Title

Development of a Modeling Framework for Analyzing Improvements in Intermodal Connectivity at California Airports

Permalink

https://escholarship.org/uc/item/586755r9

Authors

Lu, Xiao-Yun
Gosling, Geoffrey D.
Shladover, Steven E.
et al.

Publication Date

2006-07-01

CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Development of a Modeling Framework for Analyzing Improvements in Intermodal Connectivity at California Airports

Xiao-Yun Lu, Geoffrey D. Gosling,
Steven E. Shladover, Jing Xiong, Avi Ceder

California PATH Research Report
UCB-ITS-PRR-2006-14

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation, and the United States Department of Transportation, Federal Highway Administration.

Final Report for Task Order 5406

July 2006

ISSN 1055-1425

Development of a Modeling Framework for Analyzing Improvements in Intermodal Connectivity at California Airports

FIRST YEAR REPORT

Project Number: TO 5406

A Combined Quantitative and Qualitative Approach to Planning for Improved Intermodal Connectivity at California Airports

Xiao-Yun Lu, Geoffrey D. Gosling, Steven E. Shladover, Jing Xiong, Avi Ceder

Key Words

Intermodal connectivity, airport ground access, passenger mode choice, transportation provider behavior, network traffic, Nash equilibrium, IAPT (Intermodal Airport Ground Access Planning Tool)

Abstract

This report has been prepared as part of a research project developing a combined quantitative and qualitative approach to planning for improved intermodal connectivity at California airports. The quantitative approach involves the development of an Intermodal Airport Ground Access Planning Tool (IAPT) that combines an air passenger mode choice model, a model of transportation provider behavior and a traffic network analysis model. The qualitative approach will be used to enhance the quantitative analysis to account for those factors which are difficult to quantify and to provide recommended policy and planning guidelines.

This report represents a continuation of the previously submitted Working Paper, so that together they describe the main work conducted in the first year of the project. This report summarizes the work reported in the Working Paper in Chapter 3: Opportunities for Improved Intermodal Connectivity at California Airports.

This report concentrates on the modeling and IAPT design. The modeling includes two main components of the IAPT, i.e. air passenger mode choice model and transportation provider behavior model. This modeling work involves the following steps:

- System isolation (definition of problem scope): to isolate the airport ground access system from general transit systems;
- System simplification: several assumptions have been developed which greatly simplify the problem to avoid network optimization in a transit system;
- Mathematical model development and justification.

The IAPT design includes detailed software structure and functions, user interface, data base, and data flow. Plans for further development of the IAPT and recommendations for future study of airport ground access planning issues are presented.

Acknowledgements

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation (Caltrans); and the United States Department of Transportation, Federal Highway Administration. The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification, or regulation.

The guidance and support from Colette Armao, Terry Barrie and Debbie Nozuka, of the Caltrans Division of Aeronautics and Dan Lovegren, the Project Manager at the Caltrans Division of Research and Innovation, are gratefully acknowledged.

Contents

Appendices

List of Figures and Tables

Page

Figure

Executive Summary

This report describes the main work conducted in the first year of the project, including recent literature review, extensive system modeling and analysis, and Intermodal Airport Planning Tool (IAPT) design, which in turn includes definition of the function of each sub-module, overall structure, data flow and Graphical User Interface (GUI). This report is a continuation of the previously submitted Working Paper, which is summarized in Chapter 3: Opportunities for Improved Intermodal Connectivity at California Airports. The six chapters of this report are:

(1) System scope definition, structure design and simplification for modeling: The scope of intermodal airport ground access implementation planning for a given airport has been clearly defined for this project. This includes the following main components: air passengers, transportation providers, network traffic, airport authority and local government agencies. The dynamic interactions between those components, which may be unidirectional or bidirectional, are defined. Prediction of passenger mode usage must be based on understanding the behavioral characteristics of each component and their interactions. However, since the overall system is very complicated, simplifications are necessary. The main assumptions related to the simplification of the overall system are:

(a) Performance evaluation is the most interesting part for decision makers. It can be described using parameters such as travel time, VMT/VHT (Vehicle Mile Traveled/ Vehicle Hour Traveled), emissions, etc. These parameters are determined by the interactions between air passengers and network traffic, based on passenger mode choice, which is in turn affected by transportation providers' behavior.

(b) Competition is only represented between modes; i.e. all the providers in the same mode are considered to compete as one with their counterparts in other modes. Although this assumption is not realizable in practice, it is reasonable in the sense that mode behavior can be considered as a collective behavior averaged over all the providers within the mode. This simplification is

consistent with the mode choice model, and saves considerable unnecessary complexity in the transportation provider model.

(c) The modeling of airport access is distinguished from general transit system modeling in that origin, destination and routing are greatly simplified for planning purposes and there is no network optimization problem. A single air passenger access/egress path is used from each origin zone for each primary airport access mode. An access/egress path links the primary airport access mode with its auxiliary modes, potentially at both the origin and destination ends of the trip. Examples of such paths and primary modes are: (i) single mode - rental cars, taxi, shuttle van, or self-driving with airport parking, pickup/drop-off; and (ii) combined mode trips such as BART and parking, self-driving with off-airport parking, for which the primary mode is obvious. The corresponding auxiliary mode(s) can be ignored in considering air passenger mode choice. If only the primary mode is considered, there is a one-to-one correspondence between mode choice and access/egress path choice. The main advantage of this simplification is to effectively avoid the need to model the selection of the auxiliary modes throughout the regional transportation network.

(d) The relationship between airport ground access activities and decisions by the airport authority and local government is unidirectional, and is effected through the regulation of curb access on, and revenue collection from, the transportation providers. Those factors may affect passengers through prices and wait times, for example.

<u>(2) Passenger mode choice modeling: A </u>discrete choice model is used for modeling passenger mode selection. The essence of the mode choice model is to provide a probability distribution of passenger ridership from each origin zone to the given airport, based on an assumed aggregate known demand. The aggregate demand and model parameters are determined from air passenger survey data for the given airport.

