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A SURVEY OF AIRPORT ACCESS ANALYSIS TECHNIQUES - MODELS, DATA AND A RESEARCH PROGRAM

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16. Abstract

The report points up the differences and similarities between airport access travel and general urban trip making. Models and surveys developed for, or applicable, to airport access planning are reviewed. A research program is proposed which would generate a standard airport technical planning package and establish a federal airport access planning assistance program to help local agencies in planning airport access demonstrations and improvements.

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INTRODUCTION

The joint National Aeronautics and Space Administration (NASA) - Department of Transportation Civil Aeronautics Research and Development (CARD)Study Policy Report identified terminal congestion as one of the highest priority problems facing civil aviation today. One of the components of the terminal system which is sorely plagued by congestion problems is the access/egress system - the network of transportation modes used by air passengers and air cargo travelling between the airport and their ultimate origins or destinations. According to CARDS:

> "Access links to the airport are a prime cause of airport congestion.... The traveler must build large time/safety factors into his schedule because of the uncertainties of road congestion."[1]

The CARD Policy Study further points out that attempts to find solutions to the airport access problem are often hampered by market/financial, attitudinal/social, and organizational factors. For instance,

> "Some congestion is associated with modal interfaces (especially for cargo) and could be reduced by multimodal systems. Most multimodal ownerships have generally been opposed (regulatory and legal).
>
> "The profit potential for improved access/egress is not clear. Who might receive such profits is also unclear (market and financial).
>
> "Passenger preference for travel coincides with the peak rush hour traffic of the working force (attitudinal and social). The air carrier and airport operator have attempted to respond to this demand by providing sufficient capacity to meet these peak loads. The air carriers have suffered losses because of the resulting congestion in the terminal area (market and financial).
>
> "Access/egress is normally the responsibility of State and local governments. Because of other commitments, most of these governments are in a difficult financial condition (market and financial).
>
> "Airports have become known as undesirable neighbors. Proposed additions or expansions, although badly needed, usually arouse public opposition (attitudinal and social)."[1]

In addition to the above mentioned institutional constraints, the CARD Study also points out that responsibilities for airport access systems are divided among local authorities, HUD, and several modal administrations within DOT. In the past, this situation has encouraged the individual rather than integrated management of systems elements.

The CARD study recommended federally organized demonstration projects as one means to circumvent these economic, social and organizational problems. It emphasizes the need for operational demonstrations to test the effects of new methods on the operations of present systems, and market demonstrations to test the market reaction to new methods and changes in such factors as equipment, fares, routes, and service. The study also emphasizes the need to collect accurate data on price, frequency, and service elasticities, and the need to make these data available to the operator so that he can better evaluate the requirements for new systems. Furthermore, both types of demonstration programs will provide important data required for cost/benefit analyses of proposed new operational systems.

However, as the CARD Report notes, demonstration projects in the past have not always been the careful empirical experiments that they should be. These experiments would have been more valuable were there more emphasis on the gathering of data, especially market elasticity data. These data should have been collected while conducting experiments involving orderly variations in price, frequency and service choices. The message is quite clear - demonstration programs should be carefully conceived in order to yield the maximum relevant information and experience.

"In fiscal year 1971, the Transportation Systems Center (TSC) was asked by the Office of the Secretary of Transportation to initiate investigations in the general area of airport access and capacity. The resulting study placed its focus on the access/egress problem. As a first step in this task, a study of past and current literature was conducted to define the characteristics of the access problem and place it in its proper setting. In addition, a review was made of current methodology, especially in the area of demand forecasts and access/egress mode preference prediction.

This report is intended to provide a summary of these activities and a basis for a continuing effort in FY'72. The main aims of the report are:

1. To define the unique characteristics of the access/egress problem, and determine the degree to which this problem deserves special attention.

2. To review present modeling, data gathering, and demonstration methodology for the purpose of assessing their applicability to the access/egress analysis.

3. To propose an airport access research program.

The study focused on the access/egress problem for several reasons:

1. Access/egress improvements are frequently hampered by complex institutional constraints. For instance, trip ends usually lie in different administrative and funding jurisdictions, and therefore conflicting transportation objectives are involved.

2. Current airport O/D survey and modeling techniques have focused on access/egress rather than terminal processing, aircraft scheduling, satellite airports or other aspects of the airport congestion problem. The results of these efforts are the foundation upon which adequate systems evaluation methodologies must be built.

3. The issue of whether or not access/egress is merely a component of the urban transportation problem or an airport problem alone directly influences all further planning activities with respect to airport ground access.

The problem of freight access to airports is not addressed in this report. Freight will continue to increase in significance as a competitor for access/egress capacity; however, the lack of available resources forced a postponement in the study of this aspect of the access/egress problem.

The unique characteristics of access travel and some of the problems associated with these are discussed in this report. Also included are the institutional settings of airport access compared to general urban travel as determined by the CARD Study and the Institute for Defense Analysis report,[2] the required methodology and data bases needed to estimate potential benefits, cost, marketing/financial feasibility, impact and secondary effects of new technology and transportation systems changes. A review of current methodologies in the areas of modeling, surveys, and demonstration projects applicable to the previously discussed requirements is presented. A research plan is outlined to implement the development of data bases and methods outlined in the report.

SUMMARY AND CONCLUSION

The CARD study showed that ground access/egress at the major metropolitan airport is becoming an increasing prpblem. Since most access/egress trips are intra-metropolitan area trips, the question naturally arises as to whether the airport access problem is just part of the general urban transportation problem, or if it is a distinct problem that requires attention on its own merit. Airport access systems must be fairly extensive in order to collect and distribute passengers having widely dispersed origins and destinations. It is thus unlikely that major capital investments can be justified either economically or politically unless the systems serve the interurban market in addition to airport access travel. On the other hand, the trip-making characteristics of air passengers, and the visitors who accompany them, make airport access travel a clearly distinguishable form of urban travel. A large percentage of the air passengers are non-residents and are less likely to have access to private cars than residents. Air passengers fly infrequently; thus there is less familiarity and routine associated with the airport access trips than with most other urban travel such as work, school and shopping trips. Air passengers usually have baggage and may well try to keep walking to a minimum. These factors can affect modal choice and modal flexibility.

Airport access trips also distinguish themselves from general urban trips because of the unique features of the trip at the airport end. A major airport may have a central terminal complex or a number of variously configured separate terminals. Some of these configurations require some form of intra-airport transportation (IAT) system for access to the more distant parking lots, rental car lots, or mass transit systems who have a single airport terminal. It can be expected that these interface problems and excessive walking distances are factors that determine modal choice.

Due to these unique features of airport access travel and the general impact of air travel on the urban economy, the airport access problem warrants separate consideration in the analysis and planning phase of an improvement program. This is true even though the implemental solution for major capital expenditure projects will have to be developed within the framework of the metropolitan regions' requirements for urban transportation.

The uniqueness of airport access travel extends beyond travel characteristics into the institutional framework, at least as far as the "on-airport" portion of the trip is concerned. Here improvements are not only subject to the decision making of local urban governmental authorities and planning bodies, but also to those associated with the airport, i.e., the airport authority. This authority in turn must serve its primary constituency, the airlines and concessionnaires, who may have more limited objectives than overall airport access improvements.

Fragmented authority is perhaps the primary factor constraining the development of improved airport access. Local authorities tend to evaluate airport access in competitive terms, or from the standpoint of direct political impact, i.e., the number of resident air travelers. When confronted with alternatives, these decision makers tend toward solutions that meet immediate needs or require least local investment, even if these solutions do not promise the best long-range impact.

The CARD study points toward demonstration projects as a method to circumvent at least temporarily the major institutional constraints that confront airport access. This study also views demonstrations as a means for furnishing accurate data about new systems and system alternatives, both with respect to operational and market feasibility. The data can then be used to overcome decisions that are entirely swayed by the present institutional frame rather than the short and long-range impact.

Demonstrations themselves are not enough; they must be accompanied by careful data taking and evaluation so the results of the demonstration become generally apparent and can be generalized to other airports.

To overcome the many obstacles to improve airport access, DOT requires extensive data bases and integrated methods to propose convincingly alternative solutions and establish the feasibility of any proposed system change. To establish the extent to which such methodologies and data bases are available, a review was made of the applicability of existing models and the existing airport access surveys. The methodology review focused on models that analyzed the mode choice factors characterizing demand, the planning of satellite terminals, the understanding of specific subsystem operations, and the evaluation and impact of integrated transportation systems.

The review concluded that the (modal choice) models which are most sensitive to travel behavior have been developed for the urban work trip. While these models are applicable to the airport employee access problem, they do not consider the important modal choice factors in air passenger behavior, such as baggage and duration of total roundtrip journey (which is directly proportional to the parking costs residents incur if they use the park-and-fly mode). Modal choice models for intercity travel which considers access to the intercity modes treat this access as a general impedance factor and do not distinguish between access modes. Thus, these models can be used to estimate the access traffic volume, but not the mode choice of this traffic. The same comment also applies to the models developed for Satellite Terminals. While general airport access is a major parameter for these models, the models do not have to deal with modal choice in airport access. Finally, the mode choice models developed specifically for airport access were either generally unsuccessful or are still unproven. These models, however, present the basis on which further methodology and experimentation should be built.

Numerous models exist for analyzing airport terminal flow, intra-airport flow and posting, and baggage handling. These models are useful for establishing individual system sensitivities and determining system effects due to temporal changes in flow patterns. These flow patterns have direct effect on the airport ground access problem to the extent that these patterns influence the tripmakers decision process.

Models designed for the integrated evolution of transportation systems, as the NECTP, DODOTRANS and ITE models were reviewed but have no real application to airport access since they all suffer from the "weak link" problem, i.e., the overall model may be reliable but the reliability and confidence levels with respect to individual modules is highly limited. Also, experience with ITE re-emphasizes that the model concept is most responsive to the task for which it was designed, and reliability and confidence suffer as the application diverges from the original design objective and assumption.

A summary of the models/analyses reviewed is given in matrix form in Table 1, Model/Analysis Input-Output Summary.

Success of any model is restricted by the availability of realistic data for supporting and exercising the model. With this in mind, a review of available data from airport user-travel surveys was conducted. The review showed that many of the necessary trip and tripmaker characteristics are available in the Cleveland, Washington-Baltimore and New York surveys. However, the review of these surveys cannot assess their completeness for the study of airport access modal split. Nor is the lack of successful and calibrated models an argument that the data bases are inadequate. The analyses to which the data have been exposed are extremely limited; thus considerable additional work with existing data bases is required before realistic requirements for the collection of further data can be formulated.

On the basis of the above considerations, a research plan was formulated. This plan calls for providing, on a continuing basis, local authorities and communities with a better comprehension of their technical and fiscal options, and with the tools to assess these options. Specifically, the plan calls for two basic approaches:

NAME OF MODEL	MOI TYI	OUTPUT MODES CONSIDERED	OTHER NOTES
1. Reg. Plan Comm. Cuyahoga County[30] A/P Access Survey/ Model	Mo Ai Ac	1. Rapid Transit 2. Private auto 3. Limousine 4. Other-bus, taxi..	Analysis was calibrated to estimate change in the use of a mode from pre-rapid transit period to post rapid transit period.
2. Koller and Skinner[32] Wilder Limousine Service, New York	Mo Ai Ac	1. Limousine 2. All other	Discussed two forms of modal split models - Aggregate Disaggregate
3. Aerospace[34] Monte Carlo Simulation	Mo Ai Ac	. STOL . CTOL . Rail . Car	Used in two STOL feasibility evaluations Passenger attributes are assigned by random sample probability distribution
4. N-Dimensional Logit Model[35]	Mo Ai Ac	. Private car . Rental car . Taxi . Limousine . Bus . Any others desired	PMM analysis of Baltimore - Washington, D.C. Airport Access. Model is calibrated to the Wash/Balt. data.
5. Northeast Corridor Transportation Project Model System[9]	Ge Mo Mo	. Can handle all odes including ny new modes	Model system is made up of: econometric model, demand model, supply model, cost model, impact model, supply/ demand balancing model.

Table 1. Model/Analysis Input-Output Summary

	?UT		
NAME OF MODEL	MODE: TYPE	1ODES CONSIDERED	OTHER NOTES
6. I^3-Inter-city[29]-Inter-urban Inter-faces	Gene Moda	:onsiders all modes .nput	Evaluates terminal facilities and operations
7. McLynn and Watkins[16&17]	Gene Moda	;ee NECTP(No.5)	Cross elasticity model used for modal split analysis of NECTP
8. Kraft and Wohl[12]	Moda Base Beha patt	.ll modes	Cross elasticity model
9. Lave[13]	Moda base havi patt	onsiders all odes, two at a ime	Uses probit analysis technique
10. Plourde[14]	Moda base beha patt	.l ground modes	Models not calibrated. Models based on utility/disutility of auto (buy auto now/or use public transit) designed to evaluate Dial-A-Ride
11. Bock[15]	Moda base beha patt	.l ground modes	A generalized composite multi-modal network model

Table 1. Model/Analysis Input-Output Summary (Continued)

NAME OF MODEL	MC TY	?PUT ... ODES CONSIDERED	OTHER NOTES
12. Chamber-lain[37]	Ai Te Mc	ll Intra- term-nal modes - walking, con-eyor, etc.)	Produces statistics for air-craft, passengers and bag-gage and daily operations summary uses SIMSCRIPT, provides 747 impact capability
13. Rosen[39]	Ir Tı	oop trans-ortation system	Basically a cost model, deter-mines No. of cars, size, etc. needed to balance demand
14. Tanner[41]	Ba Ha	ntra-terminal aggage flow	Model of delays to A/C as a result of baggage handling
15. Karash[42]	Ba Ha	aggage flow in erminal No. bags andled Wait time for gs Man power re-irements for ggage handling	Model uses Monte Carlo method to determine outbound baggage flow, non-probablistic queueing technique
16. Barbo[44]	Ba fl	ssenger/Baggage ow Queue lengths Wait time Total pass./ g flow rate	Deterministic queueing model to explain interchange of pas-sengers/baggage at claim area. Fortran program

Table 1. Model/Analysis Input-Output Summary (Continued)

NAME OF MODEL	MODEL TYPE	DES CONSIDERED	OTHER NOTES
17. Landi and Rolfe[45]	Satel Termi Plann	Model considers utes based on st/time Provides lumes of pas- ngers through twork	Work done by RAND for PONYA - Passenger processing from arrival at airport to de- parture, "normalized gravity type model"
18. Snell[46]	Satel Termi Plann	mand flow rates access system	FASTSEM - demand shift to satellite terminals, evaluates design characteristics of satellite terminals
19. Vertol[47]	Satel Termi Plann	V/STOL Bus Train Auto CTOL	Modal split and demand model adapted from NECTP, looks at V/STOL as an intra-city factor
20. Genest	Satel Termi Plann	el aggregates racteristics all modes into abstract mode	Designed to optimize location of transportation terminals. Evaluates satellite terminal accessibility - SITECLU

Table 1. Model/Analysis Input-Output Summary (Continued)

1. Organize an Airport Access Planning Assistance Program including the demonstration of new concepts.

2. Develop an Airport Access Technical Planning Package.

The Airport Access Planning Assistance Program is needed since there is no one central authority responsible for airport access either on the national or local level. Airport access improvements are the responsibility of several agencies, each of which has other more primary objectives. Thus, airport access improvements will only be planned and implemented if they are unquestionably institutionally, fiscally and socially acceptable. Since hardly any project is ever this acceptable, a concerted federal commitment to airport access is required to overcome local inertia. To bring this federal commitment to bear on local authorities, an airport access planning assistance program is proposed. This program, if fully instituted, will help local organizations in their planning for airport access improvements and will assist local and regional agencies in obtaining and funding of airport access improvements which demonstrate innovative policy or hardware changes. Thus the program is envisioned to function as a catalyst to encourage and improve integrated planning between the multitudinous federal and local groups now directly or indirectly involved in airport access.

The objectives of the assistance program are:

1. To make available technical planning methods and data to local agencies.

2. To assume consideration of a greater number of alternatives by local agencies.

3. To demonstrate new concepts in conjunction with local agencies.

The development of an Airport Access Technical Planning Package is required to furnish local agencies not just with unrelated data and methods, but with standardized techniques and data packages. This will assure that the information gathered and developed with respect to one airport or one demonstration are, as far as possible, transferrable to new locations. The objectives of the planning package development are:

1. To specify planning methods which direct attention to and allow trade offs between many alternatives.

2. To develop a data base available to planning agencies.

UNIQUE FEATURES OF THE ACCESS TRIP

To what extent is the airport access problem a part of the more general urban transportation problem? First of all, these situations have many common characteristics. Those airports which have significant access problems are located in large metropolitan areas. As a result, a large portion of most access trips are contained in the metropolitan area and use the same transportation facilities as the intra-urban travelers. Furthermore, the same state, regional and local planners who are responsible for urban transportation system planning are also responsible for providing good airport access, at least to the extent that the airport traveler uses urban streets, highways, and urban transportation systems.

Undoubtedly, the airport access problem will continue to be closely related to the urban transportation problem. For instance, airport access systems must be fairly extensive in order to collect and distribute passengers having widely dispersed origins and destinations. It is thus unlikely that major capital system investments will be justified either economically or politically unless the systems serve the intra-urban travel market in addition to airport access travel. Therefore, any planning for airport access systems should take into account the impact between airport access and other intra-urban trip making.

On the other hand, the airport access situation is sufficiently distinct from urban transportation problems to justify individual consideration during analytical studies and the planning of improvement projects. Travelers to the airport can be classified as air passengers, employees, and visitors. It has been estimated[3] that these travelers comprise approximately 45%, 22% and 33%, respectively, of the average daily airport population. Of these, the air passenger makes the airport access trip unique. First, the primary purpose of the access system is to serve the air passenger. In addition, the air passenger brings with him the largest portion of the airport visitor population. According to the Cleveland survey, there are six visitors, on the average, accompanying every ten passengers. At the three Washington-Baltimore airports, passenger-related visitors outnumber casual visitors by two to one. The Cleveland data further suggests that there is a relationship between the number of visitors accompanying a passenger and the passenger's modal choice. Thirdly, there is evidence that air passengers exhibit different behavior from intra-urban travelers with respect to modal choice. For instance, according to the Cleveland Phase II survey, 87% of the airport employees traveled by private automobile, while only 57% of all airline passengers and 53% with an origin or destination in the metropolitan area used this access mode (see Table 2). In fact, there appear to be intrinsic reasons why air passengers exhibit more modal flexibility in access trips than other urban tripmakers, although there exists little data to substantiate this thesis. The personal experience of many travelers lends credence to this idea, as do several unique characteristics of air passengers which often can be substantiated by data. Some of these characteristics are as follows:

1. A large percentage of the population at a given airport is comprised of non-residents (50% at Cleveland,[4] 70% at Miami,[5] 30% - 50% on New York Limousine Service.[6] Obviously, a non-resident is much less likely than a resident to have a private auto available, and therefore likely to choose a different access mode than a resident. For instance, in the Cleveland Phase II survey, 67% of the residents used private cars while only 36% of the non-residents employed this access mode.

2. Air passengers fly infrequently (68% of the air passengers surveyed at Cleveland made seven or less air trips per year). It is probable that people making frequent or regular urban trips such as the work trip, the school trip, or the routine shopping trip are forced by time and cost considerations to adopt a routine mode of travel which makes the most efficient use of their resources. Due to the infrequency of their air trips, it is unlikely that air passengers have the same pressure to adopt a routine access mode.

3. Arrival and departure times of air travelers vary considerably. Clearly, the availability and attractiveness of different modes of ground transportation depend on the time of day. The availability of a friend or relative to pick up or drop the passenger off, public transit schedules, levels of congestion, availability of taxis, and personal safety on public vehicles are among the many characteristics of an access transportation system which vary throughout the day. Since the air traveler is presented with a variety of situations in which to choose his access mode, it is likely that he uses different modes in different situations.

4. Origins and destinations of air travelers are widely distributed throughout the area served by a major airport (see the Cleveland Survey results,[4] the Washington-Baltimore Survey results,[7] and the paper by Sutherland, et al).[3] The only urban situation resembling the airport with regard to funneling of passengers from diverse locations into (or out of) a focal point is the

Table 2. Choice of Travel Mode - Cleveland Hopkins Airport, September 1969[4]

Mode	Airport Employees Percent Trips by Mode	All Airline Passengers Percent Trips by Mode	Airline Passengers with Origins or Destinations in the Metropolitan Area Percent Trips by Mode		
			Resident	Non-Resident	Total
Rental Car	-	10.2	.6	15.2	7.1
Private Auto	86.9	56.8	67.4	35.6	53.2
Taxi	0.1	8.5	8.8	12.9	10.7
Limousine	-	7.1	3.4	11.0	6.9
Public Bus	0.5	-	-	-	-
Rapid Transit	11.2	14.5	19.0	18.5	18.8
Other and No Response	1.3	2.9	.8	6.8	3.6
Total	100.0	100.0	100.0	100.0	100.0

central business district. The difference between these situations lies in the wider distribution of trip ends in the larger CBD, and in the fact that most existing urban transit systems focus on the CBD, while little except highways and city streets have been provided for airport access.

5. Air passengers usually have baggage (according to the Cleveland Survey, 75% of all passengers checked at least one bag;at Miami, 67% of all passengers checked at least 2 bags). Clearly the presence and amount of baggage has a strong influence on modal choice. Trips involving change of mode, or vehicles not designed for the easy handling and storage of baggage will be less attractive to travelers with bags.

6. A large portion of air travelers are relatively affluent, or are traveling on business trips, and are therefore less cost conscious than the typical urban trip maker. On the other hand, the CARD study has pointed out that aviation is mistakenly viewed as an elite travel mode. While the median annual income of air passengers based on passenger trips is $11,992, the median income based on the individuals who fly is only $9,905. These figures show that, while the wealthier air passengers take more trips, there are certainly many users of air transportation of limited means.

Another unique feature of airport access systems is the design of their airport terminal trip end. The trip end design will depend on the airport's terminal design. A major airport may have a central terminal complex or a number of separate terminal buildings configured in linear or various types of loop patterns. Some of these configurations require an intra-airport transportation (IAT) system for access to some or all airport access/egress systems. It can be expected that the requirement for IAT transfer and/or excessive walking distance will be factors that determine modal choice.

Some other special problems are uniquely associated with the access trip. The presence of non-residents and infrequent travelers unfamiliar with travel to or from the airport requires better dissemination of information to potential users, perhaps more signs, maps, printed schedules, etc. Another potential difficulty lies in the volatility of modal choice. This implies high sensitivity of modal choice behavior to changes in the access system, which might make it difficult to predict the consequences of a planned change. Finally, the dispersion of origins and destinations makes it difficult to find an alternative to the automobile.

The major conclusions of this section are as follows:

1. Solutions to the airport access problem should be developed within the framework of the general urban transportation problem.

2. The airport access problem deserves special consideration not only because of its relative importance to the urban economy, but also because of the travel features that distinguish it from other urban trips.

3. The uniqueness of these features poses special problems in the areas of analysis, design, and operation.

UNIQUENESS OF THE INSTITUTIONAL FRAMEWORK

Development of new and improved transportation services requires agencies that can do the planning, the constructing, and finally the operating of these services. This section examines the institutional frame in which these functions for improved airport access will have to occur.

In airport access travel, one trip end is in the general urban environment while the other trip end is on the airport. Thus development of airport access systems are subject, on the origin/destination end, to the institutional frame applicable to urban traffic, while on the airport end they are subject, in addition, to the institutional frame surrounding the airports.

During the past year, DOT sponsored two studies of the problems associated with this institutional frame. One study was the IDA (The Institute for Defense Analysis) study on the institutional framework for urban transportation.[2] The other study with A. D. Little, Inc. concerned the institutional factor in Civil Aviation.[8] This study was part of the CARD Study. IDA's study reached the following major conclusions with respect to the institutional factors affecting urban transportation planning and implementation.

> "In spite of the apparent spirit and intent of Federal legislation, as reflected in the Urban Mass Transit and Federal-Aid Highway Acts, there is evidence that many urban transportation decisions are not responsive to urban needs and that a mutually satisfactory dialogue has yet to be established among communities and cognizant governmental agencies. This is despite the fact that since 1962 comprehensive planning and local review of Federally assisted projects have been legally required in urban development and highway legislation.
>
> "As a result of the existing institutional framework (i.e., administrative procedures, hearings process, decision process, organizational framework, etc.), several important problems have arisen.
>
> 1. Decision-making powers have been diffused.
>
> 2. There has been an overwhelming commitment by the various State highway departments to complete the highway network.

3. Agencies with decision-making powers have focused on immediate needs and solutions to specific situations. Often they do not have the authority to consider the entire spectrum of alternatives and the long-range impact of the immediate solutions.

4. The relative power of the bargaining agents is uneven.

5. The public hearing process does not allow a community to evaluate alternative systems."[2]

IDA's recommendations were as follows:

"Recommendation 1: DOT administrative procedures should be modified to promote or remove constraints on the consideration of a broader spectrum of community objectives and transportation system alternatives.

"Recommendation 2: Federal legislation is required if it is desired to remove some of the constraints on development of feasible alternatives.

"Recommendation 3: In order to promote comprehensive analyses that will provide the information necessary for choosing among alternative transportation systems, appropriate DOT administrative procedures should be developed." [2]

The A. D. Little study describes the state and local governmental response to the landside challenge as follows:

"a. Pseudo-Governments: Conventionally, where the private sector is confronted with many social problems, and where third-party effects abound, the government steps in and fills the vacuum. Let us examine governmental involvement in the airport problem and determine the pattern of its response. First of all, virtually all certificated airports are operated by either pseudo-governments (i.e., government-created independent authorities which may finance airport activities through revenue bonds) or by agencies of local general governments. In the former case airport revenues and governmental subventions amortize the substantial debt involved and cover operating costs. In the latter, some combination of grants, revenues, and appropriations from the communities' general fund keep the operation in the black. In practice, despite these financial ties to local government, airport operators behave as if they were private operators. That is, they are frequently well insulated from federal, state, and local government interference except within certain prescribed areas, i.e., the FAA dictates operational rules, and state and local governments restrict the geographic scope of airport activity and the general terms under which they may charge for services and raise capital. Their insulation permits them to channel funds into projects that are especially remunerative and satisfying for the operators, mortgagees, and bondholders. These projects may have little to do with improvements or research into the landside subsystem. This may be why, for instance, that one authority has gone into the lucrative real estate business but has made no successful attempt to solve its ground access problem. Such authorities pose special problems. Part of their freedom is attributable to their insulation from general government and the voters. But their incapacity to aggressively deal with problems like airport siting and access may also stem from this same insulation. Under such a mandate, the public interest suffers.

"b. Governmental Fragmentation and the Decision-Making Locus: The proliferation of local governmental bodies within a metropolitan area is a sizable institutional constraint on airport siting and access in particular. During the 1950's it was believed that consolidation, confederation, and metropolitanization of an urban region could produce a tier of government which, if not a general-purpose government, would at least be a special district with wide geographic scope. Challenged by representatives of very diverse political persuasions, consolidation and metropolitan governments floundered during the 1960's. Some saw efforts at consolidation as a plot to eliminate their right to home rule. Others charged that local control was absolutely necessary for a participatory democracy. Left largely on the starting blocks were those who saw airport congestion problems growing, and an increasing disparity between the needs and the authority and ability to meet them on a comprehensive basis. The difficulty of reconciling basic attitudes toward local government with needs originating from an entire region is a major reason for the present impasse.

"This impasse may be seen most clearly in the case of airport siting within a large urban region. Historically, land use determinations were made at the local level. The greater the number of local planning bodies and commissions, the more difficult it becomes to assemble the vast acreage needed for major airports. Only by vetoing local objections or by finding some unifying issue can siting or access right-of-way acquisition proceed. The former policy involves changing the locus of land use determinations within the governmental structure. The latter requires "super issues" which galvanize support and mitigate opposition blocs.

"Perhaps the primary factor constraining the development of improved airport access is fragmented government within an urban area and the resulting lack of coordination among the planning and action agencies within the fragments. Each governmental entity considers airport access from its own viewpoint. None consider it from a regional viewpoint. Thus, the residents of San Mateo County are less than enthusiastic about an extension of BART (Bay Area Rapid Transit) from Daly City to the San Francisco Airport (located in San Mateo). The interest of San Francisco in an SFO link on the other hand is heightened by the prospect of a BART link with Oakland Airport, a connection that could place SFO at a competitive disadvantage with Oakland as far as hub bound passengers are concerned. Hence, each locality tends to evaluate airport access in either competitive terms or from the standpoint of direct political impact - the number of resident air travelers.

"It is hardly surprising to find that the lead time involved in airport access approaches 20 years. First, the aviation industry had to become aware of the need. As one New York City official expressed it, Up until recently, no one faced the problem of airport access. The airlines and airport operator took the position that access problems of the airport were someone else's concern. But unfortunately, it is relatively simple for a community to delay access planning. Politicians respond to strident local opposition - voter sympathy is biased against large, bulky, costly projects with selected clientele. One New York regional transportation executive states that, Local footdragging set back our planning 18 months and necessitated coming in with state-enabling legislation at the '11th hour.' With local opposition at the legislative level, we did not have a chance. It is also difficult to generate support among politicians for projects that involve long lead times and which are not highly visible during the term of the incumbent. In short, a multiplicity of government jurisdictions insure multiple headaches for proponents of access.

"c. Financing: Airports and related projects require massive capital outlays. And capital requirements are accelerating. The new Dallas-Ft. Worth Regional Airport calls for project capital costs of nearly $450 million. Even STOL ports requiring modest facilities and runways may cost this much if a center city STOL strategy were to be implemented. Since most airports do not have revenues as great as those flowing to the metropolitan giants, it is difficult to market the necessary bonds unless a pledge of the communities' credit is also forthcoming. The price tag on the MTA's Kennedy rail access link along may run as high as

$150 million. With public concern over increasing public expenditures, airport development becomes a high political risk venture with visible effects on a community's fiscal capacity.

"Even with the advent of the Airport and Airway Development Act with its 50-50 Federal grant-matching formula, the financial burden to communities will still be great since Federal monies cover only airside developments - and the landside costs may amount to about three-quarters of total project cost. (So Federal matching is really more like 12.5% Federal, 87.5% local.) However, non-hub airports may place much less emphasis on terminals and put about 20% of project funds in them. It is not surprising to find, therefore, that legislators and voters are closely scrutinizing landside proposals.

"Recently, the New York State Assembly voted down the $150-million Kennedy rail access project. In San Mateo, the West Bay Rapid Transit Authority's bond issue was resoundingly defeated. By contrast, Cleveland had to put up only $6 million to get two-thirds Federal funding from HUD because it was the pioneer access project, and the airport service was easily achieved as part of the expansion of an existing regional rapid transit system. The SFO and LAX projects now under study must soon meet the financial test. Without financial help they could fail." [8]

The CARD study concluded that institutional constraints have major effects on solving airport access/egress problems and recommended that demonstration programs be used as one way to circumvent, at least temporarily, many of the major institutional constraints. The CARD study also concluded:

"Used in this way, carefully conceived demonstration programs can be very important to the future of civil aviation. Demonstration programs are experiments designed to embrace new concepts, procedures, regulations, or the blending of new technologies into existing systems. These programs should collect information and required data in a real-world environment involving the ultimate users of the system. Two types of demonstrations have been considered. One may be termed an 'operational demonstration' and would test the effects of new elements on the operations of present systems (e.g., testing the effects of a STOL vehicle on the ATC system). The other may be termed 'market demonstrations' and would test market reaction to new elements and other changes in such factors as equipment, fares, routes, and service. In either case, the demonstrations should be carefully designed to test key variables and to collect required data so that the information necessary for the guidance of R&D programs can be obtained. The role of operational demonstration in this regard is clear but market or regulatory experiments can also be very important to the R&D process. With accurate data on price, frequency, and service elasticities available, the manufacturer can better evaluate tradeoffs and requirements for new systems. Both types of demonstration programs will provide important data required for cost/benefit analyses of proposed new operational systems."[1]

From the A. D. Little study and the CARD study report, it is apparent that local authorities and the private sector require strong assurance of the market and financial feasibility of any proposed project. From these studies and IDA's analysis, it follows that local decision makers tend toward solutions that meet immediate needs or require least local investments, even if these solutions do not promise the best long-range impact.

The conclusions and recommendations of these studies imply that because of the institutional frame, the implementation of airport access improvement will require "hard sell." Local authorities must be convinced of the advisability of the improvement to overcome the inertia of the institutional frame. Demonstrations are one approach, but alone they cannot convince.

Also needed are hard data and accurate forecasts drawn where possible from demonstrations that show the impact of the improvement in terms directly related to the immediate objectives of the various local regional and national decision makers.

METHODS FOR ESTABLISHING FEASIBILITY OF SYSTEM CHANGES

Before local authorities and federal sponsors will make major commitments to the implementation of airport access system changes, they require assurance that these changes are beneficial: Is the new system fiscally viable? What will be the impact and secondary effects of the system change on the community and the environment? In addition, there must be methods for comparing alternative plans and for measuring the sensitivity of critical evaluation parameters to variations in system design and operation.

To appropriately promote and sponsor airport access improvements, DOT needs a generalized methodology for properly forecasting the effect of system changes resulting from the introduction of new services, technologies, operational procedures, schedules, pricing structure, and regulatory/legal policies. This methodology must be supported by an adequate data base and must include the ability to model a wide variety of systems in reliable settings.

The development of methods for forecasting airport access system changes involves the collection and analysis of empirical data from present systems in order to identify commonalities among various sites, discover causal relationships among key parameters, and formulate systems concepts.

The most readily available sources of data describing the present system are the airport access passenger O/D surveys. Large-scale surveys have been conducted at Cleveland, Washington-Baltimore, New York, Philadelphia, and Miami. Information furnished by such surveys include:

1. Modal choice distribution
2. Demographic distributions
3. Trip-making characteristics.

With the exception of the Cleveland survey, these surveys are limited by the fact that they are one-time snapshots, and thus do not reveal trends or time dependent properties of the variables. Another limitation of existing surveys is that standardized data collection techniques are lacking, with the result that data sets from different sites are not always compatible. One or more critical items may be missing from any two data sets. Federal standards should be developed to ensure that all O/D surveys collect certain critical information.

The inability of "single snapshot" surveys to give information about trends, or to support any inferences regarding the effect of access system innovations, can only be overcome by gathering additional data. Surveys taken before and after major access system changes such as the Cleveland rapid-transit (airport access) survey are invaluable for this purpose. It has been advocated by Hearle[9] that major centers build and maintain a data bank, continually adding data by taking, for example, O/D surveys every "k" years. Such a practice could be very helpful to the airport access planning. One apparently good, although little used, source of before, during, and after data are "surveys of opportunity;" that is, gathering data whenever the implementation of significant changes in access systems are planned. A mechanism should be established wherein DOT would be aware of any significant changes in local access systems, fares, schedules, etc., with sufficient lead time to carefully plan and execute before and after surveys.

Forecasting methodologies are necessarily based on data representing existing situations. Therefore their accuracy and reliability are proportional to the magnitude of the planned change whose effects are to be forecast. If the planned new system is expected to represent a dramatic change from the present system, special data gathering efforts may be required. For instance, one might conduct special detailed surveys of situations closely resembling the new system, even if they are at a different locale. Also, this need for data might be an excellent application of demonstration programs. Demonstrations could be used to create special situations for data gathering that approximate planned new systems.

In addition to an adequate program for assembling empirical data, models are required to analyze the data, conduct tradeoffs, and forecast crucial evaluation parameters. The models must be flexible enough to assess the effects of tradeoffs among costs, service levels, and other variables. The data base, together with the models, constitutes a technical base for forecasting and evaluating the effects of candidate access systems and innovations. The first step to be taken in providing this technical base is a survey and review of past and current methodology and surveys that relate to the airport access problem. During FY 1971, such a review was conducted and the results of this effort are reported in the following sections.

The main conclusions concerning methods for assessing feasibility are:

1. DOT needs an integrated methodology, applicable to a wide variety of airports, to forecast the results of airport access system changes.

2. A variety of well-chosen empirical data is needed to provide the insight necessary for the development of this methodology.

3. Federal standards should be developed to ensure that all O/D surveys collect certain critical information.

4. A mechanism should be developed so that "surveys of opportunity" may be conducted before, during, and after locally implemented access system changes.

5. Demonstration programs may be needed to provide data in the situation where dramatic system changes are being considered or planned.

EXISTING INVESTIGATIVE METHODOLOGIES

Modeling is a "means to the end" of problem analysis and/or synthesis. In the context of this review, reference is made only to mathematical modeling methodologies, specifically, those which can be used to provide guidance in the selection of airport access improvements. As stated in the introduction, the prime thrust of the overall review is to be in the area of modeling - to review prior as well as state-of-the-art efforts and locate any promising approaches for evaluation of concept effectiveness and impact.

