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Contents

Foreword

The papers in this Record deal with three important aspects of aviation: broad planning considerations, specific airport-planning considerations, and the impact of economic deregulation on air cargo transport.

Ashford and Benchemam develop a model that describes the choice mechanism by which passengers in central England choose which airport they use. The model is said to be transferable to the London area and useful to other airport and airline planners. It found that the most important variables for business travelers were access time to the airport and frequency of flights to desired destinations. For domestic leisure travelers, airfare was an important additional consideration.

Khan presents highlights of his findings on the determinants of travel substitution and stimulation phenomena. The factors treated include socioeconomic variables, communication needs, technical capability and cost of telecommunications and transportation, institutional and policy variables, human factors, and transportation-telecommunications trade-offs in representative spatial and service contracts.

McLeod examines a procedure based on the Regional Input-Output Modeling System (RIMS II) developed by the U.S. Department of Commerce. Since 1983, the RIMS II multiplier methodology has become the dominant economic impact methodology for evaluating regional aviation impacts. Although the application of RIMS II multipliers to the aviation industry is relatively recent, major aviation economic studies involving 30 primary commercial service and more than 200 general aviation airports are under way or completed and were examined in this research project.

Oster and Miles-McLean found that, under deregulation, air cargo rates have become lower and service patterns have changed. Shippers are said to now be relying more heavily on freight forwarders who, in turn, are developing their own air cargo transport systems. All-cargo carriers have been hurt by a number of factors, and both all-cargo carriers and package express carriers are under increasing competitive pressure from belly cargo in the half-dozen or so new, larger, consolidated passenger airlines with extensive hub-and-spoke systems.

Rubin and Lerner examine the use of information on geographic distribution of aviation activity for making a bottom-up forecast often controlled by a top-down control total. Recently completed forecasts using this technique for state plans in Florida and Ohio are examined.

The focus of the paper by Hobeika, Dona, and Nam is on clustering high-speed runway exit locations into a minimum number without cost burdening any one class of runway users and without violating the objective of minimizing total runway occupancy time of landing aircraft in a real airport environment.

Wirasinghe and Vandebona ranked terminal building configurations according to the percentage of passengers who must walk less than a specified maximum distance. They found that a T-shaped configuration was superior to both single and double concourses.

Passengers' Choice of Airport: An Application of the Multinomial Logit Model

NORMAN ASHFORD AND MESSAOUD BENCHEMAM

The authors sought to establish that airports do not have "catchment areas" as such and that air travelers make choices among available airports when they elect to travel. A model that describes this choice mechanism will permit airport systems to be planned on a more reliable basis. This work develops a model for passengers in central England based on data collected in 1975 and 1978 by the Civil Aviation Authority. The model chosen was one of discrete behavioral choice; the particular form that was successfully calibrated was the multinomial logit model. For business and inclusive tour travel, the most important variables of choice were access time to the airport and frequency to the chosen destination. For domestic and leisure trips there were three factors: air fare, access time, and frequency of available flights, in that order of importance. The calibrated model showed high agreement between observed and predicted market shares. The model was also found to be transferable to data from a separate survey of air travel from the London area. The model is expected to be of use to airport authorities and airlines in planning and determining business strategy in the increasingly competitive deregulated environment of air transport.

It is not unusual for airports to be discussed in terms of "catchment areas," as if an individual airport served a particular area of a country. The concept of catchment would, perhaps, be valid if all air trips originating in a particular area invariably used the same airport, but this is not so. De Neufville *(1)* quite rightly pointed out the error of using this term in conjunction with airports because in many situations people can and do choose the airport they will use. Air trips are not invariably drawn to a single airport. If he has a choice of airport, the passenger is likely to choose on the basis of the perceived overall level of service he obtains from his selection. In a small country like the United Kingdom where there are many commercial service airports it is not possible to adhere to the belief in nonoverlapping airport catchment areas. Little research has, however, been carried out to obtain a better understanding of how trip makers choose among the services offered by competing airports. This is partly because carrying out research on airport selection is likely to involve time-consuming and costly passenger surveys.

In this work, after the factors that determine choice had been ascertained from a priori evidence, it was decided to construct a model based on the microeconomic theory of consumer choice instead of using a regression approach that would rely on a superficial correlation between observed data. In surface transport mode choice modeling, both in the urban and the interurban cases, discrete mode choice or behavioral models have been found preferable to and more transferable than the early aggregate models. It was believed that if a consumer choice model of this type could be built, it could be useful in forecasting the redistribution of passenger traffic among airports as new facilities and infrastructure or more services are added to the system or as other facilities, unsuitable for use on environmental or other grounds, are closed. It could also be helpful in determining the optimum location of new facilities. Furthermore, the model could be useful in forecasting the redistribution of traffic that might result from improvements in airport ground access (such as the construction of a high-speed rail system or a motorway), from the effect of shifting flights from one airport to another, or from the adoption of widely varying air fare policies. It is clear from the available literature that little work has been attempted in the field of airport choice in spite of the important implications that passenger choice has for demand and the consequent need for facilities. As air traffic continues go grow, there is a need for a much clearer understanding of how demand is shared among the components of a multiple-airport system and what factors are likely to be most effective in bringing about changes in demand shares among airports in such a system.

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DATA REQUIREMENTS AND PREPARATION

The independent variables chosen from the outset of this modeling exercise were surface access time, frequency of flight service, and air fare. These variables had previously been the reasons most frequently cited by passengers for their selection of an airport in a survey carried out by the Civil Aviation Authority in 1978 *(2)*. Potentially, a large range of variables could enter into any choice model, but some variables are highly intercorrelated, and data are not always available for others. Tests were carried out on data for these three variables. They were found to be statistically independent one of another, and in combination it was found that they were capable of producing a highly significant model.

For each passenger the following data were required: surface origin, flight destination, age, day of the week on which trip was made, trip purpose, selected airport, travel time from surface origin to all competing airports, number of flights from the competing airports to the selected destination on that particular day of the week, and air fare from the competing airports to the selected destination. This sort of data is not routinely available from ordinary air transport sources. Specially organized airport surveys are generally prohibitively expensive because of the large sample size necessary to provide an adequate data base on individual airports or city pairs. Such data are, however, available from origin-destination surveys carried out periodically for the Civil Aviation Authority in the United Kingdom. The base survey data of the 1975 and 1978 surveys were made available to Loughborough University by the Civil Aviation Authority at the required level of individual trip records stored on computer tape *(2, 3)*. The analysis was carried out between 1983 and 1986. Although fare levels have changed considerably since the time of the surveys, use of the old data is valid because the model is one of behavioral choice that reflects fare levels at the time of travel. The logic of the model is unaffected by subsequent changes in the values of the variables used. A total of 40,000 passengers were interviewed for the 1975 survey and 91,086 for that in 1978. A survey of this scale was beyond the resources of this study, and the research was therefore dependent on the goodwill of the CAA in making their original trip records and associated origin-destination data available in magnetic tape format. For the purposes of this study 2,577 trip records were used. Air fare and flight frequency, which were not included in the CAA survey data, were obtained from the *ABC World Airways Guide (4)*.

Because of the availability of data in suitable form, central England was selected as the study area. The airports considered were Manchester, Birmingham, East Midlands, Luton (for inclusive tours only), and London's Heathrow. Subsequently, the following destinations were selected for purposes of analysis:

- Domestic: Belfast, Jersey, Glasgow, and Aberdeen;
- International: Dublin, Amsterdam, Frankfurt, and Brussels; and
- Inclusive tours: Palma, Alicante, and Ibiza.

Passengers were stratified on the basis of the following trip purposes:

- Domestic,
- International business,
- International leisure, and
- International inclusive tours.

It was reasoned that these four categories of passengers were likely to make different travel decisions.

Data relevant to the study included air passenger trip records (local origin, destination, airport used, flight number, trip purposes, and day of interview), frequencies of flight, air fares, and access time to the airports. These were necessary data both for the chosen airport and the rejected airports. As an example, for a passenger originating from a point somewhere in the city of Nottingham and flying to Amsterdam on a business trip from Manchester Airport on Thursday, the following were needed:

1. For the choice made:

- Computation of travel time from the point of origin in Nottingham to Manchester Airport.
- Determination from the pertinent *ABC World Airways Guide* of the number of flights leaving Manchester Airport to Amsterdam on Thursday as well as the economy air fare.

2. For the choices rejected:

- Computation of the respective travel times from Nottingham to Birmingham Airport, East Midlands Airport, and Heathrow Airport.
- Determination from pertinent *ABC World Airways Guide* of the number flights on Thursday to Amsterdam from Birmingham Airport, East Midlands Airport, and Heathrow Airport as well as the respective economy air fares.

AIRPORT CHOICE MODEL

In previous attempts at modeling air transport trips at airports, the aggregate model approach was used. Airports have been regarded as centers of attraction of potential air trips generated in zones surrounding the airport. In recognition that zones that are remote from an airport in ground access terms will generate a low number of trips, the "propensity to fly" in these zones is depressed by a factor that reflects poor ground access. This approach is inevitable if aggregate or zonal models are used.

The development during the last 15 years of more sophisticated behavioral discrete choice models suggests an approach that is likely to be considerably more accurate, is capable of calibration with considerably fewer data than required for the aggregate approach, and is transferable from one area to another. Using the disaggregate approach, generation models can be built that will model the number of air trips generated throughout a region on the basis of the socioeconomic characteristics of the population and the provision of air service. These generated trips are then assigned to individual airports by a disaggregate airport choice model such as that proposed in this work. Earlier aggregate models have not been useful for examining the impact of changes in the availability and level of service of competing airports, either because they do not incorporate airport attributes as variables or because they perform poorly even when they do include such variables. These models do not consider that individual passengers can and do make choices about which airport to use.

The behavioral model employed in this research was, on the basis of experience with its use in both urban and interurban surface transport applications *(5)*, expected to provide a better approach to the problem under study. Discrete choice models of this type have been developed on the basis of stochastic choice using the hypothesis of random utility maximization. The most widely used of these models is the multinomial logit model (MNL):

$$P_{gk} = e^{V_{gk}} / \sum_{r=1}^{G} e^{V_{rk}} \qquad (1)$$

where

P_{gk} = probability that alternative g will be chosen by individual k and

V_{gk} = $a_1X_1 + \ldots + a_n X_n$ = representative function of the utility where $a_0, a_2 \ldots a_n$ = parameters to be estimated and $X_1, X_2 \ldots X_n$ = explanatory variables.

An important application of this formulation is that the ratio P_{ik}/P_{gk} of choosing alternative i over alternative g is independent of the presence or absence of a third option, satisfying the equation

$$\text{Ln } (P_{ik}/P_{gk}) = V_{ik} - V_{gk} \qquad (2)$$

This property, termed "independence from irrelevant alternatives" (IIA), is both the principal strength and the principal weakness of this model. It is a strength because it allows the introduction of new alternatives without reestimation of the model after a numerical functional form of V has been established. It is a weakness because it requires that the alternatives be perceived as completely distinct and independent. A test based on conditional choice *(6)* was carried out for the four categories of passengers, and it can be concluded that in this study there is no violation of the IIA property. The MNL was, on balance, considered by the authors to be the most appropriate tool for modeling airport choice.

CALIBRATION RESULTS

Separate models were calibrated for business, leisure, inclusive tour, and domestic air passengers by using an original computer program written by Ben-Akiva *(7)* based on a maximum likelihood technique.

Examination of the data, in conjunction with analysis of the earlier CAA survey results, indicated that a suitable form of the utility function of the model could be written in the form

$$V = a_1 \cdot TT + a_2 \cdot FREQ + a_3 \cdot FARE$$

where

TT = travel time to the airport,
$FREQ$ = number of flights per day,
$FARE$ = air fare, and
a_1, a_2, a_3 = coefficients to be estimated in the calibration.

Statistical analysis of the data indicated that these variables were independent one of another.

In the first run, the fare parameter had the "wrong" sign for the business and inclusive tour categories (this parameter is expected to be negative). Thus the model was reestimated leaving out this variable for these two categories of passengers. The results of the calibration are given in Table 1. The likelihood ratio tests are much larger than the tabulated χ^2 at the 99 percent confidence level, which implies an excellent fit. The likelihood ratio index values of 0.88, 0.92, 0.84, and 0.92 give evidence of this. Another goodness of fit measure is how well the model predicts the share of each airport. The data in Table 2 indicate that the predicted share of each airport was close to the observed share for all categories of passengers. Aggregate direct and cross elasticities were estimated to measure the responsiveness of airport choice to changes in the explanatory variables found significant at the 95 percent confidence level. Those are given in Tables 3–6.

TABLE 1 CALIBRATION RESULTS

	Business	Leisure	Inclusive Tours	Domestic
a_1 (TT)	- 0.13605 (- 6.93)*	- 0.13788 (- 6.47)**	- 0.17787 (- 11.23)**	- 0.23254 (- 6.71)**
a_2 (FREQ)	1.6607 (6.79)*	1.07 (5.87)**	2.069 (10.69)**	2.6957 (6.61)**
a_3 (FARE)	- -	- 1.2035 (- 4.23)*	- -	- 0.74645 (- 5.22)*
Likelihood ratio test	521.03	847.02	3123.67	1746.60
Likelihood ratio index	0.88	0.92	0.84	0.92
χ^2 (0.01, df)	9.21	11.34	9.21	11.34
df	2	3	2	3

** significant at 99 per cent confidence level
* significant at 95 per cent confidence level
(t values shown in parentheses)

TABLE 2 OBSERVED AND PREDICTED SHARES

	BUSINESS		LEISURE		INCLUSIVE TOURS		DOMESTIC	
	Obs %	Pred %	Obs %	Pred %	Obs %	Pred %	Obs %	Pred %
MANCHESTER	27.57	27.10	19.63	19.94	23.87	23.13	9.96	12.00
BIRMINGHAM	25.23	25.23	59.52	55.89	33.58	34.17	35.14	31.33
EAST MIDLANDS	15.42	17.29	13.90	17.22	34.84	36.62	53.00	54.17
HEATHROW*	31.78	30.27	6.95	6.95	7.71	6.08	1.90	2.49

*Luton for inclusive tours

TABLE 3 DIRECT AND CROSS ELASTICITIES—BUSINESS

	Direct Elasticities				Cross Elasticities			
	M	B	EM	LHR	B-EM-LHR	M-EM-LHR	M-B-LHR	M-B-EM
TT	-0.77	-0.33	-0.85	-1.94	4.98	2.21	2.76	21.05
FREQ	0.31	0.26	0.24	1.79	-4.33	-3.49	-2.12	-26.87

TABLE 4 DIRECT AND CROSS ELASTICITIES—LEISURE

	Direct Elasticities				Cross Elasticities			
	M	B	EM	LHR	B-EM-LHR	M-EM-LHR	M-B-LHR	M-B-EM
TT	-0.22	-0.19	-0.67	-4.38	3.23	1.90	2.56	18.74
FREQ	0.07	0.08	0.13	2.89	-3.21	-2.03	-0.95	-14.23
FARE	-0.97	-1.26	-4.25	-6.74	25.21	25.5	23.11	31.7

TABLE 5 DIRECT AND CROSS ELASTICITIES—INCLUSIVE TOURS

	Direct Elasticities				Cross Elasticities			
	M	B	EM	LUT	B-EM-LUT	M-EM-LUT	M-B-LUT	M-B-EM
TT	-1.73	-0.52	-1.38	-7.20	6.97	2.79	5.29	11.83
FREQ	0.58	0.49	0.48	6.69	-4.02	-3.98	-3.24	-13.57

TABLE 6 DIRECT AND CROSS ELASTICITIES—DOMESTIC

	Direct Elasticities				Cross Elasticities			
	M	B	EM	LHR	B-EM-LHR	M-EM-LHR	M-B-LHR	M-B-EM
TT	-1.77	-0.62	-0.46	-9.13	7.07	3.23	6.83	28.67
FREQ	0.42	0.28	0.21	8.72	-4.41	-3.51	-3.39	-27.38
FARE	-1.96	-0.87	-0.62	-3.68	10.63	12.48	12.21	8.28

DISCUSSION OF RESULTS

It can be seen from the results that the a priori stratification of passengers into four categories, on the assumption that they make different travel decisions, was justified and that the variables expected a priori to be important were adequate explanatory variables. It is useful to measure for each category of passengers the relative importance of these variables as determinants of airport choice using the elasticity values given in Tables 3–6 and consequently to suggest some of the implications of these attributes as airport policy tools. The data in Tables 3 and 5 indicate that, for business and inclusive tour passengers, the absolute value of the direct elasticity of travel time is in all cases higher than the corresponding value of the direct elasticity of frequency of flights. From this result it can be concluded that the travel time variable is the dominant factor. Similarly, the data in Tables 4 and 6 indicate that the fare variable is the dominant factor for leisure and domestic passengers. These conclusions are summarized in Table 7.

TABLE 7 RELATIVE IMPORTANCE OF VARIABLES

	Business-Inclusive Tours	Domestic-Leisure
1st Dominant	TT	FARE
2nd Dominant	FREQ	TT
3rd Dominant		FREQ

For the British regional airports considered, it can be concluded from the elasticities tables that, as far as the passengers from the study area are concerned,

- A fare policy would give the best results in the attraction of more passengers if it were applied at Manchester Airport for domestic passengers and at East Midlands Airport for leisure passengers.
- An access improvement policy would give the best results in the attraction of more passengers if it were applied at Manchester Airport for domestic and inclusive tour passengers and at East Midlands Airport for business and leisure passengers.
- A frequency of flights policy would give the best results in attracting more passengers if it were applied at Manchester Airport for business, inclusive tour, and domestic passengers and at East Midlands Airport for leisure passengers.

It can therefore be concluded that Manchester Airport has the potential to develop into a "hub" airport. This finding supports the 1985 U.K. government White Paper on airport policies that states:

> The government is fully committed to maintaining and further developing Manchester airport as a gateway . . . for long-haul services, and as a domestic and European hub.

East Midlands Airport could also attract more passengers, particularly those on leisure trips, if the appropriate policies (i.e., lower fares) were applied. Birmingham Airport appears to suffer more from the proximity of the London airports.

The high values of the cross elasticities when there is a change in a variable characterizing Heathrow (Luton for inclusive tours) show that there is most scope for redirecting passengers originating from central England to the three regional airports. This measure could be considered by some in a negative light because there is a risk that connecting traffic at Heathrow might be lost to other European airports.

In work that will be reported in a later paper, the model was tested for transferability to another area of the United Kingdom using data collected in a subsequent survey by the Civil Aviation Authority. Pooled data and Bayesian updating techniques were used, and the model was found to be statistically transferable.

CONCLUSIONS

Disaggregate behavioral models of airport choice provide an important new tool for the airport planner. Furthermore, the possibility of transferability in time and space (after applying an updating procedure) adds to their attraction.

The results showed that the multinomial logit model used for airport choice had good explanatory ability and was successful in predicting choices actually made. The predicted share for each airport was also close to the observed share for the four categories of passengers.

As already stated, the results justified the a priori stratification of passengers into four categories and confirmed some intuitive expectations such as that nonbusiness passengers are more concerned with accessibility and less concerned with flight frequency than are business passengers when choosing among airports.

Elasticity analysis was also conducted in this study. It showed that choice was not equally responsive to changes in its determinants and therefore access time, flight frequency, and air fare cannot be viewed as equal determinants of airport choice. The accessibility variable was more important than the frequency of flights variable for all passengers. The fare variable, found to be significant only for leisure and domestic passengers, is the most important determinant for these two categories.

It appears that by influencing these determinants, the planner or operator can shift traffic from one airport to another in order to have an airport system that is more economically or environmentally efficient. Air fare differentials can be effective in attracting leisure and domestic passengers from one airport to another. For the business traveler, changes in flight frequency are much more effective in changing airport choice.

Improvements in airport access can be an efficient policy tool for shifting passengers' choice of airport, regardless of trip purpose. Obviously, airport managers and airport planners are unlikely to have much influence over the scale of the regional road transport system and therefore often have little direct control over this variable. However, a major change in the road access system, brought about independently of airport needs, may have large and previously unpredictable effects on airport choice and therefore airport demand. A case in point is the recent completion of the London Orbital route in Britain, which was planned for general easing of traffic congestion in metropolitan London. Overnight it has made Gatwick Airport considerably more accessible to the Midlands and East Anglia. In the next few years this increased accessibility will have profound effects on the distribution of traffic among the London area airports.

Because the model predicts airport share, it could be used in forecasting the redistribution of passengers among airports if another airport were to be added to the system or, on the other hand, a decision were made to close one airport in a multiairport system. Because the test of independence from irrelevant alternatives was found to be valid, the model does not need to be reestimated if one or more airports are added to or dropped from the system under consideration. There is also strong evidence that the model is transferable outside the area of calibration.

In conclusion, it can be stated that disaggregate behavioral models of airport choice provide an important new tool for airport planners and operators. Although conceptually they are more difficult to comprehend than some of the simple models now in use, their advantages in accuracy and reduced data requirements argue strongly for their adoption. From the viewpoint of airport operators, the model demonstrates that traffic at an airport will increase disproportionately to population growth as flight frequencies increase, fares fall, and surface transport links serving the airport improve. These variables are, of course, not generally under the control of the airport authority, and the airport operator almost certainly will be required to provide increased capacity as favorable changes in these factors are produced by the airlines and by investment in ground access infrastructure. Equally important is that airport authorities struggling to maintain market share must ensure that they are not displaced in the marketplace by competing airports at which flight frequencies and fares are improved to attract business and leisure passengers, respectively.

The implications of the model for the airline operator are clear. Business traffic will be attracted to an airport only if ground access and flight frequency are adequate, and ground access time is far more important than flight frequency. For the leisure traveler, fare and access time are the most important factors, and an airline operating from a particular airport must compete on that basis.

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Sociotechnical Factors in Air Travel: Some New Insights into Telecommunications Interactions

ATA M. KHAN

Recent developments in sociotechnical factors that influence the interaction of air travel demand and telecommunication systems, including technical innovations, have renewed interest in this subject. Airlines have expressed concern that they will lose a significant portion of their future business travel growth to the electronic media. To improve the scientific basis for developing estimates of replaced travel and associated impacts such as infrastructure utilization, a research project was carried out on this topic. In this paper are presented highlights of findings on the determinants of travel substitution and stimulation phenomena. A systematic investigation of factors and their interrelationships is reported. The factors treated include socioeconomic variables, communication needs, technical capability and cost of telecommunications and transportation, institutional and policy variables, human factors, and transportation-telecommunications trade-offs in representative spatial and service contexts. Analyses and compiled behavioral information lead to a better understanding of travel impacts. Complexities and uncertainties are highlighted. An attempt is made to provide insights into the determinants and their interrelationships that could form an improved basis for projecting the effects of rapidly evolving telecommunications on air travel demand and related factors.

The cost and technology of telecommunication systems are improving rapidly while the air transportation sector is experiencing congestion-related difficulties, at a number of locations, in maintaining a level of service that is attractive to business travelers. It is hardly surprising that there is considerable interest in transportation and telecommunications. Air transportation interests have expressed their concern that teleconferencing, more than any other single factor, will adversely affect the growth of business travel, which is the most lucrative segment of their market. Other interests are also desirous of knowing more about this complex subject. Telecommunications firms, agencies, and institutions would like to gain an insight into the extent of substitution for market estimation purposes. Government agencies would like to know the impacts on transportation carriers, services and facilities, and energy consumption. In the following sections are presented highlights of the findings of a research study on transportation and telecommunications in which substitution and stimulation were examined *(1)*.