<u>(3) Transportation provider behavior modeling:</u> Ideally, such a model should represent the competitive behavior of transportation providers within and between modes, but here the modeling focuses on between-mode competition. The most common way of thinking about

provider behavior is to focus on the elasticities that are observed empirically by the providers, considering the ridership shifts that result from changing service variables by one mode at a time, such as increasing/decreasing the fare or changing the operating frequencies. This approach can predict the outcomes of unilateral actions by individual modes, but it is more difficult to predict the outcomes caused by the near-simultaneous actions of multiple modes. The game theoretic approach, on the other hand, tries to capture the dynamic effects of the interactions among decisions by multiple modes. A few researchers have begun to attack the problem using this approach. In either approach, the passenger mode choice model must be tightly coupled with the provider behavior model.

(4) Performance measures for connectivity: Preliminary consideration has been given to how to measure airport ground access connectivity, beginning from prior experience with urban transit systems. However, choice of the most appropriate parameters will need further study in the second year of the project.

(5) IAPT design: The IAPT has three major components– the network traffic model, which provides travel times for road vehicles; the passenger mode choice model, which generates air passenger mode use probability across the available modes and thus vehicle trips for the given airport;, and the transportation provider behavior model, which predicts the changes in the service characteristics of the available modes. Iterations between the mode choice and provider models lead to the prediction of vehicle trips and related performance parameters. The highest level of the IAPT is the performance evaluation block, which generates performance evaluation parameters to measure the connectivity of different alternatives. Those components and the underlying data base structure are linked with a GUI, which allows model users to select alternatives, enter and update relevant data, and display the outcomes for comparison in decision making. The network traffic model is adopted from MTC's 1454 zone model running in TP+. Other models will be coded in Visual Basic.

(6) Recommendations: Some recommendations have been developed for further work for improving airport ground access planning in California, including both passenger and freight movement.

Chapter 1. Introduction

This research report documents progress on developing a modeling framework for analyzing improvements in airport intermodal connectivity. It has been prepared as part of a research project undertaken for the California Department of Transportation by the Partners for Advanced Transit and Highways (PATH) titled *A Combined Quantitative and Qualitative Approach to Planning for Improved Intermodal Connectivity at California Airports*.

The objective of the project is to use a combined qualitative and quantitative approach to analyze the effectiveness of alternative strategies for improving intermodal connectivity at airports. The qualitative approach involves a case study analysis of a selection of representative airports to identify and evaluate the potential effectiveness of alternative projects to improve the connectivity between the airports and the rest of the intermodal transportation system. This will be supplemented by a more detailed quantitative analysis of selected case study airports utilizing a mathematical model, termed the Intermodal Airport Ground Access Planning Tool (IAPT), which is being developed in the course of the research. The IAPT is being designed to provide an analytical environment that integrates existing data sources and transportation network analysis software with improved models of air passenger and airport employee travel choice behavior, as well as goods transport decisions that involve airport trips, in order to evaluate the costs and benefits of proposed projects to improve intermodal connectivity at airports. Based on the results of the case study analysis, policy recommendations and planning guidelines will be developed and reviewed with Caltrans and other stakeholders. The goal of developing the IATP is to ensure a consistent approach to analyzing alternative projects and simplify the complicated modeling and computational aspects by providing decision makers and planners with a user-friendly interface to a standard set of analysis modules.

The motivation to improve intermodal connectivity at airports results from growing pressures to reduce the volume of highway traffic generated by airport access and egress trips and to facilitate the ability of airport travelers to use high-occupancy modes. Continuing growth in air travel and air freight is generating increasing volumes of surface traffic traveling to and from airports, particularly major airports. This traffic arises primarily from air passenger trips, but airport employees and air cargo movement also contribute significant volumes of traffic at large airports. These vehicle trips contribute to congestion on the regional highway network and the local street system in the vicinity of the airport, as well as adversely impact air quality through increased vehicle emissions. The goal of improved intermodal connectivity is to encourage greater use of high-occupancy transportation modes for airport trips, particularly rail modes that do not involve use of the highway system (other than for access and egress trips to the rail stations) and in many cases use electrical power, thereby potentially reducing emissions in the area served by the airport. Improving the connectivity to rail modes leverages the public investments that have been made in these modes, and to the extent that these modes are operated below capacity (as is commonly the case) makes use of excess capacity that would otherwise remain unused.

1.1 Scope of this Report

This report forms the second deliverable of the project and describes the planned structure of the IAPT and presents the technical details of the various components of the tool. It also summarizes the findings of a set of initial case studies that explored airport access issues, data availability, and potential intermodal transportation facilities at selected airports in each of six California regions, that have been documented in more detail in a previous working paper prepared as part of the research and described in more detail in the following section.

Although airport access and egress traffic is generated by air passengers, airport employees, and air cargo activities, as well as airport support functions and other ancillary activities that occur on the airport, both the initial version of the IAPT described in this report and the current research project are primarily focused on air passenger trips. It is anticipated that future enhancements to the IAPT will address airport employee and air cargo trips.

1.2 Role of Modeling in Quantitative Analysis

The objective of quantitative analysis in assessing proposed improvements in airport ground access systems, and in particular enhancements to intermodal connectivity, is to provide a basis for estimating the likely usage of proposed facilities or services, the resulting revenues and costs involved in implementing the proposed improvements, the economic impacts on other ground access services at the airport, and changes in the environmental impacts of the ground access system. These estimates are required for planning the details of the proposed improvements, assessing their feasibility, and developing the necessary environmental documentation that will be required in many cases before a project can proceed. They are also likely to be of considerable interest to both the airport operator and other ground transportation providers serving the airport due to the anticipated effect on the economics and operation of the airport and other ground transportation services.