The basic direction of the current effort is to determine the feasibility of and, if proven, to develop a generalized methodology for evaluation of improvements at the conceptual stage. The capability requires two broad stages of development:

1. An analysis of the characteristics of demand for travel modes to the airport.

2. Incorporation of the analysis results in a cost/benefit methodology allowing system concept synthesis, integration, and evaluation.

The first stage involves determination of traveler behavior when faced with a choice of modes of travel to the airport. Understanding the mode choice behavior provides a capability to construct models which can be used to examine defined mix-of-modes system options with researcher-controlled flexibility. The ultimate goal is to duplicate, within the realm of feasible investment, the decision-making behavior of airport tripmakers having defined trip purposes who have access to a spectrum of modal options including new and untested concepts.

To cover the full set of alternatives, the investigation into the traveler decision-making process should consider the total trip to the physical point where there are no further decisions to be made which may influence his selection of access travel modes, e.g., for the departing air traveler, from his landside origin to the point where he is relieved of the responsibility for transporting his own baggage and only the walk to the aircraft remains. Where the access trip would be influenced by decisions related to the return trip or the trip duration itself, these factors must also be considered.

The second stage, that of developing an overall evaluation methodology, is required for assessing the ability of new concepts to satisfy the demand characteristics of the airport travelers. Implicit is an understanding of the overall impact that a new concept would have on airport and community environs, i.e., does the new concept create a general improvement for all affected or does it improve the air traveler's mobility while creating negative impacts to other elements of the community? Is only a small element of the population served at the expense of a much larger segment? Are there hidden benefits for the larger segment? Which, if any, segments of the access/egress trip can be improved independently without known impact on the other trip segments?

The scope of this report has been directed to a detailed review of mode choice analysis, since determining the nature of the modal split-decision process is an essential part of the development of an overall airport access evaluation methodology. However, to provide initial insight into the factors influencing analysis of system interfaces and cost/benefits, a limited selection of related methodologies was reviewed. The analysis methodologies are reviewed in three loosely homogeneous groupings. Sections are included for models emphasizing:

1. Analysis of mode choice factors characterizing demand,

2. Planning satellite terminals,

3. Understanding specific subsystem operations,

The discussion deals with the specifics of model development and application. Details of the methodologies - logic-flows, formulation, tabular presentations, etc. - are included. Treatment of survey data analysis and data expansion which were available as input to models is included in the section entitled Travel Surveys of Airport Users.

The intent of this review is to determine the applicability of available methodologies to the study and improvement of airport access. A natural followup is to develop a framework around which one can formulate overall system specifications and evaluation criteria.

ANALYSIS OF MODE CHOICE FACTORS CHARACTERIZING DEMAND

A broad criterion for model review was developed from the unique problem characteristics previously discussed. From the general nature of the problem, it was concluded that airport-access trip purpose and tripmaker characteristics were significantly different from the urban work trip and interurban travel.

However, the review was structured to examine both urban and interurban models. The broader review would serve a two-fold purpose:

1. To locate methodologies purporting an ability to predict the split between (among) the various travel modes under consideration.

2. To give insight into the difficulties other researchers have had in establishing reliable modal split relationships. The latter is an important consideration since there has been only limited effort directed toward analysis of airport access mode splits in comparison with extensive work with intercity travel and the urban work trip. The most recent modeling efforts were examined along with expository critiques of earlier efforts. By this approach, the lessons learned from the earlier methodologies could be appropriately weighed in the airport-access realm of interest. There was no attempt to find all existing airport-access modal split models. The review limited itself primarily to those models currently being developed under some form of U.S. Department of Transportation support and those located by cross reference. Any applicable methodologies that are located as the program takes direction will, of course, be considered at the time.

General Discussion of Mode Choice Analysis

To gain perspective of the problems with modal split analysis, several summary documents and generalized approaches were reviewed. Fertal[10] detailed nine models used in early modal split analyses, comparing urban automobile versus aggregate public transit. Table 3 tabulates the characteristics considered in the models. All of the models require aggregation of data on a broad scale.

Lakshmanan[11] completed an exhaustive critique of the earlier modal split methods outlined by Fertal plus the work from the NECTP and two "urban-micro" models. His following statements are relevant:

1. Analytical approaches: "... even (best) have often been modified to accommodate the absence of all the data necessary to transcribe the original theories into mathematical models".[11] Most are deterministic, i.e., "constant in/constant out."

Table 3. Variables Used in Modal Split Models[9]

Variables	Trip-end Models*					Trip-interchange Models**			
	Chicago	Pittsburgh	Erie	Puget Sound	South-eastern Wisconsin	Washington D.C.	Twin Cities	San Juan	Buffalo
Trip characteristics									
Number of trip purposes used	2	3	1	4	7	2	3	2	2
Length of trip									x
Time of day						x			x
Orientation to CBD	x	x							
Tripmaker characteristics									
Auto ownership	x	x		x	x			x	x
Residential density		x		x			x		
Income				x		x	x		
Workers per household									x
Distance to CBD		x							
Employment density							x		
Transportation system characteristics									
Traveltime						x	x	x	x
Travel cost						x		x	
Parking cost						x	x		x
Excess traveltime***						x			
Accessibility****			x	x	x				

*Allocates a portion of total person trip origins and destinations in each traffic zone are split into highway and transit trip ends prior to trip distribution.

**Total interzonal person trip movements are split into transit and highway person movements after total person trip ends have been distributed.

***Time spent outside the vehicle during a trip: walk, wait, and transfer times for transit trips, and parking delay time for auto trips.

****A measure of the level of travel service provided by the transit or highway system to trip ends in the study area.

2. Time Orientation: Points out lack of progress in development of "peak-period" modal splits due to: "the lack of agreement on the relevant factors in the modal choice process, weak data bases, and inadequate theories."[11]

3. Independent Variables: States that a factor too often ignored is "that measure which cannot be forecast with some high degree of certainty should not be included as independent variables in the model."[11]

He directs attention to areas for caution in model development:

1. Identification of independent variables,

2. Consideration of the possibility of induced demand,

3. Use of a detailed behavioral approach over aggregation of "macroscopic measures of microscopic behavior."

In closing, he provides general recommendations and directions for research. They were specifically directed to the "work trip" and are not relevant here.

Kraft and Wohl[12] are exponents of the behavioral approach stating it should provide a better explanation of why traffic performance or flow varies as conditions change. Demand relationships are discussed comparing the differences between "direct" (effect on demand for a particular mode by changes in its own independent variables, e.g., price and time) and "cross-elasticity" (effect on demand for a particular mode by changes in a competing mode's independent variables). Cross-elasticity models provide the desirable feature (over traditional "gravity" approaches where the amount of tripmaking held constant) of treating tripmaker decisions as simultaneous and interrelated rather than sequential, separate, and unrelated.

Kraft and Wohl believe that it is "necessary to account for different valuations of travel characteristics as the ultimate objective of the trip varies."[12] Also by use of a behavioral approach, "for the people having no readily available automobile, clearly the existence of a reasonable transit alternative will stimulate (induce) the generation of trips. The nature of the trip determines the model parameter values."[12] The paper stresses the important factors influencing a traveler's behavior where options exist:

1. Trip purpose

2. Alternative modes

3. Transportation system performance

4. Alternative routes

5. Hour of the day

6. Elemental price and travel time segments of the total trip, i.e., valuation of sub-modes for total trip. For pricing, consider both out-of-pocket and perceived costs.

The authors add notes of caution and direction: "Data requirements for the statistical estimation of behavioral parameters ... are enormous." Degrees of aggregation will be necessary. "... The best approach would be to develop the demand equation for an individual, to estimate its parameters and to aggregate overall individuals in zone $\underline{i}$ in order to determine the total tripmaking demand from, say, origin zone $\underline{i}$ to zone $\underline{j}$." Collinearity problems must be confronted by a priori assumptions about the behavior of individual variables; this is due to the a priori requirement for stating sign conventions of elasticities and slopes of demand/performance relationships. "The method of statistical estimation to be used depends on the nature of the assumptions regarding the signs or behavior of the slopes or elasticities." A final model requirement is stated, "... that the output units of demand and performance submodels be compatible and related directly to the engineering design problem."[12]

Besides the general behavioral model developed by Kraft and Wohl, two others were reviewed for approach and applicability. Both are urban models. Where cost and time (including the influence of income and distance) are the usual variables of interest, Lave[13] examines the influence of comfort, sex, age, auto ownership, and family size on the mode decision. His use of the probit analysis technique, though more complicated to employ, does lend itself to binary choice decision logic when considering only two modes. A linear probability function describes the influence of the following parameters on traveler behavior:

1. Difference in relative travel costs

2. Difference in relative travel times

3. Use of a commuter "value of time" (derived as 42% of wage rate)

4. Comfort variable influenced by income and distance

5. Age (if data confirms influence)

6. Sex (if data confirms influence).

Techniques for deriving relative cost (out-of-pocket or perceived) were not discussed. Relative time is a measure of total trip time rather than a comparison of the effect due to various temporal segments. Evaluation of the model was performed by maximum likelihood techniques with a resultant coefficient of regression (R^2) = .379, a stated higher value than earlier approaches had achieved. The Cook County (Illinois) Highway Department (1957) data was used for calibration.

Plourde[14] develops a model based on the utility/disutility of an automobile vis-a-vis a public transit option. A short-run (mode choice now) and long-run (buy auto for future use) formulation is structured for each of 12 markets (time-of-day, income, trip purpose). The model was designed as a tool to evaluate Dial-A-Ride, but is intended as a general model applicable to other transit modes. The assumption is that travelers view travel modes abstractly and place value on the level of service rather than the mode itself.

Plourde develops a grouping of "life cycle dummy exogenous variables" to consider traveler taste and preference factors. After inclusion of the short-run and long-run travel decisions of household members, he develops two linear models, one for short-run and one for long-run, both for travelers over 16 years of age. Formulation is included as Appendix A. Perceived time and cost variables are used for all modes. Several causal relationships were eliminated due to probable lack of data for calibration or possible problems with data multi-collinearity. The models were never calibrated using real data.

Bock[15] provides additional critique of earlier modal split models and completes a detailed analysis of factors influencing trip assignment. Included is a discriminate analysis of mode choice using several distribution estimators. The study is useful as a review of pertinent factors which possibly influence tripmaker decisions. The factors were selected from "attitudinal" questions asked by a special survey. The significant factors, which also had detailed subcategories, were:

1. General preference or absence of real alternatives
2. Cost
3. Travel time
4. Variability of travel time
5. Safety
6. Convenience

7. Comfort

8. Effort and strain of travel

9. Effects of weather

A generalized composite multi-modal network model was developed. The network, which considers walking, driving, and transit, depends on the functional relationships involving the multiple characteristics of both the user and the transportation facilities. Use of the model was considered successful for estimating auto and bus trip times but was poor for rail. The reasons given involved zonal averaging techniques and limited rail data samples (1957 CATS survey).

An investigation using area accessibility ratios as a measure of auto/transit modal split proved inconclusive.

Two interurban modal split models recently have been developed, one for the Northeast Corridor Project (NECTP) and the other for an evaluation of intercity traffic flow at an intra-city terminal interface (I^3).

The cross-elasticity model developed by McLynn and Watkins[16,17] was used for the intercity modal split analysis of the NECTP. References 16 through 27 provide background in the development and model-selection process. The modeling effort by the NECTP provides insight into many of the problems and pitfalls of integrated modeling.

The NECTP analysis is applicable to intercity demand and does not address intra-city travel problems. These models were sponsored by the U.S. Department of Transportation and developed as parts of an integrated modeling and analysis effort extending over several years. The basic elements of the model system are as follows:

"1. An econometric model which forecasts population, income employment, and land use for each of 131 analysis districts (mostly counties) of the Northeast Corridor.

2. A demand model which predicts intercity passenger travel in the corridor by city pairs and by modes of travel.

3. Supply models for air and high-speed ground modes which are sensitive to changes in output levels.

4. Cost models which, based on parametric relationships, predict elements of mode and system cost.

5. Impact models which predict the effect of transportation changes on population, employment, income and land use in county-size analysis areas.

6. Supply-demand balancing techniques which make possible simulation of supply-demand equilibrium."[19]

Figure 1 is from Technical Appendix 3 of the Northeast Corridor Transportation Project Report,[9] which provides an overview of the NECTP integrated modeling activity. Reference 27 is a brief summary of the entire effort. References 18 and 19 outline overall conclusions and recommendations. Reference 20 is a detailed bibliography including abstracts of the major documentation generated toward the goals of the NECTP. References 17, 21, 22, 23 and 26 document a sampling of the preliminary foundation analyses leading to the report Passenger Demand and Modal Split Models by McLynn and Woronka.[15] Reference 23 provides a detailed analysis of an attitudinal survey of NEC travelers - air and ground.

The attitudinal survey was conducted to determine:

1. The process of mode selection

2. The influence of the nature of the trip

3. Value considerations of travel

4. Traveler evaluations and images of the modes

5. Reactions to the future

Because intercity flow was the prime concern in the NETCP study, access time and costs to the various intercity modal interchange points were approximated from average values for all travelers within a "superdistrict."[26] The forecasting approach is summarized as:

> "The models for forecasting transportation demand have proved their capability to predict the 'split' of demand among several competing modes. This allocation of demand among the modes is based not on each mode per se but on three basic characteristics of transportation service, namely trip time, user cost, and frequency of service. By approaching the modal split in this way, it becomes possible to predict the response of the travel market to totally new modes such as tracked air cushion vehicles (TACV). Reliance by the model on three characteristics of transportation to determine modal split undoubtedly omits some of the factors which influence travel behavior. In the

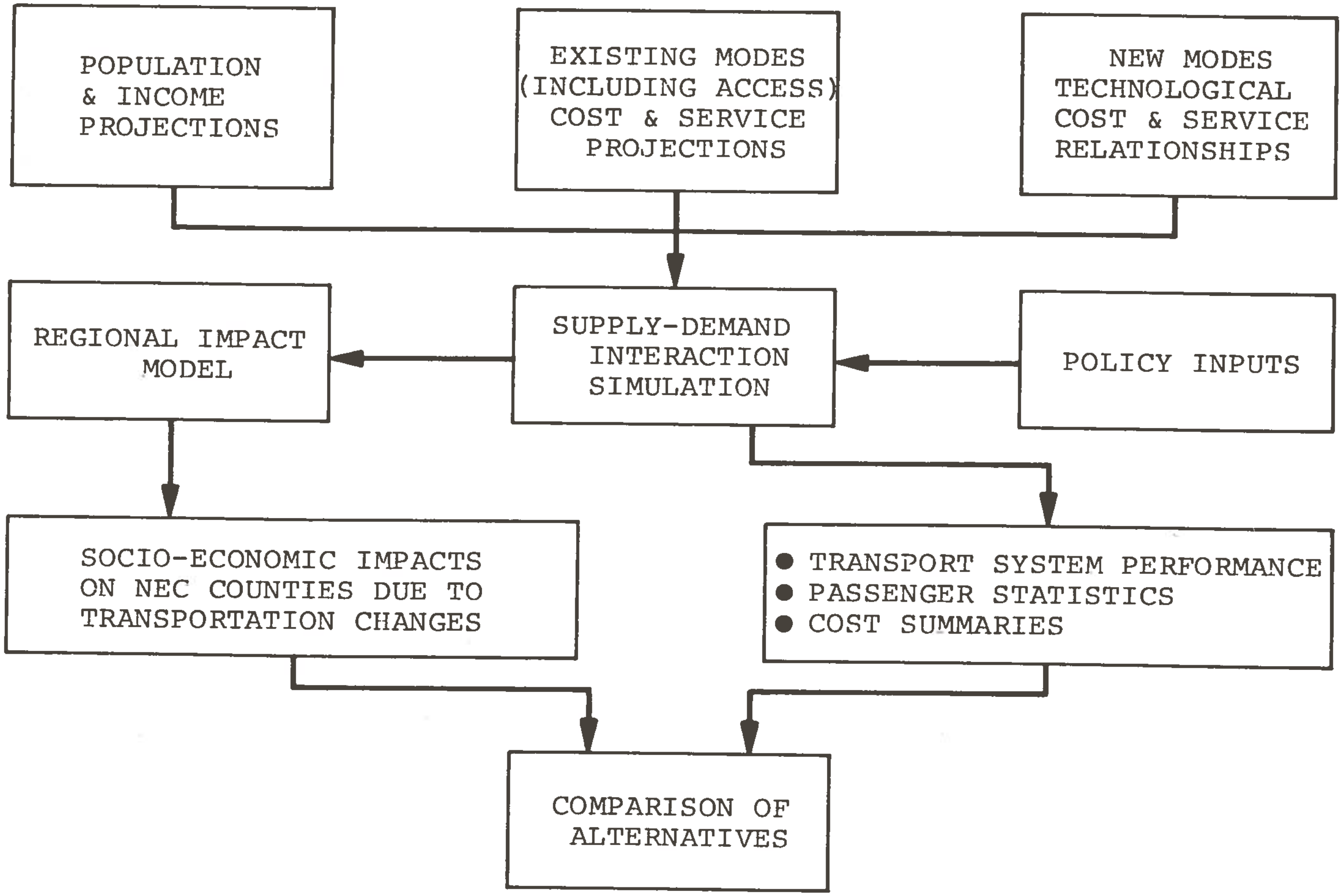


Figure 1. Relationship Between Elements of First Generation Model System

analysis of transportation alternatives in this report, other considerations such as comfort, safety, and fashion have been assumed to be equal among the modes. When these attributes differ to a degree which significantly affects modal split, the Corridor demand model becomes less useful."[19]

NECTP 230[16] and 217[25] devote considerable documentation to the problems of demand model calibration using the often sparse and disjointed data available during the development stages. Specifically, data problems existed in the following areas:

1. Intercity actual origin, destination, and mode-access characteristics

2. Traveler impedances in the terminal areas

3. Comprehensive and stratified intercity travel demand characteristics

4. Temporal patterns of intercity auto travel covering hourly, daily, and seasonal variations

5. Bus travel data

Additionally, the researchers conclude that there is a "...dearth of knowledge concerning the relative affect of the individual travel impedances on the magnitude of travel and the choice of mode. The manner in which the traveler perceives an intercity trip and the tradeoffs he makes between access time, terminal time, line haul time, and their associated costs are not fully appreciated."[25]

Several recommendations toward data gathering met fruition in the NEC Air, Auto, and Bus Travel Survey[28] completed in 1970.

Comments relative to the finally accepted demand model (prior to availability of the NEC Travel Survey) were:

"These versions of the calibrated models were subsequently incorporated into Northeast Corridor Simulation Models (CORRN) and exercised for a variety of proposed/alternative transportation configurations yielding results which were judged to be 'adequate.' The term 'adequate' rather than a more superlative descriptor of the outcome is used because, given the present state of transportation science development, great reliance must still be placed on the judgement and opinions of the working experts in this field, in evaluating the feasibility of outcomes produced by any modelling systems."[16]

Appendix B, which comments on the final formulation, is taken from Appendix 3 of the Northeast Corridor Transportation Project Report. The final Composite Analytical Gravity demand model resulted from the desire to complement the previously developed McLynn-Watkins cross-elasticity modal split model. [17] After log-linearization of both models, the method of linear least squares regression analysis was used in the calibrations. The forecasting methodology is in a continuous state of refinement as supporting data becomes available.

The Final Report, Research Study of Intercity - Intra-Urban - Interfaces (I^3) [29] evaluated terminal facilities and operation at the mode change interface between intercity passenger and commodity flow and the urban destination. The study is limited to intercity flow via common carrier. Simulation techniques are used. It is primarily a sophisticated network analysis model where minimum impedance is the desired goal. Impedance is a function of travel time, cost, and "other factors" (e.g., safety); impedances can exist within the travel arcs between terminals and at points within the terminals. Limited discussion is provided relative to determination of impedance values; discussion is directed more to their effect on flow volume. Total impedances over an arc are computed by iterative techniques with manual override options.

Appendix C is a statement of the interfacing of the three modules: demand, network, and terminal. During model development, the single most important obstacle which prevented implementation of the desired model system, without alteration, was the lack of appropriate data. (The Philadelphia-Trenton Metropolitan areas were used for calibration.)

The following important assumption is quoted:

"... it was necessary to accept a rather critical assumption, occasioned again by lack of data to test alternate hypotheses. The assumption was made that the total flows (passenger or freight) between the areas mentioned above, would not be sensitive (i.e., a function of) to the changes in the transport facilities. Rather, given the total flow from area a to area b, the path(s) taken by the flows (including decisions of mode and change of mode) would be a function of the characteristics of transport facilities (including terminals) serving between area a and area b. This assumption, while effectively eliminating area-to-area competition, as realized in flows of goods and passengers in the model system, does not vitiate the ability of the system to investigate the principal effects of transport facility changes on the patterns of those flows. It does, however, leave for future analysis an investigation of how changing transport facilities (particularly interface systems) will affect the competitive positions of different areas. This is a particularly important question when considered in the context of 'through traffic,' i.e., flows which originate outside the geographic area of interest, pass through it, and terminate outside of it. When a mode change is an implicit component of passing through the area of interest there may be significant response to such changes."[29]

In the initial stages of model development, feedback was a desirable design goal; two types were considered: economic and demographic activity response to levels of transport facilities, and improved terminal flow due to changes in facility characteristics. The Final Report, Research Study of Intercity - Intra-Urban - Interfaces (I^3) states that the second type is quite possible; however, it is pessimistic about the first as noted:

"The feedback from levels of transport facilities to levels of economic and demographic activities was not operationalized in this study. After careful study of existing "urban activities and land-use" models, it was decided that it was neither feasible, nor necessarily desirable, to implement such a model for this study. In particular, regarding the desirability, there are virtually no existing models which operate at a sufficiently micro-level of detail to usefully model the indirect consequences of the location or relocation of an interface facility. On the other hand, the development of a model to specifically deal with such micro-level detail might well prove to be too case specific to be generally applicable."[29]

The authors conclude:

"The system of models developed here is in fact useful for testing interface alternatives .... It must, however, be made clear that, due to extreme limitations of data, the ability of the model system to make absolute forecasts is rather limited. The usefulness of the system is in multiple sets of forecasts for comparison purposes. In other words, the model will provide only rough estimates of variables say in 1980, but should provide rather more accurate estimates of the differences between variables in 1980 forecast as resulting from different interface alternatives."[29]

Specific Airport Access Mode Choice Models

In light of the experience gained by researchers in earlier, more general modal split efforts, it is now appropriate to examine previous or ongoing works dealing specifically with airport access. Five models designed specifically to analyze mix-of-modes to airports are covered in this section. Two are based on an analysis of the Cleveland-Hopkins Airport Access Survey, one restricted to evaluation of a New York limousine service, one a Monte Carlo simulation technique, and one developed for use with the Washington-Baltimore survey of 1966.

Cleveland Modal Split Analysis

The Regional Planning Commission of Cuyahoga County, Ohio, attempted to develop a modal split model[30] using the data from the Cleveland Hopkins Airport Access survey. The objective was to determine air passenger diversion from prior access modes to use of the new rapid-transit link to the airport. The report is a statement of the analysis of data required to develop the mode split model. At the outset of the analysis phase of the study, it was decided to emphasize the analysis of air passengers and passenger-related visitors. The conditions that attract casual visitors to an airport or the factors that influence airport employees' mode of travel vary to a greater extent from city to city.

A preliminary analysis was conducted to identify any gaps in the data that could influence future analysis and to check the data from the origin-destination surveys against data collected from independent sources.

In summary, the conclusions were that:

1. The rapid-transit interview sampling and expansion procedures possibly contributed to total count discrepancies among the various surveys, e.g., 8% difference between air passenger survey vs. rapid-transit interviews.

2. The small number of respondents in some mode-use categories made it difficult to develop a modal split model that stratifies the users of these modes. This also happened with passenger-related visitors (4%), and they were dropped as a separate grouping.

An exploratory analysis was conducted "to identify those groups of airport travelers that are similar and could be grouped together for modal choice analysis and to identify those variables that appear to influence modal choice decisions for different groups of airport travelers."[30] From the earlier analysis, only air passengers would be stratified into different subgroups.

Tables D-1 and D-2 of Appendix D show the percentage of passengers that use the different modes of ground travel by 12 different groups in Phase I and Phase II. The selection of these groups was based on the residence of the passenger, the purpose of the air trip, and the land use at the origin or destination of the trip. The groups include two categories of residence, three categories of purpose, and two categories of land use at the origin or destination and are defined in Table 4. The table shows that 12 groups were too fine a stratification of air passengers to be used in developing a modal split model because the total number of responses in most of the groups was too small.

Table 4. Definitions of Analysis Groups for Clevelend Hopkins Airport Access Study for Phase I & II Air Passenger Mode of Travel[30]

Analysis Group	
1	Resident - Business - Private Residence
2	Resident - Business - Other
3	Resident - Personal - Private Residence
4	Resident - Personal - Other
5	Resident - Other - Private Residence
6	Resident - Other - Other
7	Non-Resident - Business - Private Residence
8	Non-Resident - Business - Other
9	Non-Resident - Personal - Private Residence
10	Non-Resident - Personal - Other
11	Non-Resident - Other - Private Residence
12	Non-Resident - Other - Other

<u>Residence Code</u>

Resident - An air passenger who resides in the seven county region of Cuyahoga, Geauga, Lake, Lorain, Medina, Portage, or Summit or who resides in the general service area of Cleveland Hopkins Airport and whose local origin or destination address is the same as his residence address.

Non-Resident - An air passenger whose residence cannot be covered by the "Resident" definition.

<u>Trip Purpose</u>

Business - Business or convention.

Personal - Personal or family affairs or vacation.

Other - School, military, crew member, other.

<u>Land Use</u>

Private Residence

Other - School, regular place of employment, other place of business, other.

It was desirable to analyze these 12 groups separately, since the use of the different modes of travel varied from group to group, and analysis files for the 12 groups were prepared with the option of combining as many of these groups as necessary during the model development phase.

An analysis was undertaken of the relationship of trip and tripmaker variables to assist in selection of modal split factors. The characteristics selected for the analysis are shown in Table 5.

Table 5. Trip and Tripmaker Characteristics

Residence
Age
Sex
Frequency of air travel
Income
Trip purpose
Baggage
Duration of trip
Day of flight
Land use at origin or destination
Private residence
Hotel-motel
Regular employment
Other business
Other
Persons accompanying to/from airport
Mode of travel
Private car
Taxi
Airport bus-limousine
Rapid transit
Other

A coefficient of contingency analysis was performed to measure the degree of association between two characteristics. The coefficient of contingency does not assume normality of the population distribution but is especially useful when dealing with two characteristics that are not ordered or continuous.

> "There are several disadvantages to the coefficient of contingency (C). Its maximum possible value only approaches 1.0 and varies with the number of rows and columns. Therefore, two different values of C are not directly comparable unless computed from tables of the same size. For a 2x2 contingency table, the maximum value of C, that is C_{max}, is .707. The maximum value increases as rows and columns are added."[30]

The results of the computations are shown in Tables D-3 and D-4 of Appendix D. To summarize the analysis:

"1. Land use at the origin or destination of the trip is the the variable most highly related to mode of travel. This variable is also very highly related to purposes of travel and residence of the air passenger. If the number of trips would allow stratification of air passengers by only one characteristic, land use appears to be the most desirable one, especially since it is also highly related to purposes of travel and residence of the passenger.

2. Purpose of travel is very highly related to most variables, especially age and sex of the air passenger, duration of trip, and land use at the origin or destination of the trip. If the number of trips would allow stratification by more than one variable, residence and purpose would appear to be the best choice.

3. The highest coefficient of contingency for both Phase I and Phase II was computed between the same two variables: residence of the air passenger and land use at his origin or destination." [30]

An analysis was also conducted to identify the modes of travel that the transit riders were diverted from and the areas where they originated or terminated their trip. Comparison of before and after data for each analysis group provided information on the diversion from each mode of travel to the rapid transit. Table D-5 of Appendix D shows the percentage of all air passengers that were diverted to the rapid transit from each mode by analysis group. Conclusions from this analysis include:

"1. Most air passengers using the rapid transit are diverted from private cars and limousines. Some passengers are also diverted from taxis and few are diverted from any of the other modes.

2. The number of passengers diverted from rented cars, hotel-motel vehicles or other modes of travel is an insignificant portion of the air-passenger population that rides the rapid transit. However, for selected groups, depending on the stratification used, it might be desirable to include rented car users."[30]

"An analysis of the areas served by the airport rapid transit was undertaken to determine the geographic areas that were served by each rapid transit station for use in developing travel times and costs to the airport by rapid transit."[30]

The data was stratified in several groupings by land use at origin or destination. A rapid transit service area was delineated which contained 88% of the air passengers who had local origin/destination within the rapid transit service area.

Based on the three stages of analysis, the development of a modal split model was attempted. Requirements were identified as:

"1. The model must accurately predict the total rapid transit ridership to the airport.

2. The input data must be available or easy to collect for most major metropolitan areas.

3. The model must be simple to apply.

4. The model must be sensitive to changes in travel time, cost, and other transportation system characteristics.

It was felt that these requirements were necessary if the modal split model developed with Cleveland data was to be useful in other areas."[30]

"The data collected before and after the opening of the rapid transit extension to Hopkins Airport provided a unique opportunity in developing a modal split model. Several structural alternatives were available:

1. Calibrate a model based on the Phase I data and test the model with Phase II data.

2. Calibrate a model based on the Phase II data and test the model with Phase I data.

3. Calibrate a model that estimates the change in the use of a mode from Phase I to Phase II."[30]

The pros and cons of the three alternatives were discussed with the following conclusion:

"The third alternative was considered the simplest and most practical approach. The possibility of developing a modal split model based on data from one phase to be tested with the data from the other phase was considered a desirable research effort requiring more time and money than was available.

The most important objective in developing a modal split model was the forecasting of rapid transit ridership. It was then hypothesized that a model could be developed that would predict the change in the use of other modes as a result of introducing the rapid transit service. The diversion from all modes to rapid transit (assumed to equal the decrease in the use of each mode from Phase I to Phase II) should then equal the rapid transit ridership. The advantage of this type of model would be its simplicity and the ease of application.... As the savings in time and cost of riding the rapid transit compared to mode M_1 increased, the diversion from mode M_1 to the rapid transit is hypothesized to increase. The diversion was expected to vary from group to group, depending on the characteristics of the tripmaker and the trip."[30]

Discussions also included:

1. "Airport access study districts: The geographical units used in the attempt to develop a modal split model were selected based on the following criteria:

    a. The number of weekly transit trips to and from an analysis district should be at least 50.

    b. The shape of an analysis district should not be irregular.

    c. An analysis district should be predominantly tied to one rapid-transit station (based on the rapid-transit service area analysis discussed previously).

    d. The total number of trips to and from an analysis district should be at least 100."[30]

    Census tracts or aggregations thereof were used as traffic analysis zones. Also, two individual areas in the CBD and at Shaker Heights were included due to high activity from those areas.

2. Air passenger groups: The 12 groups defined in Table 3 were used.

3. Selection of modes: Curves representing diversion to rapid transit were to be developed for three groups:

    a. Private car

    b. Taxi

    c. Limousine

    All other groups were considered insignificant.

4. Transportation variables: Travel times and costs were computed for private car, taxi, and rapid transit. Airport bus-limousine values were also computed, but were not completed due to problems with data. Several assumptions and formulations were used in computing costs. Several iterations were attempted to determine "average car" costs and travel times. Actual changes in the effective "traffic network" were made between Phases I and II which compound problems encountered when estimating travel times. Transfer and waiting times were computed. The following costs and thoughts are pertinent:

   a. Private car, out-of-pocket cost = $0.04/mile, and parking cost = $0.35.

   b. Average taxi fares for minimum-time path, 10% tip, and two values of waiting-time penalty were used.

   c. Airport bus-limousine: Several multi-modal combinations were involved: e.g., limo/bus, rapid transit, and walk. Expanded data techniques were used to determine weighting factors for each mode sequence involving the bus/limo.

   "A comparison between the weighting factors and the allotment of analysis districts to limousine stops revealed some illogical situations. In some cases, analysis districts that had 90% of their responses indicating 'walking' as their additional mode were tied to limousine stops that were 2 or more miles away, hardly a possibility. Consequently, logical adjustments to the weighting factors were made to bring them more in line with the transfer address data."[30]

   The various time and cost formulations and assumptions were included.

   d. Rapid transit: Formulation of time and cost included consideration of access modes to RT stations plus RT factors.

"The attempt to calibrate a modal split model using the procedures outlined above proved unsuccessful. Curves were plotted only for private car and taxi for two different analysis groups and the result was a scatter of points. Groups were then aggregated by land use only, with similar results. Finally, all groups were aggregated and no pattern or trend was noticed in the resulting plots.

The unsuccessful results can be explained by the following reasons:

1. In attempting to obtain travel time and cost data for small areas, the number of trips when stratified by group was too small to be able to compute meaningful percentages.

2. When all groups were combined, groups with different characteristics were being aggregated. In addition, the total number of trips was still too small to compute meaningful percentages, especially for taxi trips that are concentrated in few areas.

3. During the Model Development phase, several inaccuracies were encountered in the coding of downtown addresses for the Phase I survey. Similar problems are known to exist in the coding of addresses in other areas."[30]

"Although coding inaccuracies and data limitations are known to have influenced the curves that were plotted, the main problem in the attempted approach to calibrate a modal split model is the areal unit utilized. If differences in travel time and costs were measured at a smaller level, e.g., the traffic zone level, utilizing a different approach, it would probably have been possible to develop and test a modal split model."[30]

Even when dealing with a survey structured to model development, as was the Cleveland-Hopkins survey, the vague and elusive nature of the data bases cannot be overstated. Much data manipulation and analysis at various levels of aggregation and from widely diverse directions should be attempted to assure identification of causal relationships. Only after this exhaustive search for tripmaker behavioral patterns can an attempt be made at modal split model development.

Airport-Access Mode Choice - Analysis Alternatives

Wiggers[31] presents a treatment of the factors complicating an analysis of airport-access mode choice. Among these are:

1. The airport access trip represents only a part of the total trip.

2. Travelers to the airport consist of resident/non-resident factions with different mode options.

3. Many tripmakers are on an expense account.

4. Many air travelers are accompanied to the airport creating a unique tripmaker combination.

5. Baggage-handling is a complication.

6. Airport-access tripmakers have radically different travel patterns which vary throughout a day or year.

7. Land use at O/D appears to have an indirect effect on mode choice.

8. Peripheral modes have been difficult to analyze due to limited data, e.g., motel courtesy cars.

9. The multi-modal nature of limousine and rapid transit, e.g., park-and-ride, may be handled in several ways:

   a. By representative cost and time averages of access to prime mode,

   b. By representing each combination as a separate mode, e.g., taxi/limousine,

   c. By using a complex network analysis scheme.

10. Scheduling and frequency of service and the attendant interaction with airside trip scheduling influences mode choice, as well as the tripmaker concern for delay in meeting the airside schedule.

11. There is need to consider the tripmaker's option of making the outbound trip by air and returning to another terminal or by another mode.

12. Institutional factors influence the availability of some access modes.

Wiggers addresses the various models that have been developed to forecast mode splits for airport access. The distinction between the two broad categories of models, a "change model" and a "cross-sectional model," is stated:

> "The change model is calibrated using the change in ridership on the various modes from one time period to another on the basis of a change in mode availability between the two time periods. The cross-sectional model considers the mix of mode usage during a single time period and is calibrated using variances of that mix as a function of a set of independent variables. The former model is limited to describing only the effect of the change between the two

time periods and requires an assumption of adjustment to a condition of ... [all other things being equal]. The cross-sectional model runs into certain problems of determining coefficients of non-existing modes and of transferring a calibration from one area to another with possible contradictory results."[31]

Elaborating on various subcategories of the two basic approaches:

"Change Model. In a sense, a change model is based on the future being used to estimate a forecast. It requires that a demonstration be made and that the effect of the demonstration be the explanation of changes in conditions before and after the demonstration. This is very similar to techniques used in laboratory experiments in which the effect of procedure is tested by using it under controlled conditions. In applying this method to behavioral situations, the use of a control group is generally required. The purpose served by the control group is to meet the condition of ... [everything else being equal].

