs or benefits due to noise (6, 7) or to the economic impact of the airport on the surrounding community (8). In the absence of externally imposed constraints, only capacity limitations control output. Similarly, only an increase in capacity can increase the levels of costs and revenues if price changes prove ineffective at doing so. The relationships between pricing and investment can be shown to be crucially important.

Pricing, however, is often related to a particular financial target. A directive seeking to attain a misdirected financial aim may have the effect of precluding pricing at long-run marginal costs and may fail to direct investment into the most necessary areas (9). In other models (1, 5), although financial targets and the like are included, the pricing mechanism is used simply to relate revenue and output in a log-log or even linear manner. The treatment of investment policy was restricted to the specification of alternative investment scenarios (1, 2). This approach differs somewhat from that of other researchers (10, 11, 12, 13) who, in attempting to produce elegant solutions (14), proposed normative solutions. These solutions considered the

Figure 1. Fixed-capacity model.

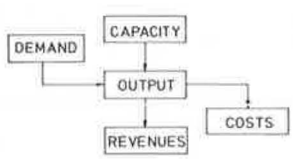


Figure 2. Investment feedback model.

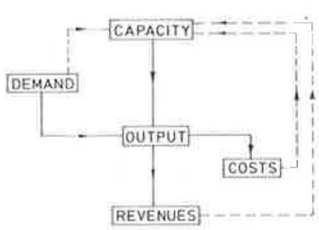
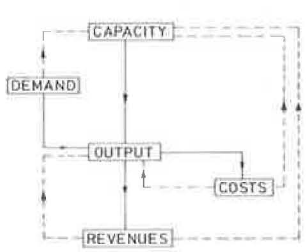


Figure 3. Investment-pricing feedback model.



relations between output and capacity and the balance between costs and revenues. The latter consideration is particularly pertinent; recent research demonstrates that, for United Kingdom airports at least, investment and development programs increase costs considerably (on the average by as much as 70 percent) without necessarily increasing revenues. Many airports operating at a loss have found that their attempts to invest their way out of financial difficulties resulted only in compounding problems.

Figures 1 through 3 show the structure of models in an increasing order of complexity. These are (a) a fixed-capacity model (Figure 1); (b) an investment model in which costs, revenues, and demand give feedback in the form of investment that modifies capacity (Figure 2); and (c) a pricing model, which is similar in structure to the investment model except that costs and revenues give additional feedback and consequent modification to output (Figure 3).

The details of the dynamic model are reported elsewhere (1, 2); the main thrust of this paper is an examination of the output measures of a number of airports to determine whether, in fact, all airports are of a similar nature and can be fitted into a simple dynamic model in which output is considered as a simple variable, easily measured in terms of passengers or movements.

DETERMINING AIRPORT TYPES

Airport demand is not totally exogenous to the airport, but is partially dependent upon the airport system in terms of such parameters as destinations and frequencies (3, 4, 15, 16, 17). A basic question the modeler should ask is whether there are stable relations among these functions and the size of the airport, as measured in terms of its level of output. Significant qualitative differences between the types of airport outputs if related to size would imply discontinuities in the scale of operations. Note that we do not discuss whether a particular airport serves a significantly larger number of destinations or a greater number of passengers than its rival airport. Rather, we attempt to determine the implication for the airport of differing output emphasis.

Output can be classified broadly into two categories: movements and passengers. A further possible breakdown of these categories is shown below.

Airport Movements	Airport Passengers
Total	Total
Air transport	Domestic
Scheduled	International
Nonscheduled	Scheduled
General aviation	Nonscheduled

This form of subcategorization was used in the multivariate analysis to examine the structure of operational output. An additional output variable used was the work load unit, which equates passengers and freight on a weight basis. One work load unit is equivalent to one passenger or 90 kg (200 lb) of freight. Previous research (5) and intuition indicate the following juxtapositions:

1. Passengers and movements;
2. International and domestic activity; and
3. Air transport and nonair transport movement.

In general, the data used in the multivariate analysis were for 18 British airports for the 4 operational years 1968 to 1969 and 1971 to 1972, inclusive. The selected airports include all those with major scheduled air transport activity within Great Britain and Northern

Table 1. Correlations between output measures.