These assessments are inherently quantitative and will generally require some form of mathematical modeling. The circumstances at each airport are sufficiently distinct that the experience at one airport is not readily transferable to another without extensive adjustments to account for the different situations. Since it is typically not obvious how to determine *a priori* what are appropriate adjustments, this is usually addressed by developing a mathematical model of the system and using this model to predict the effect of changes to the system. Such models also have the advantage that they can be designed to readily generate the large amount of situation-specific data that is required to perform related analyses, such as estimating changes in highway traffic conditions and vehicular emissions for the purpose of air quality analysis.

The central component of these analytical activities is the modeling of airport traveler mode choice behavior. The ability to predict the changes in the use of the different components of the airport ground access system in response to any given change in the system obviously depends on the ability to predict how those traveler choices will change. However, as discussed in the following section, it is also necessary to be able to model the resulting decision process of the various transportation providers as they also respond to changes in the system. The nature and extent of these choices and decisions are not usually self-evident, and an important purpose of developing formal models of how the system will respond to any given change is to help decision makers better understand these complex and interacting factors.

It is therefore important that the modeling activities are not viewed (or used) as a “black box” that produces numerical results in a way that the decision makers do not or cannot understand. A situation in which decisions are being made on the basis of the results of a model that nobody can really explain why it gave the values it did is not only unsatisfactory for the decision makers, since they do not know how much they should trust the results, but prevents any validity checking of the model itself. This is critically important in any complex situation such as an airport ground access system, where any analysis is very dependent on a large number of assumptions that are often deeply buried within the models. It is therefore essential to be able to understand how changes in the assumptions affect the results. If the results are largely insensitive to a particular assumption, then decision makers do not need to worry too much if that assumption turns out to be incorrect. However, if the results of the analysis turn out to be highly sensitive to a particular assumption, then those using these results need to satisfy themselves that the assumption is reasonable and to understand how changes in the assumption would affect the results.

1.3 Dynamic Interactions in Airport Ground Access Activities

The airport ground access system consists of a large number of different service providers in competition with each other (directly or indirectly) to meet the ground access needs of airport travelers. In turn, those travelers select their ground access travel mode on the basis of the service characteristics of the alternative services available. However, for many of these services the service characteristics are affected by their utilization. Service frequencies can be increased with more riders. Fares can be reduced if higher average load factors can be achieved. Shared-ride door-to-door services involve less circuitry picking up passengers in areas of higher trip end density. Conversely, the more operators that are attempting to serve the same market, the less traffic each will have and the harder it will be to achieve economies of density. Similarly the more airport travelers who decide to drive a private vehicle to the airport, the more congested the approach roads and terminal curbfront will become.

Therefore introducing a new or improved service will not only change the use of the other ground access services, but will result in changes in their service characteristics. Some of these changes will occur naturally due to the change in utilization while others will represent decisions by the operators to respond to the changed situation. Thus in order to properly assess the effect of a change in any one service, such as an improvement in intermodal connectivity, it is necessary to account for these dynamic feedback effects and resulting decisions by the other operators. This requires not just a way to model how airport travelers choose their access mode in the light of a given set of service characteristics, but how the transportation providers will modify their service characteristics in the light of changes in airport traveler mode choices.

For the purposes of the IAPT the critical transportation provider behaviors that need to be modeled are decisions regarding changes in service attributes that affect the modeling of air passenger mode choice. This is represented in the following diagram:

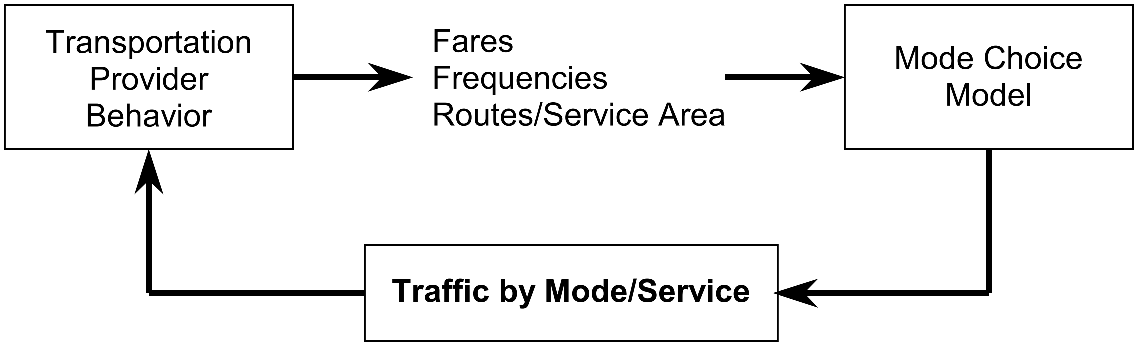


Figure 1-1: Feedback between Transportation Provider and Airport Traveler Behavior

The approach being taken to modeling the feedback process shown in Figure 1-1 forms the central focus of this report. Subsequent chapters discuss the overall modeling framework of the IAPT, the details of the mode choice model, and the approach proposed for modeling transportation provider behavior.

1.4 Capabilities and Limitations of Modeling

In spite of the essential role of formal modeling in the quantitative assessment of proposed improvements to airport ground access systems, or indeed any transportation system, it is important to also appreciate the capabilities and limitations of particular modeling approaches. In general, the more disaggregate the modeling approach, the more detailed the results can be. For example, predicting airport traveler mode choice decisions at the level of trips from individual analysis zones allows the analysis to consider resulting changes in highway traffic at the level of individual links of the regional highway network. In fact, since airport traveler mode choice decisions are influenced by individual air party or airport employee characteristics as well as the service characteristics of the different ground access modes, which necessarily differ for different trip end locations in the region, any meaningful analysis needs to be undertaken at the level of individual travel parties using a fairly disaggregate zone system.

The other level of detail that is germane to the results of airport ground access analysis is the extent to which the different ground transportation providers and services are explicitly identified in the analysis. For example, does the mode choice analysis distinguish between the different off-airport parking lots, or even between on-airport and off-airport parking? The level of aggregation at which the different transportation services are identified affects the type of question that the analysis can address, as well as how the modal service levels are expressed. While it may not matter from the perspective of the ridership on an improved intermodal connection which parking lot is used by those air parties that drive to the airport and park, it most certainly matters to the parking lot operators.