"Unfortunately for empirical airport access studies, it is virtually impossible to use a control group. This deficiency makes it extremely difficult to obtain any statistical measure of the confidence one may place in the results of the study. However, some tests may be made of the similarity of the before-and-after data, and used to form a subjective confidence level of the results."[31]

A "graphical change model" is developed which provides a series of curves reflecting diversion from one mode to rapid transit. Wiggers comments on the problems with the earlier attempt by the Cleveland area Regional Planning Commission[30] and suggests another direction to calibration. He suggests use of individual response data and forming traveler class intervals based on stratification by cost and time factors versus the former approach of aggregating by traffic analysis zones. The approach has the advantage of using larger sample sizes exhibiting similar trip characteristics. A "value-of-time" estimate is required. Wigger's paper includes an Appendix which provides a proposed calibration flow. Items considered in the model are included here as Appendix E. The proposed model generally has the form:

$$D_{ij} = \frac{\dfrac{N_{ijb}}{\sum_i N_{ijb}} - \dfrac{N_{ija}}{\sum_i N_{ija} + R}}{\dfrac{N_{ijb}}{\sum_i N_{ijb}}} \cdot 100\%$$

where R = Number of rapid transit responses.

D_{ij} = The percent of persons on mode i in class interval j.

N_{ijb} = The number of trips on mode i in class interval j before (b) the rapid transit is opened to the airport.

N_{ija} = The number of trips on mode i in class interval j after (a) the rapid transit is opened to the airport.

"Essentially, the above calibration looks at usage of mode i before and after the introduction of the rapid rail for responses having approximately the same time/cost differential with respect to the rapid transit. These changes must be normalized with respect to the change in trip generation from the before to the after period by dividing the number of trips by mode i by the total number of trips in the stratification in the before and in the after time periods."[31]

The model approach is stated (from Wigger's Appendix) as one

"... that requires the minimum amount of calibration in its application to a specific city, and the most accurate forecast for the near future. In contrast to a cross-sectional approach, however, it will not predict the use of non-rapid transit modes for airport access, nor will it forecast the use of rapid transit for an extended period without an independent forecast of the usage of current modes of airport access.

"In its calibration, the model makes use of as many variables as the data base will allow, so as to minimize its dependence on characteristics unique to Cleveland. At the same time, the amount of data needed to drive the model in its application to other cities is kept at a reasonable level.

"Since the use of before and after data in the model results in consideration of the percent change in usage of modes competing with the rapid rail, it assumes those that are diverted to the rapid transit have the same characteristics as certain stratified groups which are not diverted. To adjust for the comparative travel time and cost from a competing mode to the transit, an average travel time and cost for the transit is computed on the basis of the responding air travelers who used it. The average travel time and cost to the airport via the rapid are stratified similarly to the stratification for access by other modes to the airport, but are not mode specific. In other words, the choice of taxi, walking, public bus, or private automobile as a means to reach the rapid are not considered individually in the diversion from auto, taxi, and limousine, but are considered as averages for the air passenger groups.

"The use of 'land use' and 'residence' in the model are considered to substitute as strong indicators for the availability of the private automobile and limousine. The use of 'trip purpose,' 'income,' and 'baggage' should serve as indicators of a group's propensity for more expensive and service-oriented modes."

Wiggers states the following limitations:

"The use of the diversion curves obtained from the before-and-after data reduces a multi-modal (more than 3) situation to a bi-modal problem, i.e., diversion from mode m to the rapid. In so doing, it limits the flexibility of examining changes other than the introduction of rapid rail service, but at the same time, it considerably simplifies the analysis with a potential gain in accuracy."[31]

His assumptions include:

1. All things remain equal between sample periods, e.g., no major change in a transportation mode as well as introduction of a new mode in Phase II.

2. There is no interaction between the share of the market possessed by the other modes and diversion to the rapid, other than that accounted for with the calibrated bi-modal diversion curves.

3. The service offered by the rapid transit used in calibration will be essentially the same as that under investigation.

4. A possibly critical assumption is that stratification by the characteristics of the travelers and their trips will account for most of the variances of access to the rapid.

The model is at the proposal stage and no data is available for review. The author proposes that verification of the model can be accomplished by selecting a specific traffic zone for analysis since calibration would be done based on responses of traveler "class intervals."

He states advantages and disadvantages for using diversion curves with a "change" model:

1. Advantages

"a. Simplicity of application, if the purpose is to forecast ridership for a new rail transit service to an airport where it does not now exist.

b. Minimal or no adjustment ... calibration is accomplished on a one-time basis using the Cleveland data, and the diversion curves may then be applied 'as is' to any other U.S. city. This will result in maximum transferability of the experience in Cleveland to other U.S. cities.

c. Since the diversion curve generated from a change model relates to the time and cost savings of an individual traveler, the model would facilitate cost-benefit studies of rapid rail service to airports."[31]

2. Disadvantages

"a. Interaction between the other competing modes is not explicitly considered in the diversion to the rapid.

b. Examination of substantial changes in the service offered by the other modes must be handled by an independent method. Diversion from a mode for which a curve was not calibrated using the Cleveland data cannot be handled."[31]

Wiggers mentions development of a "mathematical change model," one which would be to curve fit the results obtained in the development of a graphical model. Any number of equation forms could be used; the form producing the smallest standard error would be selected. These, however, would also not account for the interaction between existing modes as affecting percent diversion to the rapid.

The author then elaborates on the cross-sectional models:

"The cross-sectional models are based on the extrapolation in time of modal choice that was measured during one historical time period. Calibration is dependent upon differences in the accessibility speed, cost, and other factors of the various modes. The formulation of the model is generally a rationalization of the difference in demand for each mode as a function of the differences in the mode and traveler characteristics."[31]

He further comments that "graphical cross-sectional models" are restricted to bi-model situations and therefore are inadequate when applied to the multi-model nature of the airport access problem.

He then examines "mathematical cross-sectional models," several of which have been developed for intercity applications. A summary is included in his paper of the approach and application for the following models:

1. McLynn Model

2. Discriminant Models

3. Logit Model

4. Probit Analysis

5. Regression

They are all capable of handling three or more modes and several independent variables. Advantages and disadvantages are included here as Appendix F.

Finally, the author references "abstract mode models," those having the characteristic

"...That the choice of a mode such as private automobile, limousine or taxi, is not influenced by the fact that it is a private automobile, limousine or taxi, but solely on the basis of the measurable characteristics of that mode such as travel time and travel cost (fare)."[31]

Airport user groups other than air travelers are mentioned and dismissed due to inadequacy of sample data necessary for analysis.

Contact with the author indicated that there is a current effort to develop a better representation of the highway network necessary to generate better trip time and cost characteristics.

In closing, the author outlines Federal and State/Local needs for accurate evaluation tools used in making decisions for implementing transit service to airports.

Modal Split Models For Airport Access

The discussion of models developed at MIT by Koller and Skinner[32] limited its scope to analysis of non-resident business travelers using an airport limousine service (Wilder - New York). A supporting survey[6] was conducted. Two approaches to mathematical derivation were attempted:

> "Specifically, the report discusses two general forms of modal split models, aggregate and disaggregate, and their application to airport access. Aggregate models are calibrated with zonal averages of passengers and trip characteristics. They may explain the effect of variations between zones but not those that occur within different zones, since information about these are best in the aggregation. Disaggregate models, on the other hand, attempt to explain intrazonal as well as interzonal variations."[32]

The authors completed an analysis proving that limousine and taxi price and travel time ratios exhibit low enough collinearity to allow use of both as exogenous variables in a model. They concluded that:

> "The effects of price and time can be estimated separately in this analysis although no distinction can be made between the effects of limo price and taxi price or, of limo time and taxi time."[32]

An aggregate model was developed using multiplicative demand relationships since their ability to reflect the mutual dependence of explanatory variables provides a significant advantage over linear additive models. An analysis of collinearity problems was performed resulting in identification of factors for use in the model. The final form of the model used the ratio of prices and times:

$$V_L/V_{to} = .68\left(\frac{P_L}{P_t}^{-2.33}\ \frac{T_L}{T_t}\right)^{-1.23} \qquad (R^2 = .59)$$

where: V_L = Volume of travelers using limousine

V_{to} = Total travelers to the airport from the zone of interest

P = Average price of ride from zone of interest

T = Average time of ride from zone of interest

L = Limousine

t = Taxi

The model was designed to determine the mode share for access modes by non-resident business travelers. Koller and Skinner provided the following observations and conclusions:

> "The most obvious observation is that the model ... [above] ... is more sensitive to changes in the ratio of prices than to changes in the ratio of travel times. Remembering that the model has been calibrated using the responses of passengers on business trips, this seems surprising. Many studies of trip making have suggested that businessmen are more sensitive to time rather than prices. Most of these studies have been concerned with the trip to work in urban areas, whereas this airport access analysis deals with a different process.
>
> "The indicated sensitivity of the airport travelers to price can be explained in two ways. First, many of the non-resident businessmen are in unfamiliar territory, and are probably not heading to or from an "obligation" and are less concerned about meeting specific deadlines. They, in fact, plan to arrive at the airport far ahead of the time of departure. Secondly, there is a large and significant difference in the magnitudes of costs being considered. Costs in the urban work trip study are in the range of fifty cents to perhaps three dollars. Costs in the access trip for non-resident businessmen are more likely to range between eight to twenty dollars. The higher costs for the

airport access trips would naturally scan to greater interest in costs."[32]

From the comparison of the airport-access situations to other studies:

"It would seem that the results of an analysis of the demand for airport-access systems would resemble those of a study of intercity travel more than those of intra-city analysis. Intercity travel on a personal basis tends to be irregular and to cost more than the regular commute to work."[32]

The authors plan further testing of the model validity during controlled experiments with limousine fare changes. A disaggregated model was developed for comparison purposes. It "...attempts to explain intrazonal as well as interzonal variations in behavior by using individual rather than zonal data."[32] The model developed is a binary choice model of the form:

"P (X) = f(individual passenger characteristics and modal service characteristics)
in which P(X) is the probability that an individual passenger chooses to use a particular mode. For large groups of passengers with similar characteristics and similar alternatives, P(X) can be interpreted as the modal split. Naturally, if there are more than two modes, all but one mode must be lumped together into one alternative."[32]

Of the three commonly used calibration methods, discriminant analysis was selected over probit and logit statistical techniques because of its less tedious mathematics.

Problems with a disaggregate approach are:

1. Usually, several alternatives exist.
   "A disaggregate model of a situation where there are many modes, such as airport access, can define the percent of air travelers using a particular access mode but not, in general, the split among other modes."[32] Because of the need to deal with binary choices, the desirable approach would be to model what the traveler considers to be his best two alternatives.

2. Also the "cost" implications are not straightforward.
   "Assignment of costs to the automobile used in the airport access trip is difficult due to the bi-modal nature of the auto for this trip. If the air traveler is driven to the airport, it is usually the non-traveler who actually pays the costs.

If the air traveler drives his own auto to the airport and parks, the costs depend on the length of the trip. Automobile costs for the airport access trip are therefore much more difficult to estimate than for the commuter trip where it can be assumed that each traveler drives his own auto and parks for the same period of time. This difficulty extends to estimates of the costs of other modes used in airport access."[32]

3. A "risk time" factor is involved.
"Risk time is the time interval between the time of arrival at the airport and the time of departure minus airport processing time. It is too often as long as the trip itself...Risk time might...depend on both the modal choice and the passenger characteristics...[Therefore,] the behavioral effects of travel time cannot be summed into one variable for airport access."[32]

4. Rather than stratifying data by trip purpose (a common approach), the authors suggest: "It may be more insightful for the analysis of airport access to stratify the traveller's residence, which seems more to determine alternative modes of access and his knowledge of their operating characteristics than does his trip purpose. Perhaps residency merely determines the alternatives open to particular passengers whereas trip purpose determines, at least in part, the way passengers perceive these alternatives."[32]

A comparison of aggregate vs. disaggregate models points out:

> "The disaggregate approach ... uses more of the available data than aggregate models since it takes each passenger to be a data point, whereas the aggregate model uses zonal averages."[32]

The drawbacks to the disaggregated approach (for this application) were the data limitations, which did not allow establishing the effects of changes in other modes on the mode of interest (limousine). A limitation was that the model could not consider variables such as family income, sex, and family structure, since the information was not available for non-limousine travelers. An initial formulation included consideration of travel time difference, cost difference, auto travel time and a private auto availability factor. Categories and estimating functions for travel time and cost data are explained.

Actual limousine fares and estimated taxi fares were used to compute difference in travel costs. Travel times were estimated from maps; equal speeds were assumed. Total limousine travel time was based on travel time to limousine pickup, the waiting time at the pickup, and the scheduled travel times. For non-limousine users, the potential travel time by limousine was based on the average pickup access times and waiting times for limousine users from the particular zones. The latter was stated as an assumption. Auto travel time (TT) is incorporated as a proxy for inconvenience of a friend who drops off the traveler. Auto availability (A) was included as a dummy variable assumed equal for both limousine and taxi users. Calibration of three forms was attempted with limited success. The final form of disaggregate model for non-resident air travelers was:

$$Y = -1.40 + 0.08\ TT - 4.7A \qquad R^2 = .61$$

for $Y<0$ the probability of riding the limousine was

$P<.5$

where, TT = auto travel time

A = 1, if there is someone to drive the traveler to the airport in a private car; A = 0 if otherwise

This model would not predict the effects of fare policy change for the limousine.

The authors question validity of the "t" hypothesis test results, which eliminated travel time and cost differences as insignificant, and the apparent causal relationship between auto availability and modal choice. They suggest that use of a two-mode approach is more suitable to modeling than is the "multi-modal" (one mode plus an aggregation of all others) concept, since variables representing the two competing modes can better represent the differences in modal characteristics.

The report concluded that the aggregate model would be more useful if it examined limousine policy changes. Reference 33 is a follow up and related demand study. A summary of the study results is:

1. The use of the service is strongly asymmetric in that it carries many more people, especially residents, away from the airport than to it.

2. The social and economic characteristics of limousine passengers do not differ appreciably from those of all other airport travelers.

3. A significant fraction of the riders, especially the non-residents, are "captive" to the public service to the extent that they would have great difficulty in going any other way.

4. It can also be inferred that many potential riders from out-of-town are unaware of the service.

5. Many travelers arrive at the airport well ahead of flight time, 50% of them being there about an hour ahead of time. This risk time suggests that longer distance airport access travelers are relatively insensitive to speed but quite sensitive to costs, as indeed is indicated by the calibrated modal split equation.

Aerospace Monte Carlo Simulation

Aerospace Corporation developed a Monte Carlo simulation[34] in which random samples from probability distributions are used to define traveler attributes. The traveler is ultimately assigned to a mode by use of these attributes. The simulation has been used in two applications for evaluation of STOL feasibility.

1. Feeder service study: Many origins with a single point destination, i.e., Palmdale International Airport from areas in Metropolitan Los Angeles.

2. General service study: One or several aggregated origins to one or several aggregated destinations (e.g., intercity), i.e., Portland-Seattle corridor evaluation.

The simulation sequence is generally as follows:

1. The "arena" is defined as in Figure 2.

2. Probability distributions are used to describe each traveler's attributes:

   a. Purpose and duration of trip

   b. Origin and destination door locations

   c. Traveler's "value of time" f(income)

   d. Party size

   e. Preference factor/mode

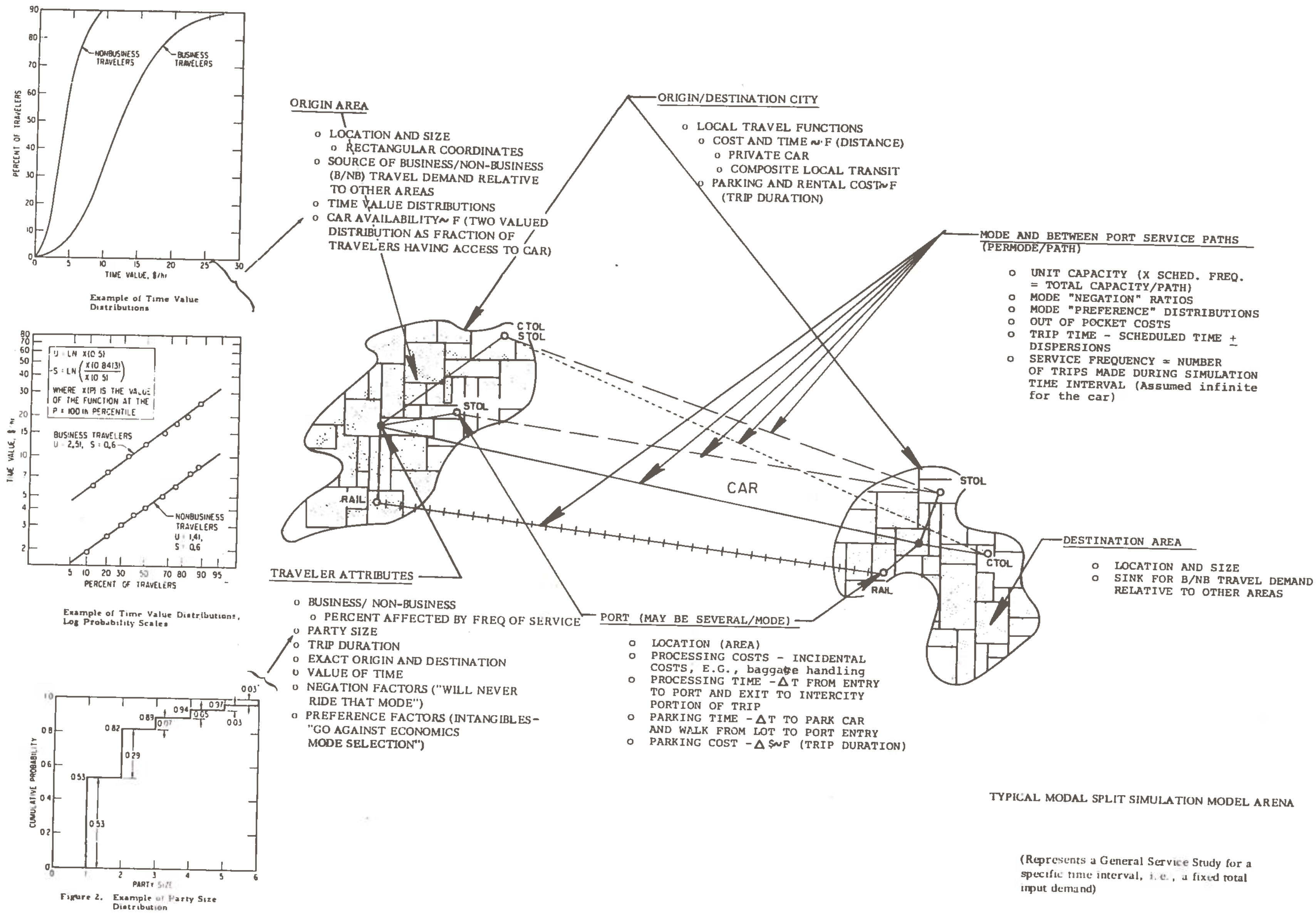


Figure 2. Typical Modal Split Simulation Model Arena[24]

f. Waiting times/mode f(service freq.)

3. The traveler's "cost functions" /mode/service path are computed and reflect:

   a. Perceived out-of-pocket costs

   b. Trip time

   c. Mode service frequency

   d. Traveler preferences

4. The traveler is assigned to the mode with the minimum cost function considering mode capacity.

5. The mode split is determined by generating a sufficient number of travelers and assigning each to his minimum cost function. Inputs are selected so time is implicitly defined as a particular interval of interest, e.g., morning rush hour.

The simulation model inputs are shown in Figure 2. Each of the input quantities represents distributions except for the simulated time interval and the total number of travelers. Output of the simulation can be obtained in two categories:

1. During simulation, outputs are traveler's records for every "n^{th}" traveler including all attributes, service path, and all cost and time components.

2. On concluding simulation, a standard set of output is available including model split reflecting various combinations of traveler attributes and modes.

Simulation is programmed on a CDC 6400/6600 using 23K words core storage in FORTRAN IV because:

1. Time is not explicitly represented,

2. Sets and queueing are not required,

3. FORTRAN random variable generators are available,

4. FORTRAN has an efficient compiler (minimum run time).

For the Palmdale and Portland-Seattle studies, the report provided data base sources and values from which the purpose of trip, relative demand, value of time, and preference factors were determined. The studies were basically to examine the modal split of adding a new system (STOL) into an existing situation. Bureau of Census and 1967 Cenus of Transportation data were used for demand data. Value of time for business (B) and non-business(NB) used standard values. Preference factors were determined by cenus data or set to zero. STOL was assumed equal to CTOL. To determine mode split for near term improvements, the approach was generally to "hold characteristics of current modes fixed and vary parameters of proposed new service" (e.g., STOL schedules and fares). The studies selected 2500 travelers as the sample size (n) which gave a worst case modal split standard deviation, σ, of 1% for a worst case probability (p) of 50% (by $\sigma = \sqrt{np(1-p)}$). Running time is situation-dependent with number of service paths and traveler's records being first order effects. On the CDC 6600, the simulation is suggested as very cost effective, since the running times were only 70 seconds (Palmdale) and 15 seconds (Portland-Seattle) to simulate and complete trade offs for all optional paths and modes of the 2500 travelers.

Future plans call for expansion of modeling details to provide more representative traveler impedances by mode, to allow accurate representation of mode networks, and to create more explicit door-to-door modes, e.g., park-and-fly, see-off-and-fly, etc. Expansion of the simulation scope is proposed to answer, "Who takes the various modes" and, "What is the effect of a new mode on overall demand (induced);" also, being added is the ability to generate more detailed statistical comparisons of various traveler attributes. Contact with Jon Buyan of Aerospace indicates they are well into the development of an urban model. This application will include various subcategories of access modes to transit ports (e.g., "kiss-and-ride" and "drive-and-ride"), as well as inclusion of more transit modes (e.g., bus, rapid rail, etc). Schedule/capacity optimization techniques are being investigated which use an iterative feedback process referred to as "demand matching."

The simulation approach has several useful features. The Monte Carlo technique is attractive from the aspect of assignment of attributes based on random samples from an input distribution, since the form of the distribution function of each attribute or combination of attributes can be flexibly dealt with externally prior to integration into the total simulation. Also, the concept of "traveler's records" provides discrete examination of the influence of traveler attribute change or transportation system characteristic change on the total mode split. Perceived out-of-pocket costs, traveler trip time, mode revenues and total mode ridership are good examples of influenced parameters. "Port" processing schemes (e.g., parking time and cost, waiting times) use distribution functions to create the desirable effect on traveler flow through the system. The simulation technique has the stated ability of allowing insight into the sensitivity of mode split as a function of traveler attributes due to the process of testing all mode and alternatives available to the traveler, each of which can be reviewed by the analyst.

The Monte Carlo approach warrants further examination since it possesses many of the features desired in an investigation of airport access. Areas warranting further critique are:

1. Possible expansion of trip purpose to include further detail(e.g., resident/non-resident and the associated effect on value-of-time).

2. Origin/destination area considerations.

3. Concept evaluation and approaches to calibration of "negation" and "preference" factors.

4. Level of breakdown of traveler's attributes and problems of assigning distribution functions.

5. Examination of transportation network replication schemes, (i.e., implicit versus explicit defintion). SIMCRIPT is currently used to do detailed network analysis prior to approximating in the mode split simulation where no sets or queueing are employed.

N-Dimensional Logit Model

This modal split model was designed by Peat, Marwick, and Mitchell by Ellis, Rassam, and Bennett[35] as part of a study[36] for the Metropolitan Washington Council of Governments funded by UMTA/FHWA. The objective of the PMM study was "two-fold: to develope an immediate-action airport access improvement program for the Baltimore-Washington region, and to develop a planning methodology useful to others in planning access improvements. It focused on the three air-carrier airports serving the Baltimore-Washington region: Washington National Airport, Friendship International Airport, and Dulles International Airport."

In selecting an approach, PMM considered the following transportation system variables when determining the market share of "new mode" placed in a competitive environment:

1. Access (egress) time to (from) main mode

2. Line haul time

3. Number of transfers, including associated waiting times

4. Schedule delay, i.e., the difference between desired and scheduled times of departure

5. Frequency of departures

6. Access (egress) cost to (from) main mode

7. Line haul cost

The model developed uses transportation system variables instead of specific traveler behavioral characteristics in analyzing the mode split. A separate model is developed for each combination of trip purpose and trip direction. The analysis addresses only business/non-business to and from the airport. Data permitting, any level of stratification appears possible, remembering that each combination involves creation and calibration of a separate model. Travel behavior is reflected in the broad content of trip purpose and trip direction.

This model scheme has the desirable feature of considering all competing ground transportation modes simultaneously. Mode impedances are defined in terms of time and cost (which can be real or perceived) and are made up of various component service measures, again in terms of time and cost. All impedance measures and combinations thereof are defined by exogenous analysis.

The model has the following properties:

1. The sum of the modal shares should equal one.

2. A given mode's share (i.e., percent traveling by mode) increases with increasing levels of that mode's service measures (e.g., travel time).

3. The shares of other modes increase or remain unchanged within the given mode's service measures.

4. Specifically, "The model is based on the assumption that

the ratio of a small change in modal split of a given mode to that of a given transportation variable is proportional to the modal split of this mode and to a linear function of the modal split of all modes. It is shown that this assumption is equivalent to stating that the elasticity of a share of a given mode, with respect to one of its own attributes, is proportional to the level of this attribute and to its share of the market, whereas the elasticity of a given mode with respect to the transportation attribute of another mode is proportional to the level of this attribute and to the market share of the remaining modes. In conjunction with the mathematical definition relating to modal split, these assumptions lead to a system of differential equations defining modal market shares as functions of the transportation attributes. This formulation does not require that the same set of variables be used to define the transportation attributes of each of the modes."[35]

"In the N-dimensional logit model, the modal split (w) of a given mode m is given by

$$w_m = \frac{\exp\left(\sum_i \alpha_{im} x_{im} + \alpha_m\right)}{\sum_j \exp\left(\sum_i \alpha_{ij} x_{ij} + \alpha_j\right)}$$

where:

1. x_{ij} is the i^{th} impedance attribute of mode j (e.g., limousine in-vehicle time, item across top of [Figure 3]),

2. α_{ij} is the calibrated coefficient corresponding to x_{ij}

3. α_j is a calibrated mode-specific constant.

As shown by the above relationship, the modal split of a given mode is least sensitive to variations in modal attributes when this mode tends to capture the greatest or smallest possible share of the travel market; it is most sensitive when the given mode captures one half of the market. These properties of the model can be graphically illustrated by singling out a given mode m and plotting, as shown in [Figure 4], its modal split,

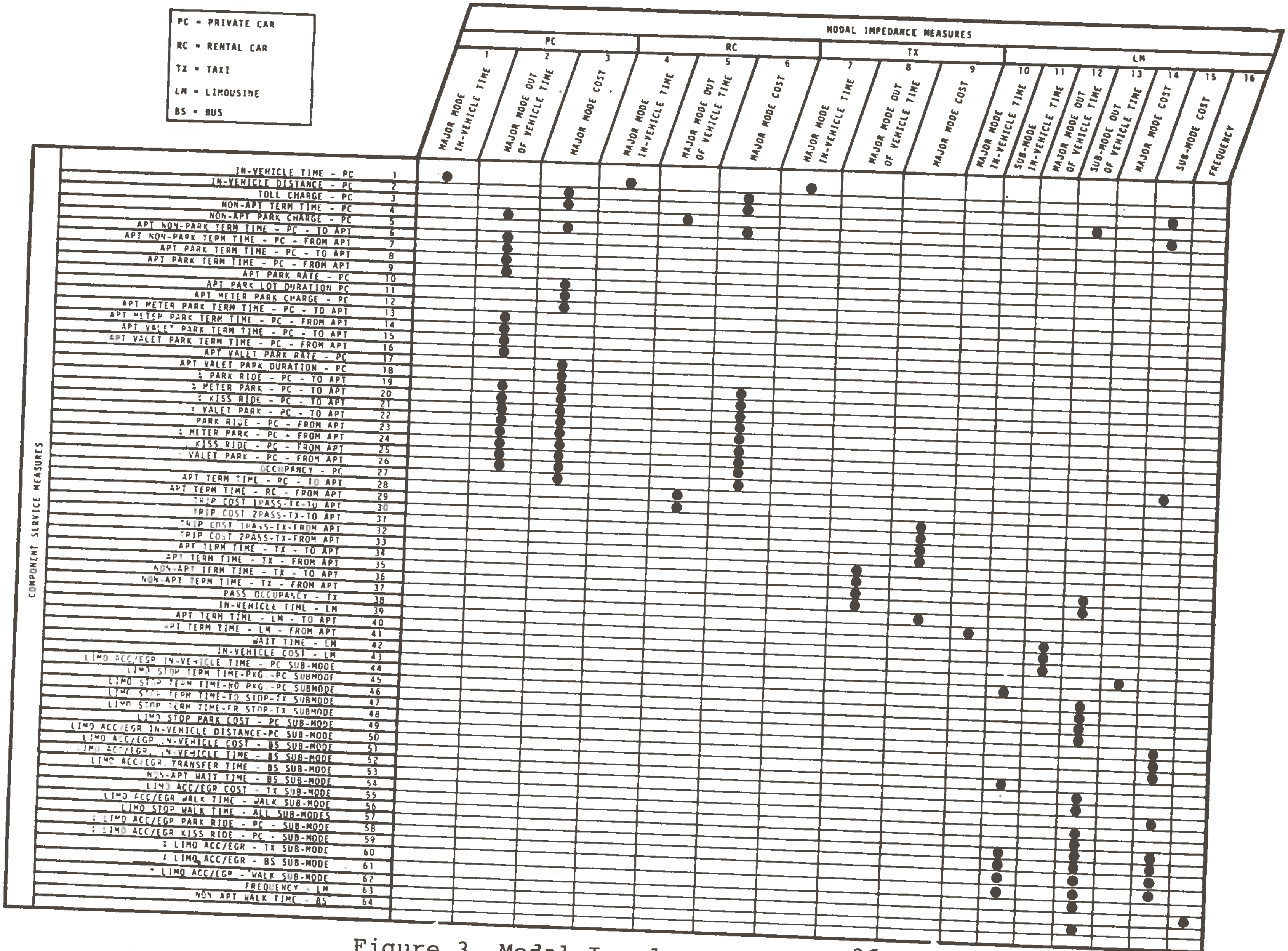
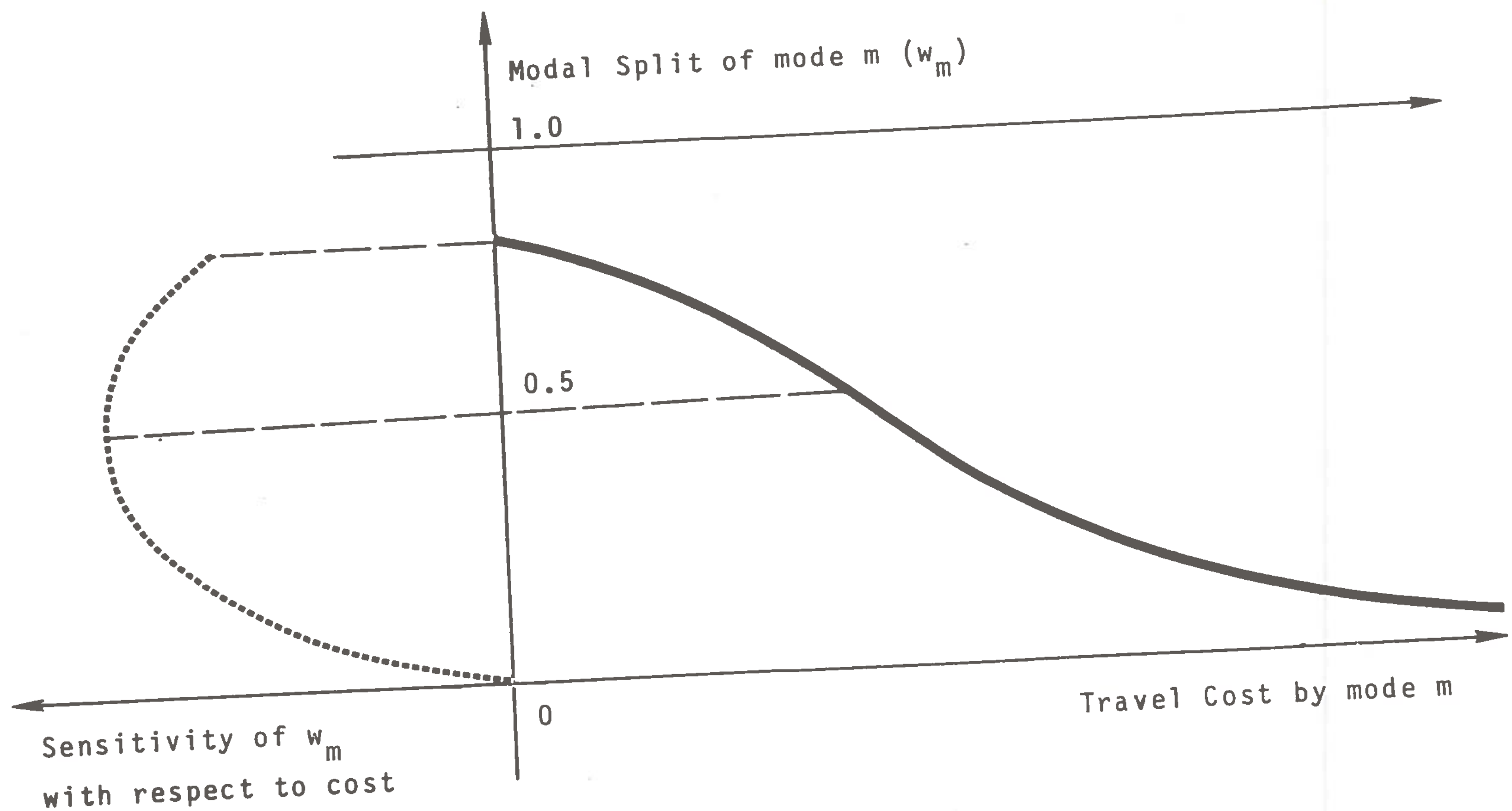


Figure 3. Modal Impedance Measures[36]



NOTE: The modal share of mode m (w_m) is a function of the attributes of mode m as well as those of the competing modes.

Figure 4. Properties of the N-Dimensional Logit Model[36]

w_m, cost (the other attributes being held constant)."36

The significant feature of the model is the prior postulation of certain relations which define and constrain the system of differential equations, e.g., property 4 previously quoted: "...modal split ... is proportional ... to a linear function of the modal split of all modes." This apparently represents an attempt to give the model some kind of causal structure, although Reference 26 did not supply a heuristic discussion of the reasons for choosing the given postulates; it only stated them. Further exploration into the implied reasons is recommended before consideration of any general application.

Mathematically, the derived assumptions are stated as best handled by logit analysis. Use of a logit function allows consideration of the independent variable that has unusually high or low values and may require the non-linear form of the cumulative distribution function to cover the spectrum of interest. Logit analysis requires the technique of "fitting" the data by iterative procedures. The modal split equation was estimated by maximum-likelihood techniques based on the Washington-Baltimore Airport Access Survey data (1966). Two estimating techniques were tried: least squares (L.S.) and maximum likelihood (M.L.). Due to the unavoidable non-linearity of the equations describing the model (the "logit" equations), transformations were introduced which required that the mean-square errors for all variables be minimized simultaneously in order to perform a standard least-squares estimation. In the M.L. estimation, however, the mean-square errors for each model share equation were minimized individually.

Because of its iterative nature and, in some cases, the large amount of observations to be processed, maximum likelihood is more time-consuming than the least-squares method. In spite of the fact that the M.L. estimation required more computing resources than L.S., Ellis, et.al. state in their conclusion that M.L. estimation might alleviate many typical calibration difficulties encountered in the use of linear regression techniques.

The authors continue:

> "Two observations should be made at this point. The first concerns the general consistency of the models within each trip purpose stratification. As much as feasible, the structure of the model should be the same for both directions. The second concerns the nature of the time and cost impedances which, in many instances, were derived from distance measures.

As might be expected, time and cost are correlated and the resulting collinearity is a source of problems since it increases, sometimes substantially, the standard error of estimate of the coefficients."35

Several prototype models were tested using various combinations of time and cost variables with directional stratification. Due to lack of data, many desirable stratification efforts were abandoned. The authors state:

> "Testing indicates that the model displays the appropriate sensitivities and adequately reproduces the aggregate trips for each mode. At a disaggregate level, estimates of the modal shares for particular zone-airport pairs displayed, at times, relatively high dispersions, due to a great extent to the lack of specific information, particularly whether a traveler was a resident or non-resident of the study region."35

The final model was calibrated by combining total time and total cost for each mode to yield a single impedance measure using the relationship between these variables:

$$(\text{Total Cost}) = \lambda^{*}\ (\text{Total Time}) + b$$

where λ and b are two coefficients determined by regression analysis. (Table G-Z of Appendix G)

> Regarding calibration of the modal split model, "Component measures of the travel service provided by each mode were derived from network analysis, fare and time schedules, ground counts at airports, and data reported and processed from the Baltimore-Washington Airport Access Study. Impedance (i.e., transportation service measure) estimation is open to a considerable range of detail and specification, particularly with respect to perceived impedances vis-a-vis actual time measures and cost estimates based on marginal or average cost models. Limited variations of an average cost impedance model were tested during calibration to determine the relative ability of different impedance specifications to discriminate between modes. The component measures were selectively combined to form impedance measures for each mode as shown in [Figure 3].* One set of impedance measure equations used in the calibration are shown in [Table G-1, Appendix G].