Measure	Air Transport Movement	Scheduled Air Transport Movement	Nonscheduled Air Transport Movement	General Aviation Movement	Total Passengers	Domestic Passengers	International Passengers	Scheduled Passengers	Nonscheduled Passengers	Work Load Units
Total movements	0.977	0.961	0.179	0.058	0.977	0.976	0.977	0.960	0.186	0.978
Air transport movement		0.988	0.157	-0.154	0.996	0.993	0.997	0.983	0.168	0.998
Scheduled air transport movement			0.001	-0.171	0.975	0.968	0.983	0.998	0.012	0.982
Nonscheduled air transport movement				0.093	0.207	0.204	0.167	-0.013	0.996	0.176
General aviation movement					-0.134	-0.128	-0.143	-0.156	0.078	-0.139
Total passengers						0.999	0.999	0.975	0.223	0.999
Domestic passengers							0.997	0.967	0.225	0.997
International passengers								0.983	0.183	0.999
Scheduled passengers									0.001	0.982
Nonscheduled passengers										0.190

Table 2. Principal components and factor analysis of output measures.

	Components			Rotated Factors		
Measure	C1	C2	C3	F_1^1	F_2^1	F_3^1
Movements						
Total	0.980	-0.015	0.192	0.985	0.101	0.134
Air transport	0.998	0.032	-0.014	0.992	0.087	-0.078
Scheduled air transport	0.982	0.187	0.002	0.993	-0.070	-0.086
Nonscheduled air transport	0.186	-0.976	-0.103	0.073	0.995	0.041
General aviation	0.133	-0.223	0.966	-0.082	0.058	0.995
Passengers						
Total	0.999	-0.022	-0.007	0.988	0.140	-0.062
Domestic	0.998	-0.056	-0.008	0.983	0.173	-0.058
International	0.999	0.018	-0.005	0.992	0.099	-0.067
Scheduled	0.980	0.198	0.019	0.994	0.083	-0.070
Nonscheduled	0.133	-0.223	0.966	-0.082	0.058	0.995
Work load units	0.999	-0.010	-0.004	0.992	0.108	-0.064

Note: Eigenvalues and percentage of variance explained are F_1^1 = 7.96 (72.4 percent); F_2^1 = 2.03 (18.4 percent); and F_3^1 = 0.99 (9.0 percent).

Table 3. Airport average growth rates and variability at selected airports from 1968 to 1972.

	Airport Movements		Airport Passengers	
Airport	Growth Rate	Rate Variability	Growth Rate	Rate Variability
Belfast	1.812	3.156	4.894	3.243
Birmingham	6.374	10.071	13.924	4.634
Blackpool	-5.705	9.507	-0.307	7.257
Bristol	0.198	16.163	21.146	19.830
Edinburgh	4.318	10.251	5.399	5.151
East Midlands	7.759	23.165	22.942	16.857
Gatwick (London)	18.304	7.803	26.634	12.105
Glasgow	4.445	1.187	8.235	5.530
Heathrow (London)	2.940	1.118	8.633	3.585
Isle of Man	-0.806	3.901	3.826	6.006
Leeds-Bradford	-4.953	9.545	2.311	4.333
Liverpool	-3.687	6.579	5.191	10.492
Luton	37.242	30.216	49.711	38.409
Manchester	6.0776	4.779	12.647	4.078
Prestwick	-5.519	7.891	7.516	20.240
Southend	-6.478	18.916	-8.646	17.253
Stansted	14.185	39.359	34.427	60.343
Teeside	9.368	37.116	21.084	13.483

Ireland. To examine the relations between variables, a correlation analysis was run on output data for the operational year 1970 to 1971. This year was chosen to permit comparison with other research work (5). Table 1 gives the correlations found between the output variables. When subjected to principal component analysis, the correlation matrix produced three principal components, C_1, C_2, and C_3, as indicated in Table 2. The total of these components accounted for 99.8 percent of the variance of the correlation matrix when subjected to the varimax procedure of factor analysis. The variance associated with each component is maximized by component vector rotation, allowing the components to be arranged in terms of the importance they play in contributing to the total variation. Three measures appear to account for virtually all the variation in the original data: total activity for factor 1 (this measure is synonymous with scheduled activity and does not differentiate among movements, passengers, and work load units), nonscheduled (charter) activity for factor 2, and general aviation activity for factor 3.