Therefore the complexity and structure of the mode choice model needs to reflect the questions that the analysis is designed to address. Since these questions may not be fully known at the time the model development is commenced, there is an understandable (and justifiable) tendency to develop mode choice models that are as detailed as the underlying data can support. However, this brings up an important constraint on the modeling process. Model development requires data on which they can be estimated. In the case of air passenger mode choice models, this includes the results of air passenger surveys that identify the ground access modes used by the travelers. If the survey questions do not identify the ground access choices at a sufficient level of detail (for example failing to ask which parking lot was used), it will be much more difficult to develop a mode choice model that can predict those choices at the level of specific services or facilities.

Another consideration that arises with airport ground access mode choice models is how to represent new services or modes that do not currently exist at the airport in question. It will obviously not be possible to include these services or modes in model choice models that are estimated directly from existing data for that airport. Where similar services exist at the airport, it may be possible to modify the model after it has been estimated to incorporate the new service based on the representation of the existing services in the model. However, where a proposed mode does not exist at all at the airport in question, determining how to modify the model to incorporate the new mode is much more challenging. This issue is discussed further later in this report.

A different type of limitation that can arise in airport ground access analysis results from the level of temporal resolution of the model. A model that is estimated on the basis of travel conditions on an average day of the year will be unlikely to do a very good job of predicting the difference in travel patterns between 5 pm on a Friday afternoon and 10 am on a Sunday morning, or between a given weekday in March and the same day in August. An analysis framework that is required to generate results that distinguish between different times of day and days of the week, or seasonal effects, will be significantly more complex and costly to develop than one that simply predicts the average use of different modes throughout the year.

1.5 Structure of this Document

The remainder of this document consists of eight chapters and two appendices. Chapter 2 contains a summary of the literature review, while Chapter 3 summarizes some of the opportunities for improving intermodal airport access in California, both based on more detailed information provided in an earlier project working paper. Chapter 4 describes the planned structure of the IAPT, including the functional design, the software structure and data flow, and the design of the graphical user interface. The following two chapters present the progress to date on developing the two key analysis components of the tool. Chapter 5 describes the air passenger mode choice modeling component of the IAPT, while Chapter 6 addresses the transportation provider behavior modeling component. These chapters describe the process being followed to develop the model components, review the relevant literature on modeling approaches, and present the results of the model development work to date. This is followed by a chapter that discusses a number of relevant issues that arise in measuring airport intermodal connectivity, including how intermodal connectivity has been addressed in more general public transit systems, the development of appropriate measures of airport intermodal connectivity, and ways to identify weaknesses in intermodal connectivity and capacity constraints in airport ground transportation systems. Chapter 8 then describes the plans for the continuing development of the IAPT in the remainder of the research. Finally, Chapter 9 presents some concluding remarks.

Supporting information is presented in two appendices. Appendix A documents the planned structure of the data tables that will form the basis of the IAPT software structure. Appendix B provides the detailed mathematical derivation of the transportation provider behavior modeling described in Chapter 6.

Chapter 2 Review of Recent Literature on Intermodal Access to Airports

The working paper *Opportunities for Improved Intermodal Connectivity at California Airports* (Lu, Gosling & Xiong, 2005) prepared as part of the research presents a review of recent literature on intermodal access to airports, including the findings of a recent study on ground access to airports in California performed for the California Department of Transportation by a consultant team led by Landrum & Brown. This review addressed airport ground access planning, intermodal transportation planning principles, quantitative and qualitative approaches in airport planning, policy and institutional issues, mode choice modeling and analysis, and airport ground access travel information. It is supported by an extensive annotated bibliography that provides abstracts and summaries of the reports and papers discussed in the review.

The literature review documented the growing interest in intermodal approaches to airport ground transportation, beginning with two workshops on ground access to airports that were organized by the Institute of Transportation Studies at the University of California at Berkeley for the Federal Aviation Administration (FAA) in 1994 that examined the role of off-airport terminals and institutional and funding issues in developing improved airport ground access services and systems (Gosling, 1994). Subsequently the FAA in association with the Federal Highway Administration (FHWA) developed a planning guide for intermodal access to airports (Shapiro, *et al.*, 1996) and then in 1998 together with the Federal Transit Administration and FHWA requested the Transit Cooperative Research Program (TCRP) to undertake a comprehensive study of strategies for improving public transport access to large airports.

The TCRP study resulted in two reports, TCRP Report 62 *Improving Public Transportation Access to Large Airports* (Leigh Fisher Associates, 2000) and TCRP Report 83 *Strategies for Improving Public Transportation Access to Large Airports* (Leigh Fisher Associates, 2002). The first report included a review of the current status of public transportation services at large airports in the United States (U.S.), including those with direct rail connections and others with only rubber-tired access systems, such as shared-ride vans and express buses, and proposed a market research approach to planning public transportation service to airports. The report also reviewed successful airport access systems in other countries and summarized lessons learned from successful rail systems. It explored new and emerging technologies for airport access, including bus rapid transit, maglev technology, and the use of automated check-in kiosks to support off-site airline check-in. Finally it examined the institutional environment and factors affecting public transportation access to large airports in the U.S. and discussed the implications of the study findings for further research.

The second report addressed the planning process for improving public transportation access to large airports. It proposed that the planning process should be based on the needs of the travelers and discussed the need to understand and document the market conditions supportive of public ground transportation services as well as the importance of demographic segmentation in market analysis. It presented strategies for improving public mode share use by airport employees and well as for improving the management of airport ground access services, and discussed issues involved in baggage handling, off-airport processing, and security considerations, as well as ways to get intermodal information to the customer. Finally, it proposed a six-step process for a market-based strategy to improve airport ground access.