METHODOLOGY

A four-step methodological framework was used to study the nature and extent of the effects of telecommunications on air travel (Figure 1). The initial step required the identification of major sociotechnical factors that affect the interaction of transportation and telecommunications. These are economic and spatial factors; urban and regional development patterns; travel context (e.g., short haul, long haul); communication needs; human factors (i.e., life-style, values, and attitudes); market pull; incentives for the use of teleconference services; perceived user benefits; quality and cost of telecommunication modes; institutional factors; regulatory policies; and support structure. In the second step, the influence and interrelationships of these variables are investigated. In the third step, knowledge gained through actual experience, surveys, and demonstrations is assessed as trends leading to increased use of teleconferencing. Finally, in the fourth step, trade-offs and travel impacts are investigated.

Because of lack of sufficient data on the use of teleconferencing, formal models could not be calibrated in this research *(2, 3)*. Instead, reliance is placed on interrelationships among the factors studied, attitudinal survey data, and trade-off analyses for drawing inferences about travel and related impacts. Also, in this paper, the scope of travel impacts is limited to air travel. Telecommunications are not likely to influence travel by intercity bus and automobile because these modes are chosen by the business traveler for reasons other than saving time and are therefore not considered competitors to teleconferencing. Passenger rail in short-haul corridors, on the other hand, may potentially be affected. However, such impacts are not covered here.

ECONOMIC AND SPATIAL FACTORS

Travel and telecommunications expenditures of organizations are affected by general economic conditions. The availability of investment capital for the development of in-house studios is also influenced by economic conditions. Travel and telecommunications expenditures could be viewed as competitors for corporate budget funds. Recent interest in all forms of teleconferencing has been due in part to the recent recession that caused businesses to look for ways to reduce costs and improve productivity. Also, if there were energy supply problems, travel would be curtailed and the prospects of teleconferencing would increase.

Spatial factors in association with the availability and quality of telecommunications systems have an impact on the interaction of travel and teleconferencing. Experience in many regions

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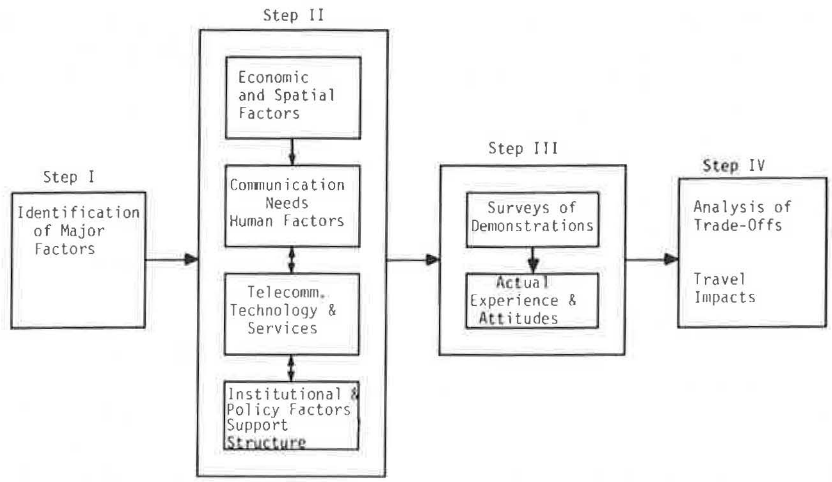

FIGURE 1 Study methodology.

in North America, the United Kingdom, and Europe suggests that telecommunications and regional development structure are mutually reinforcing. Improved telecommunications have changed business locational decisions and could potentially serve as a complement to business travel—with possible substitution and stimulation effects. Clustering of businesses and their proximity to common teleconference studios in central or satellite urban developments has the potential of inducing travel substitution.

Travel context has an effect on the interaction of travel and telecommunications. Consequently, substitution or stimulation of travel may be nonuniform for short-haul corridors, long-haul (domestic, transborder, international) routes, and Canadian North-South (low-density) travel contexts. Reasons for this include cost differentials, inconvenience of same-day return, relatively low incentive to make frequent trips to the same destination (except for frequent flyer incentives offered by the airlines), and attractions of international travel—especially for the infrequent traveler. Therefore it is appropriate to study the influence of travel context on the extent of substitution and stimulation.

COMMUNICATION NEEDS AND HUMAN FACTORS

A cornerstone of research on the interaction of transportation and telecommunications is the identification of communication needs that could be met effectively by telecommunications. Substitutable communication needs are identified on the basis of the nature of the tasks to be performed and the communicators' behavioral attitudes and preferences of medium, which are partly influenced by the attributes (e.g., quality) of the medium. Since 1970 laboratory experiments and actual demonstrations have been carried out in Canada, the United States, the United Kingdom, Europe, Australia, and Japan to study the effectiveness of a number of kinds of telecommunications relative to in-person meetings. Coupled with survey data on estimated frequencies of different types of meetings, these findings led to the identification of substitutable communication needs.

Communication needs substitutable by teleconferencing include

- Information exchange (routine): sales meetings, staff training, new product or service introductions, project control and status reporting, and committee meetings.
- Information exchange (recent events): problem solving, remote consulting, scientific and technical information, and seminars.
- Exploratory communications: identification and review of considerations basic to establishing a policy or plan of action.
- Planning: formulating a plan, establishing priorities, and selecting alternative courses of action.
- Implementation oriented: administrative activities—development, assignment of responsibilities for action (delegation of work), and scheduling.
- Crisis decision making (crisis management): speed necessary—almost instant decision required.
- Social services including those for handicapped persons.
- Medical information exchange.

Communication needs substitutable by other telecommunication systems include

- Messages and mail: electronic messaging and mail.
- Ordering items: teleshopping.
- Banking: electronic funds transfer.
- Forms processing, transmission of text and word processing, joint authorship: teletex.
- Transmission of data: data communications.
- Education: telecourse.
- Voting: interactive community television.

Most studies suggest that teleconferencing could be used effectively for about 40 to 60 percent of all business meetings. Meetings with substitution potential can be broadly classified as information transmission and exchange, planning- and implementation-oriented tasks, and exploratory (problem-solving) communications. For a number of communications, face-to-face, in-person meeting has been considered necessary for reasons that include the nature of the task (i.e., negotiations, crisis decision making, or decision making with risk) and the necessity of the proper atmosphere for in-person meetings (e.g., friendly relations, courtesy, personal contact). Recent research implies that transactional tasks (negotiations) could be carried out as well through teleconferencing *(4)*. This increases the percentage of substitutable business meetings to 70 percent or more. Telecommunication services would be a clear choice in cases involving urgency in decision making (e.g., crisis decision making, crisis management).

A number of nonbusiness communication needs are regarded as substitutable [e.g., social services, education, medical information exchange and training, voting, and shopping (for specific items)]. Social and recreational travel is generally regarded as nonsubstitutable. However, interesting observations have been reported in the literature that suggest both substitution and stimulation of travel. Telecommunications could induce travel for nonbusiness reasons as well as for such business reasons as implementation of decisions and negotiations that evolve from teleconferencing.

Human factors play a key role in the acceptance of teleconferencing as a substitute for face-to-face meetings involving travel. Likewise, telecommunication-induced travel is influenced by human factors. Research indicates that increased attention to human factors is essential when implementing teleconference systems. Specifically, promotion and software should be approached with special attention devoted to human factors.

ADVANCES IN TELECOMMUNICATIONS

A large number of advanced telecommunication services have been made possible by the confluence of the technologies of computers and communications. Teleconference services in Canada and the United States range from simple audio facilities through narrowband slow-scan (freeze-frame) video systems to full-motion two-way color video augmented with stereo audio and conference facilities.

Narrowband systems include

- Audio teleconferencing: Voice-only communication using appropriate equipment for voice amplification and transmission to enable multipoint communication among individuals and groups. A conference telephone call is the simplest form of audio teleconferencing.
- Telewriting: Electronic transmission of writing to remote television monitors, often through normal telephone lines (e.g., the "electronic blackboard").
- Telecopying: These devices transmit page-sized photocopies over normal telephone lines or special transmission circuits. Depending on equipment and system capability, transmission time could be from less than 1 to 3 min.
- Electronic mail and computer-based conferencing: These are keyboard text-based group communications media in which all exchanges take place through a computer terminal. The participants are typically not present simultaneously.
- Teletext or videotex: These are hybrid communications systems that use television technology in a variety of ways to make possible access on demand to stored information. These systems offer flexibility in selecting and viewing the information.
- Slow scan (freeze frame): This system allows still pictures to be transmitted over narrowband channels such as the regular telephone network and displayed on monitors in remote locations. In case of transmission (of participants, visual aids, or objects) over the regular telephone network, transmission times range from 6 sec for low-resolution black-and-white pictures to 5 min for high-quality color.

Broadband systems include

- Slow-scan video: It is the same system described under narrowband systems; it is often categorized as a broadband system because it uses broadband transmission.
- Interactive cable television: It is a mass communication medium with various capabilities and flexibility for audience involvement.
- Video teleconferencing: Capabilities include full-motion (compressed and noncompressed) and completely interactive television linking participants on a point-to-point basis and full-motion point-to-multipoint transmission coupled with interactive audio capability. Transmission is via microwave, coaxial cable, cable television system, and satellites. Widespread availability of fiber optics would increase the options for signal transmission.

Recently, videoconference systems have improved significantly as a result of technology that reduces transmission capacity (requirements) and cost. Satellite-based videoconference systems for domestic, transborder, and international communications were introduced in commercial services in the early 1980s. International teleconferencing has also become technically advanced because of specially designed picture-processing and signal compression equipment (i.e., codec) that overcomes the difficulty of different videoconference equipment standards in North America and Europe.

Future developments in teleconference technology include full audio stereo transmission with close approximation of physical presence, high-speed document transfer, and integrated graphics projection; compression techniques applied to freeze-frame video and associated autographic systems; higher-power high-capacity satellites; improved small-sized earth stations close to end users; time division multiple access (TDMA) for satellite capacity use; multipoint (many-to-many) videoconferencing; more efficient video compression devices; high-quality video (resolution) and stereo sound; life-sized screen projection; regular satellite access by most organizations; high-capacity local lines; availability of conference rooms with minimum access time; mobile facilities at short lead times; computer and videotex applications in video conferencing; and fiber optics (e.g., digital fiber optics systems for long-haul transmission) *(1)*.

Also, developments in automated offices (including audiographic work stations with desk-to-desk or desk-to-conference room teleconferencing, voice recognition, and numerous other innovations), mobile telephones, local area networks (LANs), digital communications, and the Integrated Services Digital Network (ISDN) in association with satellite techniques (for voice, data, and video services) will result in further advances in telecommunications *(1)*.

Improved quality, reduced cost, increased availability, and increased convenience of telecommunications services are likely to enhance travel substitution potential. Stimulation of travel, although to a lesser extent than substitution, is also probable. Until now, and even at present, a number of constraints (e.g., the high cost of videoconferencing) have inhibited the growth of teleconferencing. Further developments in technology coupled with favorable developments in other factors are likely to make widespread use of teleconferencing practical. Furthermore, the current "technology push" as well as "market pull" are expected to accelerate acceptance of teleconferencing.

INSTITUTIONAL AND REGULATORY FACTORS

A number of favorable developments in institutional factors are contributing to increased availability of teleconference systems. These include (a) ease of transborder transmission; (b) sharing of satellite capacities between Canada and the United States; operating agreements (transborder, international); and (c) cooperation of the post, telephone, and telegraph agencies in Europe with Teleglobe Canada and U.S. carriers. A number of institutional constraints, however, still remain.

Regulatory policies in Canada and the United States have already influenced the development of teleconferencing services (e.g., terminal attachment and interconnect decisions). A more competitive environment, as the result of deregulation or regulatory reform, could result in diversified, improved service at reduced cost. Future policy developments in Canada with respect to long-haul versus short-haul rates, satellite rates and capacity allocations, further interconnect activities, relaxed market entry, and other pro-competitive regulatory reforms are likely to contribute to growth of teleconference systems.

Support structures in the form of integrated sets of activities can help to promote successful applications and the integration of teleconferencing into an organization. Examples include software development, training, and promotional activities. Such activities are already under way. Favorable institutional and policy developments would enhance the environment for successful support structures.

ACTUAL EXPERIENCE, SURVEYS, AND DEMONSTRATIONS

There is a trend toward increased use of teleconferencing. A majority of user companies surveyed plan to increase their use of teleconference systems in the near future. In Ontario, about 72 percent of companies surveyed use some form of teleconferencing *(5)*. Sixteen percent of Ontario users of teleconference systems use computer conference or electronic mail. Estimates for slow-scan and videoconference systems are not available. However, these are believed to account for a relatively small percentage of use *(6)*. Audio teleconferencing installations and usage exceed those of all other electronic modes of conferencing. Freeze-frame and videoconference facilities have been installed in a small number of public and private locations. The use of private facilities of this type is rather limited whereas trends in the use of public services are relatively more pronounced *(6)*.

Revenue derived by telecommunications carriers from teleconferencing, as a percentage of total income, is about 1 percent. For a number of interrelated reasons, including lack of aggressive marketing and high cost, full-motion, compressed videoconference services of telecommunication carriers have not been used extensively in the past. Their usage is expected to grow in the future as a result of technical and cost improvements. Users of teleconferencing, ranked on the basis of their use, are business, governments (federal and provincial), universities, service industry (banks etc.), and the residential sector *(1)*. The typical user firm in Ontario is large, with six to ten branches and 500 to 1,000 employees.

Teleconferencing, according to the Ontario survey of companies, is used by almost all administrative and finance departments (92 percent) and is also used extensively by marketing and sales groups (77 percent). About 50 percent of all user firms suggest that their personnel, data processing, production, and engineering research departments use teleconferencing. Teleconferencing is also heavily used for information exchange (92 percent of users). Specifically, a majority of users use teleconferencing for problem solving (66 percent) and planning (58 percent). Other uses are committee and staff meetings (42 percent) and inspection or supervision and training (21 percent) *(5, 6)*.

A survey of North American organizations carried out by the University of Michigan revealed that travel costs of respondents had decreased as a result of teleconferencing *(7)*. Survey results obtained from the Ontario study suggest that about 25 percent of teleconference users are experiencing a drop in travel, which is attributable to teleconferencing. On the other hand, 2 percent of users see an increase in business travel as a result of teleconferencing. For those who indicated a reduction in trip making, the average decrease in business travel amounted to about 20 percent *(5)*.

TRADE-OFFS

Modal Attributes

Attributes considered by consumers in assessing the perceived desirability of travel versus teleconferencing are given in Table 1. The same attributes are likely to be considered in travel stimulation decisions. Cost of air travel by Canadian trunk carriers has been increasing, since 1971, at a rate that is slightly lower than the consumer price index. Regional air carriers have experienced cost increases that are greater than general inflation since 1979 (Figure 2). During the 1980s, air fares are expected to reflect the effects of a large number of factors including a competitive environment resulting from deregulation policies and stable fuel prices. Here it is assumed that air fares, in constant dollars, will decline by about 10 percent by the end of the decade. During the 1990–2000 period, fares are likely to rise again in real terms as a result of increases in fuel and aircraft (capital) costs. Other costs incurred during travel, namely accommodation, meals, and local transportation charges, are assumed to grow at the level of general inflation.

The influence of technology in reducing the cost of telecommunications has already been noted. The likely trend is exemplified by the international telephone charges shown in Figure 2. In the case of domestic intercity business telephone charges, the drop in price has not been as impressive as for international service because of the distance factor and possibly

TABLE 1 SELECTED ATTRIBUTES OF TRANSPORTATION AND TELECOMMUNICATIONS (level-of-service variables)

	Transportation	Telecommunications (teleconferencing)
Cost to user	Door-to-door travel, accommodation, and meals	Service including access to and egress from studios
Time	Total door-to-door travel time, layover time during normal working hours, and meeting time[a]	Travel time to and from public studio, waiting time (if applicable), and conference time[a]
Service availability	Availability of service on demand (probability of getting service at desired time, frequency, convenient departure and arrival times)	Availability of service on demand (probability of getting at desired time), availability of required features of service (e.g., graphics capability)
Comfort and convenience	Comfort—seating comfort and availability, access and egress comfort, service reliability (on-time arrival), changing vehicle (transfer)	Studio design for user physical and psychological comfort, service reliability (reliability of equipment), quality and capability of service

[a]Time spent in a teleconference meeting is generally less than that spent in a face-to-face meeting.

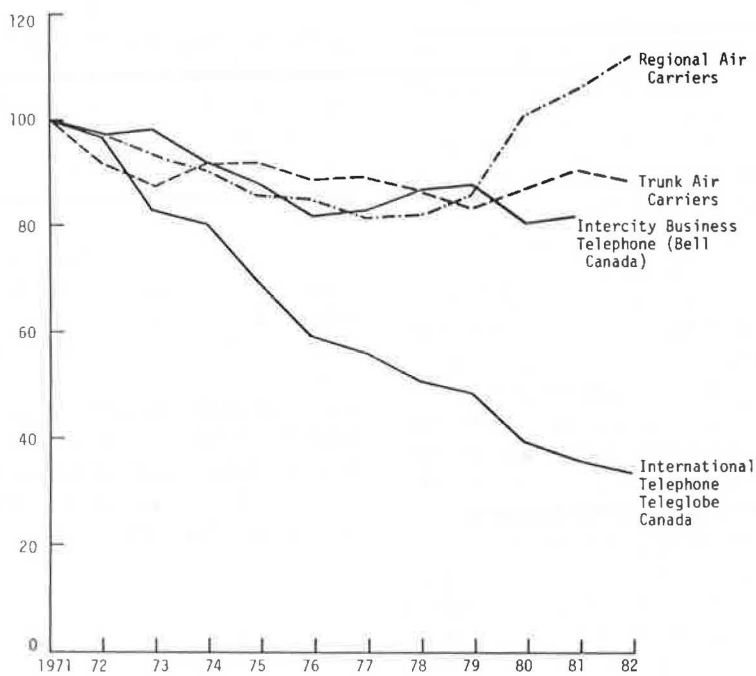

FIGURE 2 Changes in unit revenue of air carriers and price of telecommunication services (in constant dollars, 1971 = 100).

the practice of cross-subsidizing urban services from the overall revenues of the carriers. In the United States increased competition and the use of modern technology have resulted in reduced intercity business rates.

The cost of teleconferencing is likely to drop in the future. Transmission costs, which account for about 50 percent of total end-to-end costs, are expected to be about one-third of their 1985 level (in constant dollars) by the end of the decade. Consequently, teleconference charges in 1990 would be two-thirds of their 1984–1985 level. During the 1990–1995 period, other cost reductions are expected as a result of increased use of facilities (resulting from increased traffic) and shared use of local and space segment components. Therefore teleconference charges in 1995 are projected to be 50 percent of the 1985 tariff (in real dollars). For the 1995–2000 period, no further cost reductions are projected.

Table 1 gives three components of time related to in-person meetings. Among these, travel time and layover (business hours) time are generally the most pronounced. For instance, depending on travel distance, a 4-hr business meeting could easily necessitate a 2-day absence from the office. Studies show that most managers spend as much as 8 percent of their time in travel to meetings. Also, as much as 50 percent of a manager's time is spent in scheduled meetings. Because teleconferences are better organized and take less time per meeting, a manager need not spend as much time teleconferencing as would be required for in-person meetings.

As for access to public studios, there have been conflicting reports about the inconvenience encountered by customers. A recent survey by Teleglobe Canada contradicts findings of other studies by suggesting that a centrally located accessible studio would not be a constraint to the use of teleconferencing. It was found that 70 percent of respondents would use a conveniently located studio *(8)*. Because of the up-front investment required for private facilities, the option of developing in-house studios is not attractive. Also, local video wideband networks, which would be required to serve customer premises, are scarce.

Service availability is a significant attribute of teleconferencing. Although, in theory, arranging a teleconference takes less time, the availability of desired facilities could be a problem. According to Teleglobe Canada studies, about 40 percent of all business meetings involve the exchange of documents, and 65 percent of such meetings require that information be presented visually. Teleconference facilities therefore must be well equipped with conference support equipment for maximum effectiveness.

Comfort, convenience, and reliability attributes of teleconference systems have been improving because substantial research, development, design, and planning efforts have been focused on technical and human factors. Also, human factors are becoming favorable to teleconferencing because technical and managerial personnel are becoming increasingly familiar with computers and communications. The same cannot be said of air travel. It is becoming difficult to maintain a level of service attractive to the business traveler because of increasing congestion at busy airports and on access and egress facilities.

Benefits of Teleconferencing

The benefits of teleconferencing have become better known through research studies and demonstrations. Productivity improvements result from time savings and, possibly, efficient communications. Meetings conducted as teleconferences are shorter, better organized, and arranged at shorter notice than are face-to-face in-person meetings. Teleconferencing allows communication when in-person meeting is infeasible (e.g., urgent decision required). For a number of tasks, teleconferencing is a reasonable simulator of in-person meetings. Faster decision making and easy access to additional resource persons are among the highly valued benefits of teleconferencing. It can be used for improved planning for in-person meetings, and rapid follow-up meetings can be arranged for the implementation of decisions.

For multibranch organizations, the quality and quantity of communications among branch offices and between branch offices and headquarters can be enhanced. Teleconferencing makes possible improved control by management in central (headquarters) locations over branch operations. Participation of employees in dispersed offices is made possible by teleconferencing at reasonable cost—which is likely to strengthen their commitment to the organization.

Travel costs and associated inconveniences can be reduced under appropriate circumstances and conditions. According to the Teleglobe Canada survey of organizations in Ontario and Quebec, the travel cost savings benefit of teleconferencing was considered the most important criterion for selection of this mode by 97 percent of respondents. In relative terms, 82 percent of respondents credited teleconferencing with saving travel time and thereby enhancing productivity *(9)*. It offers opportunities for professional education and training, integration with other automated office technologies, planned decentralization of organizations and land use developments, energy conservation, enhanced communication with sales personnel, and marketing. User companies could enhance their image as innovators, and governments could extend their services on a cost-effective basis through the applications of teleconferencing *(10)*.