Several significant conclusions may be made. First, for some purposes of system analysis, there may be little reason to differentiate between land activity measures (passengers) and air measures (movements). Second, scheduled and charter activities are clearly differentiated in the factor analysis. Third, general aviation activity provides a third factor, orthogonal to the first two factors. The second conclusion is important from the viewpoint of the planner, who is aware that scheduled output can differ significantly from nonscheduled output in the incidence of demand on airport time. Cross-sectional analysis of either demand or output fails to identify the level of temporal variation and, therefore, results in a lack of proper design emphasis on such temporal variations.

OUTPUT VARIATIONS

Airports experience short- and long-term variations in output. The level of analysis we use does not consider the daily fluctutations, but rather focuses on those fluctuations to which the airport can adjust in an investment sense. Using the data for the period 1968 to 1972, we made an analysis of the growth fluctuations for the major British airports. The statistics derived were

1. Annual growth rates for passengers and movements, both scheduled and nonscheduled;
2. An average growth rate for the 5-year period (r);
3. The standard deviation of the average growth

rate ($\sigma_{\bar{r}}$), which is a measure of the variability of the growth rate from year to year (if we assume that forward planning is a question of estimating future trends, then this variability measure may also be used to connote predictability).

Table 3 gives growth rates and their variability for the selected airports. Using nonparametric statistical tests, we found no statistical evidence of a relation between variability and growth rate. However, there is evidence of a relation between variability in growth and operation type. As nonscheduled activity increases, variation in growth rate increases and predictability is consequently weakened. This phenomenon adds weight to the concept of a functional airport typology based on traffic type. The data would tend to support the assertion that airports with a high level of nonscheduled activity have less predictable growth rates than those where scheduled activity predominates.

We also examined short-term seasonal variations during the year. Traffic varies seasonally at all airports. High seasonal peaks may lead to congestion and, conversely, very low troughs may mean underutilization of equipment and buildings for a considerable portion of the year. The levels of seasonal variations differ greatly, depending on the nature of the airport. To make a comparative analysis of seasonal variation across the selected airports, a seasonality activity index (S_i) was computed:

$$S_i = 100/\sigma_{\overline{OD}} \times (OD_i - \overline{OD}_i) \quad (1)$$

and

$$\overline{OD}_i = \tfrac{1}{12}\sum_{i-5}^{i+5} OD_i + \tfrac{1}{2}(OD_{i-6} + OD_{i+6}) \quad (2)$$

where

OD_i = original output data, month i,
$\overline{OD}_i$ = moving mean, centered on i, the trend value, and
$\sigma_{\overline{OD}}$ = standard deviation of the mean $\overline{OD}_i$.

Seasonal profiles were constructed for the 4 years for which data were available. Although seasonal charter traffic is subject to wide variation, charter traffic for most passenger airports is only a small proportion of the total traffic. Consequently, a measure of overall seasonality can be calculated for passengers and for movements without any further differentiation. The annual measure is constructed by averaging the 12 monthly seasonal indexes. Thus, for the jth airport the annual average seasonality (Y_j) is given as

$$Y_j = \sum_{i=July}^{i=June} S_{ij} \quad (3)$$

Examples of the form of the season profiles, by type of output measure, are shown for Manchester Airport in Figures 4 through 7. Table 4 presents the summary seasonal data for all airports. Also computed was an average of the values of Y_j over the 4-year period for which data were available. This was designated as the total seasonality index (TSI_j):

$$TSI_j = \sum_{1968}^{1972} Y_j/4 \quad (4)$$

In view of the smallness of the denominator in this equation, we computed an index of variability of seasonality (IVS) without using the standard deviation. This was defined in the following manner:

$$IVS_j = \sum_{July}^{June} MD_{ij}/12 \quad (5)$$

$$MD_{ij} = S_{ij}max - S_{ij}min \quad \text{for } i = \text{July}, \ldots, \text{June}. \quad (6)$$

Table 5 indicates the values of the computed indexes for the selected airports.