At about the same time, as part of the growing interest in developing intermodal strategies to address airport ground access, the Texas Department of Transportation sponsored an extensive study on the topic that undertook a comprehensive review of the literature, identified best practices and developed case studies, and performed an assessment of alternative strategies (Mahmassani *et al.*, 2000, 2001, 2002a, 2002b) while another comprehensive study in California (Landrum & Brown, 2001) assembled information on the ground access conditions and needs at a large number of airports in the state, and examined the roles and responsibilities of different agencies.

The study for the Texas Department of Transportation undertook a survey of air travelers at three Texas airports (Dallas-Fort Worth, Austin, and George Bush Intercontinental Airport in Houston) in order to obtain a better understanding of the factors influencing the demand for different airport access modes. From the results of the surveys it was inferred that traveler preferences are influenced by their perceptions and attitudes to environmental factors as well as their individual demographic and social attributes and trip characteristics. These individual preferences then interact with the information they have about available alternatives and their prior experiences with different services to affect their decision-making and thus the demand for specific services. The researchers used a simulation approach to model the traveler response to a range of different airport access alternatives, including off-airport terminals and direct rail service to airports.

The findings of the California ground access to airports study are discussed in more detail in the working paper described above.

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) gave an impetus to addressing intermodal considerations in airport ground access planning. Lacombe (1994) suggested that inadequate ground access facilities may limit airport capacity and examined the requirements in the Clear Air Act Amendments (CAAA) and ISTEA and as they affect airport ground access planning. The paper examines the effect of institutional constraints and funding limitations that hinder intermodal approaches to improving airport ground access, and points out the necessity and opportunity for cooperation between airport authorities and urban transportation planners.

Although there has been very little consideration in the literature of the difference between the role of qualitative and quantitative analysis in airport planning, Cunningham and Gerlach (1998) examined the use of decision support systems for airport ground access planning using both quantitative and qualitative approaches. Their study undertook telephone interviews with airport and regional transportation officials to clarify issues and identify key transportation officials familiar with airport ground access planning; and conducted focus group meetings with airport ground transportation managers, local metropolitan planning organization (MPO) staff directly involved in airport ground transportation planning, and relevant staff from local transit authorities at a selected number of case study locations. They found that on the one hand, decision makers need a decision support system to provide numerical results as references for decision making while on the other hand, using quantitative modeling for strategic decision support is very difficult because (a) modelers are not confident about the accuracy of their models and transportation officials believe that the information supplied is flawed by defects in the models that reduce its value for decision making, and (b) modeling is generally believed to be very costly and difficult, while human behavior is not sufficiently understood to accurately predict how travelers make individual transportation decisions.

Cunningham and Gerlach suggested that decision makers, particularly higher level officials, tend to rely on a subjective assessment that draws on their background, beliefs, and experience. They might never use model results or cost-benefit numbers generated from models, in part because such models do not generate the type of information that they need. In practice, decision makers often base their strategic planning on their "vision" of how they think the transportation system should evolve based on their intuition and experience. In order to address this situation the authors stressed the need to improve quantitative modeling such that the models can adequately reflect passenger mode choice behavior. They also recommended a combined quantitative and qualitative approach for decision making, where the qualitative approach could involve the use of such techniques as community or airport user focus groups to identify attitudes toward airport ground access issues and likely use of proposed new services, the use of expert opinion to supplement analytical modeling, comparative analysis with airport ground access systems in other regions, and consideration of the potential implications of longer-term visions for land use development in the areas around the airport or the evolution of the regional transportation system.

The topic of airport ground access mode choice has received extensive treatment in the literature over the years, as discussed in more detail below in Chapter 3. A key aspect of air passenger choice of travel mode for airport trips is the information available to them about travel options. In the early 1990s the California Department of Transportation (Caltrans) funded a research project to examine how advanced technology might be used to improve information available to air passengers to help their airport ground access decisions (Du & Gosling, 1994). Subsequently, Caltrans funded a demonstration project at several airports in the state in which automated ground transportation information kiosks were installed in the airport terminals. As part of the demonstration program, a series of surveys were conducted of air traveler and airport user information needs and the effectiveness of the kiosks at meeting those needs (Gosling & Lau, 1995). A similar survey was undertaken a few years later at George Bush Intercontinental Airport in Houston (Burdette & Hickman, 2001) that addressed the needs of departing air passengers for flight information as well as ground access information. It focused on traditional highway travel information issues, such as traffic delays and road conditions, rather than the type of information needed to make an informed access mode choice. More recently, Lo and Szeto (2004) studied how to model traveler response to advanced travel information systems. Although their work did not directly address air passenger travel decisions, their approach may suggest ways to incorporate the role of travel information systems in airport ground access travel decisions.

2.1 The Government Accountability Office Study

Since the completion of the literature review documented in the working paper, the U.S. Government Accountability Office (GAO) has published the results of a major study on potential strategies that would redefine the Federal role in developing airport intermodal transportation capabilities (GAO, 2005). This report explores the possibility of integrating passenger air transportation with intercity passenger rail transportation in the U.S., based on the analogous experience in Europe. The "intermodal" transportation that is emphasized here is not the local transit access to and from the airport that our project is addressing, but rather the possibility of Amtrak intercity rail linkages for air travelers. In the course of the study, however, this report provided useful background information about both current and planned local transit intermodal linkages to airports in the U.S.

Major airports in Europe (Frankfurt, Paris, Brussels, Amsterdam) are increasingly well integrated with the European high-speed intercity rail network, with rail stations built adjacent to or beneath the airport terminals. This has made it possible for airlines to offer code-share arrangements with the railroads for passengers traveling to and from smaller nearby cities, and has led to the reduction of short-haul flights at these airports. National governments have encouraged these trends by providing financing for the construction of the new rail lines and stations at airports.