A number of disadvantages have been perceived: lack of personal interaction that may be regarded as essential for

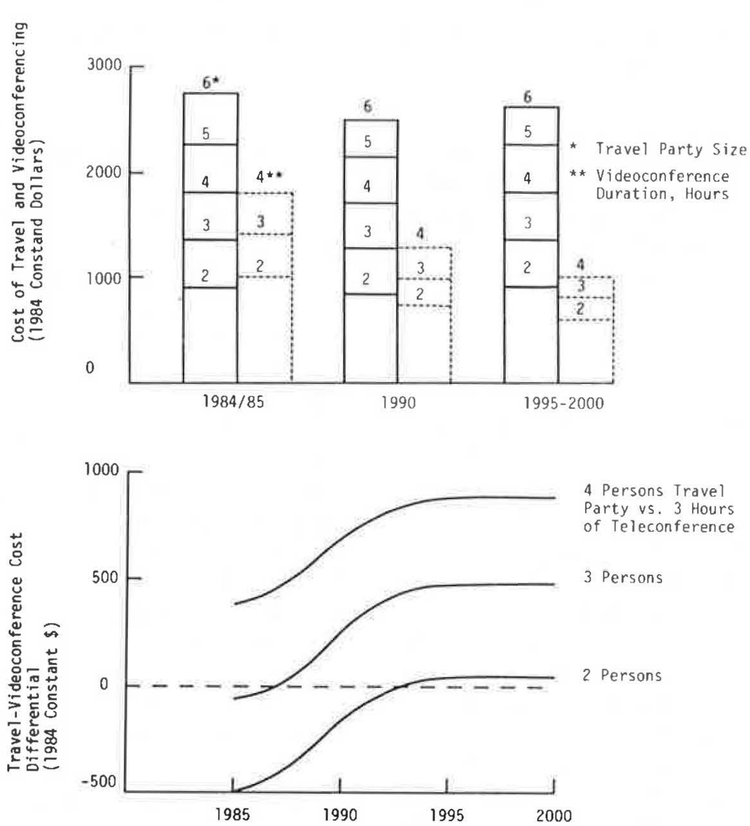

FIGURE 3 Travel versus teleconference cost differential, Toronto-Montreal.

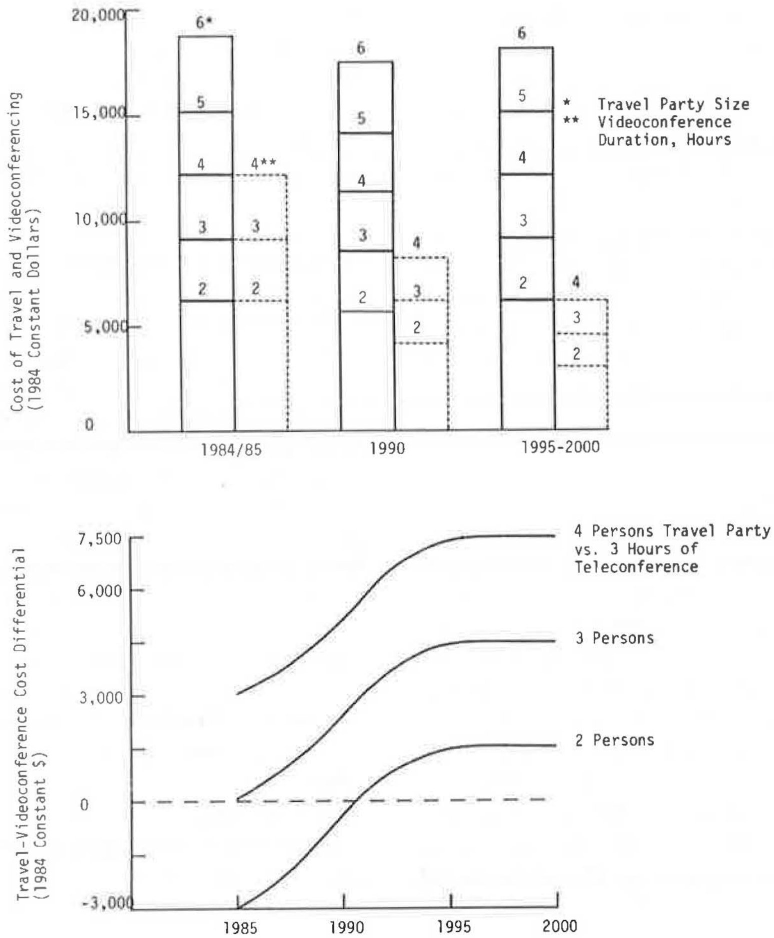

FIGURE 4 Travel versus videoconference cost differential, Toronto-London, England.

improvement and morale, working relationships, and the like; lack of social or recreational opportunities at destination, which are a by-product of travel; a feeling of frustration with teleconferencing; and perceived limitation of level of exchange for some tasks—given the quality of available systems.

Service and Cost Differentials

Cost and service (including time) are perceived by potential users of teleconferencing as its most important attributes. This implies that cost and service differentials are the most important determinants of travel substitution decisions. Cost and service differentials between air travel and teleconferencing are analyzed for selected travel routes. Generalized costs of air travel and teleconferencing are computed and compared for 1985, 1990, 1995, and 2000 (Figures 3 and 4). Cost projections were made according to the analyses presented earlier. Generalized cost differences were developed by including time costs and costs of accommodation and meals.

As expected, the cost difference between travel and teleconferencing increases over time because of a relative decrease in teleconference costs. Sample results shown in Figures 3 and 4 indicate that, at the 1985 level, teleconferencing does not yield economic benefits. However, the economic desirability of teleconferencing increases over time. For a given year, generalized cost savings increase because of an increase in the size of the travel party. At the 1984–1985 tariff levels, teleconferencing costs more than travel in the case of a 3-hr teleconference vis-à-vis travel by two persons. As the size of the travel party increases, economic benefits become much more pronounced for long-haul routes than for short-haul corridors.

North-South travel in Canada by scheduled air service on low-density routes is quite costly. In those cases in which charter air services are the only means of travel, costs are even higher. Because a high proportion of travel to and from northern Canadian regions is for business purposes, including government and institutional travel, the substitution of teleconferencing for a part of such travel would likely result in substantial monetary savings. Other factors, such as enhanced communications resulting from more frequent teleconferences and the avoidance of inconveniences associated with travel, would provide further incentives to substitute telecommunications for part of travel.

CONCLUDING REMARKS

Prediction of the extent of substitution and stimulation is fraught with risk because of the complex nature of these

TABLE 2 EFFECTIVENESS OF COMMUNICATION MEDIA AS INDICATED BY LABORATORY AND FIELD TESTS

Type of Communication	Two-Way Audio	Two-Way Audio Plus Graphics	Two-Way Audio, One-Way Video	Two-Way Audio Plus Video	Face-to-Face
Intraorganization (mostly acquaintances)					
Operating discussions	High	High	High	Very high	Best
Executive discussions	Low	Average	Average	High	Best
Interorganization (mostly strangers)					
Operating discussions	Low	Average	High	High	Best
Executive discussions	Very low	Low	Low	Average	Best

behavioral phenomena. Although the technology of telecommunications is far from mature, there is significant evidence of user satisfaction (Table 2) even in its present form. The economic and general availability attributes are, however, not favorable at this time. Also, efforts of telecommunications carriers to promote and market their teleconference services are relatively low keyed in comparison with those of air carriers. Consequently, it is hardly surprising that there is limited actual experience with the effects of teleconferencing on air travel demand.

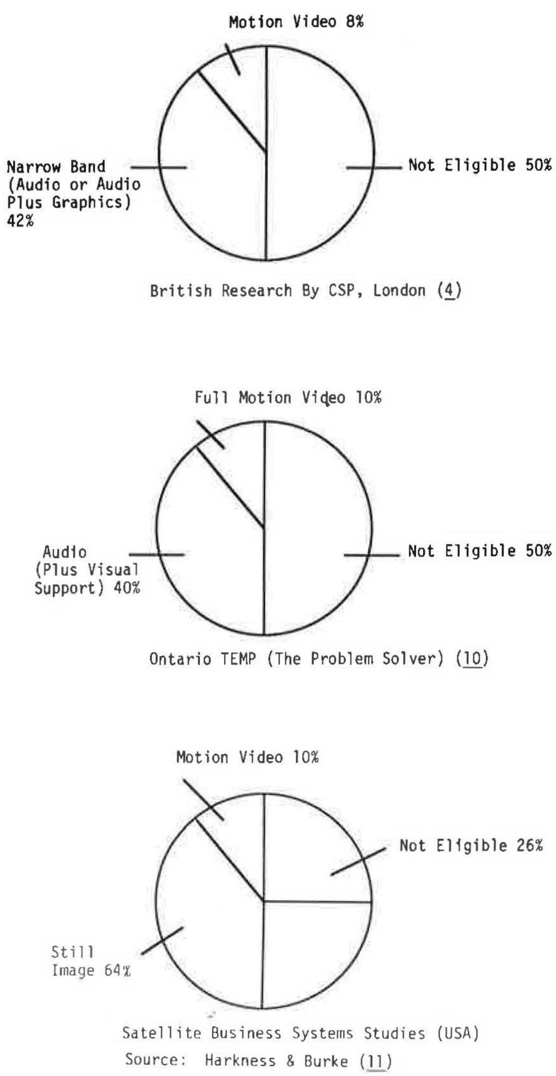

FIGURE 5 Behavioral eligibility of meetings.

Analyses and survey data reported in this paper provide a sufficient basis for stating that, under favorable conditions in the future, teleconferencing is likely to replace some air travel and that stimulation of travel is also likely to occur—although to a lesser extent. This research also provides a reasonable basis for discussion of the extent of travel impacts, although formal analytical models cannot be developed because there has been insufficient experience with communication mode choice decisions. Analysis of the generalized cost differential of travel versus videoconferencing suggests that, on the basis of projected economic benefits (i.e., savings), travel substitution is probable (Figures 3 and 4).

Numerous laboratory and field observations are consistent about the substitutability of teleconference systems for in-person face-to-face meetings (Figure 5). About 10 percent of all business meetings could be carried out effectively by videoconferencing. Because videoconferencing is an effective simulator of face-to-face meetings, it is probable that 10 percent of business meetings may not require travel.

Surveys of attitudes suggest that the upper limit of the level of substitution is 20 to 25 percent of business travel. The upper limit for the stimulation of business travel is 2 percent of base travel. It is believed that the reliability of attitudinal survey results in the "real world" is about 50 percent. These estimates obtained from attitudinal surveys should be reduced by a factor of 2. There is another reason for reducing the extent of replaced travel suggested by surveys: research indicates that 50 to 60 percent of participants in teleconferencing would not have been present if an in-person meeting (involving travel) had taken place.

Ad hoc teleconferencing (point to multipoint) is expected to have differential effects on air travel. Although travel substitution is likely on trunk routes, feeder air links would experience stimulation of travel due to travel by participants to teleconference sites.

On the basis of the foregoing, it is projected that teleconferencing may substitute for as much as 11 percent of busness travel by air. A 1 percent level of stimulation of business travel is projected for the air mode. The balance of substituted and stimulated trips leads to an upper limit of 10 percent of business travel replaced by teleconferencing. The profiles of cost differentials and market penetration of teleconference systems suggest that the curve of growth of replaced travel will be S-shaped. Travel replacement is likely to be phased—taking as much as two decades to reach its potential and, of course, subject to technological developments described in this paper and marketing and promotional efforts of the carriers.

ACKNOWLEDGMENTS

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Recommended Regional Economic Impact Procedures for Aviation-Related Projects

DOUGLAS S. MCLEOD

In this paper is presented a stepwise system, in descending order, based on sales, payroll, and employees for measuring the regional economic impact of aviation-related projects. The procedure is based on the Regional Input-Output Modeling System (RIMS II) developed by the U.S. Department of Commerce. Also presented are a brief discussion of the RIMS II methodology, general issues associated with aviation-related economic impact studies, an overview of all major studies using RIMS II multipliers, and recommended procedures for future studies. Every agency, or their lead consultants, that had completed or was conducting a major aviation-related economic study with RIMS II responded to a questionnaire used to gather information for this paper. Every respondent reported overall satisfaction with RIMS II. Input-output analysis is the preferred technique for evaluating regional economic impacts of business activity. Developmental problems associated with input-output analysis have been overcome with the development of RIMS II. Since 1983 the RIMS II multiplier methodology has become the dominant economic impact methodology for evaluating regional aviation impacts. In March 1986, 10 major aviation economic studies encompassing 30 primary commercial service and more than 200 general aviation airports were under way or completed. Because the application of RIMS II multipliers to the aviation industry is so recent, discussion and more precise guidelines on the use of the methodology as applied directly to the aviation industry are needed.

A wide variety of approaches has been employed to determine regional economic impacts of aviation-related activities. These approaches range from use of generalized economic multiplier numbers to input-output analysis. The most highly regarded and technically accurate of these approaches is input-output analysis. For instance, the Federal Aviation Administration (FAA) has stated that "the most reasonable technique (and, according to some authorities the only theoretically valid approach) to derive regional or subregional multipliers appears to be the application of an input-output transaction matrix developed for the local economy" *(1)*. The use of input-output analysis for developing local and regional economic impact studies has been retarded by the high costs associated with developing the transaction matrix, the vast data requirements, and the inappropriateness of using the coefficients developed for one region to calculate the impacts of activity in another region *(1)*. However, all of these objections to using input-output analysis have been overcome with the development of the Regional Input-Output Modeling System (RIMS II) by the Regional Economic Analysis Division of the Bureau of Economic Analysis (BEA), U.S. Department of Commerce *(2)*.

Florida Department of Transportation, 605 Suwannee Street, Tallahassee, Fla. 32301.

RIMS II multipliers are intended to show total regional effects on industrial output and personal earnings for any county or group of contiguous counties in the United States and for any of the 531 industrial sectors in the 1977 BEA national input-output tables. Thus the application of RIMS II to the air transportation industrial sector (code 65.0500) and related sectors represents only a small element of RIMS II's total applicability. The first use of RIMS II multipliers in an aviation-related project was the Florida General Aviation Economic Assessment *(3)*. The Florida Department of Transportation considered that economic analysis a great success. Subsequently, in 1984, the Transportation Research Board published a paper *(4)* on the use of RIMS II and the Florida findings.

As the result of continued interest in demonstrating aviation's contribution to local economies and more widespread knowledge of RIMS II, the aviation industry is becoming one of the largest users of RIMS II multipliers. In March 1986, 10 major aviation economic studies encompassing 30 primary air carrier and more than 200 general aviation airports were under way or completed. Thus in a period of 3 years the RIMS II multiplier methodology has become the dominant economic impact methodology for evaluating regional aviation economic impacts. Because the application of RIMS II multipliers to the aviation industry is so recent, discussion and more precise guidelines on the use of the methodology as applied directly to the aviation industry are needed. In this paper four topics are addressed:

- Brief description of the RIMS II methodology,
- General issues associated with aviation-related economic impact procedures,
- Case studies and recommended procedures for the use of RIMS II, and
- Future developments associated with RIMS II.

Case studies and recommended procedures are emphasized most.

RIMS II METHODOLOGY

Economic analysis of aviation projects may be broken into three broad areas: financial analysis, economic efficiency (benefit-cost) analysis, and impact (earnings/employment/sales) analysis. RIMS II is ideally suited for impact analysis. It has no direct link with financial or economic efficiency analyses.

The RIMS II model is based on the 1977 national input-output model's technical coefficients (trade mixes) for 531 industries; however, the most recent year county earnings and income data are used in developing the RIMS II multipliers. Thus RIMS II multipliers are essentially updated to within 1 year of a study. Frequently questions arise about the appropriateness of applying a national model to a specific region and the appropriateness of using trade mixes based on a model approximately 10 years old. RIMS II is a regional model, designed specifically to address economic impacts at the regional level. Trade mixes among industries are based on national data; however, county-specific earnings and income data are used to develop the multipliers. RIMS II multipliers have a high degree of reliability compared with far more expensive full-state input-output studies *(2)*. Although the U.S. economy is dynamic and public opinion appears to be that the economy is volatile, structural changes involving trade mixes occur gradually. When updating RIMS II from the 1972 to the 1977 national input-output model, BEA found that technical coefficients for the vast majority of industries changed only slightly. These modest changes occurred during a period of perceived major national and worldwide economic upheavals.

RIMS II is the most nationally recognized regional input model, and there have been numerous professional papers and presentations that have used it in the field of regional economics. Therefore its use has a certain degree of creditability in the economic professional community. To many people untrained in regional economics, the RIMS II multipliers frequently appear low. For instances, rarely are RIMS II total multipliers (including the initial change in demand) higher than 3.0 or earnings multipliers higher than 0.8. Use of RIMS II's realistic multipliers gives further public creditability because of their apparently low values.

The RIMS II multipliers permit examination of the comparative impacts of aviation activity expenditures on any industrial sector, including the air transportation sector. As part of RIMS II, BEA through 1985 provided earnings multipliers, direct coefficients, and total multipliers. The earnings multipliers are the most important because they allow the calculation of earnings (income) and employment impacts, which are the best measures of economic value added from aviation-related activities. Total multipliers allow the calculation of changes in final demand and are analogous to output or sales multipliers. Direct coefficients allow the calculation of the sales impact of a change in final demand (e.g., $1 million) on any other industry.

In summary, there are three major advantages to applying RIMS II to aviation-related economic impact studies. First is creditability. RIMS II is the most nationally recognized economic impact model. Second is accuracy. RIMS II has been found to be quite reliable and is a highly disaggregated system both spatially and industrially. Third is cost. RIMS II multipliers are relatively inexpensive. Thus RIMS II is an excellent economic impact model; however, two limitations exist. First, RIMS II is a static model not a dynamic model. Consequently, the impact estimates generated by the system indicate the overall change that is likely to occur but not the timing of such a change. Second, the airline industry is aggregated with other aviation-related industries, which may not account for the substantially different economic impacts of the airline industry and the other aviation-related industries.

As applied to the aviation industry, the generalized RIMS II impact methodology developed by the author consists of seven major steps:

1. Determine the scope of analysis desired,
2. Determine the regional area or areas to be analyzed,
3. Determine the RIMS II code number for each economic activity to be analyzed,
4. Obtain economic data (usually sales or salary data from primary sources) on each economic activity to be analyzed,
5. Analyze and verify economic input data,
6. Apply RIMS II multipliers, and
7. Report economic impacts.

GENERAL ISSUES ASSOCIATED WITH AVIATION-RELATED ECONOMIC IMPACT STUDIES

Three general issues associated with aviation-related economic impact studies are discussed in this section:

1. The aviation industry's self-interest in promoting high economic benefits;
2. The use of generalized, high, unscientifically derived economic multipliers; and
3. Analysis conducted by analysts without a combined knowledge of aviation and regional economics.

The driving force of many aviation-related economic impact studies is associated with promotional, marketing, or public relations purposes, not technical impact analysis. These aviation studies are used to promote the economic benefits of airports, and thus sponsoring agencies have a self-interest in the results. Such self-interest may inadvertently result in the overstating of airports' or aviation's contributions to regional economies. Two areas in which aviation's contribution to regional economies are frequently exaggerated are the inclusion of indirect benefits (without proper documentation of assumptions) and the use of high economic multipliers.

Many aviation-related economic impact studies include air tourist expenditures and resulting multiplier impacts as benefits. Clearly airports and the aviation industry play a vital role in tourism. However, the actual driving force of the air tourist industry is consumer activity during the trip, such as visiting relatives or tourist attractions, not the trip itself or the airport where the trip originates or terminates. Airports, like highways and utilities, are part of a region's infrastructure. Tourists arriving by air also usually use a region's highways and utilities. There is virtually no more logic to assigning all air tourist expenditures in a region to the aviation industry than to the region's highway or utility industries. An analysis of the impacts of tourists arriving by air is appropriate to include in an aviation-related economic impact study if those impacts are clearly associated with tourists arriving by air and not combined with economic impacts directly associated with aviation-related expenditures. The two types of benefits should not be combined because air tourist expenditures are only indirectly linked to the aviation industry and double counting of benefits is likely to occur.

Poorly constructed economic multipliers are in widespread use throughout the United States. A change in final demand (e.g., $1 million in new sales) results in the respending of that money throughout a region. The respending of money results in economic multiplier impacts. Regional output or sales multipliers greater than 3.0 (inclusive of initial expenditure) are immediately suspect to most trained regional economists as are earnings or income multipliers greater than 1.0. Furthermore, economic multipliers vary substantially among industries and regions, and the use of common multipliers raises questions of technical accuracy.

The value added from economic activity is the primary benefit to regional economies. The economic concept of value added consists of payroll, proprietor's income, and taxes, of which payroll is usually the most significant. Reporting of earnings (income) or jobs is far more relevant in economic impact studies than are output (sales) values. Sales merely represent monetary transfers, not economic worth to a region. Although earnings values are more relevant to economic impact studies, sales values are frequently stressed (or at least given equal weight) because dollar values and economic multipliers are significantly higher for sales than for earnings.

The single most important technical discipline for an aviation-related economic impact study is regional economics. However, knowledge of aviation characteristics is also important because of unique aspects of the aviation industry. Unfortunately, seldom are those two technical backgrounds closely linked. This paper contains specific guidelines for conducting aviation-related economic studies; however, for a comprehensive study, a team consisting of a regional economist and a person knowledgeable about the aviation industry is desirable.

CASE STUDIES AND RECOMMENDED PROCEDURES

Major aviation-related economic studies are defined in this paper as encompassing a primary commercial service airport or a statewide system of general aviation (GA) airports. Major studies that have used RIMS II multipliers as their foundation are given in Table 1. Care should be exercised in reviewing consultant budgets in Table 1 because they represent significantly different project scopes and client agency involvement.

To develop the table, questionnaires were sent to the sponsoring agencies or their lead consultants, or both. The list of major studies was derived from the author's knowledge and contacts with BEA, sponsoring agencies, and their lead aviation economic consultants. Representatives of every agency or its lead consultants responded to the questionnaire or discussed their projects with the author.

One section of the questionnaire requested respondents to evaluate the use of RIMS II in their projects in terms of (a) applicability to project, (b) reasonable cost, (c) confidence in accuracy, (d) ease of use, and (e) overall satisfaction. Possible responses were excellent, good, fair, or poor. Responses to the questionnaire are given in Table 2. It is noteworthy that nearly all responses were in the good to excellent range and that there was a high degree of overall satisfaction with RIMS II.

The 10 major aviation economic studies are used as the basis for a discussion of RIMS II methodology steps and recommended procedures.

Determining the Scope of Analysis

Aviation-related economic impact studies need to clearly define what economic activities are to be included. A difficulty in evaluating economic impact analyses is multiple use of technical terms, specifically direct, indirect, and induced impacts. There are fundamental differences in these terms as used in most regional economic analyses and aviation-related economic studies, and even within aviation-related economic studies. BEA uses the terms "initial" changes in final demand, "direct" impacts on industries delivering output for the change in final demand, and "indirect" impacts resulting from production required to produce industries' direct requirements and regional production required to meet consumer demand *(14)*. This author, however, recommends the following groupings of terms that better reflect the terminology currently used in aviation-related regional economic studies.

1. Direct on-site, induced on-site, and total on-site economic impacts;
2. Direct off-site, induced off-site, and total off-site economic impacts;
3. Indirect tourist, induced tourist, and total tourist economic impacts; and
4. Indirect on-site, induced on-site, and total on-site economic impacts.

Direct economic impacts refer to the initial change in final demand (generally from business sales). Induced economic impacts refer to subsequent rounds of economic activity (the multiplier effect) resulting from the initial change in demand. Total economic impacts refer to the summation of direct (or indirect, whichever is relevant) and induced economic impacts. On-site and off-site refer to whether the direct economic impact occurred at an airport. Indirect economic impacts refer to the initial change in final demand as a result of other activities indirectly related to airports, such as expenditures by tourists and nonaviation-related business at airports.