After computing a number of indexes that express the seasonality of airport operation and the variability of these operations, we subjected these indexes and the data on operational output to multivariate analysis to determine the principal factors underlying the operational performance. The results are displayed in Table 6 and Table 7, which show the results of correlation and factor analyses. The variables in the two tables are as follows:

Variable	Notation
Seasonal index	
Movements	V_1
Passengers	V_2
Growth variability	
Movements	V_3
Passengers	V_4
1970	
Movements	V_5
Passengers	V_6
Seasonal variability	
Movements	V_7
Passengers	V_8
Nonscheduled activity	
Movements	V_9
Passengers	V_{10}
1970 surplus	V_{11}
1968-1972 capital expenditure	V_{12}

The factor analysis indicates that there is little correspondence between seasonality and the usual output variables. Rather, there is a stronger correlation between seasonality and airport activity type, as indicated in Table 6. This would tend to strengthen the argument for a scheduled versus nonscheduled activity typology.

The eigenvalues of the factors given in Table 7 are as follows:

		Variance Explained	
Factor	Eigenvalue	Percent	Cumulative Percent
F_1^1	6.93	57.7	57.7
F_2^1	3.23	26.9	84.6
F_3^1	0.73	6.1	90.7
F_4^1	0.42	3.5	94.2
F_5^1	0.38	3.2	97.4

Variability is analyzed in terms of its peaks in any one month and the stability of the peak from year to year. Figure 4 and Tables 3 and 4 permit the reader to comprehend the relation between graphical form and summary statistics. With respect to the analysis of variability the study found that

1. Nonscheduled passenger activity has higher seasonality indexes than any other activity, and scheduled movements have the lowest seasonality indexes;
2. Movements are slightly less seasonally affected than passenger activity, probably a reflection of the variation in load factors common to most routes;

3. Nonscheduled output is more seasonally affected than scheduled output; and

4. Based on limited evidence, activity, in general, shows fewer seasonal variations over time as it grows.

As noted, output variability is an important, but a complicating, factor in airport management and in forward planning. Therefore, establishing relations among output, variability, predictability, and financial performance is worthwhile. The factor structure given in Table 7 shows five orthogonal factors associated with the data. These are output, variability in output, seasonality, variability in seasonality, and variability in growth.

The first factor accounts for just under 60 percent of the total variance in the correlation matrix of Table 6. The factor of size of operation is further exemplified by

Figure 4. Seasonal variation of scheduled passengers at Manchester Airport.

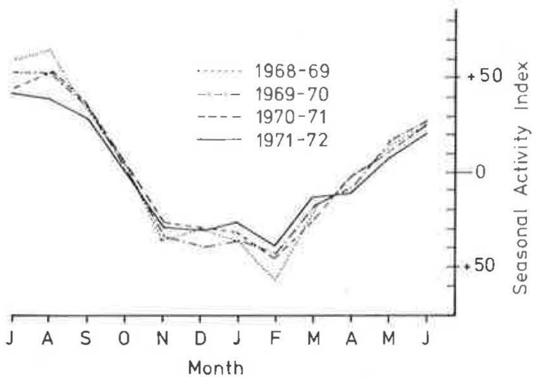


Figure 5. Seasonal variation of scheduled air transport movements at Manchester Airport.

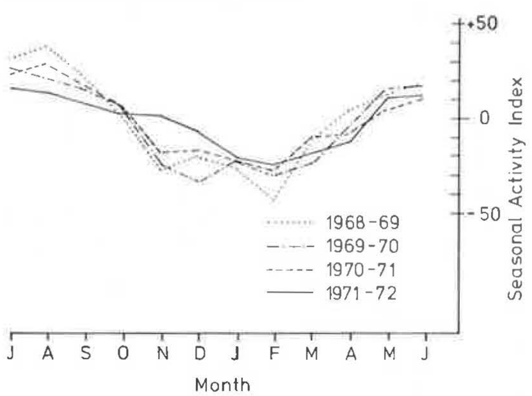


Figure 6. Seasonal variation of nonscheduled passengers at Manchester Airport.