The GAO report notes that the European experience is not readily transferable to the U.S. for a variety of reasons:

- The Amtrak passenger rail network is not nearly as well developed nor heavily used as its European counterparts. It does not provide the breadth or frequency of service to make it an attractive alternative for passengers or a code-share partner for airlines (which would require a service frequency of at least one train per hour).
- The trip ends for travelers to and from U.S. airports are not nearly as focused on the urban core locations that could be served effectively by rail as in Europe.
- U.S. airports are disinclined to encourage new access modes that could lead to a reduction in on-airport parking, which is an important revenue source for them.

- Space and cost constraints make it difficult to build large new facilities at major airports in the U.S.
- Cars remain more convenient and economical for airport access than other modes in the U.S., in contrast to the situation in Europe.

The report suggests a couple of potential policy alternatives to the federal government:

(1) providing more flexibility and alternative funding concepts to enable state and local agencies to take a more system-wide approach to providing intermodal access to airports, without any more direct federal role;

(2) increasing the federal role in planning and funding to proactively promote integration of air transportation with intercity rail and bus services. This latter strategy was dismissed because of its expected high costs relative to its benefits, especially based on expected low levels of demand in most places.

The report includes much useful background information on the current state of ground access to airports in the U.S. and the federal programs that could fund airport access projects. This was based on a survey of 72 airports (including the 68 largest ones, all large and medium hubs, accounting for 90% of U.S. enplanements in CY03) and case studies of 16 airports (including LAX, SFO, OAK and SJC). These case studies each include a table summarizing the local officials' assessments of the primary benefits and barriers to intermodal access facilities at their airports, up to one page of text describing their existing intermodal access facilities and identifying the key local stakeholder organizations and their roles, and a one-page schematic diagram showing the locations of the access points to the intermodal facilities relative to the airport terminal and parking lots.

Of the 72 airports that were surveyed:

- 64 had access by local buses
- 27 had access by local rail transit (all but one of which also had local bus access)
    - 13 of these could be accessed by automated people movers or walking
    - 22 of these could be accessed by shuttle buses

- 19 were connected to nationwide intercity bus or rail services
    - 13 were connected to Amtrak (only Newark had a direct people mover)
    - 12 were connected to intercity bus services.

The California airports that were identified as having local rail access included Burbank, LAX, OAK, SJC, and SFO. Among the airports that do not currently have local rail transit access, there are plans for adding rail transit access at ten: Cincinnati, Denver, Houston Intercontinental and Hobby, Jacksonville, Memphis, Phoenix, Salt Lake City, Seattle-Tacoma, and Tampa.

The Newark Airport example was particularly interesting because of the direct access to Amtrak's highest-density Northeast Corridor services. This led to the creation of some code sharing arrangements with Continental Airlines, some reduction of short-haul flights to and from Philadelphia, and significant usage of the Amtrak station at the airport by travelers from Philadelphia and Washington DC. The costs of the people movers used for airport connections were cited for Newark's low-speed, low-capacity, short-distance link ($357 million) and JFK's faster, higher-capacity and somewhat longer link ($1326 million).

Both federal and state/local funding sources that have been used to pay for intermodal access projects are identified in the report:

<u>Federal</u>

- FTA New Starts program for major fixed-guideway systems [competition at national level to get on the approved list of New Starts]
- FHWA Surface Transportation Program (STP) and Congestion Mitigation and Air Quality (CMAQ) Program [competition at state and local levels to get allocations from these formula grant programs]
- FAA Airport Improvement Program, for projects at airports with commercial air service and at least 10,000 annual enplanements
- Specific Congressional earmark projects
- Transportation Infrastructure Finance and Innovation Act (TIFIA) credit assistance for development of revenue-producing facilities that will be able to repay the TIFIA loans

State and local

- allocations from Highway Trust Fund
- local tax revenues, including regional sales taxes allocated for transportation improvements
- revenues from toll facilities (Port Authority of New York and New Jersey)
- local transportation improvement districts making special assessments
- state credit assistance programs analogous to TIFIA
- Passenger Facility Charges (PFCs) for projects on and owned by the airport, subject to FAA approval
- General airport revenues
- General airport revenue bonds (only for on-airport facilities)

Chapter 3 Opportunities for Improved Intermodal Connectivity at California Airports

Research undertaken during the first year of the project has identified opportunities for improving intermodal connectivity at California airports and performed a preliminary analysis of a sample of representative projects at selected airports. The results of this analysis are documented in the working paper *Opportunities for Improved Intermodal Connectivity at California Airports* (Lu, Gosling & Xiong, 2005). This section summarizes the findings of the case studies presented in the working paper that examined a range of strategies to improve intermodal connectivity at airports, including the provision of direct rail service to the airport, the creation of improved links to nearby rail stations, and the development of express bus services to off-airport terminals or regional intermodal terminals. More detailed analysis of the case studies will be undertaken in the next stage of the research using two approaches: a simplified spreadsheet model and the IAPT. This analysis will assess the likely ridership levels and economic feasibility of the different strategies, and provide a quantitative basis for considering the effect of airport traffic levels and other factors that are likely to influence the viability of potential projects.

3.1 Potential Strategies to Enhance Intermodal Connectivity

The working paper identifies three principal strategies to improve intermodal connectivity at airports:

- Direct rail service to the airport
- Improved links to nearby rail stations
- Express bus service to off-airport terminals or regional intermodal terminals.

Although direct rail service to an airport station has been proposed or implemented at an increasing number of large airports worldwide, it is typically a very expensive solution. Except in rare cases where an existing rail line runs within close proximity to an airport terminal, the engineering required to bring a rail line into a station in the airport terminal complex requires substantial capital investment. In the case of a dedicated airport line, the operating costs of maintaining an adequate train frequency must also be considered. While such an approach may be justified at the very largest airports, in general this is not an appropriate strategy for most airports.