The scope of a project may include one or more of these four economic groupings. It is recommended that each grouping be treated separately. Furthermore, great care must be taken before adding the results of the groupings because there is a high probability of double counting and irrelevancy between groupings. Analysts should also note the substantially different meaning of terms used in the aviation community and the more general regional economic professional community.

A project's scope should clearly state which of the four economic groupings will be included. If the economic impact study is of an airport, then a decision needs to be made about whether to include all activities at the airport or only those closely linked to the aviation industry. For on-site activities, many studies in Table 1 dealt only with on-site aviation-related businesses; on-site businesses not dependent on airport activity were excluded or addressed in significantly less detail. The other major type of aviation-related study is evaluation of aviation-related impacts, not simply airport-related impacts. The Pittsburgh analysis *(10)* is believed to be the most comprehensive regional aviation industry (off-airport-site) economic impact study. Examples of off-site aviation-related activities include such directly related activities as airplane manufacturing and less directly related activities such as travel agencies and hotels and motels, a percentage of whose sales is included in the analysis.

Many aviation-related economic impact studies include air tourist expenditures and resulting impacts as a benefit of airports. As was said earlier, inclusion of these indirect economic benefits is proper only if the assumptions made are clearly

TABLE 1 MAJOR AVIATION ECONOMIC STUDIES USING RIMS II MULTIPLIERS

Study Area	Date Completed (actual or scheduled)	Airports Analyzed: Primary Commercial Service	Airports Analyzed: Other (detailed/ indirectly)	Scope: On-Site Aviation Related	Scope: On-Site Nonaviation Related	Scope: Off-Site Aviation Related	Scope: Tourism	Primary Purpose of Study	Consultant Budget ($)
Florida (GA) *(3)*	1983		9/85±	X	X	X		Technical	50,000
Jacksonville *(5)*	1984	JAX	2/0	X	X			Marketing	10,000
West Virginia (GA) *(6)*	1984	CRW	0/36	X	X	X	X	Technical/ marketing	75,000
Colorado (GA) *(7)*	1985	DRO	17/66	X	X			Marketing	50,000
Anchorage *(8)*	1985	ANC	0/0	X		X	X	Technical	50,000
Washington, D.C. *(9)*	1986	BWI, DCA, IAD	0/0	X		X		Technical/ marketing	55,000
Pittsburgh *(10)*	1986	PIT	16/0	X	X	X	X	Technical/ marketing	55,000
Roanoke *(11)*	1986	ROA	0/0	X	X			Marketing	0
Virginia *(12)*	1986	DAN, PHF, CHO, LYH, RIC, ORF, HSP, SHD	40±/35±	X		X	X		115,000
Florida *(13)*	1986	MCO, MIA, TPA, MLB, PNS, TLH	20/105±	X	X		X	Marketing	70,000

NOTE: JAX = Jacksonville, Florida; CRW = Charleston, West Virginia; DRO = Durango, Colorado; ANC = Anchorage, Alaska; BWI = Baltimore, Maryland; DCA = Washington, D.C., National; IAD = Washington, D.C., Dulles; PIT = Pittsburgh, Pennsylvania; ROA = Roanoke, Virginia; DAN = Danville, Virginia; PHF = Newport News, Hampton Roads, Williamsburg, Virginia; CHO = Charlottesville, Virginia; LYH = Lynchburg, Virginia; RIC = Richmond, Williamsburg, Virginia; ORF = Norfolk, Virginia Beach, Williamsburg, Virginia; HSP = Hot Springs, Virginia; SHD = Shenandoah Valley Airport, Virginia; MCO = Orlando, Florida, International; MIA = Miami, Florida; TPA = Tampa, Saint Petersburg, Florida; MLB = Melbourne, Florida; PNS = Pensacola, Florida; TLH = Tallahassee, Florida.

TABLE 2 EVALUATION OF RIMS II USE

Study Area	Applicability to Project	Reasonable Cost	Confidence in Accuracy	Ease of Use	Overall Satisfaction
Florida (GA) *(3)*	Excellent	Good	Good	Good	Good
Jacksonville *(5)*	Excellent	Excellent	Excellent	Excellent	Excellent
West Virginia (GA) *(6)*	Excellent	Good	Good	Good	Good
Colorado (GA) *(7)*	Excellent	Excellent	Good	Excellent	Good
Anchorage *(8)*	Excellent				Excellent
Washington, D.C. *(9)*	Excellent	Excellent	Fair	Excellent	Good
Pittsburgh *(10)*	Excellent	Excellent	Good	Excellent	Excellent
Roanoke *(11)*	Excellent	Excellent	Fair	Excellent	Good
Virginia *(12)*[a]	–	–	–	–	–
Florida *(13)*	Excellent	Good	Good	Good	Good

[a]This study was not far enough along for researchers to be able to evaluate RIMS II.

presented and the benefits are separated from the benefits that result from direct expenditures. Although they vary significantly in the approach taken to tourist impact, the Pittsburgh *(10)* and the 1986 Florida *(13)* studies are good examples of the proper treatment of tourist impacts in aviation-related economic studies.

Determining Regional Areas To Be Analyzed

The delineation of appropriate regional boundaries is not precise. Factors that should be considered are what airport, group of airports, or industry is being analyzed; regional economic trade areas; possible other uses of the RIMS II multipliers; and the budget available to perform a study. A county is the smallest region to which RIMS II can be applied. RIMS II multipliers may be obtained for a grouping of counties if counties are contiguous.

RIMS II is essentially an economic model and therefore boundaries should be established by economic, not political, considerations. For many studies BEA recommends the use of Metropolitan Statistical Areas (MSAs) delineated by the Census Bureau. Primary air carrier airports usually serve an area larger than an MSA and thus expanded boundaries are justified. On the other hand, general aviation airports frequently serve smaller areas and populations, and, correspondingly, will usually result in smaller impacts per dollar of direct expenditure.

Frequently, there is a desire to determine economic impacts on a subcounty basis in aviation-related economic studies. For instance, impacts on the 5-mi area closest to an airport or on specific municipalities may be desired. RIMS II is not formulated to address those desires. An attempt may be made to use some form of percentage process using RIMS II multipliers as was done in the Washington and Pittsburgh studies *(9, 10)*; however, extreme caution must be used because of varying economic impact areas among industrial sectors (e.g., motel versus construction), location of employees (i.e., the household sector plays a major role in RIMS II multipliers and employee living patterns may be diverse), and other factors. BEA and this author do not recommend the use of economic impact analyses on a subcounty basis.

Indirectly related to determining regional boundaries is the question of what administrative level is most cost-effective in preparing these studies. As implied by the data in Table 1, the

RIMS II methodology is applicable to all aspects of the aviation industry, all sizes and types of airports, and all regions of the United States. Major studies to date indicate that studies using the RIMS II methodology can be conducted or managed at the local, regional, or state level; however, it is this author's opinion that the most cost-effective use of RIMS II is at the state or roughly comparable level (e.g., Metropolitan Washington Council of Governments, Southwestern Pennsylvania Regional Planning Commission). There are advantages to a state's conducting or managing aviation-related economic studies:

- Individual airports or regions can pool their economic resources to collectively perform economic studies at a fraction of the cost of individual studies because of economies of scale;
- Analyses are done in a consistent manner;
- A method of sampling airports that will reduce the number of individual airports to be analyzed can be determined; and
- If the analysis does not use consultants, a state is more likely to be able to form a knowledgeable team consisting of a regional economist and an aviation specialist.

In Florida *(3)*, West Virginia *(6)*, and Colorado *(7)* the RIMS II methodology was applied to general aviation airports throughout the respective states. Selected airports were analyzed and impacts for the statewide system were aggregated. In both the Florida *(3)* and the Colorado *(7)* studies, a high degree of correlation was found between based aircraft and aviation-related sales at airports. This correlation allows a quick estimate of the economic impact of any airport within those states. Also, with a transfer of technical knowledge from the consultant to agency staff about RIMS II, state personnel can conduct detailed studies at any individual airport relatively inexpensively.

The major airport economic impact studies conducted in the Pittsburgh, Jacksonville, Anchorage, and Roanoke areas clearly indicate that quality studies can be conducted for small to large primary commercial service airports. The Roanoke study *(11)* is especially interesting because it was the only study that did not use consultants, encompassed the smallest regional study area, had a low budget, and was conducted and managed by a planner without RIMS II experience. Local or regional governments desired these regional aviation economic studies and consequently they were funded through local or regional entities. However, there is similar logic for a state or comparable region to perform aviation economic impact studies where there are at least three primary commercial service airports. In the most recent Florida study *(13)*, 6 of the state's 18 primary commercial service airports are to receive detailed analyses, and, on the basis of correlation between enplanements and direct sales, the economic impact for all of the airports will be determined. It is believed that the Florida approach can result in an economic savings of at least two-thirds of the cost of airports conducting their own studies individually and will result in a consistent approach with higher-quality findings.

Determining RIMS II Code Numbers

To use the RIMS II multipliers, each economic activity to be evaluated must be identified and corresponding RIMS II code numbers determined. A listing of on-site businesses is generally available from airport managers. It is usually easy to determine what economic activity each business is engaged in; however, if uncertainty exists the business should be contacted. Accompanying the RIMS II multipliers, BEA routinely provides a table correlating the RIMS II code numbers (National Input-Output Table code numbers) with Standard Industrial Classification (SIC) numbers. Table 3 gives most business activities that will be encountered in aviation-related economic

TABLE 3 AVIATION RIMS II CODE NUMBERS

Business	RIMS II No.
Airport Management	
Administration	650500
Construction	
Runways	110400
Terminals	110202
Warehouses	110203
Airlines	650500
Fixed-based operators	
Aircraft servicing	650500
Aircraft rental	730107
Aerial spraying	400001
Federal facilities	
Air National Guard	780400
Air traffic control	650500
Airways facilities	650500
Armed forces	780400
Customs patrol	650500
Forestry Service	040000
Postal Service	780100
Weather Service	730300
On-site aviation-related	
Advertising	730200
Aircraft manufacturing	600100
Aircraft radio repair	720204
Aircraft sales (retail)	690200
Airport inspection	650701
Airport parking	750003
Airport security	730106
Airport terminal services	650500
Automobile rental	750001
Auxiliary aircraft parts manufacturing	600400
Aviation school	770402
Avionics manufacturing	620100
Avionics repair	730101
Barber shops	720300
Book stores	690200
Building maintenance and cleaning	730102
Coin-operated amusement	760206
Drinking places	740000
Drug stores	690200
Engine and propeller manufacturing	600200
Fire departments	790300
Flight insurance	770403
Florist shops	690200
Flying clubs	770403
Flying instruction	770403
Food services	690100
Freight forwarding	650701
Freight shipping	650701
Gift shops	690200
Hotels and motels	720100
News dealers	690200
Police department	790300
Repair shops	730101
Restaurants	740000
Transit service	650200
Tobacco shops	690200
Travel agents	650702

studies and can be used as a shortcut method for determining RIMS II code numbers.

Obtaining Economic Data

Having the RIMS II model available allows the analyst to devote a larger share of resources to that phase of the study that is most critical, the collection of primary economic data. To date all completed studies using the RIMS II methodology have obtained primary economic data through surveys. Although some of the RIMS II studies *(3, 7)* have devoted significant planning, manpower, project time, and financial resources to the acquisition of economic data, this phase remains the most significant obstacle to successful completion of a quality product.

The development, distribution, and collection of the surveys have varied by study, primarily reflecting consultant preferences. The survey instruments used have been generally adequate. Some were pretested *(3)* and others *(5, 7, 10)* reflected insights gained from previous RIMS II–based aviation studies. The surveys are generally short and can be answered relatively quickly. Some have been administered and collected by trained personnel from the airport manager's office *(5)*, state aviation staff *(3, 7)*, and consultants *(10)*. Other surveys were conducted by mail *(8)*. All featured, to various extents, personal follow-ups either by telephone or in person. Experience has shown that support of the surveys by airport managers is essential.

Survey response rates have been good, ranging from approximately 40 to 100 percent in the Jacksonville study *(5)*. The quality of responses has also been reported as high; however, this author believes that some of the quality of response ratings are exaggerated. From personal experience with well-thought-out, pretested surveys; proper airport manager support; advanced notice of the surveys; and well-trained and motivated survey takers, quality survey responses from on-site tenants cannot be expected to exceed 60 percent without follow-up. It is uncommon to exceed this value because of reluctance or refusal to complete the survey, lack of desire to complete the survey, tenant absence, a nonqualified person completing the survey, unavailability of requested information, or misunderstanding of questions. Only with extensive follow-up and airport management support can an analyst reasonably expect at least 80 percent of the tenants to provide quality information (e.g., 90 percent response rate and 90 percent useful responses) for a major aviation-related economic impact study. The survey effort also frequently consumes 50 to 75 percent of a project's duration.

It is this author's opinion that the major faults with the surveys are that they frequently request too much information, occasionally do not ask the most important question, and seldom indicate the reliability of responses. The RIMS II model, as well as the National Input-Output model, is driven by gross sales data. For most economic activities the most important figure to be obtained from the surveys is sales. It is usually that number (or a percentage associated with aviation economic activity) that is multiplied by RIMS II multipliers. As important as the sales number is, occasionally it is not requested in surveys.

The proper intent of most other survey questions is to reasonably verify the sales figure or to serve as fall-back numbers if a responder will not provide the sales figure or the sales figure is inappropriate. Proprietor's income (profits) equals sales value minus payroll expenditures, taxes, and other expenditures. Asking for profits on a voluntary questionnaire may be disastrous and is not recommended. However, sales will normally equal expenditures plus a reasonable profit margin. In the Colorado study *(7)* a 20 percent profit margin was used as a basis for comparison; if the stated sales were within plus or minus 20 percent of expenditures, the sales figure was used. If the sales figure varied by more than 20 percent, follow-up questions were asked.

Occasionally a business may be reluctant to supply sales or expenditure values but will supply either employee or payroll information. This employee and payroll information is useful if sales information is unacceptable, and it also serves as a check to verify sales and reliability of payroll expenditures (i.e., average wages may be out of line).

An example of a good survey is shown in Figure 1. It is brief and asks only essential sales, back-up, and follow-up information. If it is accompanied by an introductory letter, the survey form should require little effort or controversy to complete. Using a survey instrument similar to that shown in Figure 1 also allows the analyst to immediately and unobtrusively verify sales values provided. Then he or she may ask immediate follow-up questions if the surveys are personally collected or ask them later by telephone. An example of a good tourist survey instrument is found in the Pittsburgh study *(10)*, and good examples of numerous nontourist surveys are provided in the 1986 Florida study *(13)*.

Although surveys have been the exclusive source of primary economic information, opportunities exist to substantially reduce or eliminate the need for surveys. Eliminating or reducing survey efforts represents the greatest opportunity to reduce project costs. Potential sources of needed economic information include the airport manager's office and state departments of labor and commerce. Some airport managers routinely require tenants to supply information on any or all of the following: sales, employees, and payroll. If of sufficient quality, this information can be used directly.

All businesses with five or more employees are required to supply payroll data for social security. Given the high accuracy of those values, economic surveys would not be needed if the information could be obtained in an acceptable manner. The major concern is statutory prohibition against disclosure of information relating to specific businesses. However, the RIMS II model does not need to be based on individual business information; it requires information only on industrial sectors. Thus the disclosure problem can possibly be overcome by aggregating information on similar businesses. Other problems of using state department of labor information include initial coordination efforts and businesses with multiple locations in an area not being disaggregated by location. For instance, a car rental business may have six locations in a county, one of which is at an airport; however, there is no way to separate the airport location's economic activities. The Florida study *(13)* is to be based largely on state labor information with surveys supplementing that information. The success of the approach and the anticipated cost reductions have yet to be determined.

Numerous pitfalls exist in determining the economic impact of air tourists through surveys. None of the aviation-related economic studies using the RIMS II approach reflect the latest

Colorado Fixed-Based Operators Economic Survey

We would like the data to be for the 1983 CALENDAR YEAR. If your data are for a different time period, please indicate which months and year here:

____

1. Your name ______________________________
   Your business phone number ______________________________
   Your company's name ______________________________
   Your company's address ______________________________
   ____
   ____

2. Employment/payroll at your airport site:

   A. Total full-time equivalent positions (e.g., 40 hours per week, or 2,080 hours per year equal 1 full-time equivalent position)
   ____

   B. Total annual payroll for permanent and contract employees (include gross pay, social security, worker's compensation, and other directly related employee benefits) $ __________

3. What were your gross sales or revenue for the products/services you provide? $ __________

4. What was the cost of your major types of nonlabor purchases?
   $ __________

FIGURE 1 Example of economic survey.

research on air tourist survey techniques and analysis. This lack of highly sophisticated quality is primarily due to limited study budgets, limited time frames, and the relative importance of air tourist impacts to the overall scope of economic impact studies. Of the RIMS II studies that include indirect impacts of air tourists ascertained through surveys, the most comprehensive is the Pittsburgh study *(10)*.

In recognition of the high costs of tourist surveys and limited project budgets, the Florida study *(13)* approach makes use of Florida Department of Commerce *(15)* data on tourists and total expenditures and U.S. Travel Data Center *(16)* data on the breakdown of those expenditures. RIMS II multipliers can be applied to the values from these sources. If impacts of air tourists are desired, a reasonable estimate of tourists and expenditures is known, and either passenger surveys are not desired or a project budget is restricted, the Florida approach may be a viable option.

Analyzing Economic Input Data

After obtaining the initial economic data, analysts should evaluate the reasonableness of the data. From experience this author believes that for a major study it is desirable to have more than one analyst review and discuss the acceptability and subsequent application of economic data. Ideally the study team should consist of an economist knowledgeable about RIMS II, an aviation specialist, and a person knowledgeable about the business or businesses in question (e.g., survey taker, airport manager representative). Appropriate follow-up questions should be asked until the project team is satisfied that no further follow-up will yield beneficial results.

In general, sales values should be multiplied by RIMS II multipliers to determine economic impacts. The studies identified in Table 1 were properly based on business sales. However, because of specific business activity or lack of survey information, other economic information may be more appropriate. The following stepwise system, in descending order, based on sales, payroll, and employees, is recommended. The project team should evaluate the economic data and decide which process factor is the most appropriate.

1. Sales: For most businesses, this value should be used. Exceptions include airlines and businesses involved in airplane retail sales. When sales are known, the following assumptions can be made:

- Business—aircraft-servicing fixed-based operator (from survey),
- RIMS II code number—650500 (from Table 3),
- Sales—$100,000 (from survey), and
- RIMS II earnings multiplier for RIMS II Code Number 650500—0.6131 (from RIMS II tables; actual value will vary).

The earnings impact calculation is sales times earnings multiplier or $100,000 × 0.6131 = $61,310.

2. Payroll: This classification uses a Type 2 income multiplier to derive the sales for a particular business by applying RIMS II earnings and household direct coefficient multipliers. It should be used for most public enterprises and when sales figures are not provided. When payroll is known, the following assumptions can be made:

- Business—aircraft engine manufacturer (from survey),
- RIMS II code number—600100 (from Table 3),
- Sales—none provided (from survey),
- Payroll—$300,000 (from survey), and
- RIMS II earnings multiplier for RIMS II Code Number 600100—0.7120 (from RIMS II tables; actual value will vary).

The earnings impact calculation (Type 2 income multiplier procedure) includes the following steps:

- Obtain direct coefficient household multiplier for applicable RIMS II code number (600100) from RIMS II tables—0.3676 (actual number will vary),
- Calculate Type 2 income multiplier by dividing RIMS II earnings multiplier (0.7120) by direct coefficient household multiplier (0.3676) = 1.9369, and
- Determine earnings by multiplying payroll ($300,000) by Type 2 income multiplier (1.9369) = $581,070.

3. Employees: This process should be used only when the number of employees is provided or when a business does not complete a survey. Average-earnings-per-job values are applied to the real or estimated number of employees to determine payroll. When the actual or estimated number of employees is known, the following assumptions can be made:

- Business—aerial sprayer (from survey),
- RIMS II code number—400001 (from Table 3),
- Business refused to answer survey,
- Employees (airport manager or other knowledgeable person estimates how many employees work for aerial sprayer)—three, and
- RIMS II earnings multiplier for RIMS II Code Number 010100—0.5662 (from RIMS II tables; actual value will vary).

The earnings impact calculation (Type 2 income multiplier procedures) includes the following:

- Obtain direct coefficient household multiplier for applicable RIMS II code number (400001) from RIMS II tables—0.2619 (actual number will vary),
- Calculate Type 2 income multiplier by dividing RIMS II earnings multiplier (0.5662) by direct coefficient household multiplier (0.2619) = 2.1619,
- Obtain average-earnings-per-job value—$15,000 (actual value to be obtained from state department of commerce),
- Determine payroll by multiplying the estimated number of employees (three) times the average-earnings-per-job value ($15,000) = $45,000, and
- Determine earnings by multiplying payroll ($45,000) by Type 2 income multiplier (2.1619) = $97,286.

Then the procedure in Process 2 is followed.

Two procedural matters should be addressed early in any major aviation-related economic study:

1. How to handle capital improvements and
2. How to handle businesses that were operating during the study but subsequently ceased operations.

Capital investment costs are generally more volatile than sales. For instance, an airport may fund a new runway one year and have relatively minor capital improvements during the next 10 years. Under these circumstances, should these capital investments be spread over a period of years or should they reflect only the year under study? Spreading capital expenditures over time gives a truer picture of the economic impact of an airport or aviation industry for a longer period. However, using only capital improvement costs for the study year is consistent with economic data obtained for the rest of the study. Most aviation-related economic studies did not address this question and subsequently the single-year approach was used. The Colorado study *(7)* was the first to address the question early in the study, and it was decided to average airport capital improvements over the most recent 5-year period.

Most aviation-related economic studies using RIMS II have been conservative in not including any economic impact from firms that went out of business during or after the study year. However, if a business had a relatively moderate to large earnings impact, the study team may desire to estimate that impact. In the Jacksonville study *(5)* a major airline ceased operations late in the study year. The study team subsequently estimated impacts based on the proportion of enplaned passengers of other comparable airlines operating in Jacksonville at the time.

Applying RIMS II Multipliers

With the sales, expenditures, payroll, or employees figures obtained from the previous step, economic impacts of earnings and sales can be readily calculated. Relatively simple computer spreadsheet programs can be developed *(10)* to perform algebraic calculations, group businesses by industrial classification or airport location, or perform other desired functions.

Applying RIMS II multipliers to sales is a straightforward process as shown earlier. Applying RIMS II multipliers when only payroll is given involves calculating a Type 2 income multiplier by dividing the RIMS II earnings multiplier by the direct coefficient household multiplier for the industry. Until 1986 BEA routinely provided direct coefficient multipliers; however, because of business disclosure problems, BEA no longer supplies these numbers for a region. When requesting RIMS II multipliers from BEA, the project manager should discuss with BEA the possibility of obtaining direct coefficients for households or other surrogate values.

Applying RIMS II multipliers to a number of employees involves the further outside step of obtaining average-earnings-per-job or surrogate values for various industries and the region as a whole. The availability of such information varies; the state department of commerce is frequently the major source. Obtaining average-earnings-per-job information should begin early in the project to ensure its availability when the RIMS II multipliers are applied.