* Time measures and costs were broken down for each mode and submode as shown at the top of the figure.

"A data set was constructed for the references survey period (1966). This consisted of travel volumes by purpose and direction and average daily values of impedance for each mode between each of the 78 zones and each of the three airports.

"Two calibration techniques were investigated: least squares and maximum likelihood. The latter was selected inasmuch as it provided better results, particularly with regard to the sign of the coefficients which must always be negative."[35]

Testing indicated consideration of occupancy for auto and taxi was warranted and values of 1.67 and 1.40, respectively, were assumed. No reference for the values was stated.

"By adding an empirical constant to the linear forms attached to each mode, the modal mean trips were matched and the dispersions reduced for each mode. Because of the structure of the model, it is sufficient to find three such constants for the business models and two for the non-business models."[35]

"The calibrated coefficients α_{ij} and mode-specific constants α_j for the four models are shown in [Table G-3]. Measures of the ability of the calibrated models to reproduce observed data are displayed in [Table G-4].

"Sensitivity analyses of the four calibrated air traveler models were carried out to determine the sensitivity of modal split to changes in the levels of system service measures. For instance, the models were applied to a data set with a 10% greater cost for private car travel to and from airports. The results of the sensitivity analyses are presented in [Table G-5]."[35]

To summarize:

"The modal split analysis performed in this study is, to a large extent, comparable to those performed in classical urban transportation studies. These studies have generally attached a great significance to the nature of the trip end, i.e., by distinguishing between home ends and non-home ends. In the present analysis, the corollary is whether a traveler resides in the area under study. This distinction is important inasmuch as it generally determines the availability of a private car. This important information was not collected by the study. Had it been available, the stratification by residents and non-residents would have precluded, for most cases, the use of private car for the latter type of travelers. An attempt was made to supplement this deficiency by assuming that, in all likelihood, most non-resident travelers would originate in or be destined to the central business districts and, therefore, that trips should be further broken down by central business districts and residential districts. However, this approach did not improve the quality of the business-to-airport model to which it was applied."[35]

Four separate models were formulated as follows:

Travel Purposes	Direction	Modes
Business	From/to airport	Private auto Rental auto Taxi Limousine/coach
Non-Business	From/to airport	Private auto Taxi Limousine/coach

"Experience derived from this study suggests that the model can be a useful tool for predicting modal split. It is felt, however, that additional data could improve the model's forecasting capabilities in an airport access application. In particular, as mentioned earlier, it appears important to know whether a traveler is a resident of the region under study. Several other measures also could be used. They include: reliability of a mode as reflected by the standard deviation of travel times; income, which greatly determines the ability to pay; trip duration, which would give better information on parking cost; group size, which is necessary for better cost estimation. Finally, it appears that smaller and more homogeneous zones could contribute to more accurate results."[35]

Although the authors alluded to the ability of examining a new mode with the model, no discussion related to calibrating the α coefficients was included.

Of interest is the commentary from Reference 36 which the FHWA and UMTA state a need for a simultaneous, multi-choice model applicable to examination of airport-access situations. The planning guide noted that the N-dimensional model was the type model meeting these requirements. An outline of the approach suggested by the Planning Guide is included in Appendix G.

Though limited in coverage, the selections reviewed are considered a representative sample of current thinking in mode choice analysis, generally, and in airport-access situations, specifically. To properly determine and utilize travel behavior patterns, an integral consideration is understanding the influence of the operational environment and the transportation system variables on traveler flow. This area will be dealt with next.

UNDERSTANDING SPECIFIC SUBSYSTEM OPERATIONS

Once the characteristics of the trip and tripmaker can be established, and a modal split analysis capability developed, the requirement to analyze or synthesize operational characteristics of systems and to test their ability to satisfy demands becomes more meaningful. A limited selection of methodologies necessary to system design and operation were reviewed. The models are grouped by broadly homogeneous categories related to airport access and terminal flow improvement:

1. Airport terminal flow

2. Intra-airport flow and parking

3. Baggage handling

As seen by the listing, a detailed treatment of network analysis and of specific hardware systems has been omitted. The multitude of conceptual approaches related to network analysis is beyond the scope of this review. In many cases, they address only very specific applications and in this more general context would be inappropriate. Specific systems hardware and applications are of interest but are treated in much greater detail in source documentation.

Airport Terminal Flow

Chamberlain, et. al.[37] developed a model for the DOT Office of Economics and Systems Analysis for a study of 747 impacts. In abstract,

> "This report contains the documentation of the computer program that simulates the operation of an airport terminal facility. The simulation model is designed to allow for the examination of any terminal facility, with any schedule of aircraft arrivals and departures and any mix of aircraft types. It produces statistics of aircraft, passenger and baggage traffic for each arrival and departure flight, as well as a summary of daily operations at the completion of the daily schedule. In addition, space utilization within the terminal is also monitored along with the utilization of terminal personnel."[37]

The model uses SIMSCRIPT queuing techniques to modify airplane arrival times for determining airport operation impacts. Outgoing passengers' arrival and movement through airport; air traffic controllers' operations; aircraft "greeter" arrival; on-ground aircraft operations including baggage handling, disposition of passengers and baggage from an arriving aircraft; and airport staffing including shift changes are only a partial list of the items considered by the model. The model uses random number generation and probability distributions to select attributes and various event processing times.

The program was written for a Control Data 3600 computer which has two banks of core memory, each bank containing 32,768 memory locations.

Chamberlain[38] provides a 747 impact analysis using the model. Based on the results, the model is extremely valuable as a sensitivity tool. A noteworthy conclusion was that "the ultimate capacity of the terminal building [at Kennedy airport] being studied was not reached even when all flights employed 747 equipment, provided that sufficient staffing was available."[38]

The model has broad application due to its general and flexible nature. Appropriate data must be collected to provide accurate, site-specific distribution functions for several of the parameters.

Intra-Airport Flow

Intra-airport transportation (IAT) systems provide an interface between the travel method of accessing the airport and the desired point of entry into a specific terminal or terminal area. IAT's may handle air passengers and/or guests, airport employees, baggage, and air cargo. The acceptability of an IAT transfer between the access/egress travel mode and the ultimate terminal destination/origin may strongly influence the airport user's primary access mode choice. Many new systems exist in the conceptual stage; several are being implemented(e.g.,Dallas/Fort Worth International Airport) and others are in operation(e.g., Houston International, Dulles International, Los Angeles International, etc.). Each system designer has his own analytical methods for providing implementation alternatives. Rosen[39] develops a cost model evaluating an airport access transportation link using an exclusive right-of-way. The IDA's modeling methodology by Freck, et.al.[40] was reviewed because of its general nature and possible application.

Freck, et. al. conducted this IDA study for UMTA. It was an effort to locate relevant technologies and analytical techniques to improve I.A.T. primarily for people, with some consideration for baggage and no effort in the area of cargo or freight. The output was recommended as directions for R & D programs including demonstration projects.

The report provides statements that:

1. Develop the intra-airport traffic flow problem pointing out that the prime reasons for intra-airport delay are:

   a. Terminal design(i.e., airlines having their own "corporate image gates")

   b. Extensive parking requirements creating long walking distances

2. Outline four primary requirements for intra-airport transportation when changes occur in terminal configurations:

   a. In centralized terminals, IAT's must solve walking distances.

   b. In decentralized terminals, IAT's must satisfy interterminal transfers.

   c. In both configurations, IAT transfer from parking areas may be required.

   d. For remote terminal configurations(e.g., Dulles), transfer to aircraft is necessary.

The report discusses 15 IAT configurations for airports serving major hubs. Three applications are illustrated in Appendix I:

1. Parking/transit/terminal movement

2. Intra-terminal movement

3. Interterminal movement

The scope of the study is limited to IAT systems greater than 500 feet long. A technology survey is included with various capacity to determine criteria and formulations. Comparisons of systems are made to provide insight into technology gaps. A simple model was developed to determine the optimal capacity and velocity for IAT vehicles used in a loop system.

The model illustrates cost trade offs involving speed, capacity, power, etc. A sensitivity analysis was conducted to determine parameters having the strongest influence on design characteristics. Table 6 reflects the results. Other cost models were developed to assist in trade-off analysis:

1. Parking facility cost

2. Access road cost

3. IAT system costs

Model details and sensitivity curves are included in Freck and are not here because of the specific application.

Rosen's model is

"for examining the economic feasibility of constructing an automated cargo transportation link between some urban point and a major hub airport serving the area. Additionally, this technique was to be able to determine the marginal cost of transporting people on the link, as well as cargo, and to determine an overall measure of the resulting reduction in airport congestion. The full cost of procurement, development, operation and maintenance of the system was to be borne by the cargo carried on the system. Passenger revenues were to reflect only the additional expenses incurred by providing passenger facilities."[39]

"The model is constructed of modules which represent the various functional components of the system; these are illustrated in [Figure 5]. Most of the components are seen to be located at the remote station portion of the system, including:

1. A cargo loading/unloading area with docks and truck parking space,

2. Cargo handling, sorting and storage space,

3. A passenger check-in and baggage handling facility,

4. A parking lot for passengers and employees of the cargo and passenger facilities.

TABLE 6. The Relative Effects of Parameters on Loop Transportation System[40]

Parameter	Characteristics of Loop System			
	Minimum Cost	Optimal Top Velocity	Optimal Car Capacity	Optimal Acceleration
Station Spacing	+	+	+	-
Demand	+	-	+	-
Station Dwell Time	+	-	+	-
Upper Bound on Acceleration	-	+	-	+
Weight of Power Unit	-	-	-	-
Cost of Power Unit	-	-	-	-
Weight of Passenger Compartment	+	-	-	-
Cost of Passenger Compartment	+	-	-	-
Cost of Guideway	+	-	-	-
Station Cost	+	-	-	-
Number of Cars in Loop	-	-	+	-

\- Small or no effect

\+ Substantial effect

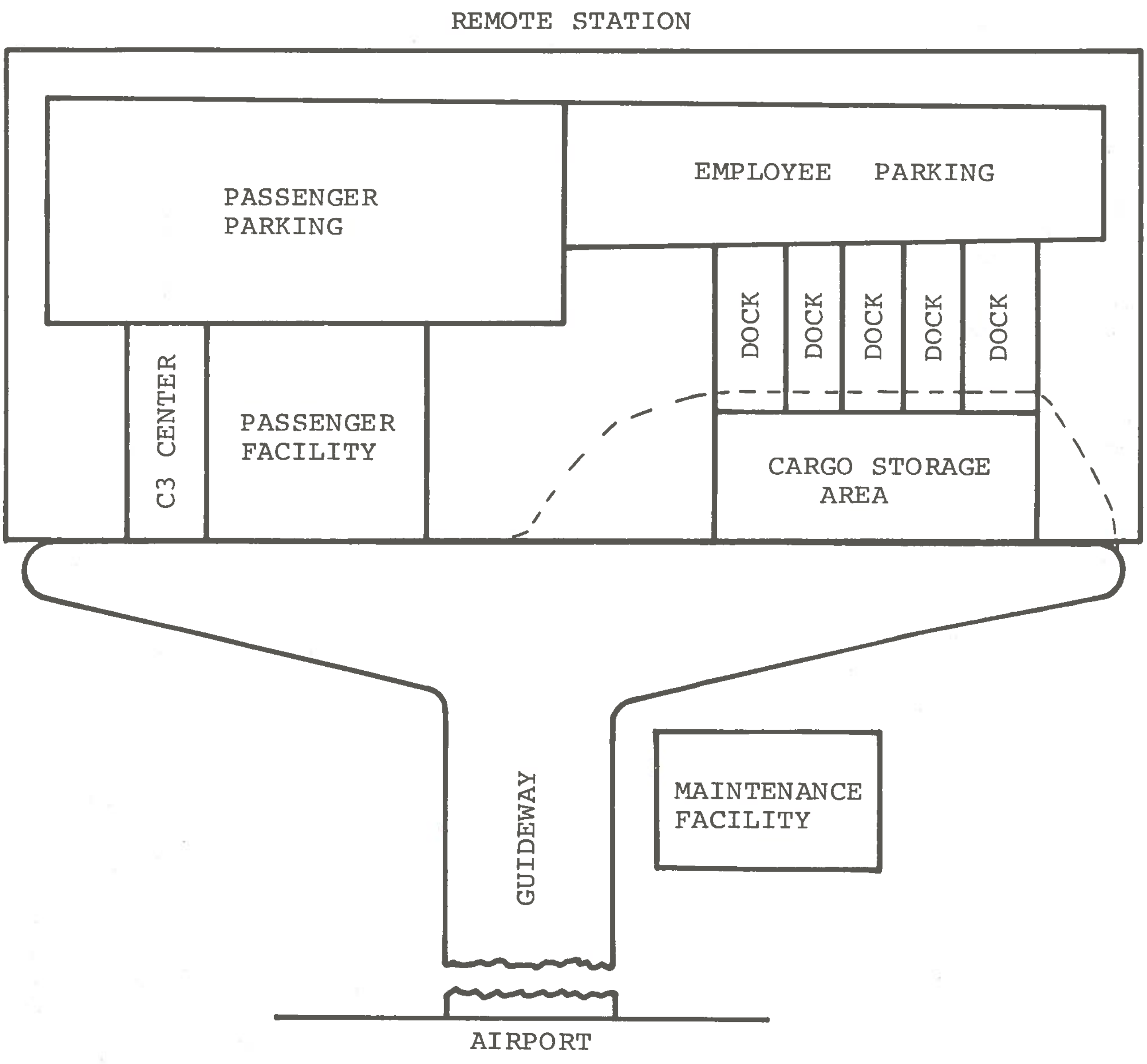


Figure 5. Transporter Link System Components[39]

"Loading/unloading platforms for the vehicles which travel on the link are considered part of the passenger facility and cargo docks. The remote station facilities are represented in the model inputs in terms of area, employees, and other special requirements per unit of service provided. The model determines the total requirements based on the specified demand.

"The vehicles and the link guideway are represented in terms of capacities and trip time. Four types of vehicles are considered: all cargo, all passenger, mixed cargo/passenger, and engines. Although the model was designed with high-speed automated ground transport vehicles in mind, proper choices of input parameter values could make the "vehicle" be a helicopter in the air or a bus on existing roadway.

"The model also provides for a guideway and vehicle maintenance facility to be located along the guideway and a communications/control facility to be located at the station or along the guideway. These facilities are represented by size, number of workers, and the special equipment they entail.

"The airport end of the transportation link is just an interface. The question of whether the link would connect with an intra-airport circulation system or branch itself to service cargo and passengers at multiple destinations is basically immaterial to the model. If the link vehicles are also used as part of the intra-airport system, some redefinition of input parameters would be required.

"The modules constituting the computer program are illustratin in [Figure 6]. These modules are called and executed in sequence by an executive program. The intermediate and final output results can be printed at various levels of detail.

"Typical peak hour demand of passengers and cargo are the driving forces in the model. These demands are specified independently for each direction of travel on the link, and with appropriate load factors, are used to develop the cargo, passenger, and parking facilities required. The station arrival and departure rates (to and from the link), when combined with vehicle capacities and link distance, yield the number of vehicles needed, round trip time and average number of trips per year. The model develops these resource requirements to keep queue delays to low levels during peak demand periods.

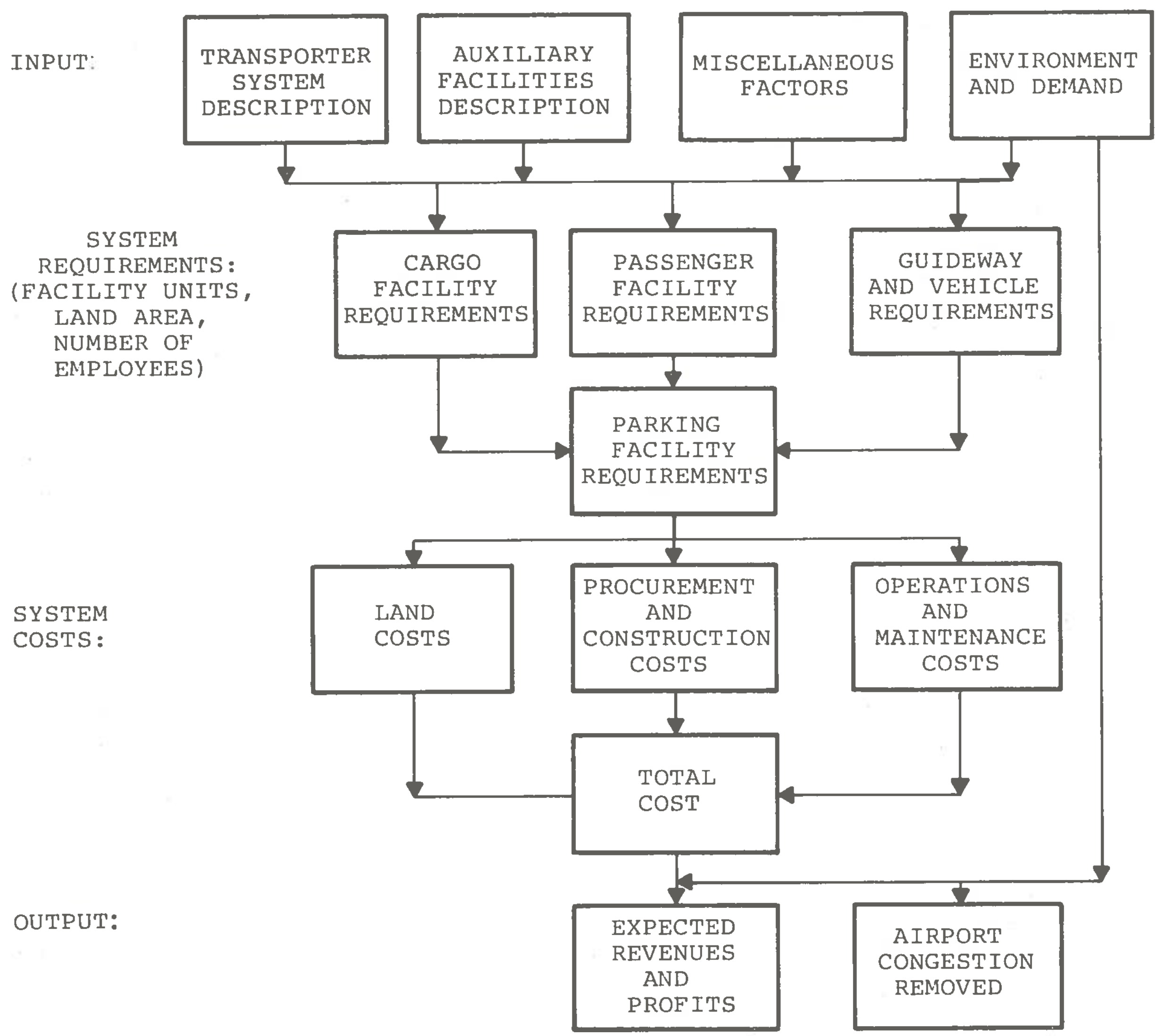


Figure 6. Model Components[39]

"The model then applies cost factors to develop procurement, construction, and operation and maintenance costs for the transport link system. Charges for cargo transport are then calculated by prorating the cost plus a profit margin over the expected demand. Passenger fares are determined similarly, but reflect only the additional cost to the system of providing a passenger facility, modifying vehicles for passenger comfort, and adding vehicles to satisfy passenger demand."[39]

"It is basically a cost model which converts service demand into system costs through the consideration of various physical factors and design options. The major types of studies in which this model is expected to find application include:

1. Analysis of the economic feasibility of adopting a transporter link system for a specific airport,

2. Comparative analysis of competitive transporter (vehicle and guideway) systems,

3. Cost reduction analysis for a transporter link system,

4. Resource requirement analysis for a proposed transporter link system."[39]

Baggage Handling

In addition to the possible ability of intra-airport transportation systems to influence the choice of access transportation mode, baggage handling also creates unavoidable decisions for the air traveler. Several analytical methodologies exist for evaluation of baggage-handling procedures and system design. Three methods were reviewed.

Tanner[41] developed a model for analyzing delays to departing aircraft as a result of inadequate levels of baggage-handling service. The model was developed as follows:

"Since the demand for departure baggage service can fluctuate over a wide range depending upon flight schedules, a deterministic model based on hydrodynamic or fluid flows is used. Application of this model is based on the assumption that, for any given airport, passenger arrivals prior to flight departure will have a characteristic distribution which can be measured and reduced to a mathematical equation. Baggage flow rate equations over any time period and for any flight schedule can then be determined by summing appropriately scaled passenger arrival equations over the desired time period. Derived flow rate equations, when applied to the fluid flow queueing model, will yield minimum service levels necessary to prevent departure delays."[41]

The model was designed to examine the check-in service levels under the influence of several departing flights scheduled in close proximity. Conclusions drawn from the study are:

"1. Scheduled flights of air carriers tend to cluster during particular intervals of the day producing large variations in the demand for baggage-handling service.

2. As a result of the time-dependent nature of demand for service, a deterministic model is most appropriate for representing baggage-handling systems.

3. Passenger and baggage arrivals prior to scheduled flight departures can be measured and described by an appropriate equation from which baggage flow rates over any interval of time can be derived.

4. Such passenger arrival distributions are believed to be characteristic of a given airport and locality; however, in the writer's opinion, large samples taken over a relatively long period of time are necessary in order to insure the validity of the distribution....

5. Inadequate levels of baggage handling service can produce sizable delays to departing aircraft. Through the use of the fluid flow queueing model and a derived baggage flow rate, such delays can be minimized or prevented by predetermining the required level of service.

6. Maximum delays to passengers standing in queues can be determined, providing an air carrier [has] an indicator of customer inconvenience caused by baggage check-in systems."[41]

Karash[42] used Monte Carlo simulation (probablistic) and deterministic queueing (non-probabilistic) techniques to investigate the flow of outbound baggage (departing flight) systems. The models were evaluated for their ability to satisfy an airport planner's and manager's needs. A report by the Ralph M. Parsons Company [43] details the characteristics of various baggage systems which might be evaluated using the models.

Karash develops the simulation model by the following rationale:

> "One method for predicting the effects of future passenger volumes on baggage systems is to simulate the system under the expected future conditions. For this purpose a GPSS System/360 simulation model has been implemented. This model simulates the processes of group arrivals before a flight, groups queueing for and being served by airline agents, and the movement of bags in and out of the bag room. The loading of the aircraft is not modeled; rather, a number is computed for the average number of man-minutes required to deliver and load the bags. The transfer process is included only for the computation of the aircraft loading time."[42]

The required data for the simulation model are listed in Table 7 and the model output is listed in Table 8. Figure 7 shows the flows of passengers and baggage as they are represented in the simulation model.

Given a schedule for departing aircraft and the number of passengers per flight, the simulation randomly generates arrival times for passenger groups, the number of bags carried, and the number of persons in a group. The distribution of bags per passenger is dependent on the type of flight. All outgoing passenger decisions dealing with ticketing and baggage handling are determined randomly. The queue discipline at ticket counters was to place the simulation group in the shortest queue and break ties systematically to favor one queue over the other.

Table 7. Data Required for the Simulation.[42]

1. Flight departure schedules for the period of interest.
2. An arrival pattern for groups utilizing the bag check-in options and ticket counters.
3. Proportion of transfer passengers.
4. The number of groups arriving per flight.
5. Bags per flight.
6. People per group utilizing the bag check-in options.
7. Proportion of groups utilizing curb check, express, and the ticket counters.
8. Number of agents on duty at ticketing for different periods in the afternoon.
9. Queue discipline.
10. Service time at express and ticket counters.
11. Conveyor travel time.
12. Schedule for bag train departures.
13. Towing time for the carts to reach the aircraft.
14. Bag loading rates from carts to aircraft.

Table 8. Output from the Simulation.[42]

1. Average line length for each 15 minute interval during the period of interest.

2. Average wait and wait distributions for groups served at express and ticketing.

3. Number of groups missing bag cut-off time and their arrival distribution before flight time.

4. Fraction of time agents are busy.

5. Bags per flight handled through the bag room. An estimate of carts required to hold these bags can be made given capacity of a cart.

6. Total number of bags arriving in the bag room for each 15 minute interval during the period of interest.

7. Manpower required in man-minutes for towing of carts to the aircraft and the loading of bags.

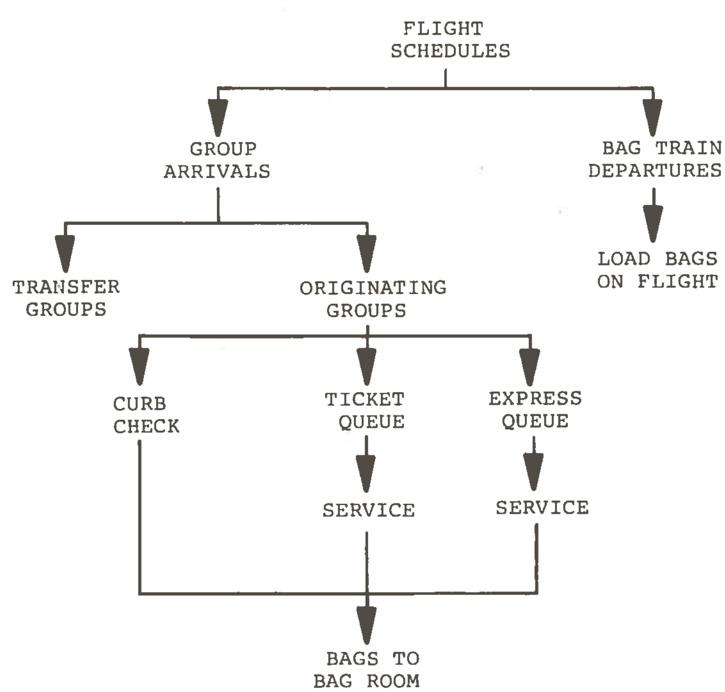


Figure 7. GPSS Simulation Model Flowchart[42]

The journey of the bags is modeled through to the loading point on the aircraft.

> "Output from the simulation includes the number of arrivals at each service during each 15-minute interval, wait time distributions for passengers at ticketing and express, and the number of bags arriving in the bag room for each 15-minute period. The length of line over time is given using a measure of the average line for each 15-minute period. Utilization of check-in agents and ticketing agents are given, and the number of persons missing bag cut-off time is recorded. The accumulation of bags by flight in the bag room is given as each bag train departure is scheduled to occur. Average loading times are given for each flight."[42]

The second model(deterministic queuing model)uses the same approach as Tanner described and as seen in Figure 8. Inputs are in Table 9. However, a diffusion correction is added to approximate the nature of queues as they pass through saturation. A FORTRAN program was developed to compute the queue statistics. Unlike the simulation model where the basic unit is the group, the deterministic approach uses the individual passenger as the basic unit. To obtain queue length, Karash states:

> "To get an approximation of the average queue length predicted by the deterministic model, queue lengths for all unit time intervals are averaged. Queue length at the end of an interval is given by the sum of the queue length at the start of the interval and the number of arrivals during the interval less the number of services. Queue lengths are constrained to be greater than or equal to zero. The average queue length for an interval is taken as one half of the queues at the beginning and the end of the interval.
>
> "Output values for the deterministic model include passenger arrivals per interval at ticketing and express, queue lengths at the end of each interval, bag arrivals per interval, and cumulative bag arrivals. Values for average wait time at each service are given. The departures of bags from the bag room and the loading process were not modeled."[42]

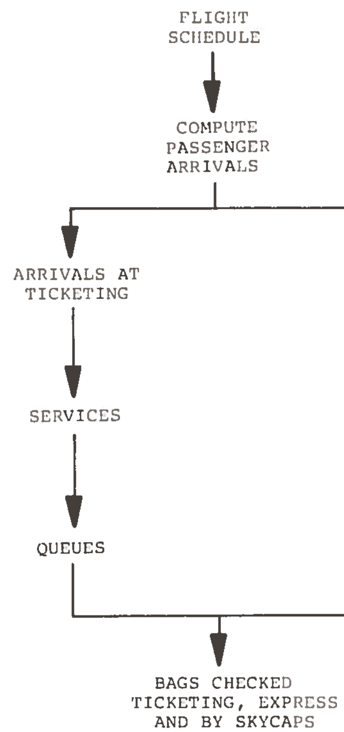


Figure 8. Deterministic Model Flowchart.[42]

Table 9. Inputs to the Deterministic Queuing Model Program.[42]

1.	Number of flights, flight departures; passengers per flight.
2.	Arrival distribution characteristics.
3.	Time at which to begin gathering line statistics and time to end the simulation.
4.	Number of separate services; fraction of passengers using the services; fraction of persons going directly to the gate.
5.	Number of changes in staffing for the ticketing and express counters; service rates at these counters.
6.	Average bags carried per passenger.

Karash provides the following model evaluation:

"The main advantages of the simulation technique are its capability for handling the time dependent, probabilistic flows of passengers and baggage and its ability to give detailed results about passenger wait time, agent utilization, bag flow rates, and bag accumulation in the bag room. Given a particular demand, the model developed for this report can be used to plan the amount of counter space that must be made available, the capacity of the sorting mechanism required, and the bag room space needed to store outbound bags.

"One drawback to using the simulation for planning purposes is its cost to run in view of the uncertainty about what the future demand for air travel will be. The price per run at the present level of detail on an IBM model 360/65 is about eight dollars at academic computer rates. Because the simulation results are probabilistic, several runs are required to determine what the future situation will look like on the average. Furthermore, the model does not search for an optimal staffing arrangement. Several runs must be made for each staffing arrangement that is to be evaluated. Since demand for airline travel 5 to 10 years away is a highly uncertain quantity, use of a less detailed and a less costly technique would seem justified provided results could be obtained that would be useful for planning purposes. Deterministic queuing theory appears to be such a technique.

"The disadvantages of the deterministic model as developed for this report include a loss of detailed results as well as a probabilistic measure of the bag input rate. Results on agent utilization, wait distributions, and the breakdown of bags accumulated in the bag room by flight are not conveniently given by the model.

"The deterministic technique with the diffusion correction nevertheless appears to be as useful for staff and counter space planning purposes as the simulation model. In view of uncertain demand in the far future, the deterministic estimates of staffing requirements and bag flow rates combined with crude estimates of bag room space needs may be all that is required. Data requirements for the deterministic model are fewer than for the simulation because the deterministic model deals with averages rather than probabilistic distributions. Since the model is not probabilistic only one run is needed for each staffing configuration to be analyzed. The cost of the deterministic model run is only about half the cost of a simulation run;

thus, the deterministic model could be practically used to examine a number of different staffing situations and to determine the sensitivity of the system to changes in demand."[42]

Barbo[44] developed another deterministic queueing model to explain the interrelationship of passenger and baggage arrival patterns at the baggage claim areas. The patterns are considered of growing concern with the coming influx of jumbo jets. The pattern is dependent on a number of factors such as terminal design features and unloading rate of the aircraft.

In contrast to passengers, baggage does not arrive at the claim area in a predictable fashion. This is due to constraints in the system or operating policies of the various airlines and airports. The model was developed to analyze the effect that different baggage delivery strategies have on the amount of space needed to handle baggage for an arriving flight. Experimental data for the study was obtained at San Francisco International Airport. The model is based on carousel operation but is generally applicable to any type of self-claim baggage retrieval system. Barbo establishes the major factors in the manual handling segment of the system which affect overall baggage flow, and discusses modeling of the mechanical portion of the system. A queueing model is developed.

Many more models exist for use in analysis of airport terminal and internal systems operations. The items selected were readily available and provided perspective from the macroscopic site location methodologies down to the microscopic analysis of various trip segments of the airport traveler.

PLANNING SATELLITE TERMINALS

The models in this general area provide background in current approaches for improving major airport access by appropriate satellite terminal location using either V/STOL systems or remote check-in facilities. The idea was to locate a cross section of models and review the conceptual approach to analysis without rigorous investigation into the mathematics or programing details.

Landi and Rolfe[45] and Snell[46] offer techniques for evaluating airline (V/STOL) and access transit terminal locations. VERTOL[47] evaluates an integrated V/STOL transportation system consisting of intermetropolitan and intra-metropolitan networks. Genest[48] examines how terminal location affects airport accessibility.

The model by the Rand Corporation[45] was designed for the Port of New York Authority to study air passenger processing strategies from trip origin to the entry point of the airside trip. It is proposed for use in evaluating passenger terminal locations and related transportation systems in terms of either average passenger trip time or average passenger trip cost, assuming that passengers will place emphasis on minimizing time or cost.

> "The data inputs required are the nodes and arcs of a road travel-time or road travel-cost network, the locations of passengers terminals in the network, the times or costs associated with each destination served by each terminal, and the volumes of passenger trips that will generate at points in the network representing population centroids. The program computes volumes of passenger trips processed by each terminal from each trip origin, the average passenger trip times or costs associated with each terminal, and the average trip time or cost for the entire system; it will also find, if desired, the locations of passenger terminals or airports in the network that minimize the overall average trip time or cost."[45]

The program uses a "normalized gravity-type model" to allocate volumes of passenger trips to given terminal locations in the network. Travel time is the sum of roadway travel time and terminal processing time from zone centroids to destination. Various ground modes can be used. Network links, because they are abstract representations, do not include capacity restraint.

Optimization is included as follows:

> "Given a fixed system of aircraft and passenger terminal facilities, the program can be asked to search for the locations of one, two, or more additional terminals that will augment the existing system in such a way as to minimize the average total trip time of all passengers. This feature of the program is usually used when site specifications are not unique or particularly complex and can be met almost anywhere in the region."[45]

However, the authors add this note of caution when attempting optimization of more than two terminals, e.g., a STOL network:

> "The optimization mode of operation is considerably less efficient than the evaluation modes discussed previously. It takes about 30 minutes to select two sites simultaneously out of a 100-node network; it is totally infeasible to select more than two."[45]

The authors are attempting to develop an improved methodology to cope with this problem.

A "value of time" is inherent in Landi and Rolfe's cost model, and they reference universal uncertainty in determining the parameter, especially in the new market area for STOL aircraft.

In closing, the authors state:

> "The method (model) we have described is not by itself a predictor of passenger trip-making behavior. It merely reflects the number of trip origins and destinations that are closer (in terms of trip time or trip cost) to each of a set of terminal facilities. If other important trip attributes, such as frequency of service, reliability, comfort, and convenience were equal among the available alternatives, the model might have considerable predictive value."[45]

Details of the mathematics, program flow, and computer implementation (including sample program listing,) are included in the reference.

The study by Snell was funded by the Office of Aviation Policy and Plans, FAA. The abstract is quoted:

> "To evaluate a variety of off-airport (satellite) air terminal concepts, an iterative evaluation model is developed that is focused primarily on time and cost impedances. An analysis is made of the entire process by which a passenger gains access to an aircraft and from this analysis, component sub-models are developed to define system demand flow rates, level of service supplied, and system costs. These sub-models are then synthesized into the desired evaluation model and a methodology to be used in establishing off-airport (satellite) terminal system planning guidelines is developed. The approach utilizes generalized or gross characteristics for the airport access process and avoids specific details of regional characteristics, airport design, and transport technology. A hypothetical example is tested and sensitivity analyses are made for a number of cost and time parameters."[46]

The FASTSEM model was developed referencing earlier works of Koller and Skinner (MIT)[32] and several Rand Corporation papers for the Port of New York Authority. Six distinct types of satellite terminal systems (STS) were studied and are included here in Table 10. Equations for cost and processing time were developed for each system to provide impedance input allowing analysis of the demand shift to the satellite terminal. Economical feasibility of the satellite concept was analyzed. Several recommendations for further research were included based on the study

Table 10. Design Characteristics of the Alternative STS Technologies 46.

System	Satellite Terminal Facilities	LINKING TRANSPORT SYSTEM					
		Vehicles Type	Speed (mph)	Size (pass)	Linking Type	Guideway Cost ($M/mile)	Airport Station Location
1. Hotel/Curb Pick-Up	none	Limousine	30	10	Hwy	0	Curb
2. Parking and Pick-Up	Shelter Parking	Bus	30	30	Hwy	0	Curb
3. Common Check-In	Terminal Parking Joint Processing	Express Bus	40	50	Portion Reserved Lane Hwy	.5	Holding Area
4. Airline Processing	Above plus Complete Airline Processing & Concessions	Fast Transit Link-1 (Ref. 18)	80	20	Separate ROW	2.	Gate
5. Multi-Modal Terminal	Major Regional Interface Facility (all of above)	Fast Transit Link-2 (Ref. 18)	100	80	Tunnel	7.	Gate
6. Off-Airport-Airport	No Passenger Facilities on Airport	Auto-Van	50	50	Separate ROW	?	Acft.

conclusion that satellite terminals are viable.