Improving links to nearby rail stations is generally a much less expensive strategy and more appropriate for smaller airports. These links may take the form of a dedicated shuttle bus service or an automated people-mover. The later may provide a higher level of service to the user, and eliminates the vehicle trips associated with a shuttle bus service, but is generally more expensive to construct and operate. The attractiveness of such links will depend on the frequency of service of both the link itself and the rail service to which it connects, as well as the fares charged for the use of the link and by the rail service. While there is no need to operate the link at a higher frequency than the rail service that it serves, it is important for less frequent rail services that the connecting link schedule be coordinated with the rail service schedule, so that the users do not incur a long wait twice.

The provision of express bus services to off-airport terminals located some distance from the airport provides another strategy to reduce the volume of vehicle trips to and from the airport. Such off-airport terminals typically provide parking at lower rates than at the airport, as well as waiting facilities for bus passengers or those waiting to pick up bus passengers. Larger facilities may also provide ancillary services, such as a newsstand or food and beverage, and some have provided airline ticketing or check-in. While the ability to check baggage at a remote location has often been proposed as a feature of off-airport terminals, it is unclear whether this is a significant factor in the attraction of such a facility and justifies the logistical complexities involved. The principal advantages of an off-airport terminal to the users are the reduction in the driving time and distance compared to driving to and from the airport, particularly for passengers being dropped off or picked up, as well as any saving in parking costs or taxi fares for those using taxi to get to or from the off-airport terminal, compared to taking a taxi all the way to or from the airport. Locating an off-airport terminal at a major transit hub also allows airport travelers to use transit to get to and from the terminal, which is likely to provide better service than taking transit all the way to or from the airport. Similarly, providing express bus links between the airport and regional intermodal terminals, such as central rail stations or transit hubs, can allow airport travelers to utilize the better rail or transit service at those locations to travel to and from their ultimate trip end, while increasing the ease of travel between the airport and those facilities.

3.1.1 Examples of Existing Services

Services representing each of the foregoing strategies currently have been implemented at various California airports.

The extension of the Bay Area Rapid Transit (BART) system to San Francisco International Airport (SFO) that opened in June 2003 provides direct rail service to the second largest airport in the state. The BART system provides an extensive and frequent region-wide network with 43 stations serving Alameda, Contra Costa, San Francisco, and northern San Mateo counties. In addition, the Millbrae BART station provides an interchange with the Caltrain rail line that serves the Bayshore corridor of eastern San Mateo County and northern Santa Clara County.

There is also direct rail service at Burbank/Bob Hope Airport, where the Burbank Airport Station is located adjacent to the airport within an easy walk of the airport terminal. Even though it is a very short walk between the train station and the airport terminal, there is (apparently) shuttle bus service between the two locations. There is a direct-line telephone at the train station one can use to call for a shuttle, and there are shuttle buses that serve the terminal's bus stops that go to the train station. This station is served by both Metrolink and Amtrak trains that provide service between Los Angeles Union Station and communities in the San Fernando Valley and along the coast in Ventura and Santa Barbara counties. However, trains are relatively infrequent outside of weekday commute hours (Metrolink is primarily a commuter rail service) and to and from points north of Moorpark in the San Fernando Valley.

Several California airports have dedicated shuttle bus service to nearby stations. At Los Angeles International Airport (LAX) there is a shuttle bus operated by Los Angeles World Airports to the nearby Green Line Metro station. In the Bay Area, the AirBART bus operated by the Port of Oakland. The Oakland Coliseum Amtrak station serves the Capitol Corridor route between San Jose and Sacramento. However, AirBART bus does NOT directly serve the Amtrak station. An Amtrak passenger has to walk to or from the AirBART bus stop adjacent to the BART Coliseum station. At San José International Airport (SJC) the Route 10 Airport Flyer bus operated by the Santa Clara Valley Transportation Authority (VTA) connects the airport terminals with the Metro/Airport station on the Alum Rock-Santa Teresa Light Rail line and the Santa Clara Caltrain station. The Port of Oakland and BART are currently pursuing a joint project to construct an automated people-mover to link OAK to the Coliseum BART and Amtrak stations and San José International Airport is pursuing an automated people-mover link between the airport and the VTA light rail line, with a possible future extension to the Caltrain line.

Two California airports currently have express bus service to off-airport terminals. The Los Angeles World Airports (LAWA) operates the Van Nuys FlyAway service between LAX and an off-airport terminal adjacent to the Van Nuys airport in the San Fernando Valley. It is noted that The San Fernando Valley Orange Line you mention is now complete and in service. This terminal provides long-term parking and waiting facilities. LAWA has recently modernized the terminal building and provided additional parking in an adjacent structure. In the past, a number of airlines maintained ticket offices at the terminal, although there was no provision for baggage check-in. In the Bay Area, Marin Airporter operates a scheduled bus service between SFO and two off-airport terminals in Marin County, at Larkspur and Ignacio near Novato (North Hamilton Parkway). Both terminals provide long-term parking and waiting facilities.

Scheduled airport bus service is also available to regional transit centers at a number of airports. Marin Airporter buses to and from the Hamilton terminal stop at the Central San Rafael Transit Center, as do Sonoma Airport Express buses serving both SFO and OAK. In Southern California, Airport Bus of Anaheim provides scheduled bus service between the Anaheim Bus Terminal and LAX and John Wayne Orange County Airport.

3.2 Intermodal Opportunities at Selected California Airports

The working paper identifies a number of opportunities to improve intermodal connectivity at thirteen California airports, including some that had been previously identified in the *Ground Access to Airports Study* performed for the California Department of Transportation (Landrum & Brown, 2001), and also presents a preliminary qualitative assessment of their feasibility. In those cases where the intermodal opportunities have already been subject to more detailed quantitative analysis as part of other studies, the results of this analysis are discussed in the working paper.