Reporting Economic Impacts

Reporting economic impacts primarily reflects the purpose of the study and the implications of the findings. As indicated in Table 1, the purposes of the major aviation-related economic studies were about equally divided between promotional/marketing and technical. However, as stated earlier, greater emphasis should be placed on earnings and employment impacts than on sales impacts. Correctly packaged, the earnings and employment impacts are effective public decision-making tools.

The most attractive and informative color brochure of the RIMS II aviation-related studies is the Colorado study *(7)*. Jacksonville's brief, attractive, one-color brochure *(5)* is a good example of an inexpensive public relations document.

FUTURE DEVELOPMENTS ASSOCIATED WITH RIMS II

In 1986 BEA began supplying RIMS II multipliers in an updated version. BEA has also developed a user handbook for RIMS II *(14)*. Updated RIMS II multipliers are revised total multipliers (overcoming a discrepancy of including the household sector), earnings multipliers, and new employment multipliers. The employment multipliers will make it easier to calculate employee impacts. Direct coefficients are no longer being supplied by BEA and therefore calculation of impacts based on payroll or employees will be more difficult. BEA is also considering further changes in the information provided.

A concern expressed by the earliest users of RIMS II for aviation-related economic studies was the aggregation of much of the aviation industry and related industries. However, since 1985, automobile rental, freight forwarding, and travel agents have had distinct sets of RIMS II multipliers. The remaining large industry that has not been disaggregated is the airline industry. This author currently recommends the use of payroll to determine economic impacts of the airline industry because of perceived inaccuracies of applying relatively high airline sales data to the RIMS II multipliers. Discrepancies in using sales data arise largely because of airports that serve as hubs and the location of main offices. For instance, U.S. Air's ticket sales have significantly different impacts at the Jacksonville airport; the Pittsburgh airport, which is a hub for U.S. Air; and in Washington, D.C., U.S. Air's national headquarters. Under these circumstances payroll is a far better measure to which to apply RIMS multipliers than are sales. BEA has expressed an interest in cooperating with the aviation industry to provide separate multipliers for the airline industry. As more studies are completed, it may become possible to generate such a set of multipliers.

CONCLUSION

RIMS II is ideally suited to evaluating regional economic impacts. Since 1983 the RIMS II multiplier methodology has become the most highly regarded and dominant economic impact methodology used to evaluate regional economic impacts of aviation. It has been used on the complete spectrum of airports from small general aviation facilities to some of the nation's largest primary commercial service airports, from an individual county level to a state level, and from Florida to Alaska. Every agency or its consultants who used RIMS II multipliers reported overall satisfaction.

As with any new methodology, discussions and more precise guidelines on use are needed. It is hoped that this paper and continuing improvements by BEA will assist the aviation community to perform more technically sound and cost-effective economic impact studies.

ACKNOWLEDGMENTS

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Air Cargo: Impacts of Adapting to Deregulation

CLINTON V. OSTER, JR., AND ROBIN MILES-MCLEAN

In November 1977, legislation was enacted to dismantle nearly all economic regulation of the air cargo industry. The resulting deregulation has had important impacts on the air cargo industry. Rates are almost certainly lower than they would have been under continued regulation, and the range of rate and service offerings has expanded. Service patterns have changed as major passenger airlines have withdrawn their freighters from service and begun to rely on belly cargo. Passenger route networks have been restructured in response to increased competition in passenger markets. Faced with changing rates and service patterns, shippers have placed increased reliance on freight forwarders. Some of the larger freight forwarders have responded to new freedoms and opportunities by acquiring and operating their own cargo aircraft, developing hub-and-spoke route networks, and entering the rapidly growing package express market. All-cargo carriers have been hurt by the combination of downward pressure on rates caused by unused belly cargo capacity and the new aircraft operations of the larger freight forwarders. Both all-cargo carriers and package express carriers face increased competition for second-day service from belly cargo in passenger aircraft, particularly because recent consolidations of passenger airlines have resulted in more comprehensive route networks served by a single carrier.

Congress deregulated the air cargo industry in November 1977, a year before the more highly publicized deregulation of the passenger airline industry. Passenger airline travel and air cargo are closely linked; more than 40 percent of both domestic and international air cargo is carried in the belly compartments of passenger aircraft. The air cargo industry has changed significantly since 1977, in large part because of deregulation's removal of constraints on competition but also because of other changes in the economic environment including passenger airline and motor carrier deregulation. Changes in the air cargo industry as it adapts to deregulation, some of the causes of these changes, and implications for future development of the industry are examined.

BACKGROUND

In a sense, the air cargo industry dates back to the 18th century; in 1783 air transport, in the form of a balloon, was used to carry mail across the English Channel. In another sense, the industry dates "only" to 1910, 7 years after the Wright brothers' first flight, when an airplane was used to carry a 60-lb bolt of silk from Dayton to Columbus, Ohio (for $71.20/lb) (*1*, p. 98). The modern air cargo industry, however, began after World War II when surplus transport aircraft and military pilots returning to civilian life coupled with a lack of regulatory restrictions made entry into the air cargo industry both inexpensive and easy. However, the combination of undercapitalization, limited managerial skills, highly variable profit potential in previously untested markets, and overcapacity of hundreds of new operations led to many bankruptcies (*2*).

Spurred by bankruptcies and other problems in the fledgling industry, the Civil Aeronautics Board (CAB) in 1947 adopted regulations for entry, routes, and rates for air cargo operations that were similar to the regulations that had been established for passenger airlines in 1938. Predictably, the period between 1947 and 1956 was one of consolidation through merger and bankruptcy. After 1956, no new all-cargo airlines were certificated although, unlike passenger airlines, the lack of new entrants was less the result of restrictive CAB policy than the absence of applicants (*2*).

In November 1977, legislation was enacted to dismantle nearly all of the air cargo economic regulation that had emerged during the 1940s. As had been the case with passenger airlines, the CAB had controlled which companies could carry air cargo, the routes each company could serve, and the rates charged for such service. Air cargo regulations also drew a sharp distinction between direct air carriers and freight forwarders. Freight forwarders, for example, were not permitted to own or operate aircraft, although after 1948 they were allowed to charter air transportation. Moreover, the regulations usually limited the geographic area within which surface transportation could be provided by air carriers and freight forwarders to within 25 mi of the airport that served as the origin or termination of the air portion of the trip. Surface carriers were generally prohibited from participating in air transportation (*3*).

There were, of course, some important exceptions to these regulations. For example, one large air freight forwarder, United Parcel Service, had obtained extensive trucking authority from the Interstate Commerce Commission (ICC). Also, similar to the commuter airline exemption in passenger service, many of the regulations did not apply to air carriers offering cargo service in small aircraft with payloads of less than 7,500 lb (*3*).

Despite steady growth from the mid-1960s to the early 1970s, evidence began to emerge that economic regulation was hindering the industry's performance. Some markets experienced a shortage of prime-time evening cargo capacity, and

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others had extremely low load factors in the bellies of passenger aircraft. In still other instances, restrictions on operating authority hindered efficient equipment use by preventing carriers from carrying freight on intermediate segments of their routes *(2)*. Restrictions on surface operations by direct air carriers and air freight forwarders hampered development of integrated surface and air transportation services.

The initial legislative proposals for regulatory reform of the air cargo industry were included in efforts aimed primarily at reducing regulation of passenger operations. In the congressional hearings and debate, almost all attention was focused on the passenger provisions with modest support for and only minor objections to air cargo reform. As the debate over passenger deregulation grew heated, the cargo provisions were removed and grafted onto a bill already in conference (H.R. 6010) that contained a series of miscellaneous aviation measures. That bill emerged from conference, was passed by both houses, and was signed by the president on November 9, 1977, almost a year before passenger airline deregulation was enacted. The principal features of the new law (P.L. 95-163) opened entry into the industry after a brief transition period; freed the industry from price controls with the usual caveat that prices could not be discriminatory, preferential, prejudicial, or predatory; and removed the major barriers to the development of integrated surface and air transportation services *(3)*.

POSTDEREGULATION TRENDS IN AIR CARGO

Assessing the impacts of air cargo deregulation is complicated by the dramatic fuel price increases that followed the Iranian revolution in 1979 and by the severe economic recessions in 1980 and 1981–1982. Passenger airline deregulation in 1978 also influenced the cargo industry as airlines adjusted passenger operations, and associated belly cargo capacity, to a more competitive environment. Moreover, motor carriers, the primary competition for many segments of the domestic air cargo market, were substantially deregulated in 1980 with resulting shifts in both the patterns of motor carrier service and the rates charged for such service *(4)*. As a result of all of these influences, the air cargo industry and indeed most other segments of the transportation industry are still in transition to a more competitive environment. Although it may be too soon to determine the eventual impacts of deregulation on the air cargo industry, several important trends have begun to emerge.

Rise of Package Express

Overnight service for letters, documents, and other small packages existed before deregulation, but much of its recent growth can be attributed to removal of regulatory restrictions. Federal Express, the largest provider of such package express service, started operations in 1973 using small jet aircraft with cargo capacities that were less than the CAB's 7,500-lb limit and thus exempt from CAB entry, route, and rate restrictions. The exemption from entry and route restrictions allowed Federal Express to build a hub-and-spoke route system. Without deregulation, however, Federal's growth might have been hampered had they been unable to take advantage of the operating economies of larger aircraft as their package volumes grew. Indeed, by the end of 1985, Federal Express no longer operated any of the small-sized jets with which it had started; its fleet of aircraft had grown to include 11 DC-10s, 18 B-727-200s, and 35 B-727-100s *(5)*.

Deregulation has also permitted new methods of operating by other companies offering package express service. Companies such as Emery, Purolator, and Airborne started as freight forwarders and, under regulation, were prohibited from operating their own aircraft. As discussed in more detail later, each of these carriers developed a hub-and-spoke route system after deregulation to avoid being forced to rely on a patchwork of offerings by other carriers. Each operates fleets similar to Federal's. Purolator, for example, uses B-727-100s and DC-9s *(6)*, and Emery uses primarily B-727-100s and DC-8s *(7)*.

The package express segment of the air cargo industry has received widespread attention in the years since deregulation. One reason, of course, is the extensive public media campaign launched first by Federal Express and then by others to promote overnight delivery services. A second reason is the tremendous growth of such services. Figure 1 shows a comparison of the annual operating revenues of three package express companies (Emery, Federal Express, and Purolator) with the combined cargo operating revenues of all scheduled airlines providing cargo services including both the all-cargo carriers such as Flying Tigers and the cargo operations of predominantly passenger airlines such as American, Northwest, and United. As

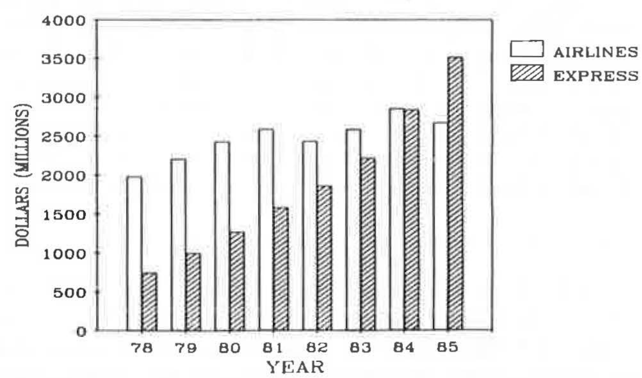

FIGURE 1 Annual operating revenues, 1978–1985 (from Air Transport Association of America, CAB, and U.S. Department of Transportation).

can be seen in the figure, package express revenues were far below cargo revenues of the scheduled airlines in 1978 but by 1985 had surpassed them by 30 percent. Although Federal Express's compound growth rate during the period was a spectacular 43.7 percent per year, both Emery (11.7 percent per year) and Purolator (18.3 percent per year) also grew much faster than the scheduled airlines combined cargo revenue growth rate of 4.4 percent per year. Such robust growth and high public profile have tended to divert attention from the other segments of the air cargo industry and the important trends emerging there.

Profile of the Domestic Air Cargo Industry

Although high revenues are earned carrying package express, such cargo constitutes a relatively small portion of total air cargo ton miles. In 1985 package express combined with mail carried for the U.S. Postal Service made up about 30 percent of domestic revenue ton miles and heavy freight accounted for the remaining 70 percent. These figures should be considered only approximate because of incomplete or missing data in some cargo operators' reports to the U.S. Department of Transportation.

Air cargo is transported by three types of carriers: by passenger airlines, as belly cargo; by freighters (all-cargo aircraft) providing scheduled service; and by nonscheduled freighters. Figure 2 shows the proportion of revenue ton miles (RTMs) in 1985 for each type of carrier in both domestic and international service. In domestic service, belly cargo (43.1 percent) and scheduled freighter service (41.6 percent) each account about the same number of RTMs, and nonscheduled freighter service accounts for the remainder (15.3 percent). The proportions are quite similar in international service; the only difference is that scheduled freighter service is slightly more important and belly cargo slightly less.

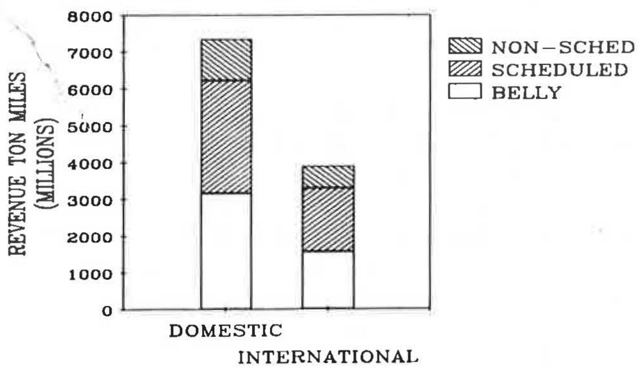

FIGURE 2 Air cargo by type of carrier, 1985 (from U.S. Department of Transportation Industry Cargo Summary, 1985).

The international market for U.S. carriers is only about one-half the size (53 percent) of the domestic market. Although the international market grew at only about 3 percent per year between 1979 and 1985, the domestic market grew more rapidly at about 5 percent per year. Air cargo deregulation, of course, applied only to cargo carried within the United States; international air cargo movements continue to be governed by bilateral agreements among countries. Air cargo traffic may actually have grown more rapidly than the RTM figures indicate. Technological improvements have reduced the weight of some air cargo packaging thereby increasing the proportion of cargo tons that is actually cargo *(8)*.

Changing Role of Freight Forwarders

In, as one freight forwarder executive put it, the "warm, protected days of regulation," air freight forwarders had a well-defined albeit limited role in the air cargo industry (*9*, p. 31). Their principal functions were to pick up and deliver shipments within a 25-mi radius of the airport, to consolidate small shipments into larger shipments thereby taking advantage of lower rates, and to market air cargo services within their geographic area. Although forwarders could charter cargo aircraft, they were not permitted to provide their own lift by owning and operating aircraft. Surface transport beyond a 25-mi radius was reserved for ICC-regulated motor carriers, which were not accustomed to providing the quick and flexible response required for ground support of air cargo. Such motor carriers were also prohibited from owning and operating cargo aircraft.

As a combined result of air cargo deregulation in 1977 and motor carrier regulatory reform in 1980, the distinctions among the participants in freight transportation have become much less sharp. One pronounced trend has been for some of the larger air freight forwarders to operate their own cargo aircraft. For example, former freight forwarders such as Airborne, Emery, Purolator, and United Parcel Service now have their own cargo fleets. Some of these forwarders acquired their own lift capability in response to deterioration of scheduled freighter service, particularly as trunk passenger airlines withdrew from freighter cargo service.

An emerging pattern for forwarders with their own lift is to operate aircraft in hub-and-spoke route networks similar to those of passenger airlines such as Eastern and Delta in Atlanta, United in Chicago and Denver, American in Chicago and Dallas/Fort Worth or, in the package express market, Federal Express with its hub in Memphis *(10)*. For example, Airborne operates a hub at a former Air Force base in Wilmington, Ohio; Purolator operates a hub in Indianapolis; Emery has a hub in Dayton; and United Parcel Service has established a hub in Louisville. For air cargo operators, and particularly operators offering package express service, such hubs offer advantages similar to those for passenger airlines. Specifically, with a hub-and-spoke network, more city pairs and lower traffic density markets can be served economically with the same fleet than could be served if only single-plane direct service were offered *(11)*.

Hubs were difficult to establish with the route restrictions of CAB regulation. Thus, as with passenger airlines, full development of hub-and-spoke systems has only been possible with deregulation's route freedoms. Thus far, only the larger forwarders have developed such systems; the small forwarders still rely on the belly cargo capacity of scheduled passenger airlines, virtually all of whom now operate hub-and-spoke route networks, and the scheduled freighter capacity of the cargo carriers.

The passenger airlines' hub-and-spoke development may well have made it easier for forwarders to provide service via a single airline to a broader range of communities. Although the typical timing of passenger flights may offer greater potential for second-day air service than for overnight delivery, the possibility of mixing passenger service with overnight freight service should not be overlooked. Eastern Airlines, for example, established late night "Moonlight Special" mixed passenger and cargo flights in 1985 in cooperation with CF Airfreight, a subsidiary of Consolidated Freightways, Inc. (*12*, p. 4). The flights provide an overnight heavy-freight delivery system and also offer price-sensitive passengers quite low fares. This service contributed to a 39 percent increase in Eastern Airlines' cargo revenues in 1985 over 1984.

Deregulation has also enabled freight forwarders to integrate surface and air transportation more smoothly by allowing forwarders more freedom to operate surface transport. Forwarders are no longer restricted to a 25-mi radius around an airport and many have obtained both intrastate and interstate trucking authority. These forwarders can now provide either surface or air transport depending on which best suits a shipper's particular needs. Although interstate trucking authority has not been difficult to get in the wake of the Motor Carrier Act of 1980, granting intrastate authority is still the domain of state regulatory commissions. Some states have liberalized intrastate motor carrier entry along the lines of federal deregulation, but others have remained quite restrictive so that some forwarders have been unable to obtain the intrastate authority they need to develop fully integrated service.

Air freight forwarders may also be assuming a larger role in shipping, although data to assess their role are limited. In 1978, however, Air Transport Association airlines received 43.6 percent of shipments from forwarders whereas by 1982 the figure had risen to almost 50 percent *(13)*. If forwarders are indeed assuming a larger role, cargo experience would again parallel passenger airline experience and probably for much the same reasons. For passenger airlines, travel agents now sell a substantially greater portion of tickets than before deregulation *(10, 14)*. When airline fares were the same for all carriers in a market and service patterns were held relatively stable by CAB regulation, a travel agent had relatively little to offer; a passenger could simply book a flight with the airline directly with little fear of missing an opportunity for a more convenient flight or a lower fare. With the often bewildering array of fare and service combinations and the frequently shifting patterns of passenger airline service, travel agents can now provide extremely valuable service in finding the best fare and flight alternative for a traveler's needs. Similarly, in air cargo the entry, rate, and route freedoms ushered in by deregulation have increased the range of cargo transportation alternatives on which a freight forwarder can draw and therefore the value of a skillful freight forwarder's ability to keep abreast of changing alternatives and find the rate and service best suited to a particular shipper's needs.

Passenger Airlines and Air Cargo

Most of the passenger airlines that operated freighter aircraft before cargo deregulation have sold their freighters and confined their cargo operations to the belly compartments of their passenger aircraft. Some of the narrow-body freighters such as B-707s and the smaller DC-8s either became uneconomic to operate in the face of rapidly rising fuel costs in 1979–1980 or could not meet the new noise standards without expensive retrofits *(15)*. The wide-body freighters, although still potentially profitable, often did not fit into the passenger airlines' longer-term strategies, particularly in light of the substantial unused cargo capacity in the bellies of passenger aircraft. American Airlines, for example, had been a pioneer in cargo transport but sold its last B-747 freighter to United Parcel Service at the end of 1984 *(16)*.

As the Eastern Airlines Moonlight Express example illustrates, some passenger airlines are turning their attention to using more of their belly cargo capacity. A wide-body aircraft such as a DC-10, an L-1011, or an A300 has about 52,000 lb of belly cargo capacity and a B-747 can have between 72,000 and 120,000 lb depending on the specific model (*5*; *17*, p. 7). Even a modest amount of cargo can have an important impact on the profitability of a flight.

Consider, for example, a DC-10-10 operating with a 65 percent passenger load factor and a breakeven load factor of 60 percent—both fairly typical values for 1985 domestic operations of the more profitable major airlines. Under these assumptions and using the average passenger yield for United Airlines for 1985 (10.6 cents per revenue passenger mile), the profit from the flight comes from the revenue from the last 13 passengers *(18)*. The same amount of revenue could be earned by adding only 6,720 lb of cargo, assuming an average cargo yield for United of 40.1 cents per revenue ton mile. Although carrying cargo adds some costs to a flight, the marginal costs of handling additional cargo, once a carrier is prepared to handle any, are not likely to be large.

The potential for such belly cargo is largely untapped. For example, the average United Airlines jet passenger aircraft flight carried only 2,250 lb of cargo in 1985. Part of the reason, of course, is that many passenger flights are at times of the day that are poorly suited for some air cargo needs. To be useful for overnight service, flights must be late in the evening or at night. However, virtually any passenger flight would be suitable for second-day air cargo service, and some freight forwarders report a growing awareness among shippers that second-day service is often adequate for their needs, particularly when it can be offered at a lower price. For example, although Federal Express has focused its marketing on more lucrative overnight service, by 1985 18 percent of its volume was second-day service, an increase from 11 percent in 1983 *(5)*. UPS also ships a substantial volume of second-day air freight, although UPS does not report a breakdown of cargo volume among different categories of service.

During much of the regulated period, rate floors hindered the ability of passenger airlines to price belly cargo capacity low enough to make second-day service a widely attractive alternative. Since passenger deregulation, most management attention has been focused on developing route networks and reducing cost structures to survive in the intensely competitive passenger markets. Such competition, however, may well be the driving force behind airline managers' increased attention to underused belly cargo capacity. As suggested previously, a relatively small addition to the cargo load can make a significant contribution to the profit of a flight thus providing an important competitive edge. Moreover, as the Eastern Moonlight Express example illustrates, some passenger airlines are exploring innovative ways of mixing passenger and cargo operations.

Cargo Rates

The wide and changing variety of rate and service combinations limits the analysis of the effects of deregulation on cargo rates to an examination of changes in aggregate rate levels as measured by total revenues divided by total ton miles (yields). Figure 3 shows a comparison of an index of average domestic passenger yield with an index of average freight and package express yield for the period 1979 to 1985. During this period, both types of service were subject to many of the same types of cost pressures including fuel price increases, interest expense during a period of record-high rates, recession-dampened demand, and so forth. As the figure indicates, cargo rates have lagged far behind passenger rates since 1979; while passenger

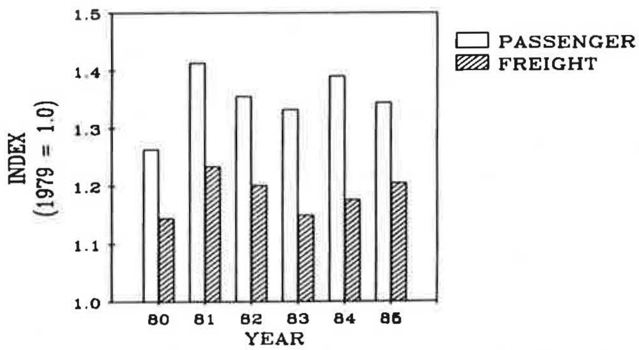

FIGURE 3 Passenger fares and freight rates, indices of yield, 1979–1985 (from Air Transport Association of America).

yield increased 34.5 percent, cargo yield increased only 20.6 percent.