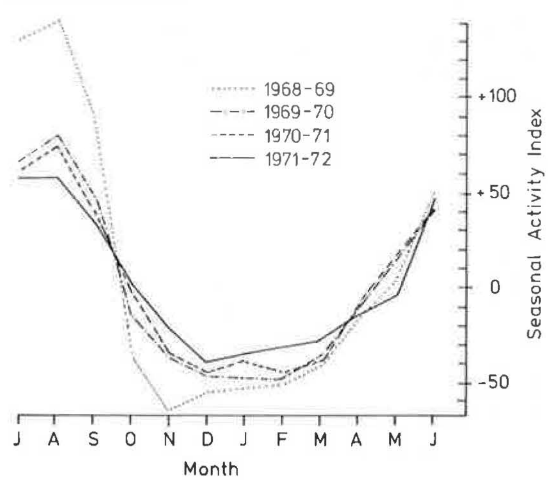


Figure 7. Seasonal variation of nonscheduled movements at Manchester Airport.

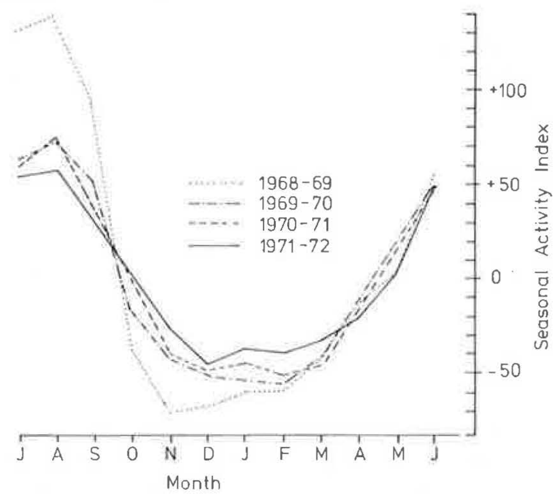


Table 4. Seasonality measures for scheduled and nonscheduled operations.

	Scheduled		Nonscheduled	
Airport	Movements	Passengers	Movements	Passengers
Belfast	13.01	24.64	88.02	126.95
Birmingham	21.36	32.32	60.87	66.07
Blackpool	65.75	79.47	63.72	129.10
Bristol	44.33	61.08	67.35	68.76
Edinburgh	20.08	27.49	80.02	86.54
East Midlands	31.55	56.46	62.59	67.97
Gatwick (London)	18.27	30.89	54.00	61.98
Glasgow	15.07	19.46	54.05	98.35
Heathrow (London)	14.94	25.48	46.69	54.57
Isle of Man	56.45	74.89	109.12	112.15
Leeds-Bradford	32.87	46.08	24.58	57.17
Liverpool	12.04	30.01	35.68	81.63
Luton	70.63	82.11	52.76	57.96
Manchester	13.91	23.75	61.32	72.05
Prestwick	23.42	58.90	76.45	102.51
Southend	36.70	60.37	30.31	61.77
Stansted	130.16	143.46	57.92	75.05
Teeside	33.41	48.46	77.33	85.00

Table 5. Total seasonality and variability indexes.