The report includes thorough documentation of the model development. Analysis results are not included here due to the much broader approach taken.

Boeing Vertol[47] describes a model for the evaluation of an integrated V/STOL transportation system consisting of inter-metropolitan and intra-metropolitan networks. The model emphasizes the interactions between the two networks. Hub-satellite city pairs may be evaluated with the model. Figure 9 is an example of the combinations. It shows the following combinations:

1. Bus, train, V/STOL, CTOL, and auto modes are competing for intercity travel.

2. The intra-city V/STOL is a feeder system to and from both intercity V/STOL and CTOL systems and is competing with other intra-city ground transportation systems for this service.

3. The intra-city V/STOL is a competing transportation system for travel between points within the metropolitan area.

4. Intercity modal connections may be either direct or indirect links.

The authors describe the following specifics used in the model:

"The V/STOL travelers: The intercity V/STOL system will service the traveler who is willing to pay a premium fare for a time savings or an increase in comfort and convenience over the competing intercity modes. Such a person will most likely be a business traveler.

"The intra-city V/STOL system will service three different types of travelers:

Type I	The short-haul intercity traveler who wishes to decrease his total trip time by taking the intra-city V/STOL to the CTOL or V/STOL airports at city H.
Type II	The long-haul CTOL traveler who wishes to decrease his travel time to and from the CTOL airports at city H.
Type III	The intra-city traveler who wishes to decrease his total intra-city trip time within

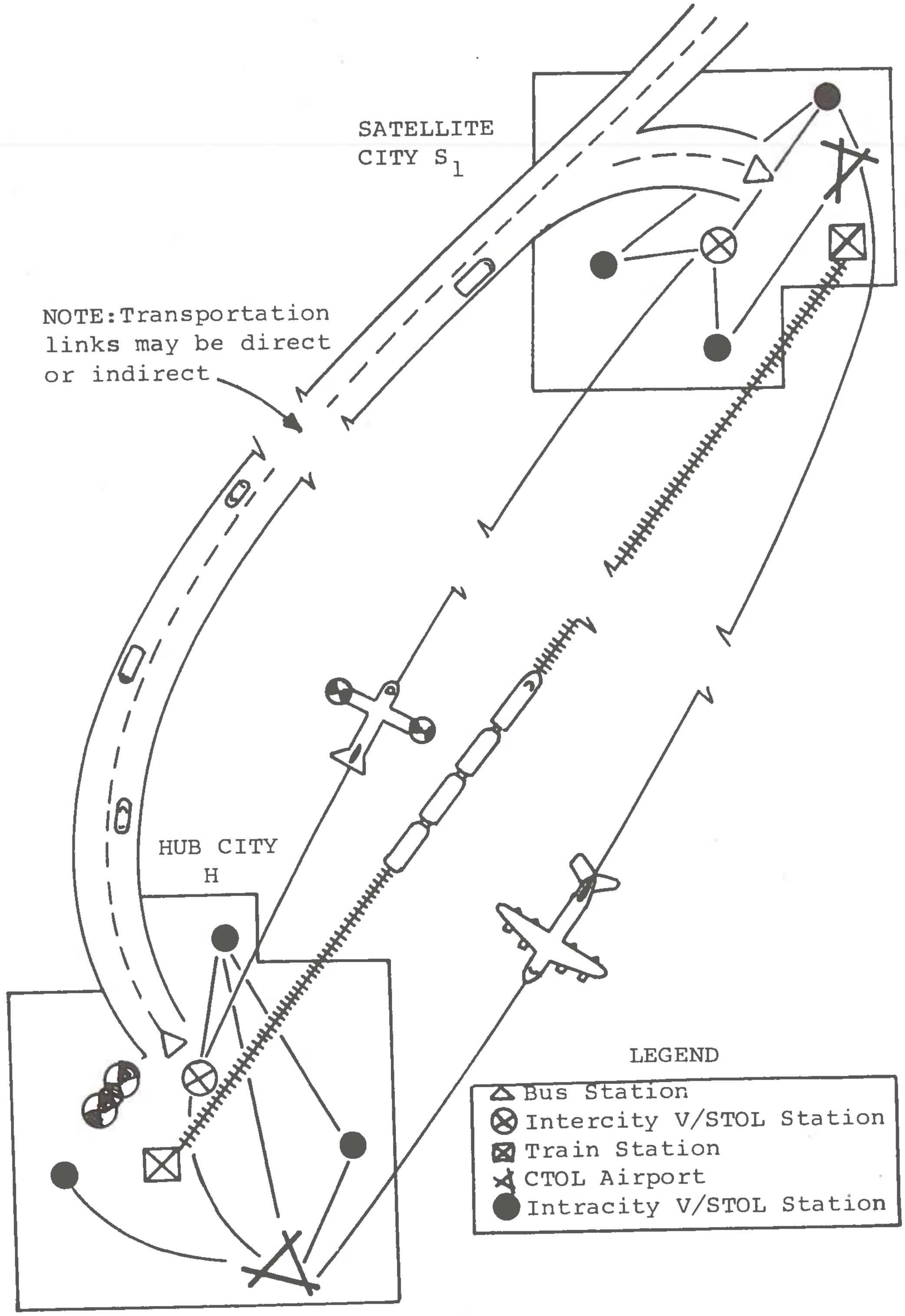


Figure 9. Intercity Travel Alternatives[47]

city H with the possibility of paying a fare premium over competing modes.

"The model differentiates between these travelers because each one used the intra-city system in a different way, during different times of the day, and for different trip purposes. Note that the Type I intra-city traveler is a special type of intercity V/STOL traveler (i.e., one that uses intracity V/STOL).

"The V/STOL airports: The inter/intra-city V/STOL systems will have at least one common V/STOL station within the hub city metropolitan area, thus minimizing transfer delays and encouraging the entire trip to be taken by a series of V/STOL flights. V/STOL stations will be located at existing intra-city transportation nodes, and parking facilities at the V/STOL station will be adequate to accommodate all potential V/STOL travelers.

"The V/STOL vehicles: The configurations used for the two systems may be different. The long-haul V/STOL may be a jet or fan STOL, a tilt wing, tilt rotor, stowed rotor, lift fan V/STOL or compound helicopter configuration, while the most economical intra-city vehicle is likely to be some helicopter configuration."[47]

Appendix H contains the overall model logic and basic flow diagram. In summary:

"The total passenger demand is forecast using a traffic generating model. The door-to-door trip is divided into three legs - two intra-metro and one intermetro, and the various feasible combinations of different modes of transportation are generated. A modal split model is then applied to determine the total demand for the V/STOL system. A scheduling algorithm is then used for route assignment taking into account demand variation over time of day. The impact of the V/STOL system on CTOL airport congestion, airport access and profitability are also investigated."[47]

The modal split and demand models are adapted from the forms used for the NECTP.

Genest developed his model as part of a series by the MIT Civil Engineering Systems Laboratory. The following is quoted from the abstract:

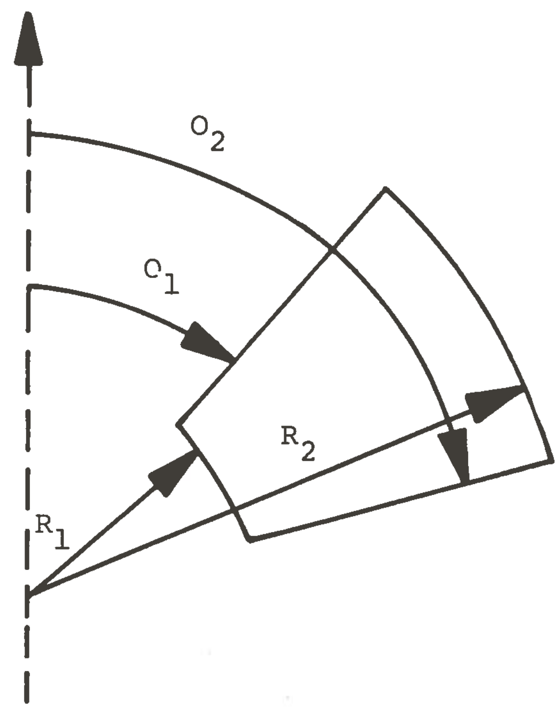
"This model report investigates the sensitivity of terminal locations with respect to accessibility as measured in terms of the time required to go from various parts of the urban area to the terminal. The analysis considers the influence of various environmental and demand conditions such as the geometry of the urban area, the demand distribution, the direction along which the terminal is located and the speed of travel. Under all conditions investigated, many near-optimal terminal locations exist, as long as the terminal is located within the metropolitan area. (A "near optimal" location is defined as having an access time less than 1.2 times the minimum access time). If the terminal is located outside the metropolitan area, the travel time increases more rapidly. Thus, within the metropolitan area, terminals should be located primarily on the basis of factors other than accessibility; however, outside the metropolitan area, accessibility becomes increasingly more important. These theoretical conclusions are supported by examinations of the relocations of the Detroit and Chicago airports."[48]

A summary of the model operation follows:

"SITECLU (Systematic Investigator of Terminal Configurations and Locations in Urban Areas) predicts accessibility consequences for exogenously-specified terminal locations.

"SITECLU represents the urban area in which the terminal is located as a group of zones defined by radial and circumferential boundaries, as in [Figure 10]. It aggregates the characteristics of all access modes into one abstract mode, and represents intra-city travel impedances by exponential or logistic isotropic travel velocity functions. The spatial distributions of population and demand may be represented by negative-exponential density functions or exogenously-specified for each zone.

"Several terminal options may be analyzed with SITECLU. Each individual terminal is specified by its location and its four impedance times. A terminal configuration may be made up of up to 10 full-service terminals located at different points of the urban area. Alternatively, up to nine satellite terminals may be specified which provide transfer to a principal full-service terminal. Finally, a network of high-speed access links may be superimposed on the continuous travel surface. Of all these options, only the location of a single terminal is considered in this report.



R_1: Smaller Radius

R_2: Larger Radius

O_1: Smaller Azimuth

O_2: Larger Azimuth

Figure 10. The Four Parameters of a Zone[48]

"Three environmental conditions were varied to test their effect on accessibility for a given terminal location: the geometry of the urban area, the spatial distributions of travel demand, and the distribution of intra-city speeds. The geometry of the urban area was varied by considering four abstract urban areas, namely circular sectors of 90°, 180°, 270°, 360°, all with a 20 mile radius."[48]

The distribution of demand for intercity travel was varied by considering eight negative-exponential demand density functions. The distribution of intra-city travel impedance was varied by assigning different values to the parameters of logistic travel velocity functions.

SUMMARY AND CONCLUSIONS

In the selection of works reviewed, modal split models dealing with urban and interurban travel provided insight into modeling where the trip purposes and mode selection had received greater study. Modal split models dealing specifically with airport access were reviewed for applicability in a generalized airport access improvement methodology.

Other models reviewed included terminal location techniques, inter/intra-terminal flow analysis schemes, cost-effectiveness approaches, integrated transportation system analysis (including impact consideration and optimization methodologies), and other detailed analyses relating to airport access in some application.

A detailed restatement of conclusions from the various modeling approaches would be redundant but the following highlights are pertinent:

Observations

Modal Split

Modal choice decision logic can best be defined if the behavior of an individual traveler facing a selection of transportation alternatives can be predicted. To better understand the advantages of travel behavior analysis, works by Kraft and Wohl,[12] Lave,[13] and Lakshmanan[11] were reviewed. These proponents suggest the use of cross-elasticity models treating trip-maker decisions as simultaneous and interrelated. The nature of the trip determines the modal parameters. Plourde[14] and Bock[15] provide insight into evaluation of user/mode selection causal relationships. The models developed were aligned to the urban work trip and, though different from the airport access trip, elaborated on the potential of an understood travel behavior. All point to the significant data requirements implicit in the study of travel behavior.

The NECTP[19] and I^3[29] methodologies consider modal split in a very broad scope as part of the intercity travel picture, and are not specifically aligned to a detailed analysis of the demand characteristics involved with accessibility of the prime intercity mode. Both modeling efforts do stress the sensitivity of the overall methodology to a successful forecast of modal split. Determination of "impedance" functions, so strongly used by I^3, represents the most pressing area for research, i.e., the factors influencing modal split. The ultimate use of them in evaluating proposed traffic flow strategies is the area best address by I^3.

The airport access modal split models were generally unsuccessful or unproven. The Cleveland[4] and Wiggers[31] models are of interest since the Cleveland-Hopkins survey data was used. Cleveland's model was unsuccessful due apparently to data aggregation techniques; Wiggers' "change" model, using a different approach to analysis, is untested and is restricted to a determination of single mode diversion to transit. The airport limousine service analysis by Koller and Skinner,[32] though analyzing a very selective problem, has identified several characteristics of non-resident air travelers using a limousine service. In light of their results, the concept of small scale experimentation is given credence. Though generally a costly approach, the Aerospace Monte Carlo[24] simulation has inherent flexibility and control available to the analyst. The approach is worthy of more detailed review to determine the true capabilities and limitations when considered for airport access. The current specification of trip purpose and trip characteristics is insufficient to allow a detailed analysis of airport access modal split. The N-dimensional logit[35] model allows detailed specification of service measures and mode attributes to be reflected as trip time and cost characteristics, but does not consider specific travel behavioral factors. Rather, the behavioral characteristics are implicit in the specific model of interest, e.g., non-business/resident from airport. The model is the most flexible reviewed that allows definition of a spectrum of multi-modal characteristics.

Calibration and performance are somewhat unclear because of data base problems in the situation reviewed but may prove useful after further calibration and application.

Subsystem Operations

Freck (IDA)[40] details 15 basic configurations of intra-airport transportation systems, each serving in various degrees of accommodation; the parking areas, transit connections and intra/interterminal flow. This study is the most comprehensive available to date. Rosen[39] develops a cost tradeoff model to evaluate an exclusive right-of-way access system. Tanner,[41] Karash,[42] and Barbo[44] develop simulation techniques which allow detailed analysis of baggage handling operations, important since this consideration may influence the trip-maker's decision process.

Many analytical tools exist to duplicate physical system operations. Most have been developed for examination of this facet of overall airport operations. These models are most useful for establishing individual system operational sensitivities to determine system effects due to temporal changes in traveler flow patterns into, through, and out of the airport for both land and airside. For instance, the simulation model by Chamberlain[38] contains a flexible, generalized approach to evaluation of terminal flow considering impacts on either the air or landside.

Satellite Terminals

Methodologies are available for examining most conceivable facets of airport location and planning, e.g., Landi,[45] Snell,[46] Boeing VERTOL Corporation,[47] and Genest.[48]

Conclusions

Mode Choice Analysis:

Airport access mode choice analysis must be sensitive to traveler behavior. A basic understanding of individual travel behavior patterns continues to be the most feasible and widely accepted approach when attempting to determine the effect of placing new transportation concepts into an existing area.

Relevant factors influencing the behavior of the air traveler must be agreed on. In all three areas of review - urban, inter-urban and airport access - many models exist or are being developed which attempt to predict modal choice decisions based on analysis of behavioral factors. Various statistical techniques have been used to confirm causality, eliminate collinearity, and calibrate mode choice relationships. As yet, none agree on any standard causal relationships. Levels of statistical significance differ with varying explanatory comments. Methodologies vary in all areas: Stated assumptions, hypotheses, analytical approaches, results, and conclusions. All admit weakness of one form or another, especially inadequate data to convincingly identify causality.

It is possible that causality is not clearly hypothesized because of lack of familiarity with the situation being investigated. Analysts may choose data which gives only a partial view. Viewing this cannot adequately give the entire perspective.

Selection and confirmation of trip purpose and tripmaker causal relationships are essential when calibrating models by using situation data where a bias may exist. A generalized methodology will necessarily require calibration using several data sources, probably where different causal biases have been detected. Calibration of a truly generic model to all (or most) situations may not be feasible; however, any approach to mode choice analysis should begin with a basic selection of causal factors related to the situation of interest.

Confirmation of these factors and their level of influence may require a continuing evaluation of situations where a significant transportation system change is planned. Continual research may also be required to determine the values and sensitivities of various causal factors, i.e., coefficients will themselves be a function of the socio-economic-political environment existing at the forecast period of interest.

Data inadequacies must be defined and factored into future research efforts, and data gathering, storage and retrieval procedures should be standardized. Data and its meaning in the environment being investigated seems to be the significant inhibitor to identification of causal relationships. Survey data from traveler surveys is generally coded and readily available for analysis. However, pertinent supporting data essential to network synthesis seems to be available in random fashion with varying levels of completeness. Indeed, the relevant depth and complexity of network replication is unclear and not uniform. To further complicate analysis, statements of possible bias are seldom available as part of a data package. Where data is collected from different time periods, expansion to a common time point increases the probability of significant bias, i.e., during the expansion period significant local events or traffic route changes may be overlooked and distort the approximations necessary in the network configuration. Because of unknown biases, data aggregation procedures are invoked which disguise the causal factors being pursued. This often restated data problem continues to support the theory that a Federally-sponsored transportation data bank requiring standardized update procedures may be a worthwhile investment.

A standardized analytical technique to perform mode split computations is desirable. Standardization of airport access modal split models (similar to the BPR packages) does not now exist though it seems possible. As described in a previous chapter, the trip to the airport does have several unique characteristics. Yet, some degree of generality is required. Identification of causality, as already pointed out, needs further research and agreement.

Standardization permits better overall understanding and confidence in modeling results as well as reinforcing the concept and applicability of common data bases. Two basic analytical approaches exist:

1. Simulation: Very appealing from the aspect of giving the researcher visibility into the influence of many variables on an individual's travel decisions. Also, the most costly modeling technique due to the inherent flexibility allowed.

2. General mathematical formulation: Does not allow the researcher as much freedom in changing variables. The researcher must be ever conscious of the assumptions constraining the validity of model results. This approach, though often requiring iterative computations, is generally more cost-effective than simulation.

To properly evaluate a standardized approach, trade offs of the features of the two basic approaches must be considered.

Satellite Terminals and Subsystem Operations

Catalog generalized system operations models as a package available to planning groups. The outputs must be sensitive to system design specifications. Individual model input/output should be compatible with interfacing system considerations and with a baseline data format. All system details cannot be generalized, but the objective is baseline analysis and specification of an integrated system operation.

TRAVEL SURVEYS OF AIRPORT USERS

Traveler surveys provide a portion of the data base which is the input to transportation studies and generally result from:

1. Evaluation or determination of specific proposed transportation system changes:

    a. Policy changes in existing system

    b. Physical changes to the existing system

    c. Addition of new modes into the system

2. Assemblage of information to understand transportation behavior for long-range planning.

Those surveys comprising the first grouping are generally done as part of a metropolitan area planning effort, some to determine the degree of success of new ideas exercised in demonstration projects. Group two surveys, such as the Cleveland Hopkins Airport Access Survey,[4] are few. The "1967 Census of Transportation" also falls in this grouping, but is generally too broad for application in detailed analysis.

Many past data-gathering efforts have been oriented toward expansion of highway facilities. As a result, reliable traffic forecasting techniques have evolved over the years. However, few of the data bases from the past have supported an analysis of the "character of demand" for travel. Rather, they support an axiom that all people prefer to travel by auto and provide only enough data to forecast an even greater demand for auto facilities.[11] Data bases often are incomplete in that they consist of the survey material in combination with:

1. Limited supporting transportation network analysis information[23]

2. Supporting data from a different period of time with broad assumptions necessary about demographic or transportation system changes that have occurred in the interim[19]

3. Incomplete information on alternate modes of transportation available to the surveyed travelers[13]

Often analyses are weakened by the assumptions required in order to "fit the analysis to the data." A CONSAD study,[11] the Northeast Corridor Project,[25] a modal split analysis by the Cuyahoga County, Ohio Regional Planning Commission,[30] and a model calibration effort by Rassam, Ellis and Bennett[35] specifically mention difficulties in detailed analysis of transportation demand due to data-base inadequacies.

The "approach to analysis" is the driving function when weighing the value of, or need for, data. Obtaining new data is expensive; therefore, every effort should be made to take advantage of existing data bases including travel surveys. The selected approach to analysis would hopefully avoid some of the problems already mentioned above and minimize the need for new data. Therefore, to support any further analysis, a selection of surveys was reviewed having specific applicability to airport access:

1. Washington National -- 1960
2. New York -- 1963
3. Washington - Baltimore -- 1966
4. Philadelphia -- 1967
5. Toronto, Canada -- 1968
6. Cleveland - Hopkins -- 1968-9
7. New York Limousine -- 1970
8. Boston Logan -- 1970
9. Lambert - Saint Louis Municipal - 1969
10. Northeast Corridor Study Efforts

Tables 10, 11, and 12 reflect the type of data available in the surveys. Table 10 contains trip purpose and trip maker characteristics, Table 11 depicts the extent of the surveys, and Table 12 the travel mode information available. Magnetic data tapes for Washington - Baltimore, Cleveland, and New York, are available; others may be: further applicable surveys will continue to be sought after.

Several surveys have been used in developing modal-split analyses - the Cleveland-Hopkins by Cleveland[4] and Wiggers[31], the Washington - Baltimore by PMM[35] and the New York Limousine by MIT.[33] The following paragraph entitled "Northeast Corridor Study Efforts" includes data gathering efforts that were required to investigate interurban modal splits for the Northeast Corridor Project and were considered useful in an overview to integrated transportation system analysis. Demonstration projects for which surveys were conducted are summarized in "Review of Demonstration Program," since the approach to concept demonstration was more pertinent than the resultant survey data. Other comments relative to problems with surveys and data bases are found in abstracts of analyses where particular problems occurred("Existing Methodologies"). The following paragraphs review surveys of particular interest.

REVIEW OF SURVEYS

Origin/Destination of Washington National Airport Users - 1960

The specific goals of the survey were:[49] to determine local origins and destinations of airport users for all time periods throughout a one-week period (serious snow accumulations sharply curtailed survey operations on one of the survey days) and to examine other factors (e.g., mode of ground transportation, trip time) for relevance to the airport access/egress problem.

Included in the survey were both departing and arriving scheduled airline passengers, airport employees, and passengers on non-scheduled aircraft. There was a small number of respondents among passengers on non-scheduled flights. Visitors to the airport were not sampled. The analyses done were based on data from two main sources: scheduled airline passengers and airport employees. Questionnaires completed by the respondents themselves were the means of data collection used throughout the survey.

For departing passengers, questionnaires were distributed and collected by flight attendants. When the flight attendant was unable to perform these duties, a special short-form questionnaire, which the respondent was asked to drop into a mail-box, was employed (these comprised 9.3% of the total departing passenger questionnaires given out). For arriving passengers, the mail-back form was used exclusively. The method of collection for airport employees was not mentioned. The response rate for the employees was 95% from a sample of 12.5%. The report does not provide the total response rate of all distributed questionnaires.

For a summary of the type of data collected by the survey, see Tables 11, 12, and 13. As seen in Table 11, the survey provides limited data relative to trip-maker characteristics. The report made no mention of a data tape or deck.

Table 11. Trip Purpose and Trip-Maker Characteristics

DATA \ SURVEY	Washington National (1 Airport) 1960 Departure	Washington National (1 Airport) 1960 Arrival	New York (3 Airports) 1963-1964	Washington-Baltimore (3 Airports) 1966	Philadelphia (1 Airport) 1967	Cleveland Hopkins (1 Airport) 1968-1969	New York Limousine Service (2 Airports) 1970	Boston Logan (1 Airport) 1970
Flight Origin/Destination	*	*	*	*	*	*	*	*
Local Origin/Destination	*	*	*	*	*	*	*	*
Description of Local Origin/Destination	*	*			*	*		*
Access Mode	*	*	*	*	*	*	*	*
Trip Purpose	*		*	*	*	*	*	*
Trip Duration						*	*	
Sex			*	*	*	*	*	*
Age			*	*		*	*	*
Income			*	*		*	*	
Ticket Class			*					
Traveler's First Flight?			*					
# of Trips Past 12 Months			*					
# of Trips From/To This Airport in Past 12 Months	*		*			*		
Level of Education			*	*				*
Residency			*		*	*	*	*
Occupation			*	*				*
Business or Industry			*	*				
Traveler Used More Than One Travel Mode To/From Airport				*		*	*	*
# of Companions in Access/Egress Vehicle				*		*		*
# of Companions on Flight				*		*	*	
# of Children on Flight						*	*	
# of People in Other Vehicles Who Came To Airport Because of Traveler				*				
Airport Arrival Time-Flight Departure Time	*			*		*	*	
Parking Facilities Used				*				*
Parking Duration				*				
Parking Lot To Terminal Time								
# of Baggage					*	*	*	*
Checking Baggage at Airport								
Checking Baggage at Remote Terminals								
Perceived Access/Egress Time	*						*	1
Traveler's Opinion of Access/Egress Time	*							1
# of Airport Employees	*			*	*	*		*

1. Available from airline employee questionnaire

Table 12. Extent of Surveys

Study	Length of Survey	# of People Coded (All Categories)	% CBD as O/D	% On Business Trip	Private Auto as Access/Egress Mode	Median Family Income	Median Age	At Least Some College	% Male
Washington National (1 Airport) 1960	1 week	5,000 800 employees	43%	81% Departing	34% Departing 30% Incoming				
New York (3 Airports) 1963-1964	1 year	22,000	45% Manhattan	63%	50%	$15,000	40	78%	76%
Washington-Baltimore (3 Airports) 1966	6 days	67,200 3,300 employees	25% for passn.	73%	76% National 94% Dulles 92% Friendship	$15,900	33	86%	81%
Philadelphia (1 Airport) 1967	5 days	15,000	16%	70%	50%				82%
Cleveland Hopkins (1 Airport) 1968-1969	1 week 1968 1 week 1969	36,750 51,200	10%	50%	62% Before 54% After	Can Be Calculated	Can Be Calculated		74%
New York Limousine Service (2 Airports) 1970	2 days	500		72%		Can Be Calculated	Can Be Calculated		74%

Table 13. Travel Mode Information

Access Modes / Survey	Boston Logan (1 Airport)	Washington National (1 Airport) 1960	New York (3 Airports) 1963-1964	Washington-Baltimore (3 Airports) 1966	Philadelphia (1 Airport) 1967	Cleveland Hopkins (1 Airport) 1968-1969	New York Limousine (2 Airports)
Private Car - DF	*	*		*	*	*	5
Private Car - PF	*	*		*	*	*	5
Private Car - SF	*			*		*	5
Rented Car	*	*		*	*	*	
Taxi	*	*		*	*	*	5
Airport Limousine	*	*		*	*	*	*
Public Bus	2	*		*	*	*	
Rapid Rail Transit	3					*	
Motel/Hotel Courtesy Car					*	*	
Government Vehicle		*					
Railroad	4				*		
Airplane	*						
Combination of Modes		*		*	*	*	1
Other	*	*		*	*	*	

DF: Car Driven Away After Drop-Off

PF: Car Parked At Airport Parking Lot

SF: Car Parked But Driven Away By Another Person

1. One Of Which is a Limousine
2. Suburban Bus and Rapid Transit & Shuttle Bus
3. Rapid Rail Transit & Shuttle Bus
4. Commuter Train & Rapid Rail Transit & Shuttle Bus
5. Access to The Limousine Service

New York 1963-64

The data from this survey was extracted from Reference 6. Because of the nature of an ongoing effort by the Port of New York Authority (PONYA), further investigation as to relevance of the data is planned. The survey was conducted between April, 1963, and March, 1964, to determine if seasonal variations exist for domestic air travelers departing from the three major New York City airports. The reference comments on possible biases induced by the study decision to drop certain categories which had a lower than desired return rate. However,

> "From the airport-access point of view, the most valuable results of the survey are data on the local origin of passengers which can be stratified by user groups, time of day, and season of year."[6]

Initial contact with PONYA indicates that much related survey data is available. New York is progressing in its plans to develop rail transit service from Manhattan to Newark and Kennedy airports. Because of the proposed change in mix-of-access-modes to the airport, an ideal opportunity exists to analyze before and after changes in travel patterns in a situation where much of the before data may already be available. The quality and quantity of the data need further examination before any conclusions can be drawn. In any case, the PONYA development will provide a change in modal split, the analysis of which should confirm or assist in the calibration of a successful modal split model.

Washington - Baltimore Airport Access Survey 1966

The Washington-Baltimore Airport Access Survey[7] was conducted to collect information about the use of three airports, National, Dulles, and Friendship, all of which serve the Washington-Baltimore area. The principal objectives were to determine the volume and variability of airport traffic, the geographical distribution of points of local origin and destination of the airport trips, and the ground traffic characteristics of airport users. The data was to be used by the DOT/OHSGT in their studies of the Northeast Corridor.

The survey is a behavioral study of various groups of airport users: air passengers (commercial airlines and general aviation), airport employees, and casual visitors.

The airports themselves were considered closed systems within which vehicles and persons arrived from, or departed to, the outside world. Data was collected from three sources; a survey of people using each airport; a five-day cordan count of traffic flows; and the records of ground transportation lines, air carriers, and airport employers.

Commercial airline passengers and airport employees were given self-administered questionnaires. These questionnaires were collected by assigned personnel except when the respondents preferred to mail them back in the pre-addressed, postage-paid envelope. General aviation passengers were given mail-back forms only (these comprised a small number of all air travelers). Casual visitors had three options: return questionnaires to a member of the survey team stationed in the airport, place questionnaires in survey boxes located at convenient locations, or mail back the questionnaires. Air passengers and casual visitors were surveyed everyday of the six days, selected randomly in advance. Although initial plans provided for administering the questionnaires to all flights, about 60% of the flights at the three airports were finally surveyed. The return rates of the arriving and departing passengers were 44.5% and 40.3%, respectively, leaving open the question of total sample cross-sectional validity.

In order to determine the number of trips generated by each type of airport user, the retrieved sample of respondents was expanded to the counts provided by the Air Transport Association and the airport employers records. Samples of the casual visitors' survey were not expanded because it was not known what percentage was surveyed. The tables 10, 11, and 12 summarize the type of data gathered.

A summary report of the study is in Volume I of the Washington-Baltimore Airport Access Survey. The basic data tabulations are contained in Volume II. Volume III describes, in detail, the survey design, data collection, coding, processing, sample expansion, evaluation, and recommendation for future surveys. Data tapes are available. Volume IV contains data-processing information. Reference 50 provides more detailed data description of the information on the tape.

The survey data has been used in a planning effort by the Washington Council of Governors; modal split model was calibrated. The model was used to forecast area needs, and results were reported in an Immediate-Action Improvement Program.

Details of the modeling effort and analysis are included here in the paragraph called "N-Dimensional Logit Model." The approach to analysis pointed out that lack of "resident/ non-resident" information from the survey caused difficulty in model calibration. From the survey, Figure 16 provides a summary of the categories of users making trips to the three Washington area airports. Reference 51 provides a summary of survey results and suggests two suburban access improving alternatives: an urban VTOL system or air service patterned to airport transportation problems. The policy change involves modification of the air service patterns of the three airports in order to provide more balanced (long and short hand) service from all three and implies the addition of point-to-point, airport-to-airport transportation. Though the residency information is missing, other useable data relative to mix-of-modes is available and should be evaluated in greater depth.

Philadelphia International Airport - 1967

The Philadelphia International Airport In-Flight Origin-Destination Study of 1968[52] was conducted "to meet the objectives of developing transportation criteria for architectural and engineering planning and to test the adequacy of access routes, and parking facilities."[52]

Air passengers (departing and arriving) and airport employees were surveyed in this five day (Monday-Friday) study during November 1967. During the survey, there were over 2,200 commercial take offs and landings. These were comprised of 231 inbound flights and 229 outbound flights, each of which was surveyed inflight once during the survey period. Also included in the survey were air-taxi and charter services. Parking lot and traffic movement was determined from manual and automatic traffic counts and analysis of several weeks of parking lot "time stamp" tickets. Worthy of note by Corradino and Ferreri[53] is that the questionnaire return rate was only 67.2%(10,133 of a possible 15,070). This seems out-of-order for an in-flight survey, "captive audience," but no explanation was provided.

The survey documents contain details of processing , techniques, statistical sample selection procedures, and tables of summary data. Corradino summarizes the survey effort including this comment about cost:

"An interesting fact about this survey was its cost. In total, \$1.49 per interview was required to complete the surveying task. This cost included charges for engineering work and its support, as well as machine

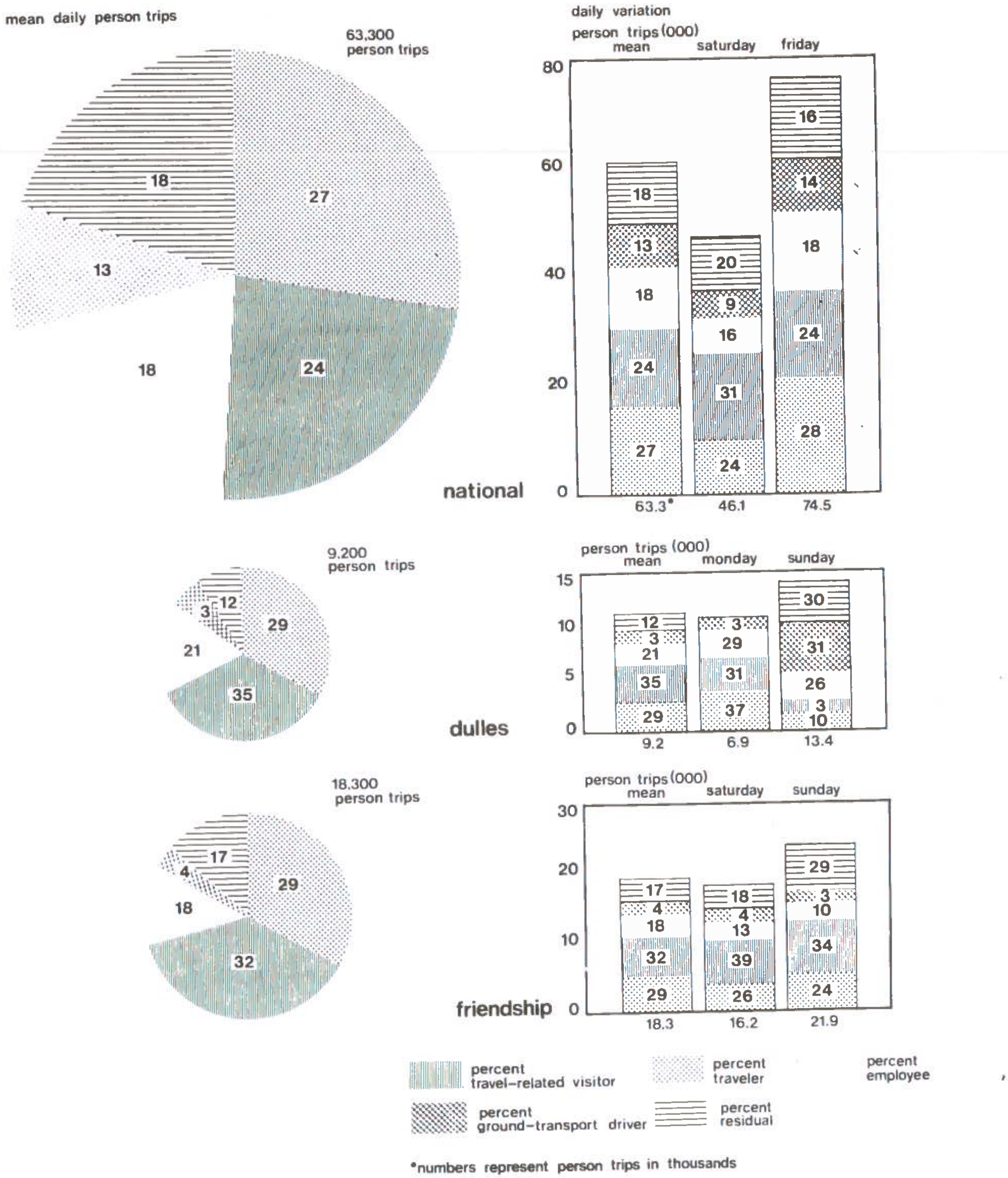


Figure 11. Person Trip Volume and Variability by Airport User Inbound and Outbound[7]

> and material costs. It covered the complete operation from design of the questionnaires, through coding of returns to editing and processing the coded data."[53]

Traveler's trip duration is not available in Tables 11 through 13, which is essential in modeling "out-of-pocket" cost considerations.

Table 14 reflects some principal findings. Via the 1968 basic documents, recommendations were submitted to the Philadelphia Deputy Director of Commerce for Aviation. These were based on the original forecast of air-travel predictions. The 1969 supplement was necessary when the air travel forecasts were updated by Airborne Instrumentation Labs (AIL)[54] and discussed by Stafford.[55] The conclusions from the earlier report indicated that rapid transit could not be recommended without detailed capital operating cost studies and proposed upgrading of highway facilities as the alternate solution. AIL forecast much greater air travel growth than originally predicted. After re-evaluation, the supplementary study concluded that the originally proposed roadway improvements and airport parking facilities would be insufficient. It recommended a rapid-transit extension to the airport to reduce traffic levels to the capacity of the roadways.