Both average cargo and passenger yields have been affected by a changing mix of traffic during the period. An increasing percentage of passenger traffic has traveled at low-yield discount fares since 1979 so that standard fares have risen faster than the yield index suggests. Conversely, in cargo markets, high-yield package express service has grown faster than heavy freight so that a measure of standardized rates has probably increased less than the combined yield index. Thus, if indices of standardized rates had been used instead of yields, the gap shown in the figure would probably be even wider.

Experience before deregulation was markedly different from that after 1979. Between 1972 and 1978, before the effects of either cargo or passenger deregulation, domestic freight yields grew at an average annual rate of 8.5 percent, far greater than the average annual growth rate for domestic coach passenger yields of 4.8 percent *(19)*. Thus before deregulation cargo rates were growing faster than passenger fares, but after deregulation cargo rates grew more slowly and actually declined in real terms when the effects of rising factor costs were taken into account. For example, between 1978 and 1982 passenger yields increased 45 percent (in nominal terms) and cargo yields increased 34 percent, but at the same time the consumer price index increased 59 percent and the CAB index of airline input costs increased 87 percent *(20)*. There appears to be little doubt, therefore, that cargo deregulation has led to lower cargo rates in much the same way that passenger airline deregulation has reduced average passenger fares *(10)*.

Some of the downward pressure on cargo rates may well have come from pricing response to excess belly capacity in passenger aircraft. United Airlines, for example, had a lower freight yield in 1985 than in 1979, but its passenger yield increased 42.8 percent during the same period. Similarly, both American Airlines and Northwest had declining freight yields between 1980 and 1984.

The average yields for belly cargo are substantially below the average domestic yield for Flying Tigers, by far the largest all-cargo carrier. Flying Tigers offers different service characteristics and has different underlying costs. All-cargo service is better suited to providing overnight service, and freighter aircraft have far fewer size and commodity constraints on the cargo they can carry, which means that belly cargo cannot compete for a portion of an all-cargo airline's business.

In the case of Flying Tigers, there are also some important underlying cost differences. In much the same manner as those of the passenger airlines, Flying Tigers' costs, particularly labor costs, had reached high levels under regulatory protection; for example, Flying Tigers' average annual wage for members of flight crews was $115,000 in 1986 *(21)*. In late 1986, Flying Tigers sought a 25 percent wage cut and work rule changes in contract negotiations with its pilots in an attempt to become cost competitive and avoid having eventually to withdraw from the air cargo business *(22)*.

In addition to competition from passenger airlines, another source of downward pressure on air cargo rates has probably been falling motor carrier rates after enactment of the Motor Carrier Act of 1980. By offering competing service, motor carriers constrain air cargo rates for short and medium hauls and for nonovernight service. Lessened motor carrier regulation has stimulated a wider array of innovative motor carrier services, including some that are often competitive with air cargo for door-to-door elapsed transport time.

CONCLUSIONS AND PROSPECTS FOR THE FUTURE

Deregulation has almost certainly resulted in lower air cargo rates than would have prevailed under continued regulation and has expanded the range of rate and service offerings to shippers. Major passenger airlines have withdrawn their freighters from service in favor of reliance on belly cargo and have restructured their passenger route networks into hub-and-spoke systems in response to passenger deregulation. Faced with changing rate and service patterns, shippers have placed increased reliance on freight forwarders to seek out and provide the rate and service combinations that best suit their needs.

Freight forwarders, in turn, have been freed from many of the regulatory constraints under which they had historically operated. Some of the larger freight forwarders have responded to new freedoms and opportunities by acquiring and operating their own cargo aircraft, developing hub-and-spoke route networks, and entering the rapidly growing package express market. Others have engaged in more aggressive marketing of traditional freight services, extended surface operations beyond their previous 25-mi limit, and provided more closely integrated surface and air operations.

The prederegulation all-cargo carriers have been hurt by the combination of the downward pressure on rates, caused in part by excess capacity in belly cargo, and the new aircraft operations of the larger freight forwarders. As was the case with passenger airlines, regulation, by basing rates on average industry costs, dampened incentives for careful cost control and gave these carriers a legacy of high costs primarily attributable to high wage rates *(23)*. The result for many all-cargo carriers has been a string of annual financial losses as they struggle to reduce costs.

If the future looks grim for those all-cargo carriers that cannot reduce costs substantially, it may be brighter for freight forwarders and belly cargo in passenger airliners. Although the preferred timing of passenger flights may not be well suited for overnight shipments, most flights are well suited for second-day air cargo service. Moreover, the postderegulation growth of large hub-and-spoke networks allows many more city pairs to be served without the added complication of interline transfers. As the airline industry completes its transition to a deregulated environment, these route networks can be expected to stabilize thereby making it easier for a passenger carrier to provide predictable cargo capacity.

Intense competition in passenger service can be expected to keep pressure on the airlines to use the belly of the aircraft to make greater contributions to a flight's revenue. Increased emphasis on using belly cargo capacity could mean added business for freight forwarders, particularly those associated with Air Cargo, Inc., which have traditionally handled the pickup and delivery portion of passenger airlines' air cargo business.

Conversely, some passenger airlines may follow a variant of Eastern's example and develop exclusive arrangements with motor carriers to handle surface pickup and delivery of air cargo shipments. The Air Cargo, Inc., freight forwarders are free to "feed" their cargo to the major passenger airline that best suits the shipper's needs in much the same manner that independent commuter airlines are free to feed passengers to the major carrier that best suits the traveler's needs. The importance of feed traffic to the profitability of passenger operations has led the major airlines to develop marketing alliances with commuters in an attempt to capture more of that feed *(16)*. The same competitive pressures and the same potential for additional cargo to enhance profitability could lead the airlines to develop similar arrangements with motor carriers to capture more cargo feed. The airlines could establish such exclusive arrangements with freight forwarders or look to motor carriers who already have national or nearly national distribution networks in place. Motor carriers specializing in less-than-truckload shipments would appear to be particularly attractive candidates because such alliances could offer a shipper either air or surface transport depending on the specific need.

Such service—perhaps focused primarily on second-day service at reduced rates—could become an increasingly important feature of the distribution systems of manufacturers of high value-to-weight ratio goods. For such goods, which appear to be a growing part of the U.S. economy, air cargo distribution might make it possible to maintain fewer regional warehouses with attendant cost savings without decreasing service to customers.

In sum, air cargo deregulation has resulted in reduced rates and increased service options for most shippers and an expanded role for freight forwarders in helping shippers find and select the options that best suit their needs. The combination of competitive pressures in passenger airline service and underutilized belly cargo capacity will almost certainly lead passenger airlines to increase their emphasis on cargo operations. The transition to a more competitive environment has not been without turmoil, nor is that transition yet over, but the indication to date is that the new competitive environment will better serve the needs of most shippers.

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Forecasting for Aviation System Planning

DAVID RUBIN AND NEIL D. LERNER

Aviation system planning forecasts, unlike other aviation forecasts, require information on the geographic distribution of activity to make possible evaluation of the trade-offs between nearby facilities in the attraction of activity, such as originating air passengers or based general aviation aircraft. To obtain forecasts of this geographic distribution, it is necessary to develop base demographic data and forecasts for defined geographic areas within the study area. Using these demographic forecasts, bottom-up forecasts of aviation activity can be generated, often controlled by a top-down control total. These activity forecasts are then assigned to airports on the basis of accessibility and service level considerations, using either manual or computerized methods. Demographic forecasts for small geographic areas are difficult to obtain and often must be generated from current data and larger area forecasts. The exceptions to this are the urban transportation planning data sources for most urban areas. The federally mandated urban transportation planning process includes the forecasting of variables that affect urban travel at a Transportation Analysis Zone level. Aviation forecasts were recently completed as part of the Continuing Florida Aviation System Planning Process and the Ohio Aviation System Plan Update, using the techniques of top-down forecasts controlling bottom-up distributions, with the bottom-up data based, for the urban areas, on urban transportation planning data and, for the rural areas, on current data and regional forecasts.

Aviation forecasts are done for several reasons by aircraft manufacturers, airlines, investment analysts, the Federal Aviation Administration (FAA), airport owners, and state and local governments. Each of these forecasters brings to the task an agenda of needs, data sources, and expectations. The forecasts differ accordingly. For instance, the forecast being used to determine the viability of a bond issue is inherently more conservative than the master plan forecast being used to determine land acquisition needs, as well it should be because the consequences of erring on the high side are much greater. Aviation system planning also has a particular set of needs to forecast and special data requirements to meet those needs.

Aviation system planning forecasts are special cases because it is not sufficient to simply develop a forecast of future demand. It is also necessary to determine where this demand will come from in order to formally include competition between facilities in meeting the demand. Not all system plan forecasts have appropriately addressed these special needs. This paper is a discussion of some of the unique requirements, processes, and data needs of aviation system plan forecasting, illustrated by recent examples.

Aviation system planning, as mandated by the FAA, is the analysis of the need for and location of airports within a geographic region, usually a metropolitan area, substate region, or state *(1)*. To plan for a system of airports and determine the future activity levels at the airports in the system, the relationship between aviation activity and the location of aviation users must be determined. Aircraft owners, pilots, and air passengers choose the airport they use, and that choice is based on a multiplicity of factors, including travel time from points of origin, costs, and accessibility to the desired service—be it a tie-down space for a single-engine aircraft or a commercial flight to Los Angeles. System planning is intrinsically based on an analysis of that choice, and the forecasting process must therefore facilitate the analysis of the choice.

The methods for analyzing choice drive the process of forecasting. Most of the current methods are derived from urban travel planning and use data available from urban travel simulation models. These models are in use in nearly every metropolitan area and have generated data bases of socioeconomic data by small geographic area (Transportation Analysis Zones or TAZs) that can be used for aviation forecasting. They also have travel time data from each of these zones to all other zones, often for peak and off-peak travel by car, bus, or rail. The steps of generation and distribution can be used with these data for air carrier trips, based aircraft, or pilot activity.

REQUIREMENTS OF THE SYSTEM PLANNING FORECAST

To plan for a system of airports, the activities that determine airport capacity and congestion must be forecast. These are the same activities that master planning forecasts require, although there is a need for greater detail for master planning. They include aircraft movements and basing requirements and the passenger movements that determine terminal and access needs. For system planning, the interaction of several airports affects how activity is allocated to each. Therefore, if forecasts are to be generated before alternatives are developed and evaluated, they have to be independent of the system. It could be argued that the system itself will affect the forecasts. Accepting that argument would require a reiteration of the forecasting process for each alternative to reflect the induced activity caused by increased convenience or the lessened activity caused by a loss of facilities. Most system plans have not forecast induced or restrained demand.

The way to forecast aviation activity independent of the airport is to forecast it where it begins—in transportation planning parlance, where it is "generated." Air passengers begin trips at home, at the workplace, or at a hotel. Owners of based

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aircraft begin either at home or at work—depending on how the aircraft is used. The trip to the airport is an essential part of the air trip, and the choice of airport is affected by that ground trip as well as the available services at the airport.

After air trip generation forecasts have been made, the trips must be distributed to facilities. In regions with multiple commercial airports in competition with each other, such as Washington-Baltimore, New York–Newark, or San Francisco–Oakland, the choice of airport has been studied and is a function of travel time, choice of modes, fares, and schedules of available flights at the alternative airports. People will drive past one airport to get to a more distant airport with a convenient flight. Airport choice has been modeled *(2, 3)* as has airport access mode choice *(4)*. These models are patterned after the mode choice models of the urban transportation planning process. Decisions about which airport to use to base an aircraft or from which airport to rent an aircraft are based on similar considerations—travel time, facility level, availability and cost of aircraft storage and maintenance, and capacity and congestion factors. These, too, have been modeled *(5)* but are more commonly considered in a qualitative manual process *(6)*.

PREDICTOR VARIABLES

Whether done manually or by computer, the distribution process requires a forecast based at the origin of the trip, not the chosen airport. This necessitates a basis for forecasting activity within the region. There are two ways to accomplish this, either top down or bottom up. In a top-down forecast, the region as a share of the nation or the state is forecast, and this control total is allocated to zones within the region. In a bottom-up forecast, aviation activity is forecast for the zone on the basis of the socioeconomic characteristics of that zone, and zonal forecasts are accumulated to obtain a regional forecast. The two methods can be used independently or together, with one controlling the other. Either way, the distribution of activity to zones requires the availability of forecasted predictor variables.

One of the difficulties that distinguish system plan forecasts from other aviation forecasts is the need for predictor variables that are applicable at the zone level. The best predictors for commercial air travel, at the national and international level, are national economic variables such as Gross Domestic Product or National Income. These become useless for forecasting even at the state level because no historic data or forecasts are available. There are few economic activity forecasts below the state level. Population forecasts are often the only ones available at county and municipal levels because of their importance for educational facilities planning. Employment, income, sales, and other economic activity forecasts are generally not available.

The exceptions are the variables forecast for urban transportation planning. Thanks to the federally encouraged urban transportation planning process *(7)*, nearly every urban area with a population of more than 100,000 has done a transportation study using the standard four-step urban transportation planning process or a modification thereof. The four-step process includes trip generation, trip distribution, mode choice, and trip assignment. Trip generation requires socioeconomic forecasts by zone, and the other three steps require travel times between zones on the highway network. As a minimum, trip generation requires population; employment; and an income surrogate, often automobile ownership. In more sophisticated studies, retail employment, school enrollment, density measures, transient accommodations, and other factors are also forecast and used in the modeling process. (Many studies include consideration of special generators such as airports and major institutions. They then need the airport activity forecast as an input.) Thus, as a by-product of the urban transportation planning process, there often exist forecasts of local demographic and economic variables as well as coded roadway networks with travel times.

If these data are readily available, they can be used in aviation activity forecasting. Historical air travel activity correlates well with population and employment, and the coefficients of these regression equations can be used as a basis for distribution. Income surrogates are especially useful in predicting the origins of aviation activity, which correlate strongly with upper-income areas. Specific employment forecasts are preferred to general ones because the trips generated by different types of employment are quite different. Office employment generates an order of magnitude greater number of air carrier trips than manufacturing employment *(8)*.

For areas for which these data are not readily available, they can be developed from population forecasts and current data if the assumption of continuing current relationships can be made. This is particularly useful in a region in which many of the counties have an urban transportation planning process with available data and the remaining rural counties do not. Forecasts from the Bureau of Economic Activity (BEA) of the U.S. Department of Commerce for the nonmetropolitan portions of the BEA region *(9)* are useful. These forecasts provide control totals for employment and income and can provide forecast growth rates.

SURVEY DATA

Trip generation is substantially easier with survey data. An inventory of the ownership of based aircraft will provide a base-year distribution that can be correlated with the available predictor variables to develop the coefficients to use in forecasting changes. A survey of departing or arriving passengers can provide the base-year distribution and the basis for forecasting changes. An air passenger survey can also provide data on the choice of airport access mode; the basis for choosing among airports; the trip generation rates of individuals (e.g., how many air trips have you taken in the last 12 months?); and the attractiveness of unusual land uses that do not lend themselves to ordinary treatment, such as resorts, retirement communities, or large institutional land uses. The air travel generated by Disney World or the Pentagon is not readily ascertained by traditional forecasting techniques without the benefit of a survey. Many airports regularly conduct surveys of departing or arriving passengers, within the terminal or on the aircraft, for use in airport facility planning. These surveys can be modified to provide the data needed for system planning.

If there is a strong basis for allocating base-year activity to zones, the distribution of forecasts can be used to allocate only the changes. This prevents anomalies from occurring when the forecast equations do not properly replicate the base year for a particular zone or group of zones.

EXAMPLES FROM RECENT EXPERIENCE

Forecasts have recently been completed for the Continuing Florida Aviation System Planning Process *(10)* and the Ohio Aviation System Plan Update *(11)*. These forecasts are both based on statewide control totals projected using top-down methodology based on national and state regression equations using available forecasted socioeconomic variables. In Florida, population, employment, and accommodations are the three socioeconomic variables. In Ohio, they are population, employment, and total personal income.

In both states, zone systems were developed to distribute the aviation activity. Zones in the metropolitan areas with urban transportation planning processes are aggregations of TAZs. Zones in rural areas are counties or census enumeration districts within larger counties. For each zone, current and forecast values were required for the three forecast variables. These data were available from the urban transportation planning data bases but had to be developed in the rural areas. BEA forecasts for multicounty areas were apportioned to the zones within those areas on the basis of current data.

Activity was then distributed to zone using, for most forecasts, the coefficients from the regression equations as a basis. For the Florida origination forecast, data from a Florida tourism survey were used to develop trip generation rates. Each forecast socioeconomic variable was then multiplied by the appropriate coefficient to calculate a forecast. The sum of the forecasts for all zones was normalized to the control total. If current activity data by zone were available, only growth was forecast for each time period. For general aviation aircraft, the FAA's Census of Civil Aircraft was sorted by county and zip code and assigned to zones as base data. Growth was then distributed and added to the base. For air carrier originations for which there were no survey data, total values were forecast for each year.

The forecasts by zone were then assigned to airports—in Florida using computer models and in Ohio using manual methods. Travel time and availability of services were the major factors considered in the assignment process. The base-year assignment was balanced to base-year, airport-specific data as a model calibration exercise.

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Optimal Location of High-Speed Runway Exits Using Automated Landing, Rollout, and Turnoff

ANTOINE G. HOBEIKA, EDGAR L. DONA, AND AMADOU S. NAM

The reduction of runway occupancy time through the use of high-speed exits is one of the research activities carried out to improve the operational use of runways. Proper hardware and software technologies are being developed to minimize runway occupancy time per landing aircraft in future air traffic control environments. On the software side, a probabilistic computer model is being used to define exit velocities, exit locations, and turnoff path profiles under automated landing, rollout, and high-speed turnoffs using embedded magnetic cable sensors. However, the computer model does not determine how to combine these exit locations into a practical number of turnoffs that satisfy various aircraft mixes. The focus of this paper is on clustering these exit locations into a minimum number without cost-burdening any one class and violating the objective of minimizing the total runway occupancy time of landing aircraft in a real airport environment.

The success of air transportation is indeed phenomenal. Today it is not only an accepted mode of transportation, it is accommodating a significant percentage of the interstate and international transportation market. In the transcontinental and intercontinental passenger transportation market, it has already become the accepted mode.

Success has been accompanied by sociological, environmental, and operational problems. Capacity and delays, created by the lack of capacity, have become today's primary concerns. The growing public objection against the expansion of present operations and the building of new facilities, however, has narrowed the options available for solving the problem. How to increase system capacity without violating the present norms and degrading system safety is the challenge faced by system developers.

Research and development programs of the National Aeronautics and Space Administration (NASA) and the FAA are addressing several aspects of the airfield problems, foremost of which are improvement of operational use of runways; provision of efficient flow control, spacing, and management of aircraft in the terminal airspace; upgrading computer and communication technology usage; and reducing the effects of wake vortex and aircraft noise *(1)*.

In improving the operational use of runways, the reduction of runway occupancy times by using high-speed exits is one of the research efforts carried by NASA. To achieve an increase in density of arrivals at congested airports, separation distances between aircraft should be decreased and both runway occupancy time and its related standard deviation should be minimized. The research and development (R&D) programs at NASA are working on hardware and software technologies to achieve reduced runway occupancy times. During initial design studies, a goal of 40 sec maximum occupancy time was considered by the Terminal Configurated Vehicle Program. Automated landing, rollout, and high-speed turnoffs using the Microwave Landing System (MLS) and magnetic cable sensors embedded in runway pavements as navigational aids are being studied as ways of reducing runway occupancy time *(2–6)*.

A probabilistic computer model has been developed by Douglas Aircraft *(7)* to define exit velocities, exit locations, and turnoff path profiles. The model comprises two parts, namely, (a) a routine that establishes the time required from threshold to start of exit with a probability determination of an exit velocity and (b) a subroutine of time required in the turnoff to clear the runway using an optimized path. The times determined from each part are added to yield the total runway occupancy time that, probabilistically, will be the unique value selected for this study—occupancy times not exceeding 40 sec. This time interval is measured from the instant the aircraft crosses the runway threshold until it completely clears the runway.

The model is capable of determining the runway exit location and turnoff path geometry for any specific aircraft model, subject to the selected maximum runway occupancy time of 40 sec. In a real airport environment, however, the established exit locations need to be bunched into fewer numbers while conforming to regulatory restrictions and aircraft operational and maintenance cost constraints (tire and brake wear). Bunching is required not only for economic reasons (fewer turnoffs mean less required concrete) but also to obviate possible confusion of the pilot in choosing an exit.

PROBLEM

It becomes apparent that the solutions provided by the probabilistic model need to be modified to be practically feasible. More specifically, the practical number and the optimal locations of turnoffs from a single runway to accommodate a wide variety of aircraft have to be determined, subject to the following study constraints:

1. The maximum runway occupancy time is maintained for each landing aircraft (40 sec in this study),

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2. The reliability of the system must be such that there is a 99.99 percent chance that an aircraft will exit at the optimally designated location, and
3. The FAA minimum standard separation between exits of 750 ft is not violated.

In synthesizing the various model results into a feasible turnoff configuration, two major problems exist. The first concerns the multiplicity of options imposed by the several input parameters of the model. These parameters, which are aircraft landing characteristics (such as velocities and deceleration rates at various points on the runway), can be individually varied, and, consequently, different runway occupancy times and reliabilities are achieved. This problem can be addressed by reducing the dimensionality of the available options so that only variables for which the model results are highly sensitive will be varied in the analysis.

The second problem concerns the effect of combining several exit paths in one location. The critical path is determined by choosing the aircraft that is most constrained by lateral motion. That aircraft, which exhibits the largest turning radius, tends to follow an exit path closer to the runway. Thus, if such a critical path is adopted, aircraft with slower speeds and smaller radii of exit path need more time to clear the runway and might violate the maximum time constraint of 40 sec.

Figure 1 shows this phenomenon; CD is the resultant exit location after the path profiles of a fast and a slow aircraft are combined. The most plausible solution to this problem is to iterate lower deceleration rates for the slower aircraft so that it can exit at a higher speed. The other option, imposing higher deceleration rates on faster aircraft, translates to increased tire and brake wear.

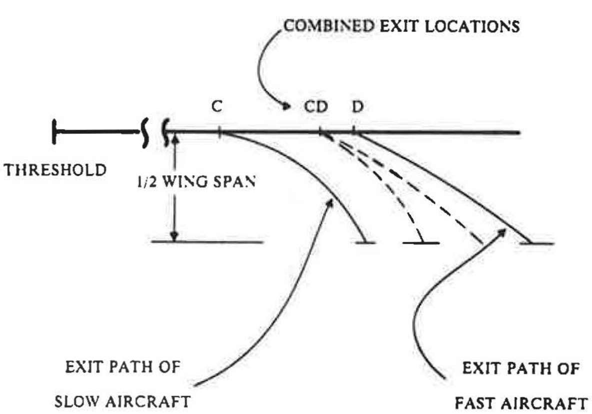

FIGURE 1 Problem of combining exits.