	Seasonality		Variability	
Airport	Movements	Passengers	Movements	Passengers
Belfast	14.94	27.09	7.28	7.92
Birmingham	26.56	40.28	11.07	17.82
Blackpool	61.87	73.48	16.31	15.73
Bristol	44.97	54.25	24.45	39.47
Edinburgh	20.77	28.36	14.02	13.41
East Midlands	34.98	57.76	15.87	15.15
Gatwick (London)	39.24	55.01	19.94	24.91
Glasgow	18.22	26.68	12.99	14.84
Heathrow (London)	15.64	26.44	6.24	6.09
Isle of Man	56.37	74.66	11.17	13.24
Leeds-Bradford	30.41	45.68	20.40	17.44
Liverpool	14.35	35.31	8.07	9.62
Luton	51.92	57.91	25.93	29.76
Manchester	22.50	39.61	10.12	13.22
Prestwick	28.73	71.55	21.73	42.37
Southend	34.00	59.66	19.68	26.02
Stansted	60.42	76.36	41.83	45.13
Teeside	38.52	56.72	25.79	27.19

Table 6. Correlations among variables of output, seasonality, and growth.

Variable	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}
V_1	1.00											
V_2	0.86	1.00										
V_3	0.68	0.62	1.00									
V_4	0.67	0.66	0.78	1.00								
V_5	-0.34	-0.41	-0.37	-0.23	1.00							
V_6	-0.29	-0.38	-0.33	-0.19	1.00	1.00						
V_7	0.78	0.76	0.83	0.87	-0.38	-0.34	1.00					
V_8	0.62	0.79	0.64	0.80	-0.36	-0.33	0.89	1.00				
V_9	0.66	0.51	0.68	0.86	-0.17	-0.11	0.79	0.68	1.00			
V_{10}	0.62	0.55	0.64	0.79	0.17	-0.11	0.75	0.74	0.95	1.00		
V_{11}	-0.34	-0.40	-0.33	-0.22	0.99	0.98	-0.38	-0.38	-0.20	-0.22	1.00	
V_{12}	-0.20	-0.26	-0.22	-0.13	0.96	0.96	-0.26	-0.27	-0.15	-0.16	0.97	1.00

Table 7. Factor analysis of output, seasonality, and growth.

	Principal Components		Rotated Factors				
Variable	C_1	C_2	F_1^1	F_2^1	F_3^1	F_4^1	F_5^1
V_1	0.807	-0.220	-0.160	0.434	0.846	0.032	0.207
V_2	0.817	-0.125	-0.223	0.280	0.811	0.396	0.153
V_3	0.813	-0.215	-0.187	0.480	0.327	0.151	0.776
V_4	0.835	-0.404	-0.064	0.719	0.309	0.299	0.322
V_5	-0.636	-0.769	0.973	-0.055	-0.154	-0.082	-0.181
V_6	-0.591	-0.803	0.979	0.002	-0.126	-0.099	-0.112
V_7	0.918	-0.261	-0.199	0.590	0.429	0.436	0.382
V_8	0.857	-0.219	-0.203	0.539	0.352	0.719	0.157
V_9	0.785	-0.434	-0.052	0.947	0.228	0.075	0.168
V_{10}	0.777	-0.420	-0.056	0.935	0.227	0.188	0.109
V_{11}	-0.640	-0.759	0.974	-0.110	-0.145	-0.087	-0.048
V_{12}	-0.538	-0.812	0.987	-0.106	-0.010	-0.013	0.020

the close correlations between (a) capital expenditure and fixed assets at the end of the study period, (b) surplus and passengers ($r = 0.984$), (c) surplus and movements ($r = 0.991$), (d) investment and movements ($r = 0.963$), and (e) investment and passengers ($r = 0.965$).

The second factor firmly links nonscheduled activity with variability in growth. The period of 1968 to 1972 saw considerable growth in charter activity for British airports. Exceptions to the rule that nonscheduled activity is unpredictable are airports that specialize in charter traffic. The main traffic at these airports showed less growth variability, even though it was charter. The third, fourth, and fifth factors are of limited explanatory value. None of these factors contributed more than 6 percent to the variation of the correlation matrix.

CONCLUSIONS

The paper emphasizes the importance of an appropriate scale for measuring output for airport system modeling. Only after airport type has been considered is a discussion of the problems of estimating parameters of the model appropriate. Any good model structure must parallel reality in its important facets; therefore, a model must be dynamic in nature (18). Feedback, therefore, has been considered and included. Feedback assumes crucial importance in the area of policy formulation.