Corradino applied the survey results to a study of the asymmetry of access travel:

> "Trip data developed through the in-flight survey enabled tests to be performed to determine whether the number of trips made by air travelers from locations within the metropolitan area to the airport equal the number of trips made from the airport on an average weekday. Five statistical tests were conducted. Each was performed for the Philadelphia metropolitan area, the individual counties that comprise the metropolitan area, and the Philadelphia CBD."[56]

Table 14. Summary of Conclusions[52]

- Only 16% of all air travelers have a trip origin or destination in downtown Philadelphia -- more than 8 out of 10 air travelers are going to other points in the Delaware Valley.
- Seven out of 10 air travelers are on company business with "pleasure" trips as the next highest category at 14%.
- Private automobile is the predominant access mode to the airport - - half the air travelers gain access by private car with another 10% using rental cars. Downtown Philadelphia generates more "common carrier" traffic than all other segments of the region put together.
- Male air travelers outnumber females by better than 4 to 1. Approximately three-quarters of male air travelers were on company business with the largest category of females being the 44% who made pleasure trips.
- Approximately 70% of air travelers check at least one bag.
- Airport employees also show a scattering of origins with the largest group (44%) living in the city of Philadelphia. Delaware County accounts for the second highest proportion of airport employees with 34% residing in that area. Almost 9 out of 10 airport employees travel to work by private automobile.

Conclusions were:

"...A one-directional survey, properly designed and conducted, accurately mirrors the reverse direction of travel. In this way, one-half the in-flight survey effort can be eliminated and survey costs reduced without lessening the survey accuracy. A comparison of the trip information developed by the in-flight survey with comparable data produced through a home-interview survey indicates that the latter technique cannot be used to reconstruct fully ground travel generated by airports because of the absence of data on nonresident air travelers. Any analysis of airport ground travel based on data drawn from home-interview surveys should be supplemented by an examination of non-resident air passenger traffic."[56]

The conclusion that a one-directional survey accurately mirrors the reverse direction of travel was proven statistically only for geographical origin/destinations. There is no proof that the access modes to and from the airport are symmetrical, information which is important to transportation system planners.

The Philadelphia access improvement program should provide good "mix-of-modes" information for incorporation into future traveler behavioral studies. Investigation into the details of improvement is appropriate to ascertain the value and level of any further data collection.

Toronto International Airport 1968

The Toronto survey[57] is quite limited in that only 6.2% of out-bound air passengers during the survey week was sampled. In-bound air passengers, airport employees, and airport visitors were not included. In view of the small percentage of people canvassed and of the limited scope of the survey, the study cannot be representative of airport activity and thus is not useful in large-scale analysis. Canadian air-traveler characteristics may also vary considerably from United States patterns and possibly reduce analysis of the data to an inappropriate academic exercise.

Cleveland-Hopkins Airport Access Survey 1968-69

The Cleveland-Hopkins Airport Access Study[4] was undertaken to determine the effects of a new airport extension. to the rapid transit line from the Central Business District. Free parking lots were available to transit patrons at most of the suburban stops except the airport. At the airport, pay-lots were available and an approximate 5-minute walk separated the lots from the air terminal.

The survey report is a behavioral study. Results are to be used to help develop a modal choice model that can help assess the feasibility of rapid rail service to airports in other cities of the U.S. The survey and analysis effort were sponsored by the DOT/Office of the Assistant Secretary for Policy and International Affairs.

Data was acquired by means of a survey of air passengers, airport employees, and visitors going to and/or from Hopkins Airport. Two surveys were conducted: one before the completion of the new rail extension, the other, one year later, after completion. Questionnaires were distributed, completed, and collected immediately (passengers in flight, employees at work). No mail-back format was used. Personal interviews were used when questionnaires were not suitable (visitors in the airport and riders on the rapid transit extension line were interviewed in this manner).

Included in the study volume, "Survey Procedures," were the following suggestions for improving future surveys:

1. Use survey personnel to the fullest extent in actually distributing and collecting materials from the airline flight crews.

2. Plan on-board airline surveys 3 to 4 months in advance to insure adequate time for coordination with the airline.

3. Use personal liaison with groups involved in conduct of the survey to better stress the workings and importance of the survey.

4. Use survey personnel to gather control information essential to data expansion. They can recognize omissions and inconsistencies more quickly than airline employees.

5. Surveys of airport employees should be done by personal interview or, if self-administered surveys are necessary, use survey personnel to distribute, explain, and collect the questionnaires.

6. Get larger samples of casual visitor responses because of the indicated instability of this segment of the airport travelers.

In addition to the traveler survey, other data was required to support a comparison of travel time and costs between the rapid transit line and other modes of travel. All of the highway travel times and costs for private cars, taxis, and limousines are based on data obtained from the files of the Northeast Ohio Areawide Coordinating Agency (NOACA). All data obtained by the survey and the format for computer processing are contained within the 5 volumes of the survey study and the accompanying data tapes. The data collected in Phase I and Phase II of the Cleveland Hopkins Airport Access Study indicated:

"1. 57.6% of the 3,600 average daily rapid transit riders to or from the airport are air passengers. Only one-quarter of the air passengers that ride the rapid transit start or end their trip in the Cleveland Central Business District.

2. 13.2% of the air passengers using the CTS Airport Rapid Transit transfer to or from the Shaker Heights Rapid Transit System and make as many as 25 local stops in addition to the transfer on their trip to or from the airport.

3. 14.5% of all air passengers originating or terminating their trip at Hopkins Airport ride the rapid transit. Of greater significance, more than 25% of all air passengers with origin or destination in the rapid transit service area ride the rapid transit.

4. The opening of the rapid transit extension to Hopkins Airport resulted in declines for three modes of travel - private cars, taxis, and limousines. The limousine service showed the greatest decline (46.6%), followed by taxis (26.0%) and private cars (8.2%). Rented cars and hotel-motel and other courtesy vehicles both showed an increase. All modes of travel, however, showed a decline in the rapid transit service area.

5. More than 30% of the air passengers with origins or destinations in the Cleveland Central Business District, the University Circle Area, East Cleveland, Cleveland Heights, South Euclid, University Heights, and Lyndhurst ride the rapid transit to or from the airport.

6. The typical air passenger taking the rapid transit is male (80.1% of the passengers who ride the rapid), has an annual family income over $15,000 (61.2%), is on business or traveling to or from a convention (58.6%), checks only one bag or none (82.4%), and is traveling by himself (72.3%). Sixty-two percent of all air passengers riding the rapid transit check at least one bag on their flight.

7. 4% of passenger-related visitors traveling to Hopkins Airport use the rapid transit extension.

The opening of the extension resulted in declines in two modes of travel for this group - private car (3.6%) and limousine (41.2%). Although rented cars and taxis both showed an increase in use, limousines, rented cars, or taxis are not used by passenger-related visitors to any great extent.

8. 8.4% of the airport employees rode a public bus to work before the rapid transit extension opened. A much larger number of employees (18.1%) expressed the intent to make frequent use of the rapid transit extension. After the extension was opened, 11.2% of the airport employees were using the rapid transit for their trip to work. However, there is only one rapid transit station at the airport near the Main Terminal Building. Only half of the employees work in the Main Terminal Building and most of them live near the airport and own at least one car.

9. 17% of the rapid transit riders to or from the airport are casual visitors, i.e., persons traveling to the airport to sightsee, eat at the restaurant, obtain trip information, conduct business, or use the airport service facilities."[4]

Additionally, it was observed that all income groups were represented in the ridership of the rapid transit line. Non-resident business men and students used the line to a greater degree than the other groups.

Since this survey was structured to develop a modal split model, it contains more correlative data in a larger sample than most other studies. Tables 10 through 12 confirm the level of data stratification that is available. Limited approaches to model development have been attempted as seen in References 30 and 31. Both used discriminant analysis with diversion curves as output. The former was unsuccessful, the latter is not yet complete. The section entitled "Existing Methodologies" of this report contains more details of the two modeling efforts.

As was mentioned in Modal Split Analysis by Cleveland Regional Planning Commission,[30] the total number of weekly air passenger rapid transit trips from the rapid transit interview survey differs by 8% from the air passenger survey results. Possible causes are data-expansion procedures and incorrect modeling assumptions. Also, a modal split model was determined not meaningful for respondents using rented cars, or hotel-motel vehicles. This survey has the most potential of those reviewed and should provide the development of a data base to conduct modal split analysis.

New York Limousine Service - 1970

The aim of this survey and study by Skinner and Koller[6] is to answer several questions: Are the socio-economic characteristics of airport-limousine passengers different from those of air travelers in general? Are there significant user groups of limousine passengers which have specific characteristics in common? How do limousine passengers perceive their alternate modes of access to the airport?

Data obtained by this behavioral study is listed in Table 10. Two sets of almost identical questionnaires were used: one for passengers going to the airport, the other for passengers coming from the airport. The questionnaires were distributed and collected immediately when possible, thus insuring a high response rate (90%). Passengers generally had ample time to answer the questions while riding in the limousines. Mail-back questionnaires were given to those passengers who did not complete them enroute from the airport.

The survey results were summarized in tables and plots, consisting briefly of:

1. Socio-economic characteristics of limousine and air passengers when compared to 1963 PONYA data

2. Resident and non-resident air passenger knowledge of access modes available to them

3. Amount of luggage carried by various categories

4. Data on arrival times before flight departure

5. Tabular compilations of all the data obtained including a market penetration analysis

Data from this survey was used to aid the following studies: <u>A Demand Analysis</u>[33] and <u>Modal Split Models for Airport Access.</u>[32] Both were conducted by members of M.I.T. and are further treated in "Existing Methodologies" of this report.

Data format and storage techniques were not investigated since the sample was small and too limited for assessing the general airport-access, modal split choices. However, a detailed treatment of a specific modal split situation, where a fairly captive audience was available to analyze, is provided. The study is of current interest since M.I.T. and the Wilder Limousine service plan further tests of the recommendations resulting from the survey, thereby providing a "before-and-after" data analysis.

Boston-Logan, 1970

This survey's results is the preliminary summary of findings for an access survey conducted in June, 1970 by the Massachusetts Department of Public Works.[58] A data tabulation includes:

1. Hourly volume of private passenger cars
2. Hourly volume of taxis
3. Hourly volume of limousines
4. Subtotal hourly volume of all passenger vehicles
5. Hourly volume of buses (excepting MBTA)
6. Hourly volume of all trucks
7. Hourly volume of 2-axle trucks
8. Hourly volume of multi-axle trucks
9. Hourly volume of all vehicles
10. Hourly volume of person trips
11. Hourly volume of MBTA bus person trips
12. Ratio of manually classified vehicles to automatically classified vehicles by hour

A detailed schematic of the cordon area is presented in the survey including influences of the main arterials feeding the airport. Two data summary sets of interest are:

a. "Occupancy rates per vehicle are predictably higher in airport-generated trips. In addition, the main access (Route C-1) generates significantly higher occupancy rates than the secondary accesses which service predominantly on-site work trips. Sunday occupancy rates are highest of all. The rates are as follows:

Route C-1 Ramps Sunday	2.4 persons per car inbound
	2.6 persons per car outbound
Route C-1 Ramps Weekdays	1.8 persons per car inbound
	1.96 persons per car outbound
Frankfort Street, Porter Street, Maverick Street	Weekday 1.2 both directions[58]

b. A growth from 24,900 vehicles in 1967 to 28,600 in 1970 equals a growth rate of 4.7% annually on the primary automobile arteries into the airport. The study pointed out, however, that the most vigorous growth at Logan is in truck service to the air freight operations and that the service uses a different primary access route than the noted arterials.

An air traveler interview package was included. Pertinent characteristics are recorded in Tables 10-12. As seen in Table 11, detailed information on utilized access modes is being collected. Also, a combination of rail transit service and shuttle bus are one of the access modes available. Other data taken by the survey but not noted in the Tables includes attitudinal information collected to determine traveler preference relative to proposed rapid transit improvements. Improvement options involved system changes; e.g., intra-airport rail additions and express bus additions from downtown and suburbs. Transit policy changes included scheduling, improved terminal and vehicle appearance, and baggage handling.

Muehlberger[59] provides a good synopsis of the access problem at Logan Airport. He discusses the present system and its inadequacies in light of projected demand. Improvements in the access rail transit system and the need for an intra-airport transit system are also included.

The Mass DPW has been contacted to determine the availability of data. The Boston improvements involve significant mix-of-modes including use of an airport IAT. In light of the forthcoming changes and expected changes in existing mode ridership, this development is a desirable area for observation of passenger behavioral trends.

Lambert-St. Louis Municipal - 1969

Voorhees and Associates[60] summarized the results of an airport-access study for the Lambert-St. Louis municipal airport. The objective was to study air travel demand impacts to 1990. Approximately 60,000 terminating and originating air travelers were interviewed. The data does not include information relative to trip origin or destination. Linear-regression models were developed based on "types and intensity of land use" of 387 transportation zones surrounding the airport. Information on the survey and study was limited to the referenced document.

Northeast Corridor Transportation Project (NECTP)

Three sources related to demand analysis and survey procedures required for the NECTP were reviewed. Of particular interest were the procedures for determining access/egress parameters to the various modal terminals. Rothenberg and Prokopy[25] develop the elements of a traveler's intercity trip including access time and cost and terminal access time and cost, where:

1. Access time and cost are the time required to drive from home to the terminal parking lot with the associated out-of-pocket (OOP) costs required for the trip. OOP costs..."vary from 2.3 cents per mile to 3.8 cents per mile, depending on speed of travel, and all toll charges."[25]

2. Terminal-access time and costs are the time involved from entering the parking lot to scheduled gate departure (purchase tickets, checkbags, etc.), and the associated parking costs.

Egress times and costs are symmetrical at the trip destination. Access and terminal impedances are developed based on limited data. A basic assumption underlying the access impedances is stated: "...that the typical trip has a residential origin and a central city (CBD) destination."[25]

Travel time is assumed to be the most direct route and an average of peak/off-peak travel times.

Because of data limitations, the analysis approach used existing survey data wherever possible. The Washington-Baltimore Airport Access Survey, the PONYA in-flight surveys, the Philadelphia International surveys, and the Washington O/D survey were used in the NECTP analysis. A complete review of the study and results are beyond the scope of this document; however, the summary comments related to data problems are included in the paragraph called "Understanding Specific Subsystem Operations." The Northeast Corridor Intercity Travel Survey will fill a part of the data void.

Two related documents propose intercity survey needs and procedures. PMM[61] develops site-selection alternatives for the Northeast Corridor based on a methodology of determining travel behavior. Selection factors fall in three broad categories:

1. Economic activity index

2. Spatial-cost separation

3. Level of service by mode

Definition of the factors is included in Appendix K. Based on the factors and a factor weighting scheme, five alternative Corridor site combinations are evaluated.

ABT Associates[62] propose a sample design and survey procedures for regional travel between specific district pairs. Screenline procedures are recommended over other alternatives. Household surveying requires recall of important travel details over a past period. However, aggregation at the desirable level of geographical detail would be difficult, and cost of field work would be prohibitive. Real-time interviews at terminals and highway sites (nodal sampling) may require sampling for long periods of time to identify traveler groups representing a small fraction of the population. Coverage would be inadequate because site-selection requires that the collected data be analyzed at any desired level of geographical detail. Screenline sampling provides, first, for sampling the target population of the survey region at survey sites, and then for determining the county pairs on the basis of information obtained from the sample itself. The report covers the mathematical design and definitions of the survey population, the survey procedures and questionnaires and reasons for their selection, the overall plan for implementation, and guidelines for controlling the fieldwork. Cost documentation and control requirements necessary to implement a survey of this magnitude are also discussed.

SUMMARY AND CONCLUSIONS

Many of the necessary trip and trip-maker characteristics are available in the Cleveland-Hopkins Airport, the Washington-Baltimore and the New York surveys. However, a review of existing surveys cannot testify to the completeness of an adequate data base for studying airport access. Since modal split model calibration is a desirable end product, continued evaluation is necessary to establish the adequacy of correlative demographic and network analysis information. As noted earlier, other analysts have had limited success, but many variations of data manipulation are possible and it is felt that the selected surveys have considerable room for further exploration before thought is given to stating new requirements for data.

The variability in existing survey techniques and resultant data bases leads to the following suggestions for a Federal role:

1. Provide new directions for standardized surveys and data base correlation.

2. Develop a technique for review and evaluation of transportation studies being conducted in all metropolitan areas. The objective would be to select candidate programs for before and after surveys with prime consideration being a significant change in one of the many transportation modes. Cleveland-Hopkins is the only current example; the general trend implies a cross section of data from various metropolitan areas. At a minimum, model consistency should be confirmed with data from two metropolitan regions and the model must be continually evaluated as new data becomes available.

3. In correlation with 2, establish guidelines for funding of surveys which would function as a standard consideration for grants involving studies by areas planning changes in existing transportation systems.

REVIEW OF DEMONSTRATION PROGRAMS

A limited review of demonstration programs was made to assess their usefulness in developing new airport access systems and services. Demonstrations have many purposes

1. They create an awareness of new opportunities among local officials and the traveling public. Local government units, airlines and ground transportation operators are more willing to invest resources in new access systems if they have assurance of market and operational feasibility. Studies can furnish this assurance only to a limited degree. However, no argument is more convincing than: "This system worked very well when it was tried at the XYZ airport."

2. Demonstrations can be used to establish the technical and operational feasibility of a transportation concept in an operational environment. This is particularly useful for new, unproven modes of transportation to provide a limited demonstration prior to making the capital investments for a full scale system.

3. Demonstrations can be used to establish market feasibility, particularly to establish market elasticity of various service and fare levels.

4. Demonstrations can be used to obtain transportation planning data, to forecast travel behavior with respect to new and changed transportation services.

SAN FRANCISCO DEMONSTRATION

Demonstrations have not been widely used in airport access. To the best of our knowledge, only one, the UMTA-funded air-cushion-vehicle (ACV) demonstration in the San Francisco Bay area between the San Francisco and Oakland airport,[63] has involved airport access. The purpose of this demonstration was to determine the operational and economic feasibility and public acceptance of air-cushion vehicles as a means of airport access and public transportation in metropolitan areas.

Since the only vehicle available for the demonstration was the 14-passenger SK-5, manufactured in England by Westland Aircraft, Ltd. and modified in the United States by Bell Aerosystems Company, the tendency to assign the qualities of the SK-5 to all existing and future ACV's must be carefully avoided. Vehicles which are larger, more comfortable and more economical are being developed, and many of the apparent limitations of the SK-5 may be eliminated.

Where airport access and public transportation can be performed primarily over water, utilization of ACV's is operationally feasible. ACV's can operate compatibly with and in close proximity to other airport and marine traffic. Operation during low visibility and darkness seems possible but the necessary procedures have not been fully developed.

Trip cancellations due to high winds and waves were numerous, especially during summer afternoons when the winds in the San Francisco Bay area frequently exceed 20 knots. However, this is considered due to the characteristics and limitations of the vehicles used rather than to ACV's generally. The use of larger, heavier craft would not require cancellations under similar conditions.

Cancellations due to mechanical malfunction of the vehicle or equipment were also more frequent than should be experienced. However, much of the equipment used in the SK-5 was off-the-shelf and not optimized for the operating environments; for example, simple items such as windshield wipers gave undue amounts of trouble. When items such as these are developed with the ACV in mind, and when ACV's are constructed by American firms so that spare parts are readily available, mechanical reliability of the vehicles will be greatly improved.

ACV's are primarily suited for over-water applications, although they can operate over land. For regular overland operation, clean rights-of-way or taxiways are essential. Nonetheless, vehicle skirt wear is appreciable, and skirts require considerable maintenance. Improved skirt designs and materials, which would reduce friction between the skirts and the ground, and proper operator technique should help to provide increased skirt life with less maintenance and greater flexibility.

Although ACV operators do not require extensive training, experience in a responsible position and sound judgment are invaluable. The ACV control systems are similar to those of aircraft; however, many of their operating characteristics over water are like those of vessels. Flying experience in either fixed or rotary-winged aircraft or marine experience of comparable responsibility would be of great benefit. Thus, if the airman is adaptable to the way of the sea and the seaman has the necessary aptitude anticipation for the craft's high speed and aerodynamic control, both have equal potential as ACV operators.

Personnel assigned to maintenance should be fully qualified mechanics, preferably with experience in the maintenance of aircraft since ACV systems and maintenance procedures are similar to those of aircraft. Proper maintenance of the vehicles is essential to satisfactory performance.

Of the three principal factors affecting economic feasibility-passenger revenues, direct operating cost, and indirect operating cost, only the direct operating cost developed during the project is useful. For the SK-5 ACV it came out to be approximately $ 0.23 per seat-mile, based on the following: use primarily in an overwater environment, annual utilization of 1,800 hours per vehicle, block speed of 50 mph, and a 14 seat capacity.

This operating cost is high compared to most other types of transportation. As larger vehicles are constructed, the operating cost per seat-mile will undoubtedly be reduced. Presently however, operation of the SK-5 vehicles in public transportation appears to be economically feasible only in special applications, such as on short, point-to-point routes; over relatively calm water; connecting points generating large volumes of passengers who are willing to pay a premimum fare; and for which alternative routes are more lengthy and time consuming.

The information developed on indirect operating cost is of limited value in appraising potential feasibility of other ACV operations since this cost can vary substantially from company to company. Also, because the ACV fares were the same as SFO Airlines' helicopter fares, including the various reductions for through-fares used by agreement with long-haul air carriers, there was no opportunity to determine what the level of fare should be to generate maximum revenue. Therefore, the revenue which was collected does not give a good indication of the potential feasibility. On the other hand, the information obtained with respect to the direct cost of operating SK-5 ACV's, primarily in an overwater environment through an extended period, will allow appraisals to be made of potential economic feasibility based on individual estimates of indirect costs and local marketing studies.

The passenger acceptance of the ACV service was gratifying and encouraging. Even at this early stage of development, people seemed to enjoy riding it. No doubt, much of the enthusiasm was due to the novelty of the craft that "skims on a cushion of air;" however, larger vehicles are developed with increased comfort and economy, passenger acceptance will most likely increase also.

GROUP CAB RIDING AT LA GUARDIA

In addition to the UMTA-funded San Francisco Demonstration, there have been innovative locally funded transportation projects that can be classified as demonstrations. Two such demonstrations occurred in New York in 1968 and 1969.

In 1968, a group cab-riding experiment was conducted at the Eastern Shuttle Terminal of La Guardia Airport in which persons not traveling together share the same cab. If this demonstration had been successful it would have been extended to all of La Guardia and Kennedy Airport. When the experiment ended prematurely on December 31, 1968, the New York Times printed the following account of the experiment:

> "Group taxi riding begun as an experiment last April from La Guardia Airport, Queens to Manhattan, sputtered to a halt last night.
>
> "The experiment ran out of money with which to pay dispatchers, who were directing passengers at the airport to cabs.
>
> "In its nine months of operation the program drew a mixed reaction from passengers, cab drivers, and city officials. It was designed to provide those who arrived on shuttle flights from Boston and Washington with cheaper rides into Manhattan from the Eastern Airlines Terminal. If successful, it was to have been expanded to other terminals.
>
> "But many travelers, particularly businessmen on expense

accounts, were not concerned with the group-riding saving of $1 or slightly more. Many other travelers, however, liked the plan because of the saving and also because at rush hours it virtually guaranteed them a taxi.

"Many cab drivers complained that the group riding should have been allowed only during rush hours, because at other hours the demand for cabs was so light that long lines of taxis developed.

"The Lindsay administration which proposed the experiment and helped set it up, praised it at the outset and again yesterday. Deputy Mayor Robert W. Sweet issued a statement yesterday noting that the "experiment was successful" and expressing regret that no method of financing could be developed to save group riding.

"Eastern Airlines financed the experiment during the first eight months at a cost of $42,000, which the carrier felt was more costly than the benefits it was deriving from it.

"The city, and the Metropolitan Taxicab Board of Trade, which represents the taxi fleets here, then attempted to develop a new financing plan.

"Bernard Lerner, executive director of the fleet organization, suggested that the fleets pay a substantial part of the cost of dispatchers, but he wanted Eastern and the men who owned their own cabs and used the dispatchers to contribute as well. Negotiations to work out this three-way arrangement failed this week.

"Deputy Mayor Sweet expressed the hope that the experiment could be revived, but he did not suggest how it could be financed.

"The taxi fleets have proposed group riding from both La Guardia and Kennedy International airports only during the rush hours and with higher fares from Kennedy to induce drivers to go there and pick up fares.

"The Lindsay administration has been reluctant to recommend to the City Council any increase in cab fares."[64]

PAN AMERICAN'S SATELLITE TERMINAL

In 1969, Pan American started a satellite terminal and bus collection service for Kennedy Airport in the New York suburban area. This was mainly a market feasibility demonstration. Due to the institutional frame, however, it also contained overtones of an operational feasibility demonstration. When the service was announced, the New York Times described the demonstration as follows:

> "In a major innovation for the air traveler, Pan American World Airways has decided to go into the suburbs to collect passengers and - it hopes - relieve crowding at Kennedy International Airport.
>
> "The airline said that under the plan, to be implemented next month, it would establish a network of "subterminals" on Long Island, in Westchester County and Connecticut, and in the Bronx and Brooklyn.
>
> "Passengers from those areas booked on Pan American flights may go to the suburban terminals, present their tickets, check in their baggage, choose the seat they want on a plane and board a small bus. Then they will be taken directly to Kennedy to board their planes, by-passing the airline's terminal check-in facilities.
>
> "In most cases, airline spokesmen said, passengers will have to walk through the Pan American terminal building to reach their planes. But in some instances, passengers may be deposited directly on the airport ramp next to their planes.
>
> "Returning passengers will be able to ride the airline bus back to the suburban terminals, which will have 'limited' parking spaces for private cars, the airline said. As one spokesman said:
>
> > 'A passenger will be able to check in his bag at White Plains, or one of the other terminals, and he won't see it again until he reaches Buenos Aires or wherever he's going.'
>
> "At some time in the future, the airline said, helicopter service may be offered from the suburban terminals to the Kennedy terminal. Pan American already offers passengers 'on call' helicopter service to the airport from a heliport on East 60th Street in Manhattan."

The new service ran into two problems. First, an established limousine operator filed suit against Pan American for operating an improperly licensed service since it had no license from the City of White Plains or the New York Public Service Commission. Pan American argued that since it is an interstate carrier, CAB has sole jurisdiction over its service and city ordinances do not apply to it. Secondly, and more importantly, the service never attracted sufficient passengers to make the satellite check-in-limousine service fiscally feasible. At times the buses carried only one or two passengers.

After operating the service for nine months, in March 1970, Pan American joined American, Eastern, TWA, and United in a six-month trial of what the airlines called "Metropolitan Airport Terminals." The airlines utilized the local limousine carrier from Greenwich, White Plains and Manhasset. However, because of the airlines own financial problems and insufficient traffic, the experiment was dropped at the end of the trial period.

Given stronger financial backing, more publicity, more frequent service or different fare structures, it still remains questionable whether the two New York experiments could have developed successful access alternatives. However, one factor is apparent: there are diverse viewpoints among travelers and carriers on the desirability of various access mode mixes. Some travelers do not care for group taxi riding; operators seem to like it when taxis are in short supply (rush hour) and do not care for the system when taxis are in excess supply (off hours). Established limousine services considered the satellite terminals undesirable competition, as indicated by the suit filed against the experimental service.

OTHER DEMONSTRATIONS

Several other (non-airport-access) research efforts, conducted in relation to federally financed Urban Transportation demonstrations, were also reviewed. These studies, like those in connection with the San Francisco experiment, concentrated on assessing the technical and fiscal feasibility of the new services. Many were unable to come up with a meaningful assessment of market feasibility due either to the short duration of the project or to the limited scope of the demonstration.

Both local and intercity travel patterns vary widely with respect to time of day, day of week, month of year, holidays and weather conditions. Thus a break-in period plus a minimum of one year of operation is necessary to measure the acceptance of the service. Furthermore, if the service is subsidized-that is if, even in the long run and one does not expect to recover the initial capital expenditures-it behooves one to question the effect of the service (or service changes) on overall travel patterns, i.e., Did the service generate new trip making, or primarily mode diversion? Who benefits? Who is hurt? Very few of the demonstration projects (for instance the Skokie Swift Study) tried to answer any of these crucial questions specifically, but these are precisely the questions which must be answered to effectively plan new transportation services. Furthermore, these problems can only be solved empirically by observing transportation service changes.*

CONCLUSIONS

1. Only limited use has been made of demonstrations in airport access.

2. Only the study of changed travel behavior through change of service can answer some of the basic travel questions associated with airport access. Thus demonstrations can be an important source for the development of travel data.

3. The minimum length of demonstration needed to establish the market feasibility of a new service or change in service has not been established; however, a break-in period plus one year of operation appears to be the minimum requirement.

4. Most studies associated with demonstrations have not addressed the question of the effect of service level trip generation and modal split patterns, nor can they be considered to be meaningful cost/benefit studies.

5. The attractiveness of new transportation services can be handicapped by limited capital investment.

6. Since one important purpose of demonstrations is the creation of public awareness of new transportation services (or options), demonstrations that fail due to underfinancing can give an unwarranted negative impression of the new services, and thus fail to enhance public acceptance of a promising new transportation mode.

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* Michael Arrow of Northwestern University is currently conducting a review of federally-sponsored demonstration projects as a master's degree project. His thesis reportedly contains quantitative evaluations of some of the factors mentioned here. The thesis, as an HRB paper, will be available in late 1971.

A RESEARCH PLAN

This plan is based on the conclusions drawn in the preceding sections, many of which are neither new, nor revolutionary. However, they do point to the continued worsening of the problem of airport access at the major metropolitan airport and reveal no overall plan for solving the problem. The long-range plan presented here calls for providing local authorities and communities with a better comprehension of their technical and fiscal options, and with the tools to assess these options on a continuing basis. Specifically, the plan calls for two basic approaches:

1. Organize an Airport Access Planning Assistance Program including demonstration of new concepts.

2. Develop an Airport Access Technical Planning Package.

The approaches are interwoven to a degree, using common data and analysis wherever possible. Each are developed in separate paragraphs. Table 15 lists a task plan. Figure 17 reflects the interrelationship of the tasks in a time-phased schedule. Table 16 states various milestone outputs from the Program.

Table 15. Task Plan (Sheet 1 of 3)

I. Organize an Airport Access Planning Assistance Program

- A. Develop Baseline Program
  - 1. Specify goals
  - 2. Develop joint DOT programs
    - a. Review current Federal Support
    - b. Review all active access improvement programs.
      - (1) Survey Federal sources
      - (2) Survey airport managers and planning agencies
    - c. Define guidelines for demonstrations
      - (1) Define basic criteria
      - (2) Specify Federal role in developing experiments
    - d. Specify interfaces; program latitudes and constraints
- B. Critique and Finalize Planning Assistance Concept
  - 1. Critique via seminar of Federal, regional, and local agencies
  - 2. Specify program details
- C. Implementation Program
  - 1. Promulgate assistance plan
  - 2. Implement program to improve planning process

Table 15. Task Plan (sheet 2 of 3)

3. Develop a demonstration plan

    a. Perform a trade off analysis

    b. Prepare a demonstration plan

II. Develop an Airport Access Planning Package

A. Problem Definition and Methods Review (complete in FY 1971)

B. Establish an Airport Access Data Base (Begun in FY 1971)

1. Baseline the data required

2. Collect available data

3. Incorporate into a data management system

    a. Develop data management options

    b. Implement system

    c. Define user request procedures

C. Initiate a Basic Research Program

1. Perform basic research into demand

    a. Analyze relationships

        (1) Determine travel behavior

        (2) Establish air growth forecast sensitivities

        (3) Determine local factors which can influence national air growth

Table 15. Task Plan (sheet 3 of 3)

b. Structure demand and modal split models

2. Perform basic analysis of impacts caused by access improvements

a. Analyze relationships

(1) Establish relationship of airport accessibility

(2) Determine factors impeding regional acceptance

b. Develop techniques of impact analysis

(1) Investigate analytical methods

(2) Develop impact models

3. Investigate cost methods

a. Define spectrum of cost factors

b. Review analytical methods

c. Develop cost models

D. Develop an Integrated Methodology

1. Develop program interface requirements

2. Integrate Modules

E. Promulgate the Planning Package

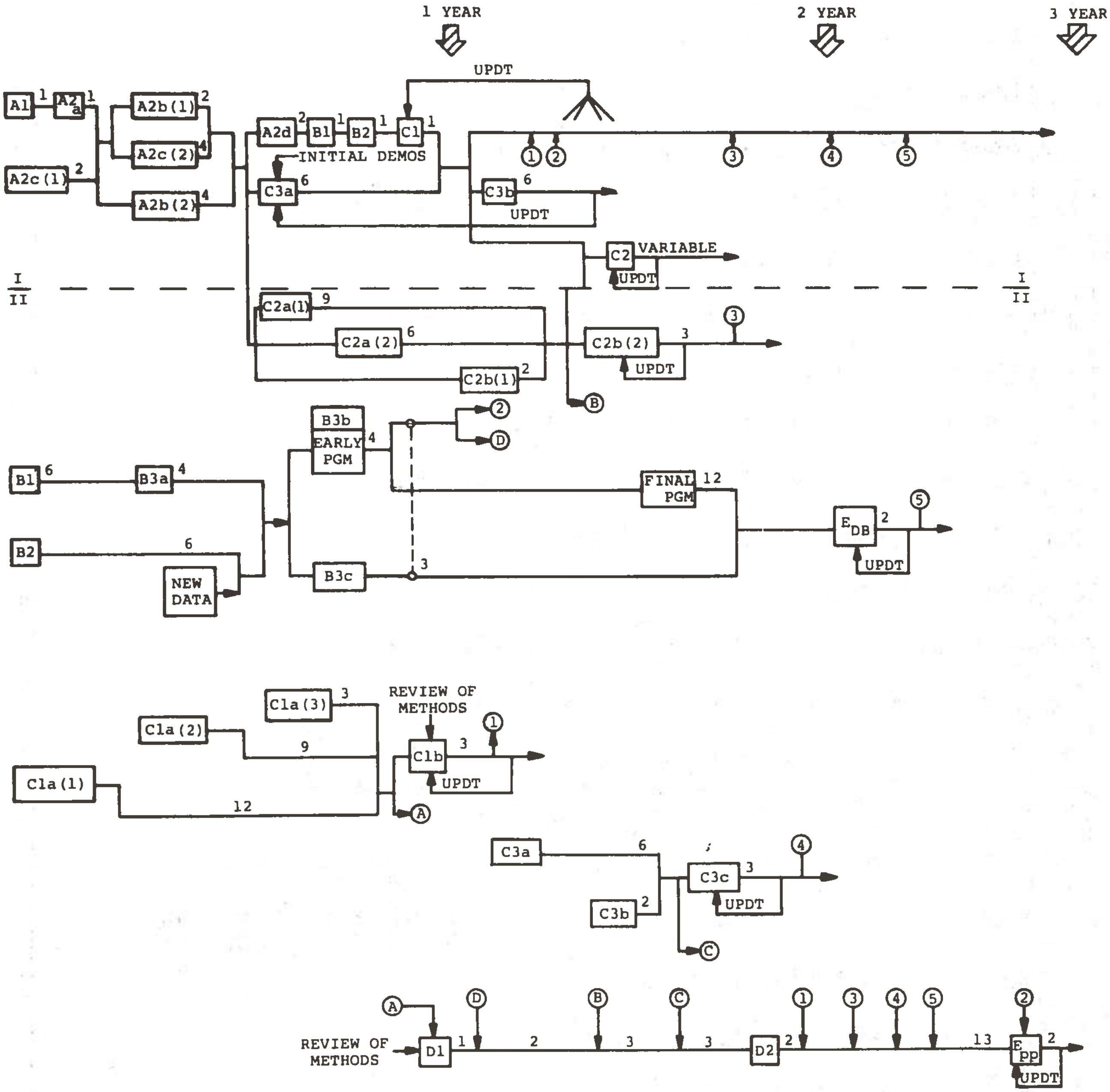

Figure 12. Interrelationship of Tasks in a Time-Phased Schedule

Table 16. Outputs from Research Plan

Baseline Organizational Concept
Results of Federal Survey
Results of Airport Manager Survey
Statement of Demonstration Guidelines
Pre-Critique Planning Assistance Proposal
Final Planning Assistance Package
Results of Demonstration Trade-Off Analysis
Demonstration Plans
Report of Requirements for Data Base
Specification for Data Management System
Data Base Operational Procedures
Report on Travel Behavior Analysis
Report on Air Growth Forecast Sensitivities
Report on Local Accessibility Factors
Statement of Factors Impeding Regional Acceptance
Review of Impact Methods of Analysis
Specification of Impact Models
Statement of Federal Program to Aid the Planning Process
Specification of Cost Factors
Review of Cost Analysis Methods
Specification of Cost Models
Statement of Integrated Program Interface Requirements
Various Integration Studies
Final Program Definition Document
Final Technical Planning Package

I. Organize an Airport Access Planning Assistance Program

There is no one central authority responsible for airport access either on the national or local level. Airport access improvements are the responsibility of several agencies, each of which has other higher priority objectives. Thus airport access improvements will be planned and implemented only if they are unquestionably institutionally, fiscally and socially acceptable. Since hardly any project is ever this uniquely acceptable, a concerted federal commitment to airport access is required to overcome local inertia. To bring this federal commitment to bear on local authorities, an Airport Access Planning Assistance Program is proposed. This program, if fully instituted, will help local organizations in their planning for airport access improvements, and will assist local and regional agencies in obtaining and funding airport access improvements which demonstrate innovative policy or hardware changes. Thus the program is envisioned to function as a catalyst for integrated planning between the multitudenous federal and local groups now directly or indirectly involved in airport access.