The results of a study conducted as an attempt to provide a practical solution to the problem of optimizing high-speed exit locations for a single runway under the operating constraints defined previously are presented in the remaining sections of this paper. A modified version of the referenced probabilistic computer model, which runs on an IBM PC/XT, was used to analyze the turnoff path profiles, exit velocities, and exit locations of several generic and several specific aircraft types corresponding to Terminal Planning System (TERPS) A, B, C, and D categories.

PROBABILISTIC COMPUTER MODEL

The Probabilistic Computer Model of Optimal Runway Turnoffs, developed by McDonnell Douglas Corporation for NASA, is a simulation routine that tracks the aircraft from touchdown location to runway clearance. It stochastically draws normally distributed samples of touchdown speeds, touchdown locations, exit velocities, and speeds at different distances from the exit entrance. The algorithmic approach employed by the model is discussed briefly herein. However, a more complete discussion of the model, its components, and the pertinent mathematical equations and variables is presented in a separate document *(7)*.

The runway operations being modeled are shown in Figure 2. After reading the input data set consisting of aircraft landing characteristics and their related deviations, the program sequentially computes (a) Distances A and B; (b) speeds during landing; (c) standard deviations of the speeds; (d) occupancy times at each point; (e) Distances A, B, and C, together with the corresponding speeds, for aircraft traveling one standard deviation below the average; (f) occupancy times to Points A, B, and C for aircraft traveling one standard deviation below the average; (g) specification of arbitrary speed ranges and the probability associated with them; (h) probability of exiting; (i) minimum occupancy time; (j) Z-values of occupancy time (assumed to be normally distributed); (k) interval midpoints; (l) average runway occupancy time; (m) percentage of aircraft exiting; and (n) average speed at exit.

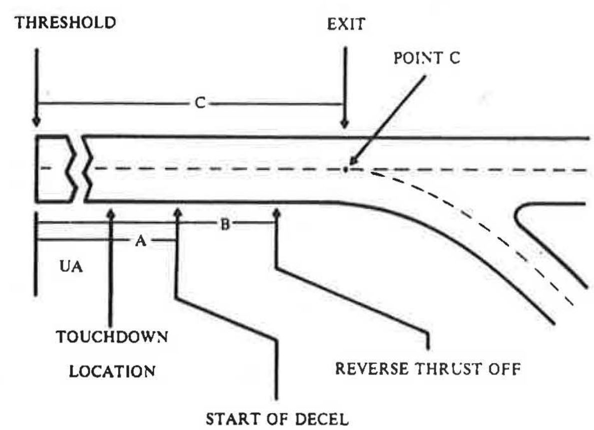

FIGURE 2 Runway operations simulated *(7)*.

A flowchart outlining the computational procedures and the internal manipulations involved is shown in Figures 3 and 4. The main program (Figure 3) and the subroutine called EXPATH (Figure 4) *(7)* are iterated until reliability and maximum runway occupancy time requirements are satisfied. The final outputs of the model for an aircraft defined by its touchdown speed, deceleration rate, weight, and estimated exit location include runway occupancy time, exit speed, probability of making such an exit, and coordinates of points along the turnoff path.

CATEGORIES AND CHARACTERISTICS OF AIRCRAFT

A variety of aircraft, from the general aviation type to the wide-body jet transport, operates in an airport environment.

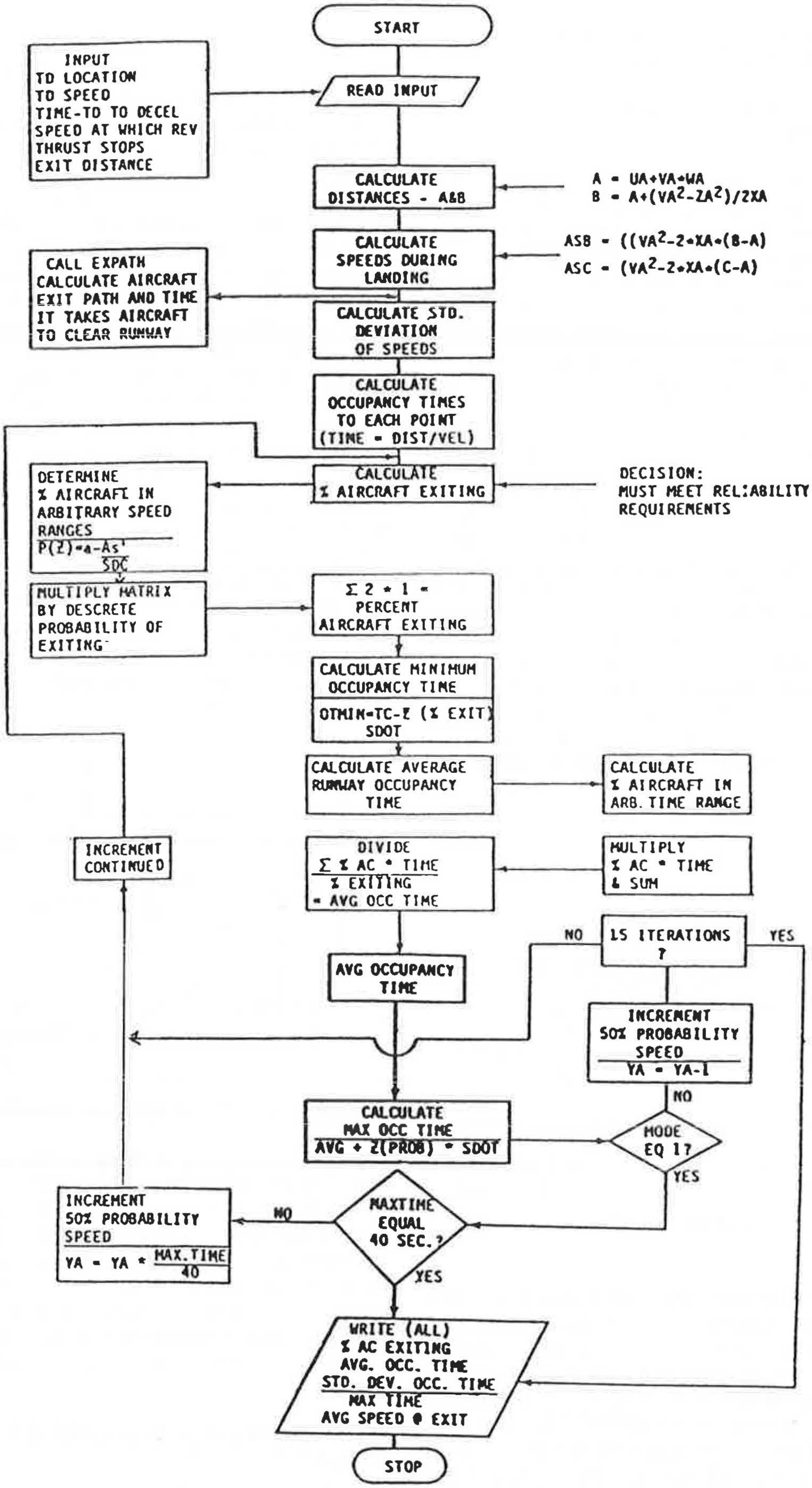

FIGURE 3 Flowchart of the model *(7)*.

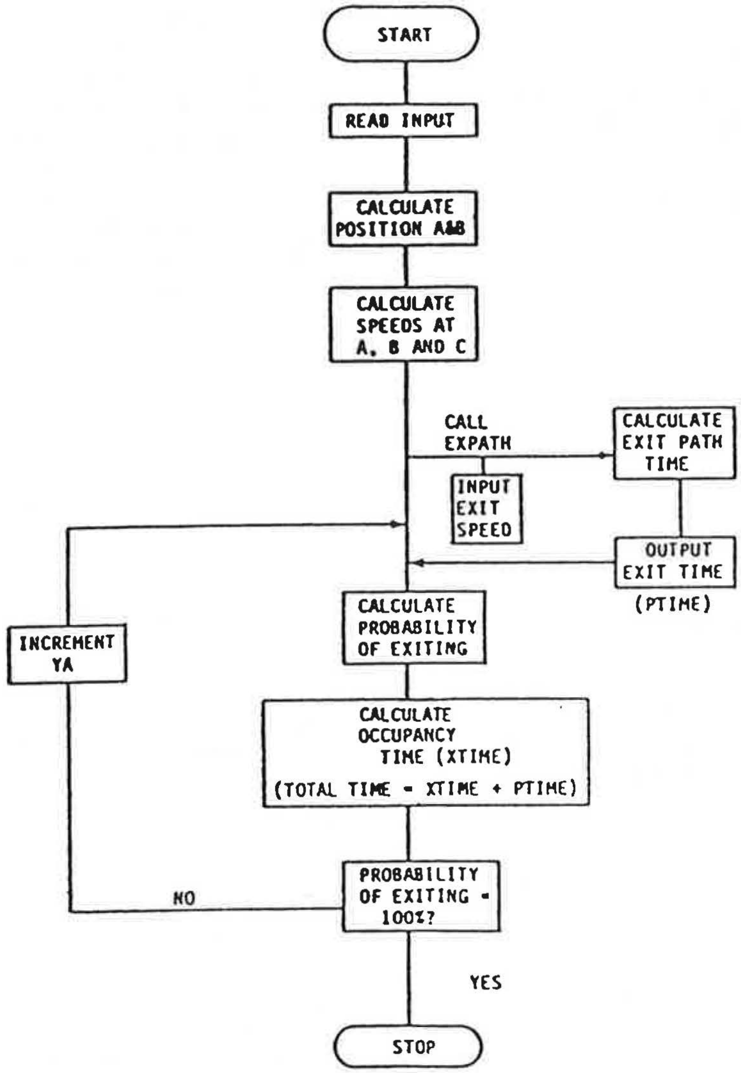

FIGURE 4 EXPATH subroutine *(7)*.

Characteristics such as aircraft weight, dimensions, and cornering limits play important roles in the design of airfields in general and the design of high-speed exits in particular. To bracket the high-speed turnoff performance variability that can occur in a particular category, two generic aircraft, S (slow/small) and F (fast/large), are defined in each of the four TERPS categories. Such categorization is influenced primarily by the range of approach speeds and aircraft weights.

The TERPS generic aircraft used in the study, together with their associated landing characteristics, are given in Table 1. Two specific aircraft, the Boeing 747 and the Lockheed F104, are included to demonstrate extreme landing conditions. The B747, in particular, was included because it is the largest and most difficult commercial aircraft to maneuver, so that a design based on it would tend to be on the conservative side.

ANALYSIS OF RESULTS

Figure 5 shows the optimal exit locations for the eight generic aircraft considered. Shown are the eight different exits, located between 1,286 and 5,860 ft from the threshold, needed to individually accommodate the eight generic aircraft. The optimal exit locations for the B747 and the F104 are 5,170 and 8,400 ft, respectively. An exit is considered optimally located when the constraints of maximum runway occupancy time of 40 sec and a reliability of 1 miss for every 10,000 landing aircraft are met.

Clustering the possible exits into the smallest practical number is accomplished in two stages. Initially, the separation distances, shown in Figure 5, are examined to determine the mutually exclusive exits on the basis of the criteria defined previously. The mutually exclusive paired exit locations, those that have little separation distances, are at 2,285 and 2,355 ft; 3,654 and 4,225 ft; 4,225 and 4,805 ft; 4,805 and 5,515 ft; and 5,515 and 5,860 ft from the threshold. In the second stage, a series of computer runs is made to analyze the sensitivity of the model results and to select the final configuration. It was found that the model results are highly sensitive only to the location of the exit and the deceleration rate before turnoff *(9)*. Consequently, the investigation involved only these two parameters.

Each exit location is taken as a candidate to represent a cluster of several exits. By considering the reliability and maximum runway occupancy time criteria stated initially, the turnoff performance and the path profiles along all candidate exits are evaluated. The results are summarized in Table 2.

TABLE 1 AIRCRAFT LANDING CHARACTERISTICS (Millen, Scott, Rivera and Tutterow, A Probabilistic Runway Occupancy Time and Exit Path Optimization Study with Lateral Ride Comfort, unpublished NASA report; *8*)

Generic Aircraft	Landing Characteristics										
	UA	US	VA	VS	WA	WS	XA	XS	YS	ZA	NTIP
AS	500	10	66	5	3	1	2.5	1	1	55	39
AF	500	10	118	5	3	1	2.5	1	1	55	40
BS	1000	20	110	10	4	1	4.0	.5	1	90	34
BF	1000	20	164	10	4	1	4.0	.5	1	155	56
CS	1500	30	181	10	5	1	5.0	.5	1	155	48
CF	1500	30	230	10	5	1	5.0	.5	1	175	103
DS	1500	30	211	15	5	1	5.0	.5	1	175	87
DF	1500	30	260	15	5	1	5.0	.5	1	255	150
Specific Aircraft											
B747	1500	30	230	10	5	1	5.0	1	1	190	130
F104	1500	30	370	25	5	1	6.0	2	1	150	35

LEGEND:

UA = Touchdown Location from threshold (ft)
US = Standard Deviation Of UA (ft)
VA = Aircraft Speed at Touchdown (ft/sec)
VS = Standard Deviation Of VA (ft/sec)
WA = Time from Touchdown to Start of Deceleration Before Exit (sec)
WS = Standard Deviation of WA
XA = Deceleration Rate of Aircraft Before Exit (ft/sec/sec)
XS = Standard Deviation of XA (ft/sec/sec)
YS = Standard Deviation of YA, the 50-percentile cumulative normal distribution of speeds at exit entrance (ft/sec)
ZA = Speed at which Reverse Thrust is Shut Off
NTIP = Distance from Aircraft Nose to Wingtip

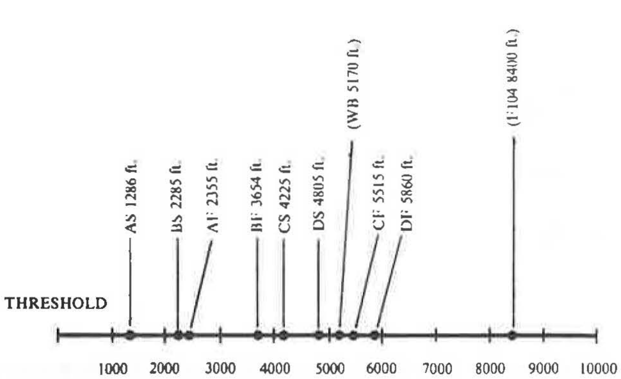

FIGURE 5 Exit locations.

TABLE 2 EVALUATION OF POSSIBLE EXIT SOLUTIONS

Exit Location (ft. from threshold)	Clustered Generic Aircraft	Comments
1286	AS	Lone candidate
2285	AF, BS	Small lateral displacement results in BS exceeding 40 sec maximum occupancy time
2355	AF, BS	Preferred solution
3651	BF, CS	Preferred solution
4225	BF, CS	BF requires risky deceleration maneuver to take this exit
4805	DS	Only possible solution to meet the time requirement
5515	CF, DF	Too close to the 4805 ft exit
5860	CF, DF	Preferred solution

The final configuration, showing the five optimal exit locations for the eight generic aircraft and the corresponding path profiles, is shown in Figures 6 and 7. Separate exits would be needed for military F104 and jumbo aircraft such as the B747 because of their landing speed and size, respectively, that affect cornering characteristics. Moreover, the final solution is unique. If the 5,515-ft exit were chosen to accommodate generic aircraft CF and DF, the previous exit would be located 4,225 ft from the threshold, and the 3,654-ft exit would not exist. It is apparent that, in the latter case, at least two generic aircraft (BF and CS) would not meet the established requirements.

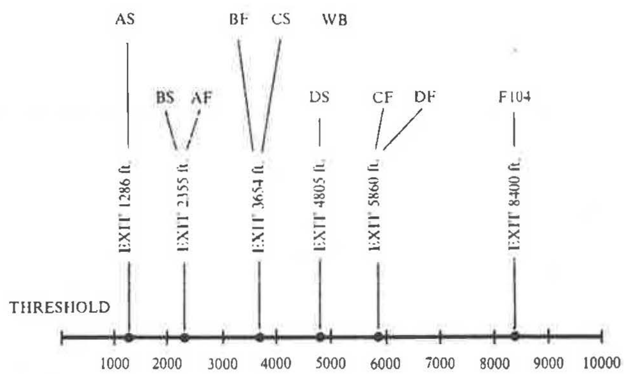

FIGURE 6 Final solution.

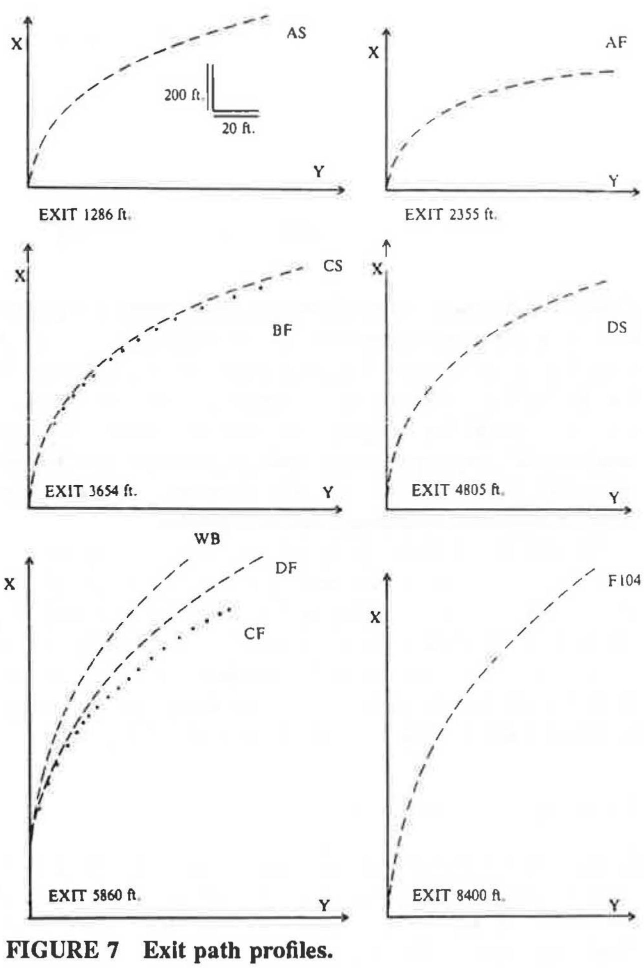

FIGURE 7 Exit path profiles.

CONCLUDING REMARKS

The use of high-speed turnoffs to support a high density of runway operation in future air traffic control environments appears promising. However, a study of combining the exit locations of TERPS generic aircraft into a minimum number of exits has shown that a reduction from eight to five exits for TERPS classes means that any future plans to install embedded automatic turnoff guidance facilities at airports serving all TERPS category aircraft must include a multiplicity of embedded paths. The difficulty of finding a final solution is further compounded if, instead of generics, specific aircraft models are used in the analysis. An alternative solution to this problem is the use of a modified Brandt drift-off system. Unlike the original version, which extends almost throughout the entire runway, the modified version can be localized along the critical points where the accommodation of certain aircraft, say the B747, with other aircraft appears to be a problem.

In cases in which the combination of several exits in a single location is indeed possible, there is still the problem of a slow aircraft clearing the runway without violating the maximum runway occupancy time. Several path profiles emanating from the same exit location are too confusing. A single path, on the other hand, will require a conventionally slow aircraft to exit at unusually high speed and low deceleration rate, which can prove dangerous. A possible solution to this is use of a "fanned exit" wherein the two extreme path profiles for the clustered aircraft exits are used to define inner and outer radii for the compound exit curve. Such an exit is shown in Figure 8.

Although the probabilistic computer model is sufficiently general to include the major factors of aircraft performance, it does not include site-specific parameters such as airport altitude, temperature norms, effective runway gradient, or different runway configurations and turnoff designs. A further improvement can be achieved by adding a subroutine to ease the computational procedure of bunching several exits for different aircraft with varying deceleration rates.

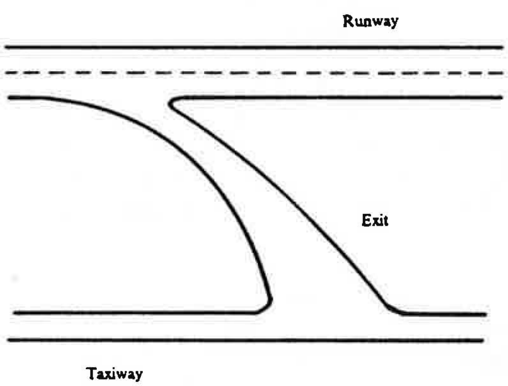

FIGURE 8 Fanned exit.

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Passenger Walking Distance Distribution in Single- and Dual-Concourse Centralized Airport Terminals

S. C. WIRASINGHE AND U. VANDEBONA

Walking distance within an airport terminal is one important measure of the level of service provided to passengers. The probability distribution of the walking distance of a passenger is used to compare various single- and dual-concourse centralized configurations for a planned airport terminal defined by a given number of identical gates. The walking distance distribution is obtained by using a simulation technique. Terminal configurations are ranked according to the percentage of passengers who must walk less than a specified maximum distance. The effects of installing moving walkways to reduce the effective walking distance are also analyzed. In the numerical example given, a T-shaped configuration is found to be superior to single, basic dual, and rectangular (with moving walkways) configurations.

Walking distance within air terminals is one important measure of the level of service provided to the passengers. Conventional planning methods make reference to the maximum walking distance within an airport *(1)*. However, with simulation techniques, it is possible to investigate the probability distribution of the walking distance of a passenger in a planned airport terminal, which would allow realistic estimates of the level of service in terms of walking distance to be made early in the planning process. Availability of the walking distance distribution would also facilitate selection of terminal configurations that reduce the number of passengers who have to walk excessive distances.

Clearly, passenger walking distance is only one of many factors, such as land constraints, baggage-handling system, taxiing time, landside access, and security requirements, that have to be considered along with capital cost when a terminal configuration is being chosen. However, from the point of view of the level of service provided to passengers, it is one of the most important factors.

Walking distance distribution depends primarily on terminal configuration. This paper deals only with simple configurations in which one or two concourses radiate from a centralized terminal block. However, many small- and medium-sized airports belong to this category. These terminals are called quasi-linear terminals because of their linear geometry and to distinguish them from linear gate arrival terminals. A quasi-linear terminal has a central block that houses the ticketing and baggage-handling areas and aircraft gates that are located on both sides of the concourses. It is a special case of a pier-finger terminal with at most two fingers. The analysis of passenger walks in pier-finger terminals with more than two fingers is more complex and will not be discussed here.

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Walking distances can be modified for the benefit of users by the inclusion of moving walkways. The effects of moving walkways on the distribution of passenger walking distance are also investigated.

CENTRALIZED QUASI-LINEAR TERMINAL CONFIGURATIONS

The model is applicable to the following quasi-linear terminal configurations:

1. Single concourse,
2. Basic dual concourse,
3. T-shaped dual concourse, and
4. Rectangular dual concourse.

Figure 1 is a schematic diagram of a single-concourse terminal. It is assumed that the ticket counters and baggage-handling areas are on separate floors and arranged uniformly in a total distance 2α on both sides of the entrance to the concourse. The arrival and departure gates are assumed to be arranged uniformly on both sides of the concourse. The concourse length is assumed to be β.