Investment must be considered the most important decision affecting airport systems. This is due not only to the degree to which it can affect the supply of physical plant, but also to the scale of investment itself, which for airports is substantial. Moreover, new construction in runway additions, terminal extensions, or even new airports, all increase the supply potential of a national airport system and cannot, therefore, be considered peripheral and marginal to it. Mistimed and ill-directed investment may be worse than no investment at all.

Clearly, new investment should be considered only against a background of growing demand and future revenue increases. Demand and revenue, in turn, require an appreciation of the differences between airports and the likely inherent variations in growth rates. The study pointed out where growth variability is likely and where seasonal influences can be expected to be of maximum importance and presented problems of congestion or underutilization.

In summary, the paper indicates that airports differ greatly in function. Planners must recognize a typology or taxonomy of airport types according to function.

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Development and Application of an Airfield Simulation Model

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Many major airports experience aircraft delays caused by increasing aviation activity and decreasing airfield capacity. But the traditional solution to the problem—building new airports or expanding existing ones—is often infeasible because of environmental, financial, or institutional constraints. Instead, managing demand or improving operational efficiency seems to offer the best opportunities for relieving airport congestion. We discuss the quantitative techniques available for evaluating the merits of managing demand or improving operational efficiency and then describe our preferred technique—an airfield simulation model. An airfield simulation model requires a large data base, but its output can be selected and tailored to individual situations. It can be used to investigate different elements of the airfield and to provide the finest level of detail for short-term planning and summary outputs for analyzing longer term problems.

The air transportation industry experienced rapid growth during the 1960s, partly because jet aircraft (with increased speed and seating capacity) replaced propeller aircraft in the airline fleet. By the summer of 1968, the air transportation system was severely congested; very large delays became an everyday occurrence at some major hub airports.

Aircraft delays dropped considerably in the early 1970s because an economic downturn reduced traffic growth to less than half of previous predictions, the introduction of wide-bodied aircraft increased passenger capacity, and the Federal Aviation Administration (FAA) introduced an hourly aircraft movement quota at five of the nation's busiest airports (Chicago O'Hare, John F. Kennedy, LaGuardia, Newark, and Washington National). In late 1973, a severe fuel shortage further reduced aircraft traffic.

Aviation activity has increased since then. At some airports, traffic is now at record high levels and delays are once again on the upswing. Increased delay stems from increased aviation activity and reduced airfield capacity. New air traffic control rules, implemented to ensure safety for aircraft flying behind or below heavy jets that produce significant wake turbulence, have reduced airfield capacity.

Past response to increasing congestion was construction of new airports and major expansion of existing ones. But current environmental, financial, and institutional constraints reduce the feasibility of this approach at most major airports. The current situation indicates that severe airport congestion may occur in the near future. Managing aviation demand and implementing operational, procedural, or minor physical improvements offer some of the best opportunities for relieving airport congestion.

Quantitative techniques are needed for measuring aircraft performance on the airfield under different situations. These measures of performance can be used to analyze the operational feasibility of various improvement options and can also be used as inputs to economic analysis. Analytical and simulation models for estimating airfield capacity, delay, and travel times have been developed to assist in these analyses. These models are being utilized increasingly at major airports to help in decision making on airfield improvements. This paper discusses the different types of models available and describes an airfield simulation model developed by Peat, Marwick, Mitchell and Company and its application at several major airports.

MODELS OF AIRCRAFT PERFORMANCE ON THE AIRFIELD

A number of different models of aircraft performance, which are oriented to different objectives, are available. For example, Peat, Marwick, Mitchell and Company has a series of models that estimate airfield and airspace capacity, aircraft delays and travel times, controller workload, collision risk, noise exposure, and air pollution. Our discussion is restricted to models that measure aircraft delays and travel times.

Aircraft delay is the difference between the actual time it takes an aircraft to operate on an airfield and the time it would take to operate without interference from other aircraft on the airfield. Thus, delay is defined in terms of a difference in travel times or by an amount of waiting time. Two principal types of models may be used to compute airfield delays—analytical models and simulation models.

An analytical model is a set of mathematical equa-