Objective

A. Make Available Technical Planning Methods and Data

Supply technical planning methods and data to planning agencies to assist in their development of airport plans. Methods will promote the concept of national airport system planning stressed by the Airport and Airways Development Act of 1970. The program will involve a nucleus of professional DOT staff available to consult and furnish technical guidance to the regional planning bodies in their efforts to solve specific airport access problems.

B. Assure Consideration of a Greater Number of Alternatives

Initiate the mechanism necessary to encourage direct intercourse between the airport planning and urban/regional transportation planning processes. Review and recommend new directions for Federal support of multimodal systems which may cross various institutions and regulatory lines.

C. Demonstrate New Concepts

Promote demonstration projects to create national awareness of a spectrum of new transportation concepts, all directed toward minimizing airport access difficulties. New concepts of transportation improvement abound.

Public exposure is necessary where radical changes or new systems are involved. Operational and/or market feasibility must be proven. The U.S. Department of Transportation should support demonstrations which expose new approaches to improvement and will be applicable to many airports and many types of travelers. To meet these objectives, the demonstrations must be well defined, planned, financed, executed, recorded and exposed.

Program Management

To organize an effective Federal Airport Planning Assistance Program, a planning, steering and review committee that represents all the departments, agencies and administrations which have policy responsibility for some aspect of airport access is required. At a minimum, the committee should consist of representatives of OST(TST,TPI,TEU), FAA, FHWA, UMTA, CAB and the ICC. The responsibility for organizing and managing the technical assistance program should be assigned to an intermodal agency within DOT.

A. Develop Baseline Program

1. Specify goals of program

- General exposure of new concepts - hardware in R&D, policy ideas, regulatory and institutional change
  - Taken to the level of public exposure where general reticence to new ideas may exist
- Direct access to Federal/industry team of experts
  - A planning methodology sensitive to dramatic transportation system changes
  - A data base reflecting details of "what has been" and how it might relate to the area's specific situation
- Demonstration of new policies and systems
  - Should expand list of regional alternatives by impetus of supporting Federal funding, project development and assistance in avoiding institutional delay.
  - Will reinforce the idea of a National Trans-

portation Concept where the nation as a whole benefits from individual regional improvements.

- Improve portal-to-portal service for all air travelers in general.
- Bring air travel within reach of lower income groups.
- Apply an attractive force to the more public transit oriented international market.

2. <u>Develop joint DOT program</u>

a. Review current specifications(e.g., grants-in-aid) for Federal support to airport access improvements in areas of:

- Project planning and execution
- Technological assistance
- Institutional management
- Regulatory change
- Data gathering and project analysis
- Financial aid

b. Review all active access improvement programs.

- Locate detailed problem areas, general and specific, which would require significant change or "new concepts" to improve airport access.
  - Determine status of various programs where exposure of new concepts is or could be of value in the National viewpoint.

(1) Survey of Federal Sources

- Requests for study funding
  - Grants-in-aid programs
  - National needs study
  - Modal agency offices
    - Demonstration programs

        - Other

- <u>Determine status of programs</u>
    - Who has planned/rejected changes?
    - Who is making changes?
    - What is basic area of improvement?
        - Access to airport
        - On-site airport traffic flow
        - Terminal flow, including baggage
        - Airside
    - What is stage of study or implementation?
        - Are any having problems?
        - What kind?
    - What demonstrations are planned, directly or indirectly related to airport access?
    - Who, what, where are new concepts and R&D projects having possible application?

- <u>Compile Information</u>
    - List of Federally-supported programs ongoing & contacts
    - Summary of desires from needs studies
    - List of area studies ongoing or recently completed
        - List of transportation planning agencies working problems
    - List of recognized authorities in Airport Design, generally, and Access Problems, specifically

(2) Survey of airport managers and planning agencies(selected from earlier Federal survey)

- Determine status of Improvement Plans
  - What is current plan to solution?
  - What are individual immediate problems? Should solution be a short/intermediate/long range one?
  - Why or how is it a problem?
  - What are (were) alternatives considered?
    - Against what background are (were) alternatives selected?
    - Institutional constraints
      - Local
      - Federal
    - Trade-off Criteria
      - Cost considerations, including methods of financing
      - Temporal (short/intermediate/long range)
      - Unacceptable development and/or implementation risks due to
        - Technological gaps
        - Uncertain safety factors
        - Questions of equipment reliability
        - Other
- Compile information

- Status of programs including problems of planning and implementation

c. Define guidelines for demonstration

(1) Define basic criteria for Federal support of demonstrations

- Is of national interest i.e., could emerge as an improvement having general application.
- Would enjoy a significant level of public exposure.
- Resulted from proper consideration of alternative solutions.
    - Justified by adequate analysis
- Tests new ideas to point of apparent system stability.
    - Policy change
    - New system
    - Improved system
    - Regulatory change
    - Crossing of traditional institutional or regulatory framework (Federal or local)
- Would provide data for new insight into nature of transportation.
- Involves a risk which would have eliminated it as an alternative without additional Federal support.
- Would require high capital investment (possibly with uncertain return).
- Would require long-term implementation period (against general political desire to get quick exposure).

- Requires technology at uncertain stage of development.

- Other

(2) Specify Federal role in developing experiment

- Coordinate with regional authorities to develop and agree on conceptual planning and implementation of the experiment. Specify review and approval milestones.

- Monitor progress of experiment; provide periodic critique of progress.

- Collect data for further analysis and use in developing reliable transportation needs and forecasting techniques. Continue to update national data base and overall planning package specification.

- Assure adequate national exposure to real experiment and to conclusions related to success or failure of the basic objective. Emphasize possible impacts on potential for air travel growth.

d. Specify joint DOT interfaces; assistance program latitudes and constraints

B. <u>Critique and Finalize Planning Assistance Concept</u>

1. <u>Critique assistance plan</u>

a. via a seminar of public agencies, e.g. planning agencies, consultants, academic community.

2. <u>Specify program details</u>

a. Specify final organizational structure and operating procedures.

b. Establish an advisory staff familiar with new transportation projects and concepts

- Must include specialists familiar with all segments of airport access trip plus foreseeable alternatives including alternatives to improving Hub airport access (e.g. V/STOL, HSGT, terminal design changes, airside regulation and redistribution to increase capacity and reduce demand).

C. Implementation Program

1. Promulgate assistance program.

2. Implement program to improve planning process.

   a. Recommend Federal direction, where appropriate, to minimize impedances to planning process, e.g., funding procedures (grants).

   b. Establish a program to detect and eliminate areas where Federal influence may undesireably bias or eliminate selection of access improvements.

   c. Recommend new directions for changes in policy, regulation, and institutional framework.

      - Demonstrate feasibility, where necessary.

3. Develop a demonstration plan.

   a. Perform a trade-off Analysis.

      - Analyze each prospective demonstration project and site in light of basic demonstration criteria and Federal support required.

        - Matrix of specific problems sites against alternative solutions

        - Listing of physical, political and temporal constraints in implementation of various alternative at specific sites. Should include prospective sites where improvement is:

          - Required/desired; and is in some stage of being:

            - Accepted

            - Planned

            - Executed

- List of projects using a new concept which will influence airport access

b. Prepare a demonstration plan

- Recommend a matrix of demonstration projects and sites for short/intermediate/long range improvements. Reflect demonstration criteria and Federal support required. Plan should consider urgency of each of the various projects and level of analysis required. Emphasis will be placed on projects stressing longest range improvements.

II. Develop an Airport Access Technical Planning Package

The methodology and survey review showed that considerable work pertinent to airport access has already been performed by local agencies with and without Federal assistance, and by the CARD study. However, these materials have not been brought together and have major deficiencies. To effectively assist local and regional agencies, a technical planning package is needed. This particular program proposes to develop such a planning package by making maximum use of already existing methods and data.

Objective

A. Specify Planning Methods Which Direct Attention to and Allow Trade Off of, Many Alternatives

Specify a methodology which allows consideration of alternatives responsive to local/regional goals and still supports the concept of an improved total air travel service in the nation as a whole. The planning process would be most sensitive to alternatives which provide a more uniform, accommodating landside service which takes advantage of the availability of an extremely flexible, ever-broadening air travel service. The methodology will be available as a planning package supplemental to currently accepted Federally-sponsored packages and computer specifications.

B. Develop A Data Base Available To Planning Agencies

Specify and develop a data base responsive to airport access analysis. The data base would evolve with the planning package. Demonstrations may be required to fill the data gaps. It would be available to all interested parties.

Program Management

Due to the intermodal aspects, the program should be sponsored by OST (TST) rather than one of the modal administrations. The technical management of this program should be assigned to the same group as the technical development of the Airport Access Planning Assistance Program.

A. Problem Definition and Methods Review (completed in FY 1971)

B. Establish an Airport Access Data Base (began in FY 1971 continuing)

   1. Baseline the data required to support concept of universality of methodology

      a. Establish periodic review and update procedures in light of evolutionary methodology.

      b. State future data requirements, e.g.,

         - Survey "situations of opportunity."

         - Specify demonstration projects where necessary.

   2. Collect available data.

   3. Incorporate into a data management system available to the broadest spectrum of users (must interface with other Federally sponsored programs).

      a. Develop data management options.

         - Specify input/output formats

         - Other special, but generally required data manipulation routines

      b. Implement system (abbreviate form early; final configuration in 1 year)

      c. Define operational procedures for user request

C. Initiate a Basic Research Program

   1. Perform basic research into factors influencing air traveler demand and decision making criteria (began in FY 1971).

a. Analyze relationships

(1) Determine travel behavior when facing access alternative, i.e.,

- Mode choice distribution
- Demographic distributions
- Trip-making characteristics, e.g. trip purpose, duration

(2) Establish factors to which air growth forecasts (demand) are sensitive, e.g.,

- Greater ability to travel
    - Four-day work week
    - Larger international market traveling to U.S.
    - Lower relative trip costs (jumbo jets) reach lower income groups
- Improved accessibility to air travel mode
    - Upgraded public transit
- Reduced temporal constraint on capacity
    - Alternative intercity ground modes
    - Satellite airports

(3) Determine local accessibility factors which directly or indirectly influence national growth of air travel

b. <u>Structure Demand and Modal Split Models</u>

2. <u>Basic analysis of impacts caused by access improvements</u>

a. Analyze relationships

(1) Establish relationship of airport accessibility to overall regional development, e.g.,

- How does/can improvement of one relate to other?
- What are cross-related area impacts-to users, operators, local governments, and physical region?
- Which of the unique characteristics of the airport access trip should influence the regional planning of transportation systems?

(2) Determine what specific factors are impeding regional acceptance of new ideas.

- Determine which categories of impedance to access improvement are most universal.
- Specify the interfaces which allow direct intercourse between airport planning projects and the urban/regional transportation planning process.

b. Develop techniques of impact analysis

(1) Investigate analytical methods of predicting regional impacts as a result of a significant change in transportation systems.

(2) Develop (select) impact models.

3. <u>Investigate cost methods</u>.

a. Define spectrum of cost factors.

- Must be generalized considering engineering design specifications

b. Review analytical methods for predicting resource requirements and costs of various transportation alternatives.

- Must be general enough to support the concept of abstract modes, that is, functional increment costs, e.g. a basic guideway can be evaluated with several command/control options

c. Develop (select) cost models

D. <u>Design an Integrated Heuristic and Analytical Methodology</u>

Methodology will be responsive to airport access short/intermediate and/or long-range improvement It should provide guidelines to a basic sequence of analysis and have the following general capabilities:

- Forecast demand for various trip purposes.
- Accept various conceptual transportation system options.
- Establish mix-of-mode ridership equilibrium for each alternative option basing decisions on travel behavior.
- Predict consequences of various alternatives when satisfying demand, e.g., ridership of various modes, demand shifts, resource requirements and costs.
- Aggregate consequences of each alternative set of options and determine total impacts (benefits/disbenefits) on users, operators, governments, and social considerations.
- Provide comparison of various alternatives using goal-related factors to allow trade off and possible redefinition of options.
  - Must direct consideration to the total spectrum of alternatives to regional airport travel, e.g., satellite airport or intercity ground modes.
- Calibrate and verify elements of the methodology by use of existing data. New data requirements will be stated only when existing proves unsatisfactory. The goal is to develop a sound methodology compromised to a minimum by shortcomings in data.

1. <u>Develop program interface requirements</u>
2. <u>Integrate modules</u>

E. <u>Promulgate the Planning Package to Appropriate Agencies</u>

- Provide for update and refinement procedures

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APPENDIX A

FORMULATION OF SHORT-AND LONG-RUN MODAL CHOICE FUNCTIONS[14]

"The short-run mode choice function for travelers over 16 years of age with drivers' licenses is defined as

$$MCSR_{ij} = \alpha_0 + \alpha_1 \Delta IT_{ij} + \alpha_2 \Delta OT_{ij} + \alpha_3 \Delta SRC_{ij}$$
$$+ \alpha_4 CH_i + \alpha_5 EH_i + \alpha_6 UH_i$$
$$+ \alpha_7 YSM_{ij} + \alpha_8 YSF_{ij} + \alpha_9 YM_{ij}$$
$$+ \alpha_{10} MSM_{ij} + \alpha_{11} MSF_{ij} + \alpha_{12} MM_{ij}$$
$$+ \alpha_{13} OSM_{ij} + \alpha_{14} OSF_{ij} + \alpha_{15} OM_{ij}$$

where

$MCSR_{ij}$ = utility of choosing auto over transit in the short-run by traveler j in household i

ΔIT_{ij} = in-vehicle time difference between transit and auto for traveler j in household i

ΔOT_{ij} = out-of-vehicle time difference between transit and auto for traveler j in household i

ΔSRC_{ij} = short-run cost difference between transit and auto for traveler j in household i

CH_i = number of children in household i

EH_i = number of employed adults in household i

UH_i = number of unemployed adults in household i

and the life cycle variables for each traveler j in household i [are below]:

YSM_{ij} = young (16 to 29 years old), single, male (1 if yes, 0 if no)

YSF_{ij} = young, single, female (1 if yes, 0 if no)

YM_{ij} = young, married (1 if yes, 0 if no)

MSM_{ij} = middle-aged (30 to 54 years old), single, male (1 if yes, 0 if no)

MSF_{ij} = middle-aged, single, female (1 if yes, 0 if no)

MM_{ij} = middle-aged, married (1 if yes, 0 if no)

OSM = old (55 years old plus), single, male (1 if yes, 0 if no)

OSF = old, single, female (1 if yes, 0 if no)

OM = old, married (1 if yes, 0 if no)

The probability that a traveler j in household i will choose auto is equal to

$$P[\text{choose auto}]_{ij} = \frac{e^{MCSR_{ij}}}{1 + e^{MCSR_{ij}}}$$

The value of in-vehicle time for the short-run traveler is equal to $\frac{\alpha_1}{\alpha_3}$.

The value of out-of-vehicle time for the short-run traveler is equal to $\frac{\alpha_2}{\alpha_3}$.

"The long-run mode choice function for all travelers over 16 years of age is defined as

$$\begin{aligned} MCLR_{ij} = b_0 &+ b_1 \Delta IT_{ij} + b_2 \Delta OT_{ij} + b_3 \Delta LRC_{ij} \\ &+ b_4 CH_i + b_5 EH_i + b_6 UH_i \\ &+ b_7 YSM_{ij} + b_8 YSF_{ij} + b_9 YM_{ij} \\ &+ b_{10} MSM_{ij} + b_{11} MSF_{ij} + b_{12} MM_{ij} \\ &+ b_{13} OSM_{ij} + b_{14} OSF_{ij} + b_{15} OM_{ij} \\ &+ b_{16} DL_{ij} \end{aligned}$$

where

$MCLR_{ij}$ = utility of choosing auto over transit in the long-run by traveler j in household i

ΔLRC_{ij} = long-run cost difference between transit and auto for traveler j in household i

DL_{ij} = driver's license status of traveler j in household i (1 if yes, 0 if no)

Other variables as previously defined.

"Since the long-run mode choice decision is a household decision synonomous with the auto ownership decision, the average (unweighted) utility of the household of choosing auto over transit is equal to the following:

$$\overline{MCLR}_{i} = \frac{\sum_{j=1}^{n_i} MCLR_{ij}}{n_i}$$

where

$\overline{MCLR}_{i.}$ = unweighted average utility of all long-run travelers in household i

n_i = number of long-run travelers in household i.

The probability that household i will purchase (choose) an auto is then equal to

$$P[\text{buy auto}]_i = \frac{e^{\overline{MCLR}_{i.}}}{1 + e^{\overline{MCLR}_{i.}}}$$

The value of in-vehicle time for the long-run traveler is equal to $\frac{b_1}{b_3}$.

The value of out-of-vehicle time for the long-run traveler is equal to $\frac{b_2}{b_3}$."[14]

APPENDIX B

DEMAND AND MODAL SPLIT EQUATIONS USED BY THE NECTP19

"The present demand model, in forecasting travel between zone pairs, uses only zonal population and income as travel-generating and attracting measures, and trip time, trip cost and trip convenience (as measured by frequency of service) as attributes of the transportation service. The current form of the estimating equation for total demand being used by the Corridor project is given by:

$$T_{ij} = B_1 (P_i P_j)^{B_2} \left(\sum_K W_{ijk}\right)^{B_3}$$

where

T_{ij} = Average number of daily intercity passenger trips between area i and area j via all modes.

P_i, P_j = Total number of families with income greater than $10,000 in areas i and j, respectively.

W_{ijk} = The level of transportation service provided by mode k between area i and area j.

B_1, B_2, B_3 = Coefficients estimated by statistical calibration.

The allocation of total demand to individual modes is given by:

$$T_{ijk} = \frac{W_{ijk}}{\sum_{\text{all modes}} W_{ijk}}$$

where

T_{ijk} = Average number of daily intercity passenger trips between area i and area j via mode k.

$W_{ijk} = \alpha_1 (t_{ijk})^{\alpha_2} (c_{ijk})^{\alpha_3} (F_{ijk})^{\alpha_4}$

t_{ijk} = Perceived trip time, including local access and egress, between area i and area j by mode k.

c_{ijk} = Perceived trip cost, including local access and egress, between area i and area j by mode k.

F_{ijk} = Convenience measure based on daily departure frequency for mode k.

$\alpha_1, \alpha_2, \alpha_3, \alpha_4$ = Coefficients estimated by statistical calibration.

"The explicit use of only three factors to characterize a transportation mode assumes that other factors influencing travel decisions such as safety, comfort, and reliability are more or less the same for new modes as well as for the old modes for which data have been derived.

"TAB-31 DEMAND MODEL

"The demand model which was used for the analyses for this report was the one most acceptable to the project staff at the point in time at which the analyses began. Much research was performed on demand models under the project's auspices before that time, and research has continued since then.

"The project has found it extremely difficult to forecast patronage for many modes of transportation simultaneously and consistently. Many models developed for this project and by other investigations have predicted demand for one or two particular modes acceptably well but have failed to handle the competition between several modes in a reasonable and consistent manner. It has taken much research to finally find one acceptable formulation.

"The particular formulation which was focused upon separates the estimation of total demand for a city pair from the estimation of the modal split or market share of a particular mode. The total demand model is a function of socio-economic characteristics of the cities and of the total transportation service provided. The modal split model is a ratio of a term representing the attributes of one mode to the sum of similar terms for each mode.

"Two separate models were initially developed having this general formulation. However, the two formulations differed in the way they represented many components of the model. These approaches were merged and the combined model was tested. Further improvements were made on this merged model and the result became the model used for this report.

"Further develpment of demand models has occurred since the analyses of alternative transportation systems reported on in the report were completed. No new formulations have been developed, but the one that has been used has been modified in two important ways. These are:

1. Demand can now be stratified into business and non-business trips.

2. A new parameter has been inserted into the demand model to control induced demand. Without time series data to estimate this parameter, the fraction of a new mode's patronage which is induced must be determined from analyses of information from other situations.

"The project has recently derived usable demand data stratified by business and non-business purpose categories. These data are not definitive, and represent the forceful merging of data obtained from disparate sources. Still, they have proven usable. New elasticities of demand for each strata have been calculated. More stratification analyses will continue as better data are acquired.

"For business trips, a price elasticity of -0.33 and a time elasticity of -3.44 have been calculated. These values agree with many observers' estimates. For non-business trips, the price elasticity is -1.18 and the time elasticity -1.00. Analyses of surveys show that non-business trips include two types: trips of short duration, such as visits and personal business trips, where travel time is important, and trips of long duration, such as vacations and prolonged visits, where price is more important than travel time. Probably the non-business trips should be further stratified, if data become available, to give more reasonable elasticity estimates.

"The Cenus of Transportation of 1967 has shown that each of the existing modes has a different mix of business and non-business trips. Hence, the average elasticities for each mode based on these mixes and on business and non-business elasticities can be calculated. For airlines a time elasticity of -2.8 and a price elasticity of -0.55 is obtained in this way. This last number differs from the value of -1.3 which the CAB has measured for the price elasticity for airlines, but is in line with what most carriers believe. Rail elasticities for time and for cost are -1.9 and -0.86, respectively. Bus elasticities are for time, -1.3, and for cost, -1.1. Auto elasticities are for time -1.5, and for cost, -1.0."[19]

APPENDIX C

THE I^3 DEMAND, NETWORK, AND TERMINAL MODELS[29]

"The Demand Model perforns the following functions:

> "The I^3 Demand Model determines the relationship which existed in a predetermined base year between selected socio-economic variables and specified originating and terminating areas, and the traffic flows of goods and persons exchanged by the "centroids" of area sub-divisions within the designated study area and the "centers" of representative rest-of-the-world areas, and applies the ratios expressing these relationships to projections of the socio-economic variables which have been exogenously made for at least one of the future years under study, in order to produce projections of the traffic flows likely to occur under the assumptions implicit in the model."29

The model is designed to operate on three types of goods traffic flows: bulk, special, and general goods movements; and two types of person traffic flows: business and other person trips.

"The Modes Choice and Assignment (Network) Model is described as:

> "The Mode Choice and Assignment Model was developed to simulate a multi-modal metropolitan transportation system. The primary purpose of the model is to provide a tool that will be useful in evaluating the effects of terminal location on a transportation system. The model operates in a network representation of a transportation system. The effects of terminal location are dependent on the efficiency with which terminals can process goods, the structure of other network components and their relationship to terminals, and on the demand for transportation services (input)."29

The model operates using a network of arcs between sources/ sinks or branches on the transportation system. The arcs represent vehicle and route. Transfer between modes occurs at "terminals." Access/egress arcs indicate that the source/sink is served directly by a particular mode. The model performs three functions in developing demand flow from point to point:

"(1) It determines the K(where K is prespecified by the user) best paths from each source to each sink on the network. A path is 'best' if it minimizes the sum of the impedances on the arcs it contains.

The criteria for determining these paths is based on the assumption that consumers of transportation services will select their route from among the least inconvenient routes. Inconvenience is expressed mathematically in the model as a function of time and cost. The time, cost, and other factors (such as safety) influencing consumer choice are computed for each arc on the network. The impedance or total inconvenience, to travel on an arc is computed as a linear combination of these individual inconveniences, or disutilities.

The impedance (inconvenience) on a path through the network is the sum of the impedance on the arcs comprising the path. Since consumers act to minimize the combination of disutilities, the 'best' path from a source to a sink is the path with the least impedance and this is the path we would expect most consumers to use. Several (K) of these paths are computed by the model."[29]

"(2) It distributes demand along the lowest impedance paths according to

$$W_k = \frac{e^{-u_k}}{\sum_{i=1}^{m} e^{-u_i}}$$

where W_k is the fraction of the total demand to be allocated to the k^{th} best path.

u_i and u_k are the impedance values of the i^{th} and k^{th} best paths, respectively.

m is the total number of minimum paths calculated."[29]

"(3) The Mode Choice and Assignment Model utilizes a delay function which recalculates the impedance (descriptors) of the arcs on the network as the network is loaded. The new impedances are a function of the old impedances (input), the capacity of the particular arc in question, and the volume exhibited on the arc. New impedances are calculated after each iteration through the model."[29]

To initialize the network, the user must place an initial volume of traffic by commodity or passenger class on each arc. These represent the level of intra-urban traffic which will act as an impedance to the intercity traffic flow. The arcs have direction, thereby allowing non-symmetrical traffic flow from sources and sinks. Various combinations of manual control and machine iteration are options available to simulate the impedance and volume or capacity-restraint relationships. The volume of traffic changes only for intercity traffic since intra-city is fixed.

The Terminal Model (TERMSIM) is composed of two parts: the simulation, a modified form of TRANSIM and the post processor which provides output. It is summarized as:

> "...a terminal is conceptually viewed as a network of linked nodes through which pass various types of traffic units. The nodes generally represent processing stations, queues, and/or decision points that affect the flows of the various traffic unit types in the model system. The network links correspond to the paths of flow from node to node that are available to the traffic units, As far as the user is concerned, there are only four main components that require definition in constructing a model. These are: (a) traffic unit definition; (b) operating element definition; (c) definition of operating rules that establish prescribed, conditional, and/or probabilistic flow patterns that traffic units must adhere to in moving from one operating element to another and (d) definition of the initial status of the system at the time the simulation begins.
>
> 1. Traffic units are the entities that flow through the model system.
>
> 2. Operating elements are the links and nodes of the terminal network.
>
> 3. System operating rules define the logical decisions or function distributions controlling the traffic flow through each link or node.

The terminal model allows a combining of links and nodes and their attendant impedances to replicate the flow of various commodity or passenger categories through a terminal.

The following discussion details the model interfaces:

> "The demand model having generated area-to-area flows of goods and passengers, the next model in the system, the Network Model, allocates the flows to specific paths, both route and mode. In this model, all modes are treated simultaneously, with the connections between modes (the terminals) being included as pseudo-

links of the network. For example, at a railroad siding where railroad cars are loaded and unloaded from and to trucks, the network model would have a link representing the truck-to-rail transfer. Given, for example, a specified quantity of goods or passengers from area a to area b the network model goes through the following procedures:

(1) For the specific traffic type calculate the net time and cost for each path through the multimodal network (including terminal transfers) from area a to area b.

(2) Choose the k best paths (usually 2 or 3 paths).*

(3) Based on the relative impedance quantity of each path, allocate a proportion of the total flow to it such that the total flow is allocated to the k best paths from area a to area b.

(4) After all origin-destination flows have been allocated to paths, then for each link the total volume will be computed. The total volume is then used in computation in a volume-delay equation of 'new' travel times for the network lines.

(5) Steps 2 4 are repeated until the changes in volumes are negligible from one iteration of this process to the next.

"Several assumptions and approximations are made with the network model and its data. First, the 'networks' processed by the network model are in fact abstract representations of the actual transport networks. Second, in the absence of the actual data, the time and cost figures for the network links are estimates based on a variety of figures from published sources. Third, in the absence of actual flow data for the study area it is not presently possible to do more than a reasonableness evaluation of the model outputs. Finally, there is an operational constraint on the model which allows only one terminal of each type in each areal unit. This implies that the numbers describing the terminal transfer links in the networks are representative of aggregates of terminals. All of these simplifications are indicative of required future study efforts."29

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* A path is "best" if it minimizes the sum of impedances on the arcs it contains.

Volume III of the _Final Report-Research Study of Intercity-Intra-Urban Interfaces (I^3)_ contains considerable discussion of the various elements in the model, a detailed listing of assumptions, required inputs, output options (including sample program listings), and the various computer implementation details including run times.

APPENDIX D

RESULTS OF CLEVELAND REGIONAL PLANNING COMMISSION MODAL SPLIT STUDY[30]

Table D-1. Cleveland Hopkins Airport Access Study Air Passenger Mode of Travel by Analysis Groups, Phase I (1968)[30]

Analysis Group	MODES																Total
	No Response		Rented Car		Private Car		Taxi		Airport Bus--Limousine		Hotel-Motel Bus		Public Bus		Other		
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	
Resident-Business-Private Residence	24	.15	295	1.83	12,765	79.31	1,583	9.83	1,196	7.43	10	.06	118	.73	105	.65	16,096
Resident-Business-Other	7	.20	182	5.31	2,288	66.85	364	10.63	468	13.69	33	.98	10	.29	71	2.07	3,423
Resident-Personal-Private Residence	32	.26	80	.67	9,712	80.91	1,069	8.91	935	7.79	14	.12	122	1.01	40	.33	12,004
Resident-Personal-Other	2	.32	18	2.52	390	53.43	84	11.49	198	27.21	8	1.09	17	2.27	12	1.66	729
Resident-Other-Private Residence	21	.48	20	.47	3,808	87.75	178	4.10	245	5.64	6	.13	48	1.10	14	.32	4,339
Resident-Other-Other	2	.35	11	2.48	161	35.98	24	5.39	65	14.47	12	2.71	137	30.72	35	7.88	447
Non-Resident-Business-Private Residence	2	.09	219	10.18	1,540	71.71	137	6.36	213	9.91	0	---	23	1.05	15	.70	2,148
Non-Resident-Business-Other	177	.80	4891	22.02	8,176	36.81	3,334	15.01	4,351	19.59	896	4.03	99	.44	287	1.29	22,210
Non-Resident-Personal-Private Residence	36	.45	302	3.85	6,612	84.23	300	3.83	517	6.59	20	.26	45	.57	18	.22	7,850
Non-Resident-Personal-Other	13	.63	376	18.60	674	33.34	364	17.99	443	21.90	81	4.03	40	1.96	31	1.55	2,021
Non-Resident-Other-Private Residence	22	1.31	14	.81	1,434	83.63	74	4.32	138	8.05	2	.12	28	1.64	2	.13	1,715
Non-Resident-Other-Other	50	1.73	249	8.61	532	18.45	710	24.59	888	30.75	115	3.99	249	8.62	94	3.26	2,886
Totals	367	.51	6657	8.77	48,092	63.39	8,221	10.84	9,657	12.73	1,198	1.58	933	1.23	724	.95	75,868

Table D-2. Cleveland Hopkins Airport Access Study Air Passenger Mode of Travel By Analysis Groups, Phase II (1969)[30]

Analysis Group	MODES																Total
	No Response		Rented Car		Private Car		Taxi		Airport Bus--Limousine		Hotel-Motel Bus		Rapid Transit		Other		
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	
Resident-Business-Private Residence	8	.04	352	1.91	13,184	71.61	1,351	7.34	854	4.64	20	.11	2,533	13.76	109	.59	18,411
Resident-Business-Other	3	.07	132	3.24	2,534	62.42	241	5.93	281	6.92	19	.47	803	19.78	47	1.17	4,060
Resident-Personal-Private Residence	22	.16	112	.81	10,338	74.57	1,082	7.81	477	3.44	8	.06	1,781	12.84	43	.31	13,863
Resident-Personal-Other	4	.48	14	1.71	428	51.08	23	2.73	100	11.95	23	2.77	243	29.03	2	.25	838
Resident-Other-Private Residence	8	.18	29	.66	3,527	79.87	117	2.64	88	1.98	3	.07	635	14.38	10	.22	4,417
Resident-Other-Other	0	.00	7	1.59	116	27.62	5	1.10	11	2.66	7	1.77	268	63.54	7	1.72	422
Non-Resident-Business-Private Residence	0	.00	245	16.53	831	55.93	90	6.04	43	2.90	14	.91	261	17.56	2	.13	1,485
Non-Resident-Business-Other	97	.42	6,022	29.05	4,475	21.59	2,781	13.41	2,754	13.28	1,310	6.32	3,125	15.07	169	.81	20,732
Non-Resident-Personal-Private Residence	5	.06	330	4.13	6,369	79.58	213	2.66	261	3.27	30	.37	795	9.93	0	.00	8,004
Non-Resident-Personal-Other	14	.77	246	13.91	660	37.30	218	12.34	247	13.96	93	5.26	281	15.89	10	.58	1,768
Non-Resident-Other-Private Residence	5	.35	25	1.69	1,142	77.37	43	2.92	28	1.90	10	.65	220	14.88	4	.26	1,476
Non-Resident-Other-Other	7	.42	131	7.47	299	17.02	332	18.90	243	13.86	311	17.72	397	22.60	35	2.02	1,755
Totals	173	.22	7,646	9.90	43,904	56.85	6,494	8.41	5,388	6.98	1,848	2.39	11,341	14.68	439	.57	77,232

Table D-3. Coefficient of Contingency Trip End Trip-Maker Characteristics, Phase I[30]

	Residence	Age	Sex	Frequency of Air Travel	Income	Purpose	Baggage	Duration of Trip*	Day of Flight	Land Use at Origin or Destination	Persons Accompanying To/From Airport
Residence	---	---	---	---	---	---	---	---	---	---	---
Age	---	---	---	---	---	---	---	---	---	---	---
Sex	---	---	---	---	---	---	---	---	---	---	---
Frequency of Air Travel	.299/.707	.198/.866	---	---	---	---	---	---	---	---	---
Income	.014/.707	---	---	.343/.866	---	---	---	---	---	---	---
Purpose	.053/.707	.466/.816	.479/.707	.405/.816	.358/.816	---	---	---	---	---	---
Baggage	---	---	---	---	---	.243/.816	---	---	---	---	---
Duration of Trip*	.256/.707	.246/.866	---	.325/.913	---	.453/.816	.451/.866	---	---	---	---
Day of Flight	.066/.707	.101/.866	.169/.707	.176/.913	.148/.866	.254/.816	---	---	---	---	---
Land Use at Origin or Destination	.535/.707	---	---	---	---	.449/.816	---	---	.211/.894	---	---
Persons Accompanying To/From Airport	.018/.707	---	.264/.707	.306/.866	---	.373/.816	---	.290/.866	.206/.866	.233/.866	---
Mode of Travel	.361/.707	.173/.866	.163/.707	.109/.894	.155/.866	.280/.816	.143/.866	.174/.894	.116/.894	.527/.894	.380/.866

*Computation based only on those passengers returning to Cleveland or expecting to return to Cleveland within the next few weeks.