Figure 2 is a schematic diagram of the basic dual-concourse terminal configuration. The service counters are arranged uniformly in the distance 2α in the terminal block. The length of each of the two concourses is $\beta/2$. Again, the arrival and departure gates are arranged uniformly along both sides of the concourses.

The T-shaped dual-concourse configuration is a simple modification of the basic dual-concourse configuration in which aircraft arrival and departure gates are not only on both sides of the concourses but also adjacent to the terminal block at the top of the T. Figure 3 is a schematic diagram of such a configuration. The arrival and departure gates are arranged uniformly over a total distance of $4\beta + 2\alpha$. For a given number of gates, the T-shaped configuration requires a shorter concourse than does the basic dual-concourse configuration. Therefore a reduction of passenger walking distances can be realized by selecting a T-shaped configuration.

Figure 4 is a schematic diagram of a rectangular dual-concourse configuration. This configuration can be considered

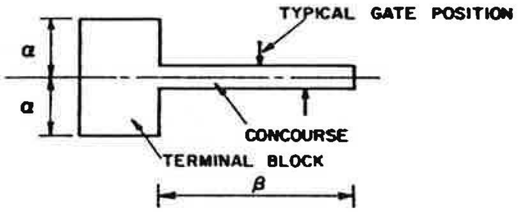

FIGURE 1 Single-concourse centralized terminal.

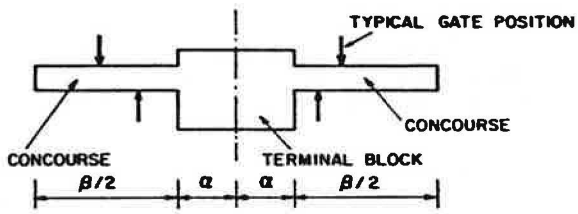

FIGURE 2 Basic dual-concourse centralized terminal.

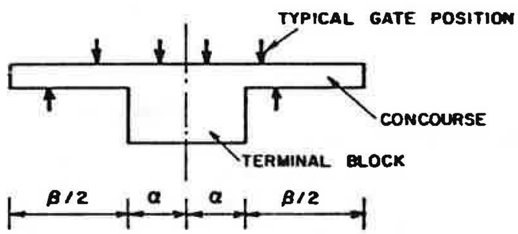

FIGURE 3 T-shaped dual-concourse centralized terminal.

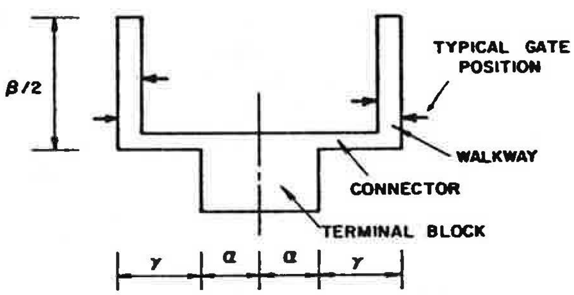

FIGURE 4 Rectangular dual-concourse centralized terminal.

a generalization of the basic dual-concourse configuration with the addition of connectors that provide access to the concourses from the terminal block. From the perspective of walking distance, the basic dual-concourse configuration is equivalent to a rectangular configuration in which connector length α is equal to zero. The angle between a connector and a concourse can range from zero degrees (basic) to 90 degrees (rectangular) depending on the shape of the land area available for the terminal. Walking distances are unchanged if the connector length is kept constant.

Connectors are ideal locations for moving walkways. In practice, some passengers walk on the moving walkway and others stand. Both of these types of passengers, as well as those who avoid the walkway, are considered in obtaining the walking distance distribution of passengers.

SIMULATION MODEL

The simulation proposed here is for use early in the planning stage when various terminal configurations are being considered and compared.

The movement of individual passengers in an air terminal is traced in the model. Passenger movement to retail centers and convenience facilities is not considered. Walking distance between the parking area and the terminal is not considered because it is assumed to be the same for all four configurations. The emphasis here is on measuring the mandatory walking distance within the terminal for the users of the airport.

Passengers are classified as

1. Hub transfers,
2. Normal transfers, and
3. Arrivals and departures.

Hub transfers are preticketed and there is no need for them to walk to a ticketing counter in the terminal block. They walk directly to the departure gates from their arrival gates. However, they have to walk through the central terminal block in a dual-concourse configuration if the arrival gate is in one concourse and the departure gate is in the other concourse.

The normal transfers who transfer from one aircraft to another, but who have to be reticketed at the terminal block, must walk to the terminal block and be served at a ticket counter. Then they walk to the departure gate.

The third category of passengers is arrivals and departures. Arriving passengers walk from the arrival gate to assigned locations in the baggage-handling area. Departing passengers walk from the ticketing counters to the departure gates.

The arrival and departure gates are allocated to all three types of passengers on the basis of an appropriate continuous uniform probability distribution. For passengers who require service at the ticketing or baggage collection areas, service location is allocated according to a continuous uniform probability distribution along an appropriate portion of the terminal block.

At the configuration selection stage of the planning process, it is difficult to estimate the effects of reductions in walking distance that may be achieved later (when the airport is operational) by assigning particular aircraft to particular gates. At this stage, the simulation model cannot account for nonuniformities in the allocation of passengers to gates. The model is useful, however, for obtaining an insight into walking distance distribution according to gate location, ticket counter, and baggage claim selection policies that can be postulated at the initial stages of terminal design.

Further, the long-run distribution for allocating gates to passengers (as schedules, aircraft types, and even airlines change) may be close to uniform if all gates are designed to take most aircraft types because it is not always possible to give priority to large aircraft when assigning close-in gates.

These uniformity assumptions are not valid for analyzing the operation of a functioning terminal (as opposed to a terminal in the planning stages) if airlines consciously select gate positions to minimize walking distances of passengers. For example, adjacent gate positions may be selected for two particular aircraft to reduce the walking distances for a majority of transferring passengers. Preferentially allocating gates closer to the centralized terminal block to relatively larger aircraft would also contradict the assumption of a uniform probability distribution for gate position allocations. Gate assignment policies for functioning airports, which minimize passenger walking distance, have been studied by Babic et al. *(2)* without explicit consideration of transferring passengers.

Initial selection of an appropriate configuration (during the planning stage) and subsequent assignment of aircraft to gates (during the operational stage) are both important for minimizing passenger walking distances.

Measurement of Walking Distance

The walking distance parameters that are generated for a single-concourse configuration are given in Table 1. Two random deviates (β_1 and β_2) are generated for each hub transfer to denote the distance to the arrival gate and to the departure gate, respectively, from the entrance of the particular concourse. For each normal transfer, an additional parameter (α_1) is generated to represent the distance to the entrance of the concourse from the ticketing counter allocated to the passenger. For a nontransfer, only one aircraft gate position is generated (β_1). In this description, $0 < \beta_1 < \beta$, $0 < \beta_2 < \beta$, and $0 < \alpha_1 < \alpha$.

The walking distance parameters that are generated for a basic dual-concourse configuration are given in Table 2. If a transferring passenger has to walk from one concourse to the other, then, irrespective of the relevant ticket counter location, the passenger must walk the full 2α width of the central terminal block in addition to the distances within the concourses. Nonhub transferring passengers who have their arrival and departure gates within the same concourse have to come to the terminal block to process their tickets for the onward trip. It is assumed that these transferring and arriving passengers will find their respective ticket counters in the half of the terminal block closest to their concourses. It is also assumed that the baggage-handling areas will be distributed such that arriving passengers can be served in the half of the terminal block closest to the relevant concourse. The limits on β_1 and β_2 are given by $0 < \beta_1 < \beta/2$ and $0 < \beta_2 < \beta/2$.

Table 3 gives the walking distance parameters of passengers in a T-shaped configuration. The random deviates β_1 and β_2 in the T-shaped configuration are measured from the centerline of the terminal block instead of from the entrance to the concourses as described for previous configurations. The conditional probability density of a passenger walking to a given location along the face of the terminal block is one-half that of the conditional probability density of a passenger walking to a given location in the concourse section, because gates are available on both sides of the concourses and on only one face of the terminal block. Notice that $0 < \beta_1 < \alpha + \beta/2$ and $0 < \beta_2 < \alpha + \beta/2$ for the T-shaped configuration.

Measurement of Walking Distance on Walkways

The additional passenger walking distance parameters due to connectors in rectangular dual-concourse terminals are given in Table 4. If a passenger stands on the moving belt, the distance walked in the connector is assumed to be zero. Though passengers may perceive a finite walking effort even while standing on the walkway, that effort is not quantified here. If the passenger walking speed is V and the walkway speed is V_w, the walking distance for passengers walking on the walkway is given by

$$\gamma_w = \gamma/(1 + V_w/V) \quad (1)$$

Notice that all normal and hub transfers walking from one concourse to the other have to traverse a connector twice. Some of these passengers may walk on both occasions, whereas others may walk only in one direction and ride in the other direction.

It is further assumed that the "walking" passengers walk and the "standing" passengers remain stationary relative to the walkway during the time spent on the walkway.

WALKING DISTANCE DISTRIBUTIONS

The advantage of walking distance distributions is that they allow the planner to determine whether an acceptable level of service, as measured by walking distances, can be provided by a terminal. Walking distance distributions also allow the planner to identify the types of passengers who have to walk excessive distances. When such categories have been identified, it may be possible to devise operational or configurational changes to reduce the walking distances of the affected groups.

The walking distance frequency distribution is obtained for the types of passengers mentioned previously. The simulation model output also shows the percentage cumulative frequency distribution of walking distance for different passenger categories. Further, the model outputs the mean, median, standard deviation, coefficient of variation, and coefficient of skewness of the walking distances for each category of passengers.

All simulations reported here are performed with 33 percent of all passengers considered as transfers. One-half of the transfers are considered hub transfers. A total of 10,000 passengers are simulated for each application.

Single-Concourse Configuration

Figure 5 shows the percentage cumulative frequency distribution of walking distance for a single-concourse terminal in which the half-block width of the terminal (α) is 100 m and the concourse length (β) is 600 m.

The cumulative walking distance distribution can be used to evaluate the proportion of passengers that will have walking distances within an acceptable range. Previous authors have suggested limits in the range of from 250 to 350 m for acceptable unaided walking distance in air terminals *(3, 4)*. If 350 m is assumed to be the limit, then Figure 5 shows that only 50 percent of the total passengers experience walking distances within acceptable limits. The figure also shows that 90 percent of normal transfers and 50 percent of nontransferring passengers walk more than 350 m.

TABLE 1 WALKING DISTANCES IN SINGLE-CONCOURSE CONFIGURATION

Type of Passenger	Arrival Gate	Ticket Counter	Departure Gate	Walking Distance
Hub transfer	β_1		β_2	$\lvert\beta_1 - \beta_2\rvert$
Normal transfer	β_1	α_1	β_2	$\beta_1 + \beta_2 + 2\alpha_1$
Nontransfer	β_1	α_1		$\alpha_1 + \beta_2$

TABLE 2 WALKING DISTANCES IN BASIC DUAL-CONCOURSE CONFIGURATION

Type of Passenger	Concourse	Arrival Gate	Ticket Counter	Departure Gate	Walking Distance
Hub transfer	Same	β_1		β_2	$\lvert\beta_1 - \beta_2\rvert$
	Both	β_1		β_2	$\beta_1 + \beta_2 + 2\alpha$
Normal transfer	Same	β_1	α_1	β_2	$\beta_1 + \beta_2 + 2\alpha_1$
	Both	β_1	α_1	β_2	$\beta_1 + \beta_2 + 2\alpha$
Nontransfer		β_1	α_1		$\beta_1 + \alpha_1$

TABLE 3 WALKING DISTANCES IN T-SHAPED CONFIGURATION

Type of Passenger	Concourse	Arrival Gate	Ticket Counter	Departure Gate	Walking Distance
Hub transfer	Same	β_1		β_2	$\lvert\beta_1 - \beta_2\rvert$
	Both	β_1		β_2	$\beta_1 + \beta_2$
Normal transfer	Same	β_1	α_1	β_2	$\lvert\beta_1 - \alpha_1\rvert + \lvert\beta_2 - \alpha_1\rvert$
	Both	β_1	α_1	β_2	$\lvert\beta_1 - \alpha_1\rvert + \alpha_1 + \beta_2$
Nontransfer		β_1	α_1		$\lvert\beta_1 - \alpha_1\rvert$

TABLE 4 ADDITIONAL WALKING DISTANCE IN RECTANGULAR DUAL-CONCOURSE CONFIGURATION

Type of Passenger	Concourse	Walking on Walkway	Standing on Walkway
Hub transfer	Same	0	0
	Both	$2\gamma_w$ or γ_w	0
Normal transfer		$2\gamma_w$ or γ_w	0
Nontransfer		γ_w	0

Table 5 gives the mean and standard deviation parameters for the four quasi-linear configurations. Vandebona and Wirasinghe *(5)* have described an analytical model suitable for the computation of mean and standard deviation of walking distances in centralized quasi-linear terminals and cross verified the analytical results with the means and standard deviations available from the simulation model.

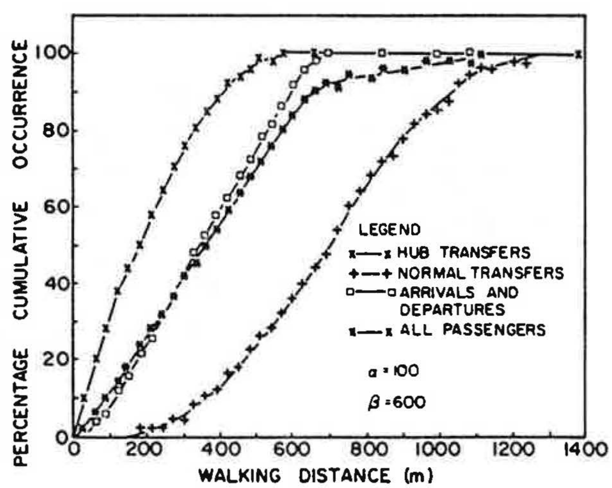

FIGURE 5 Walking distance distribution for single-concourse configuration.

Basic Dual-Concourse Configuration

Figure 6 shows the percentage cumulative walking distance distribution in a basic dual-concourse configuration. For the purpose of comparing walking distances, the numerical values selected for α and β are unchanged form those for a single-concourse configuration. Therefore the half-block width of the new centralized terminal block is 100 m. Each concourse is 300 m long.

According to Figure 6 and Table 5, the basic dual-concourse configuration reduces the walking distances of most categories of passengers. The types of passengers who experience long walking distances are the hub and normal transfers who walk from an arrival gate in one concourse to a departure gate in the other concourse.

Almost 80 percent of all passengers in the dual-concourse terminal experience walking distances within the acceptable limit of 350 m. However, almost 90 percent of passengers transferring from one concourse to the other walk distances greater than the acceptable limit because they have to cross the full width of the terminal block.

TABLE 5 WALKING DISTANCE PARAMETERS BY SIMULATION

Type of Passenger	Percentage Simulated		Single Concourse (α = 100, β = 600)	Basic Dual Concourse (α = 100, β = 600)	T-Shaped Dual Concourse (α = 100, β = 500)	Rectangular Dual Concourse (α = 100, β = 600, γ = 50)	
	Single Concourse	Dual Concourse				Without Walkway	With Walkway[a]
1. Hub transfers (same concourse)	16.5	8.25	198 (141)	99 (73)	106 (78)	103 (72)	103 (72)
2. Normal transfers (same concourse)	16.5	8.25	695 (250)	399 (135)	302 (130)	499 (140)	437 (141)
3. All same-concourse transfers (Categories 1 + 2)		16.5		249 (185)	204 (145)	301 (227)	270 (222)
4. All other-concourse transfers		16.5		498 (122)	390 (132)	602 (117)	540 (118)
5. All transfers (Categories 3 + 4)	33	33	446 (321)	373 (200)	297 (167)	451 (235)	405 (213)
6. Arrivals and departures	67	67	349 (174)	199 (91)	151 (88)	249 (91)	279 (92)
7. All passengers	100	100	381 (238)	257 (160)	199 (138)	316 (181)	279 (168)

NOTE: Standard deviation is shown within parentheses.
[a]Walkway speed is assumed to be one-half of mean walking speed.

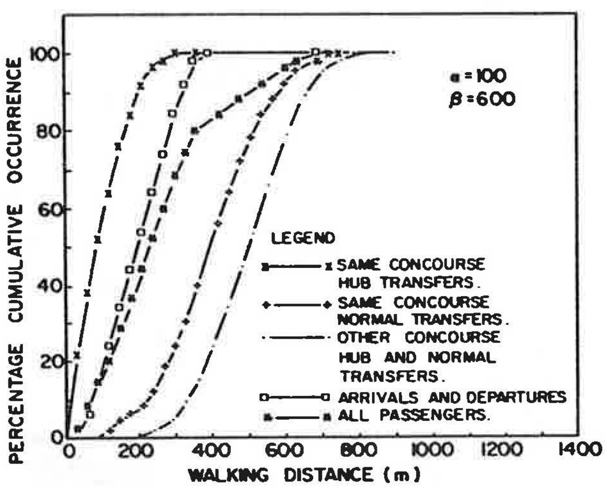

FIGURE 6 Walking distance distribution for basic dual-concourse configuration.

T-Shaped Dual-Concourse Configuration

In the T-shaped dual-concourse configuration, the β-value is reduced to 500 m because gates are also available along one face of the block that is 100 m long. Figure 7 shows that even further improvements in walking distance distribution can be obtained by adopting this configuration. About 90 percent of the passengers have walking distances within the acceptable limits. These improvements are due to the reduction in concourse length and the availability of some gates that can be directly accessed from the terminal block.

EFFECT OF WALKWAYS ON WALKING DISTANCE

Consider the rectangular configuration shown in Figure 4. A T-shaped or basic dual configuration will always give shorter walking distances than a rectangular configuration. Consequently, rectangular configurations should be adopted only if required by other considerations. The α- and β-values are assumed to be the same as those for other non-T-shaped configurations. To minimize walking distance, an attempt should be made to minimize the length of the connectors leading to concourses. However, adequate separation should also be provided between parallel concourses to allow for taxi lanes and sufficient clearance for parked aircraft. According to U.S. Department of Transportation *(3)* requirements, the rectangular configuration would require connectors at least 50 m long (i.e., γ = 50) for nose-in aircraft parking.

Figure 8 shows that only 65 percent of passengers walk acceptable distances in the configuration if the connectors are not equipped with moving walkways.

It was mentioned previously that the simulation model can be used to evaluate the effect of walkways. Passengers are

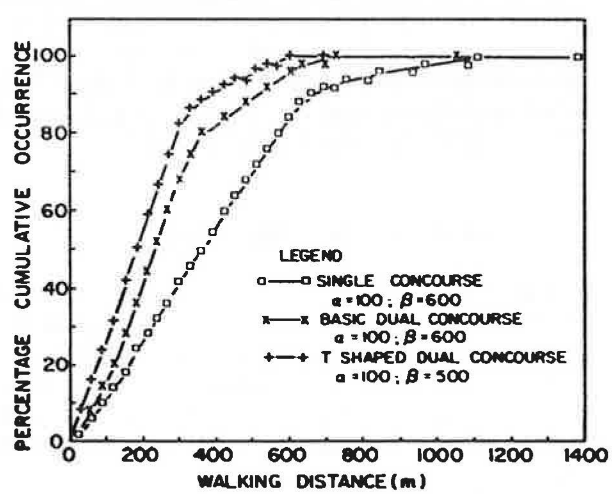

FIGURE 7 Comparison of walking distance distributions.

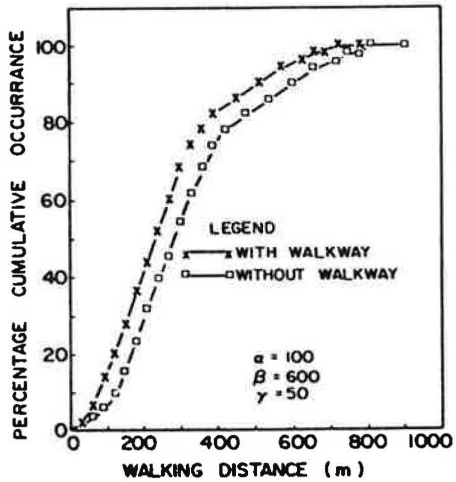

FIGURE 8 Walking distance distribution for rectangular configuration.

classified in three categories according to their behavior when they negotiate a connector: avoiders, walkers, and standees. Walkway avoiders are passengers who would use the alternative walking path beside the walkway. Horonjeff and Hoch *(1)* demonstrate that the percentage of people bypassing the walkway at an airport ranges from 9 to 20 percent, depending on the volume of passenger traffic, and that about 70 percent of the users of the walkway will be standees when passenger headway is less than 10 sec. On the other hand, the relative number of walkers increases when the walkway is less congested. For example, all users walked on the walkway when passenger headway was greater than 20 sec. It is assumed in the application described here that there are equal numbers of standees and walkers and that there are 10 percent avoiders.

Generally, mean passenger speed (V) is 85 m/min. Operating speeds of low-speed walkways are in the range of 35 to 55 m/min *(1, 6)*. The speed of the walkway in proportion to the mean walking speed is assumed to be 0.5 for the simulation.

The simulation is conducted with the walkways installed in the full length of the connectors of the rectangular configuration. The data in Table 5 indicate that, except for hub transfers who walk within a single concourse, all passenger categories benefit from the introduction of walkways. Figure 8 shows walking distance distributions before and after the introduction of walkway. Walkways increased the acceptability of the walking distance for up to 75 percent of passengers from the previous 65 percent level.

CONCLUSIONS

The simulation technique can be used to estimate the passenger walking distance distribution of a particular terminal configuration. The distribution can be used to compare various terminal configurations and to estimate improvement in level of service in terms of walking distance of passengers when moving walkways are introduced.

The simulation program that is currently available can be used to study any quasi-linear terminal configuration during the initial planning stages. Simulations of other (nonlinear) configurations are being developed *(7)*.

A comparison of the fraction of passengers who walk distances not more than the acceptable maximum of 350 m, for the various quasi-linear configurations, is given in Table 6. The T-shaped configuration provides the best level of service from this point of view. Further investigations (not reported in this paper) show that the T-shaped configuration is suitable for most fractions of transfers. A single-concourse terminal can, however, minimize walking if (almost) all passengers are hub transfers.

TABLE 6 COMPARISON OF QUASI-LINEAR CONFIGURATIONS

Configuration	Percentage of Passengers Walking Less Than 350 m
Single concourse	50
Dual concourse	80
T-shaped	90
Rectangular	65
Rectangular with walkway	75

An advantage of the simulation technique is the obtainability of walking distance distributions in addition to the walking distance statistical parameters. Walking distance distributions provide a better means of comparing different options than do parameters such as maximum walking distance.

One objective of the planner in selecting a terminal configuration could be to maximize the percentage of passengers that would walk less than the acceptable limit for walking distance. Walking distance distributions facilitate the comparisons required for this purpose.

ACKNOWLEDGMENTS

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