Table D-4. Coefficient of Contingency Trip and Trip-Maker Characteristics, Phase II[30]

	Residence	Age	Sex	Frequency of Air Travel	Income	Purpose	Baggage	Duration of Trip	Day of Flight	Land Use at Origin or Destination	Persons Accompanying To/From Airport
Residence	---	---	---	---	---	---	---	---	---	---	---
Age	---	---	---	---	---	---	---	---	---	---	---
Sex	---	---	---	---	---	---	---	---	---	---	---
Frequency of Air Travel	.280/.707	.194/.866	---	---	---	---	---	---	---	---	---
Income	.035/.707	---	---	.322/.866	---	---	---	---	---	---	---
Purpose	.093/.707	.450/.866	.499/.707	.374/.816	.357/.816	---	---	---	---	---	---
Baggage	.035/.707	.155/.866	.259/.707	.199/.866	.163/.866	.308/.816	---	---	---	---	---
Duration of Trip	.135/.707	.386/.866	---	.287/.913	---	.587/.816	.543/.866	---	---	---	---
Day of Flight	.032/.707	.106/.866	.188/.707	.168/.913	.154/.866	.260/.816	.187/.866	---	---	---	---
Land Use at Origin or Destination	.562/.707	---	---	---	---	.435/.816	.233/.866	---	.208/.894	---	---
Persons Accompanying To/From Airport	.044/.707	---	.304/.707	.284/.866	---	.395/.816	.259/.866	.332/.866	.226/.866	.257/.866	---
Mode of Travel	.376/.707	.159/.866	.191/.707	.094/.894	.133/.866	.265/.816	.163/.866	.197/.894	.128/.894	.511/.894	.395/.866

Table D-5. Diversion of Trips to Rapid Transit by Analysis Group[30]

Analysis Group	Mode of Travel												Phase I	Phase II
	Rented Car		Private Car		Taxi		Limousine		Hotel-Motel Bus		Other		Total	Total
	Difference	% Difference	Difference	% Difference	Difference	% Difference	Difference	% Difference	Difference	% Difference	Difference	% Difference		
Resident-Business-Private Residence	-0.1	-5.5	7.7	9.7	2.5	25.4	2.8	37.7	-0.1	-83.3	+0.1	9.2	16,096	18,411
Resident-Business-Other	2.1	39.5	4.4	6.6	4.7	44.2	6.8	49.7	0.5	51.0	0.9	43.5	3,423	4,060
Resident-Personal-Private Residence	-0.1	-14.9	6.3	7.9	1.1	12.3	4.4	56.5	0.1	50.0	0.1	6.1	12,004	13,863
Resident-Personal-Other	0.8	31.7	2.4	4.5	8.8	76.6	15.3	56.2	-1.7	-160.0	1.4	84.3	729	838
Resident-Other-Private Residence	-0.2	-42.6	7.9	9.0	1.5	36.6	3.7	65.6	0.1	46.2	0.1	31.3	4,339	4,417
Resident-Other-Other	0.9	36.3	8.4	23.3	4.3	79.8	11.8	81.5	0.9	33.2	6.2	78.7	447	422
Non-Resident-Business-Private Residence	-6.4	-62.9	15.8	22.0	0.3	4.7	7.0	70.6	---	---	0.6	85.7	2,148	1,405
Non-Resident-Business-Other	-7.0	-31.8	15.2	41.3	1.6	10.7	6.3	32.2	-2.3	-57.1	0.5	38.8	22,210	20,732
Non-Resident-Personal-Private Residence	-0.3	-7.8	4.7	5.6	1.2	31.3	3.3	50.1	-0.1	-38.5	.2	100.0	7,850	8,004
Non-Resident-Personal-Other	4.7	25.3	-4.0	-12.0	5.7	31.7	7.9	36.1	-1.2	-29.8	1.0	64.5	2,021	1,768
Non-Resident-Other-Private Business	-0.8	-98.8	6.3	7.5	1.4	32.4	6.2	77.0	-0.5	-416.7	0.1	100.0	1,715	1,476
Non-Resident-Other-Other	1.1	12.8	1.4	7.6	5.7	23.2	16.9	55.0	-13.7	-343.4	1.2	36.8	2,886	1,755
Total	-1.1	-12.5	6.5	10.3	2.4	22.2	5.8	45.6	-0.8	-50.6	0.4	42.1	75,868	77,232

APPENDIX E

INPUTS TO GRAPHICAL CHANGE MODEL (FROM APPENDIX OF MODAL SPLIT ANALYSIS[30])

"<u>ZONE FILE A</u> records contain for each zone z:

- Nearest transit station code number.
- Zone code number.
- Transit fare to airport.
- Distance to nearest rapid transit station.
- Travel time from zone centroid to the nearest rapid transit station for each transit access mode j.
- Travel cost from zone centroid to the nearest rapid transit station for each transit access mode j.

"<u>ZONE FILE B</u> records contain for each zone z:

- Zone Code number.
- Average travel time from zone centroid to the nearest rapid station for each cell of the σ' stratification.
- Average travel cost from zone centroid to the nearest rapid transit station for each cell of the σ' stratification.
- Average travel time from the nearest rapid station to the airport.
- Transit fare to the airport.
- Travel time to the airport via mode i.
- Line haul travel cost to the airport via mode i.

"<u>RESPONSE FILE A</u> (Rapid only) records contain:

- Trip purpose.
- Baggage.
- Local O & D.
- Land use.
- Transfer vehicle.
- # of related visitors.
- Party Size.
- Duration of Trip.
- Income.
- Residence.
- Expansion factor.
- Rapid Station.
- Distance of zone to Rapid Station.
- Transit access time.
- Transit access cost.

"<u>RESPONSE FILE B</u> (Non-rapid only) records contain:

- Survey period.
- Trip purpose.
- Baggage.
- Local O & D.
- Land use.
- Arrival/Departure Vehicle.
- # of related visitors.
- Party size.
- Duration of trip.
- Income.
- Residence.
- Expansion factor.
- Independent variable x.

TABLE 1
Competing Sub-modes

1. Auto-parked	5. Limou-auto
2. Auto-non-parked	6. Limou-taxi
3. Taxi	7. Limou-bus
4. Rent-a-car	8. Limou-walk/other

TABLE 2
Rapid Transit Sub-modes

1. (rapid) - auto
2. (rapid) - taxi
3. (rapid) - public bus
4. (rapid) - walk/other"[30]

APPENDIX F

ADVANTAGES AND DISADVANTAGES OF CROSS-SECTIONAL MODELS[30]

"(3.2.3) Advantage of Cross-sectional Models

"The general advantage of these models is that they are capable of forecasting all modes simultaneously,i.e., they can forecast the share of market of all modes based on the mix of values of the independent variables related to those modes. Sensitivity analysis can be conducted on any of the independent variables. The cross-sectional model also can be calibrated with data from one point in time.

"(3.2.4) Disadvantages of Cross-sectional Models

"Most of these models suffer from the 'red and green bus syndrome.' This refers to the property that if one of the existing mode is arbitrarily divided into two modes, e.g. half the buses are painted one color while the other half a different color, the model will forecast a greater total demand for the arbitrarily divided two modes [than] it would for the mode when considered singularly.

"Another problem is that when a new mode is introduced for which an empirical calibration does not exist, either coefficients identical to those of the existing modes must be used, or that the coefficients must be subjectively estimated.

"The McLynn and the Logit model in particular must be calibrated on the zone level rather than the response level. This limits the degree of stratification possible, and also may place limitations on sensitivity to such factors as walking distance to the rapid. The data can be stratified to increase sensitivity to some of these variables, but the sample size will increase very rapidly."[30]

APPENDIX G

INFORMATION RELATED TO APPLICATION OF THE N-DIMENSIONAL LOGIT MODEL[36]

Table G-1. Impedance Measures Formulas[36]

$$Y_{1,t} = Y_{1,f} = X_1$$

$$Y_{2,t} = X_4 + (X_6)(X_{21}) + (X_8)(X_{19}) + (X_{13})(X_{20}) + (X_{15})(X_{22})$$

$$Y_{2,f} = X_4 + (X_7)(X_{25}) + (X_9)(X_{23}) + (X_{14})(X_{24}) + (X_{16})(X_{26})$$

$$Y_{3,t} = \left[(X_2)(\alpha_1) + X_3 + X_5 + (X_{10})(X_{11})(X_{19}) + (X_{17})(X_{18})(X_{22})\right]\left[\frac{X_{19} + X_{22}}{X_{27} - (X_{21} + X_{20})(2.0)}\right] + \left[(X_2)(\alpha_1) + X_3 + X_5\right](X_{20} + X_{21}) + (X_{12})(X_{20})$$

$$Y_{3,f} = \left[(X_2)(\alpha_1) + X_3 + X_5 + (X_{10})(X_{11})(X_{23}) + (X_{17})(X_{18})(X_{26})\right]\left[\frac{X_{23} + X_{26}}{X_{27} - (X_{25} + X_{24})(2.0)}\right] + \left[(X_2)(\alpha_1) + X_3 + X_5\right](X_{24} + X_{25}) + (X_{12})(X_{24})$$

$$Y_{4,t} = Y_{4,f} = X_1 \qquad Y_{5,t} = X_4 + X_{28} \qquad Y_{5,f} = X_4 + X_{29}$$

$$Y_{6,t} = \left[(X_2)(\alpha_2) + X_3 + X_5 + \alpha_3\right]\left[\frac{X_{19} + X_{22}}{X_{27} - (X_{21} + X_{20})(2.0)}\right]$$

$$Y_{6,f} = \left[(X_2)(\alpha_2) + X_3 + X_5 + \alpha_3\right]\left[\frac{X_{23} + X_{26}}{X_{27} - (X_{25} + X_{24})(2.0)}\right]$$

$$Y_{7,t} = Y_{7,f} = X_1 \qquad Y_{8,t} = X_{34} + X_{36} \qquad Y_{8,f} = X_{35} + X_{37}$$

$$Y_{9,t} = (X_{38} - 1.0)(X_{31})(0.5) + (2.0 - X_{38})(X_{30})$$

$$Y_{9,f} = (X_{38} - 1.0)(X_{33})(0.5) + (2.0 - X_{38})(X_{32}) \qquad Y_{10,t} = Y_{10,f} = X_{39}$$

$$Y_{11,t} = Y_{11,f} = (X_{44})(X_{58} + X_{59} + X_{60}) + (X_{52})(X_{61})$$

$$Y_{12,t} = X_{40} + X_{42} \qquad Y_{12,f} = X_{41} + X_{42}$$

$$Y_{13,t} = (X_4 + X_{45} + X_{57})(X_{58}) + (X_4 + X_{46} + X_{57})(X_{59}) + (X_{47} + X_{36} + X_{57})(X_{60}) + (X_{56} + X_{57})(X_{62}) + (X_{64} + X_{54} + X_{53} + X_{57})(X_{61})$$

$$Y_{13,f} = (X_4 + X_{45} + X_{57})(X_{58}) + (X_4 + X_{46} + X_{57})(X_{59}) + (X_{48} + X_{37} + X_{57})(X_{60}) + (X_{64} + X_{54} + X_{53} + X_{57})(X_{61}) + (X_{56} + X_{57})(X_{62})$$

$$Y_{14,t} = Y_{14,f} = X_{43}$$

$$Y_{15,t} = Y_{15,f} = \left[X_3 + X_5 + X_{49} + (X_{50})(\alpha_1)\right]\left[\frac{X_{58}}{X_{27} - (X_{59})(2)}\right] + \left[X_3 + X_5 + (X_{50})(\alpha_1)\right](X_{59}) + (X_{55})(X_{60}) + (X_{51})(X_{61})$$

$$Y_{16,t} = Y_{16,f} = X_{63}$$

X = component service measure

Y = modal impedance measure

α_1 = cost per mile for private car

α_2 = cost per mile for rental car

α_3 = fixed charge rental car

t = to airport

f = from airport

subscripts refer to figure 5

		Index of Determination R^2	Regression Coefficient λ ($/min)	Constant Term b($)
TO AIRPORTS	Private Car	.842	.02130	.270
	Rental Car	.846	.04370	4.528
	Taxi	.892	.15753	-1.702
	Limousine	.252	.02369	1.252
FROM AIRPORTS	Private Car	.851	.02112	.314
	Rental Car	.805	.04278	4.619
	Taxi	.833	.18613	-2.195
	Limousine	.196	.01940	1.601

$$\text{COST} = \lambda * \text{TIME} + b$$

Table G-2. RELATIONSHIP BETWEEN TOTAL TIMES AND TOTAL COSTS FOR EACH MODE[36]

Table G-3. Coefficients for Selected Models[36]

		Business Trips		Non-Business Trips	
		To Airport	From Airport	To Airport	From Airport
Private Car	Time	- .0401	- .0276	- .0342	- .0144
	Cost	-1.9097	-1.3031	-1.6058	- .6767
	Const.	0.0	0.0	0.0	0.0
Rented Car	Time	- .0265	- .0150	-	-
	Cost	- .6030	- .3505	-	-
	Const.	1.7187	- .9498	-	-
Taxi	Time	- .0624	- .0642	- .0631	- .0573
	Cost	- .3962	- .3447	- .4025	- .3082
	Const.	2.0495	1.2519	.3610	1.2998
Limousine	Time	- .0224	- .0106	- .0177	- .0104
	Cost	-1.0646	- .5482	- .7922	- .5348
	Const.	1.6664	- .1488	-1.0416	- .0237

Table G-4. Calibration Measures[36]

MODEL	MODEL STATISTIC	MODE: PRIVATE CAR	MODE: RENTAL CAR	MODE: TAXI	MODE: LIMO/COACH	MODEL	MODEL STATISTIC	MODE: PRIVATE CAR	MODE: TAXI	MODE: LIMO/COACH
BUSINESS TO AIRPORT	Observed Mean	103.1	19.2	83.2	31.5	NON-BUSINESS TO AIRPORT	Observed Mean	57.8	22.9	8.2
	Estimated Mean	103.4	19.1	83.0	31.4		Estimated Mean	57.6	23.1	8.1
	Correlation Coefficient	.96	.88	.99	.88		Correlation Coefficient	.96	.95	.67
BUSINESS FROM AIRPORT	Observed Mean	75.4	20.7	79.9	61.4	NON-BUSINESS FROM AIRPORT	Observed Mean	45.8	17.6	14.5
	Estimated Mean	75.3	21.1	80.2	60.7		Estimated Mean	45.0	17.4	14.4
	Correlation Coefficient	.92	.88	.99	.96		Correlation Coefficient	.95	.97	.87

MODE	MEASURE	CHANGE	AVERAGE NUMBER OF TRIPS AND PERCENT BY MODE									
			PRIVATE CAR		RENTAL CAR		TAXI		LIMO/COACH		TOTAL	
			TRIPS	%	TRIPS	%	TRIPS	%	TRIPS	%	TRIPS	%
		BASE SYSTEM	234.4	44.4	33.8	6.4	168.1	31.8	91.8	17.4	528.1	100.0
PRIVATE CAR	COST	+10%	218.5	41.4	36.6	6.9	175.6	33.3	97.3	18.4	528.0	100.0
TAXI	COST	+10%	240.3	45.5	34.7	6.6	159.0	30.1	94.1	17.8	528.1	100.0
		+20%	245.8	46.6	35.4	6.7	150.5	28.5	96.3	18.2	528.0	100.0
		+30%	251.0	47.5	36.2	6.9	142.6	27.0	98.2	18.6	528.0	100.0
LIMO/ COACH	TIME	+10%	238.7	45.2	34.9	6.6	170.4	32.3	84.1	15.9	528.1	100.0
		+20%	242.8	46.0	35.9	6.8	172.3	32.6	77.1	14.6	528.1	100.0
		-10%	229.9	43.5	32.8	6.2	166.0	31.4	99.4	18.8	528.1	100.0
		-20%	225.5	42.7	31.7	6.0	163.8	31.0	107.1	20.3	528.1	100.0
	COST	+10%	239.7	45.4	35.0	6.6	170.8	32.3	82.5	15.6	528.0	100.0
		+20%	246.7	46.7	36.5	6.9	174.6	33.0	70.3	13.3	528.1	100.0
		-10%	227.4	43.1	32.3	6.1	164.5	31.1	104.0	19.7	528.2	100.0
		-20%	219.9	41.6	30.8	5.8	160.8	30.4	116.6	22.1	528.1	100.0

Table G-5. Modal Choice Sensitivity[36]

Three study types suggested by Airport Access: A Planning Guide are:

"The assessment study includes:

- a definition of the objectives, criteria, viewpoints, and constraints;
- an identification of the problems or deficiencies based on preliminary data;
- an identification of the possible improvements to be gained from (1) a more detailed study of particular facets of the air-interface system and (2) the study of trade-offs between functional sub-systems or between operating policies; and
- the allocation of study resources leading to the definition of detailed study design.

"The assessment study is perhaps the most crucial of the three types; it provides the foundation for evaluation, establishes the time frame for the study, selects the scale and detail of study, identifies the political, institutional, and operational mechanisms which characterize the situation, and channels study resources into appropriate areas which show promise of improvement. Too often the assessment study is virtually bypassed or given insufficient consideration in the overall development of planning improvements and, yet, many of the problems of implementation and decision-making could be eliminated, were an adequate assessment study undertaken.

"In the second type of study, a policy planning study, alternative systems are tested and evaluated. Although longer-range planning would be typically accomplished in this study, there is no requirement for a distant planning-horizon. This study type is just as valid for evaluating short-range economic and operational policies with respect to relative impacts on overall service and financial feasibility. In all but the most resource-constrained programs, this type of study is required to gain better understanding of the complexity and characteristics of the access travel market, and to enable an objective trade-off between alternative investments and policies. A policy planning study would typically include: data acquisition, access-demand forecasting, generation of alternative system improvements, preliminary financial and management planning, and systems evaluation.

"Operations studies include special-purpose studies that are either reasonable to perform independently from an integrated planning study, require greater detail, or are necessary for input to the policy-planning study. These studies might include such topics as airport network circulation, airport signing, parking, information systems, or selected link improvements for the highway system. These studies may vary in time frame and detail as determined in the assessment study. They may consist of special studies that are linked to longer-range policy planning, such as access mode technology assessment, impacts of evolving governmental structure, and alternative financial and management schemes. Short-range special studies are discussed in Chapter III.

"The 'product' of the planning process is a recommended program for implementing airport access improvements stemming from the special or operational studies, the policy studies, and the evaluation framework established in the assessment study. Organizational, financial and management recommendations should also be presented in conjunction with the improvement program."[36]

APPENDIX H

VERTOL'S V/STOL EVALUATION METHODOLOGY [47]

"OVERALL MODEL LOGIC

Table H-1 shows the overall flow chart for the model. The blocks in the flow chart each reflect major analysis segments of the model. Several of these 'sub-models' will be individually described in detail in the following section of this paper. Inputs to the model are organized into seven different files. The file definitions and summary list of input requirements are shown in Table H-2 .

"V/STOL aircraft configurations are first generated by the VASCOMP II routine. VASCOMP II (the VSTOL Aircraft Sizing and Performance Computer Program)* is designed as a rapid computational tool to gice visibility to comparative design studies of V/STOL aircraft systems. VASCOMP II outputs will be used within the transportation model for determining aircraft procurement costs and aircraft mission-performance characteristics.

"The Intercity Market Share Module is designed to determine intercity mode split. It will aggregate the influences of intracity transportation systems to and from intercity modal stations. In order to effectively evaluate these influences, a multi-stage trip or true door-to-door passenger trip is evaluated. Hence, a trip from hub city H to a satellite S_1 is defined as a three-stage process:

- Leave origin at City H and travel by means of intercity transportation mode(s) to an intercity modal station.
- Travel by an intercity transportation mode from City H to an intercity modal station at City S_1.
- Travel from the intercity station at City S_1 to final destination by means of intercity transportation mode(s).

"Within the Market Module, an element called the MULTISTAGE TRIP ATTRIBUTE GENERATOR will determine the attributes (i.e., travel costs, times, delays, frequencies) of all multi-stage trip alternatives from zones in City H to zones in City S_1.

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* Schoen, A.M., uses Manual for VASCOMP II, The Boeing Company, Vertol Division, D8-0375, 1968

Table H-1. Overall Model Flow Chart[47]

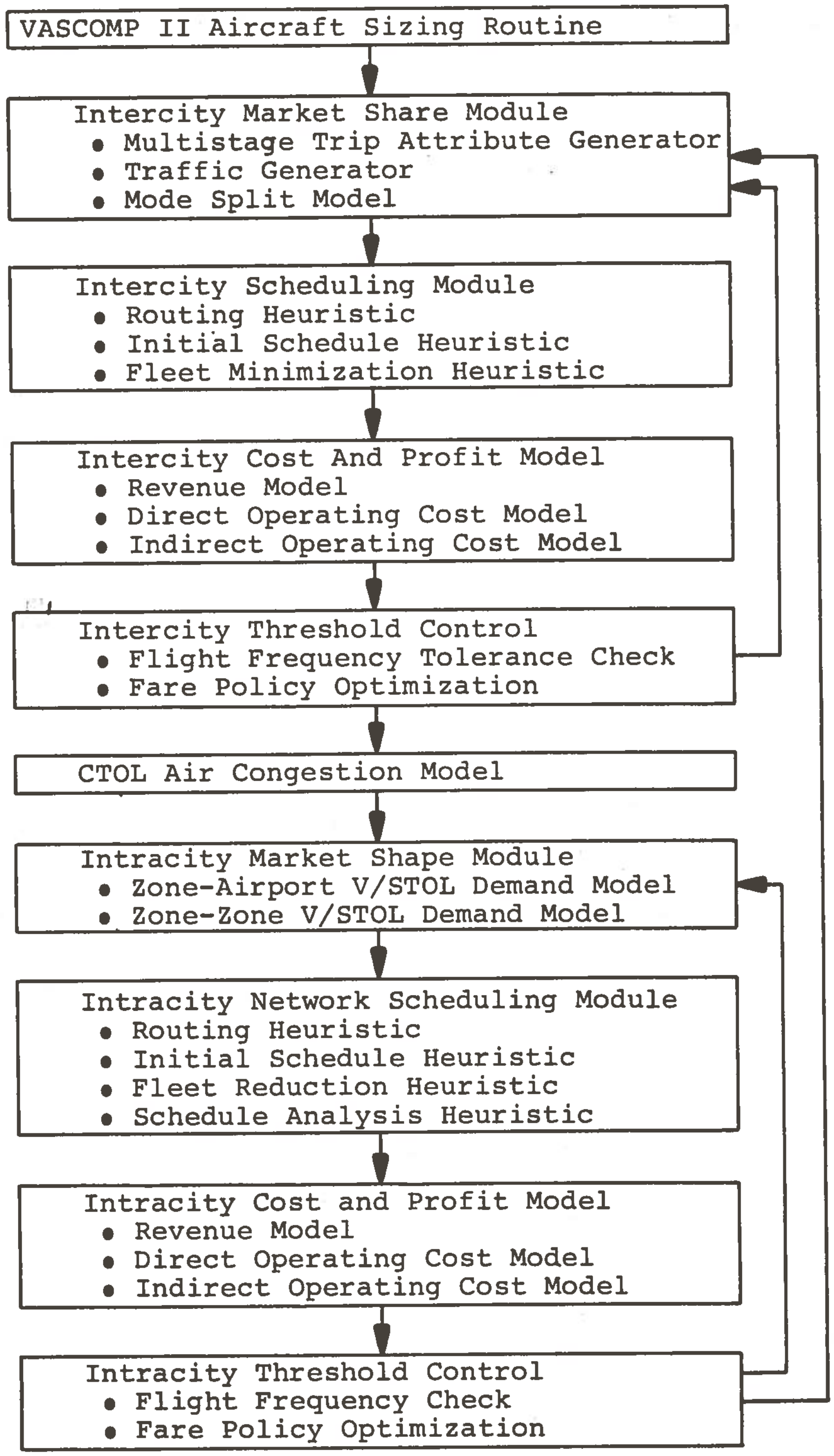

Table H-2. Summary of Input Files[47]

FILE NO.	FILE NAME- INFORMATION
(1)	Mode Files
	V/STOL File (Cost function, time function, dummy attributes) CTOL File Train File Bus File Auto File Dummy Mode File
(2)	Hub City File
	Location of City Zonal Data No, of zones Zone locations Population information(% of total travellers, % of population, other) Intercity mode data (station locations) Intracity mode data (station locating, mode times, costs, schedules)
(3)	Satellite City File
	Index No. Location Zonal data (include no. of zones, location, population information) Intercity mode data Intracity mode data
(4)	City Pair File
	Index No.'s Total travel demands - all modes Demand pattern over day Intercity Mode data (times, costs, schedules)
(5)	Technical File - Intercity
	Demand parameters (demand function coefficients) Multistage attribute generator parameters Scheduling parameters Threshold control parameters Cost parameters Congestion parameter Control parameter
(6)	Traffic Data Intracity
	Zone to airport traffic data Zone to zone to traffic data
(7)	Technical File - Intracity
	Demand parameters Zone to airport Zone to zone Scheduling parameters Threshold control parameters Cost parameters Control parameters

"A TRAFFIC GENERATOR routine will then determine the total number of daily intercity passenger trips from the hub-city zone to the satellite city zone. A MODE SPLIT MODEL will then apply the abstract mode concept for determining the number of travellers taking each competing intercity mode. The abstract mode concept assumes that a passenger views his trip as being a series of attributes (i.e., costs, comfort, time, convenience, safety) rather than a ride on a preferred piece of hardware. The MODE SPLIT MODEL will also generate the number of intercity travellers taking the competing intracity modes.

"Next, the Intercity V/STOL Scheduling Model will schedule intercity V/STOL aircraft within the Hub-Satellite framework. This routine will take demand levels, aircraft size, aircraft block times and will determine routes, schedules, and fleet size. The routine will attempt to determine the smallest fleet necessary to satisfy demand requirements at specified minimum levels of passenger service.

"Once configurations, fleets, schedules, and passenger traffic have been determined, the COST AND PROFIT MODEL will evaluate the costs and revenues generated by the intercity V/STOL system. Passenger revenues will be determined from predicted demand levels. Profit or loss will then be calculated.

"INTERCITY THRESHOLD CONTROL is a decision block that serves a dual purpose: (a) It evaluates differences between initial assumed frequencies used for modal split and frequencies calculated by the Intercity V/STOL Scheduling Routine and returns control to the Intercity Market Share Module with the updated frequencies (if they are not within some specified tolerance); and (b) it evaluates the profitability of the intercity V/STOL system, readjusts fares as necessary, and loops back to the Intercity Market Share Module in an attempt to optimize system profit. This model element may or may not be used as specified by the model user, but may, however, give valuable insight into fare structuring policies.

"The AIRPORT CONGESTION MODEL will show the effects of the intercity V/STOL system on CTOL airport congestion.

"Work on the subject of airport congestion* provides

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* Warskow, M.A. Capacity of Airport Systems in Metropolitan Areas, AD-623-134, 1964

relationships between average aircraft delays and airport movement rates for different airports. Inputs to the congestion model will be forecasted short-haul and long-haul CTOL traffic. Hence, the penetration of V/STOL into the CTOL short-haul air market (determined previously in the model) will reflect changes in total traffic at the CTOL airport.

"Outputs will include average expected CTOL delays with and without V/STOL competition, distributions of delays during peak hours of operation, annual hours that the airport is expected to exceed specified limits on average delay, and delay costs.

"INTRACITY MARKET SPLIT MODULES is an element that contains market split routines for the zone-airport travellers and zone to zone travellers and will determine the Type II and Type III intracity V/STOL passenger demands. These demands will be displayed in the form of a trip table - an intracity V/STOL station to station demand matrix. When this trip table (intercity passengers taking intracity V/STOL), which was generated in the INTERCITY MARKET SPLIT MODULE, a comprehensive trip table of total intracity station to station demands will have been generated.

"INTRACITY NETWORK SCHEDULING MODEL routes aircraft over the intracity V/STOL network and attempts to satisfy demands specified in the final intracity V/STOL trip table. The logic and ground rules used in this subroutine is similar to that used for the INTERCITY V/STOL SCHEDULING routine.

"Similar to its counterpart in the intercity model, the INTRACITY COST AND PROFIT MODEL will compute costs and revenues as a function of the intracity V/STOL configuration, fleet size, schedules, and passenger traffic levels. Direct operating costs will be based on a cost methodology designed for the evaluation of an ultra short-haul V/STOL system. Profit or loss for the system will then be calculated.

"INTRACITY THRESHOLD CONTROL serves a function similar to its counterpart for the intercity V/STOL system. It is a decision block that evaluates profitability and the compatibility of the frequencies generated by the INTRACITY NETWORK SCHEDULING MODULE and those assumed in the INTERCITY MARKET SHARE MODULE and the INTRACITY MARKET SHARE MODULES. Changes in fare levels are made and the model will transfer control to the

INTRACITY MARKET SHARE MODULES until a specified threshold profitability or minimum loss posture is achieved. Control may be transferred back to the INTERCITY MARKET SHARE MODULE when assumed service levels were incompatible with those generated by the INTRACITY NETWORK SCHEDULING MODULE."[47]

APPENDIX I

SAMPLES OF AIRPORT DESIGNS REQUIRING INTRA-AIRPORT TRANSPORTATION SYSTEMS[40]

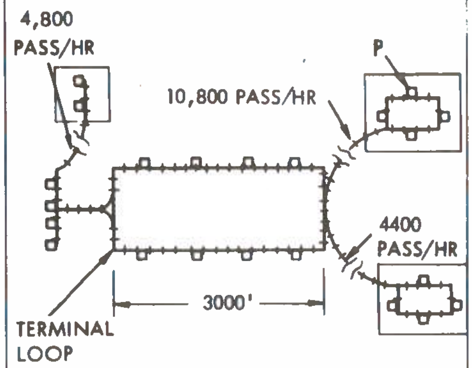
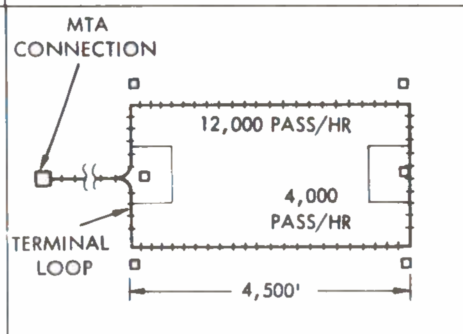
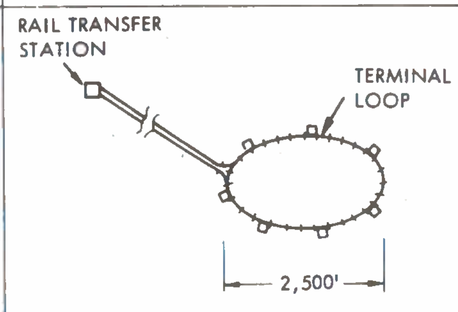
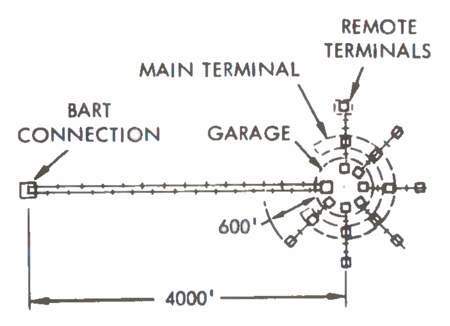
AIRPORT (RANK)	LAYOUT (□ TRANSIT STATION; -+- TRANSIT ROUTE; ▭ PARKING LOT)	PEAK DEMAND PASS/HR MAINLINE	PEAK DEMAND PASS/HR STATION	NO. OF STATIONS	MAX SPEED MPH	1975 TOTAL GATES	1975 ENPLANING M PASS/YR
L.A. 3		20,000	4,000	22	30	120	20
BOSTON-LOGAN 9		12,000	4,000	6	15		8
J.F.K. 2		2,000		10	30	~ 130	20
SAN FRAN-CISCO 5		20,000	6,000	20	15	90	12

Figure I-1. Parking/Transit/Terminal Movement [40]

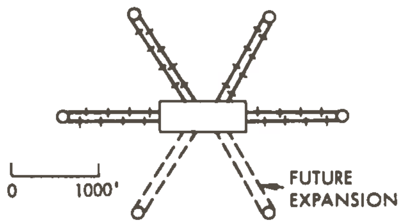
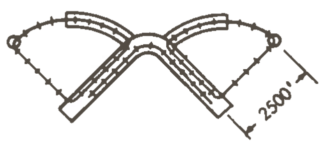
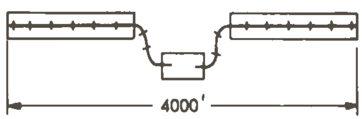
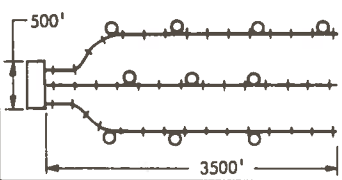
AIRPORT (RANK)	LAYOUT ▭ MAIN TERMINAL, O REMOTE TERMINAL, ┼┼┼ TRANSIT LINE	PEAK DEMAND PASS/HR	NO. STATIONS	1975 TOTAL GATES	1975 ENPLANING PASS. M/YR	SOLUTION
TAMPA 26		5,000	8	40 (60)	4	100 PASSENGER CARS
SEATTLE 22		6,000 (14,000 1980)	6	58	4	3 100-PASS. CARS ON A LOOP 1 CAR SHUTTLE
ST. LOUIS 16		5,000		50	5	
PITTSBURG 13		6,000 (12,000 ULTIMATE)		56 (80-100 ULTI-MATE)	6	

FIGURE 2. Intra-Terminal Movement

The application of an automated system to St. Louis and Pittsburgh airports may include a requirement for baggage handling in addition to passenger service. In this case, switching at the remote terminals and main terminal may be required to permit baggage and passenger cars to proceed to different pickup and delivery points.

In intra-terminal loop applications, the peak demand occurs at the main terminal station since all passengers from one or more remote terminals have the main terminal as their common destination. To handle these capacities the central terminal station must be serviced by a relatively large car. Assuming that two cars can load and unload each minute, a 40-passenger car is required for a 5000-passenger/hr

Figure I-2. Intra-Terminal Movement 40

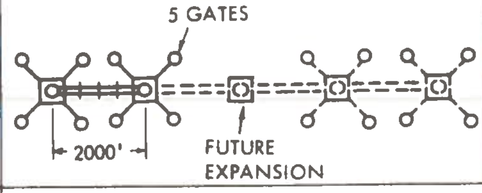
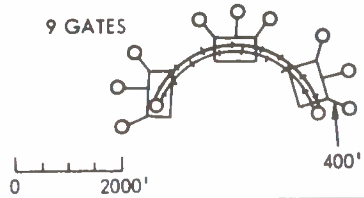
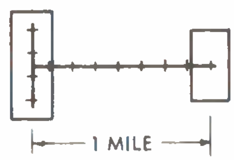
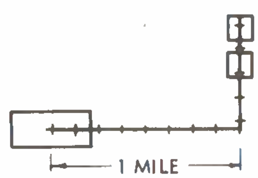
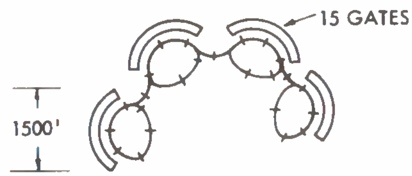
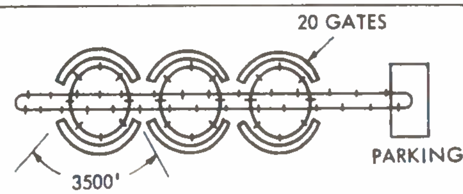
AIRPORT	LAYOUT ▭ TERMINAL BUILDING O REMOTE TERMINAL ↔ TRANSIT LINE	PEAK DEMAND PASS/HR	NO. STATIONS	SPEED MPH	1975 TOTAL GATES	1975 ENPLANING PASS. M/YR	SOLUTION
GROUP A							
HOUSTON 20		1,200 ~10% TRANS-FER	5		40 (80)	4	3-8 PASS. CAR TRAIN
PHILA. 12		≥ 2,000	7		77	5	
NEWARK 11		≥ 2,000	5		81	12	
MEMPHIS 28		375	4	15	50	3	
ATLANTA 4		4,000 45% TRANS-FER	3	15	150	13	
GROUP B							
KANSAS CITY 19		3,600 5-10% TRANS-FER	12?	30	45 (60)	4	4 CAR TRAIN 30 PASS./CAR
DALLAS-FT. WORTH 7		2,000 (4,000 1980) 35% TRANS-FER	18?	30	100 280	9	

Figure I-3. Interterminal Transfer 40

APPENDIX J

SURVEY SITE SAMPLE SELECTION FACTORS[61]

"Economic Activity Index

A measure of economic activity was needed to reflect the advantage that one area may have over another in competition for the travel market. Because population and employment are generally considered good measures of economic activity, they were selected as components of an index formulation, as follows:

$$I_{e_{ij}} = \frac{\sqrt{P_i E_j} + \sqrt{P_j E_i}}{2}$$

where

$I_{e_{ij}}$ = Economic activity index for a pair of districts i and j;

P_i = Population of district i;

P_j = Population of district j;

E_i = Employment of district i;

E_j = Employment of district j.

"While another form of this equation may provide equally good results, the key question is whether an economically large district combined with a small one will generate similar characteristics of travel to two medium-sized districts. Sufficiently fine stratification or groupings should help to overcome this problem.

"Spatial-Cost Separation

"Spatial-Cost Separation is particularly important to the selection process in order to reflect the effect of distance, time and cost on travel characteristics. Because cost of travel is generally a function of distance and because the average speed of automotive travel is probably very nearly equal for all inter-district trips, highway travel time was used as a selection criterion for spatial-cost separation.

"Level of Service by Mode

"The third element used as a factor in selecting district pairs was modal level of service. Combined in this element are such variables as access time, headway or trip frequency, and mode availability. An average level-of-service index was calculated for each common-carrier by the following formulation:

$$I_s = \frac{10{,}000}{\text{Access Time} + 1/2\ \text{Headway} + \text{Egress Time}}$$

where

Access Time = Auto travel time from the origin district centroid* to the origin common-carrier terminal.

1/2 Headway = One half the average scheduled time between common-carriers traveling between the origin terminal and the destination terminal.

Egress Time = Auto travel time from the destination common-carrier terminal to the destination district centroid."[61]

*District centroids represent the center of district movement and activity.