3.2.1 Southern California

Burbank Airport is currently served by a station that provides access to Metrolink and Amtrak trains, although these are relatively infrequent, as noted above. The Red Line of the Los Angeles Metro terminates at North Hollywood station, about 4 miles to the southeast of the airport. An extension of the system beyond North Hollywood to Van Nuys, Reseda and Chatsworth in the San Fernando Valley, termed the Orange Line, is under construction. A shuttle bus link could be provided to the North Hollywood station, which provides frequent service to downtown Los Angeles seven days a week and connections to other Metro lines that provide service to large parts of the Los Angeles basin. At present, the majority of Burbank air passengers come from the San Fernando Valley to the west of the airport or communities in the San Gabriel Valley to the east of the airport. A link to the North Hollywood station would serve communities between North Hollywood and downtown Los Angeles served by the Red Line as well as communities in the San Fernando Valley served by the Orange Line when it opens. Travelers to Burbank Airport from communities in the San Gabriel Valley would need to take the Gold Line into downtown Los Angeles to connect to the Red Line in order to use Metro Rail. Since there are fairly direct freeway links between the San Gabriel Valley and Burbank Airport, it can be expected that relatively few airport travelers from the San Gabriel Valley would find this an attractive way to reach the airport. However, the Red and Orange Lines will still serve a significant share of the Burbank Airport market.

John Wayne Orange County Airport currently has no dedicated link to any regional rail system. However a shuttle bus link between the airport and the Tustin Metrolink and Amtrak station about 4 miles to the northeast of the airport would provide access to trains serving communities between downtown Los Angeles and San Diego, as well as the Metrolink Inland Empire-Orange County line serving communities in Riverside County and connections to other Metrolink and Los Angeles Metro lines that provide service to large parts of the Los Angeles basin. However, relatively few air travelers using John Wayne Airport have trip ends outside Orange County due to the more extensive air service available at Los Angeles International Airport to the northwest and Ontario International Airport to the north. It is therefore unlikely that improved intermodal connections at John Wayne Airport would attract significant numbers of air passengers to the airport from other airports in the region. While the communities served by the Metrolink Orange County Line account for about 60 percent of the Orange County residents using John Wayne Airport, for many of these trips the time involved in accessing the nearest station, riding the train, and then riding the shuttle bus to the airport would be significantly longer than driving to the airport. In particular, most trip origins in Irvine, which account for about 12 percent of the total, are closer to the airport than to the Irvine station.

Therefore it is likely that the percent of air passengers who would use such a service would be quite small. However, it may attract a number of airport employees who are more likely to be familiar with the train schedules. since they make the trip on a regular basis.

Long Beach Airport currently has no dedicated link to any regional rail system. However the Blue Line of the Los Angeles Metro Rail system runs about a mile and a half to the west of the airport and connects downtown Long Beach with downtown Los Angeles. A bus link to the Willow station on the Blue Line would provide access to communities between Long Beach and downtown Los Angeles, as well as connections to other Metro lines that provide service to large parts of the Los Angeles basin. The airport has recently experienced a significant growth in traffic as a result of the introduction of air service by jetBlue Airways and other airlines serving the airport. In consequence, it is likely that the airport is now drawing air passengers from a wider area in the Southern California region. This suggests that an improved connection to the regional rail system might attract some of these air passengers. Also, since the air service at the airport is primarily targeting low-fare travelers, it is likely that many of those air passengers would be attracted to an improved transit connection. At present local bus service between the airport and stations on the Blue Line is relatively infrequent, particularly at weekends, and rather circuitous. A shuttle bus link to the Blue Line Willow station would take about 10 minutes in each direction, so it would be possible to provide service every 30 minutes with only one vehicle per shift. A less expensive way to provide equivalent service would be to modify the route of the Long Beach Transit Route 102 bus, which currently provides half-hourly service on weekdays with stops at the Willow station and on Spring Street on the southern boundary of the airport, but does not serve the terminal, to include the airport terminal in the route and add evening and weekend service. This might attract sufficient additional riders to be attractive to the transit operator without any subsidy from the airport.

The California *Ground Access to Airports Study* identified four potential intermodal connectivity projects at Los Angeles International Airport (LAX): expansion of the current Van Nuys FlyAway bus terminal in the San Fernando Valley; development of new FlyAway terminals elsewhere in the region; an extension of the Metro Green Line to the Airport; and an airport people-mover link to the Green Line. The expansion of the Van Nuys FlyAway bus terminal was initiated by LAWA and completed in summer 2005. The Metro Green Line currently extends past LAX to a terminus in Redondo Beach, with a station (Aviation/LAX) adjacent to the airport and served by a free shuttle bus connection operated by LAWA. The LAX master plan update that is currently in progress envisages a major reconfiguration of the airport terminal area, with an automated people-mover link to an intermodal facility located at the Aviation/LAX station. Therefore additional FlyAway terminals at new locations in the region would appear to be the only intermodal connectivity project identified in the study that remains to be addressed. In 2001 LAWA commissioned a market analysis of a number of potential sites for new FlyAway facilities in the region (Leigh Fisher Associates, 2001). The analysis examined alternative sites in four corridors, as well as the feasibility of a terminal located at Union Station in downtown Los Angeles, and developed estimates of average daily ridership from each site for the peak month (August) in 2000, 2005 and 2010. The sites were then compared using a scoring system and the preferred site identified in each corridor.

Ontario International Airport currently has no dedicated link to any regional rail system. However the Metrolink San Bernardino Line runs about 2 miles to the north of the airport, while the Metrolink Riverside County Line runs about one mile to the south of the airport. A shuttle bus link serving the Rancho Cucamonga station on the San Bernardino Line and the East Ontario station on the Riverside Line would provide access to Inland Empire communities served by both lines, as well as connections to other Metrolink and Los Angeles Metro lines that provide service to large parts of the Los Angeles basin. In 2004 Ontario International Airport handled about 6.9 million air passengers. According to an air passenger survey performed for LAWA in 2001 about 56 percent of air passengers were residents of the region. If 10 percent of resident air passengers in zones served by Metrolink and 5 percent of visitors were to use the trains to access the airport, this would translate into an average ridership of about 500 air passengers per day using the shuttle bus service between the Metrolink stations and the airport. Assuming the shuttle buses operate on a 30 minute headway from 5:00 am to 10:00 pm, this would require about 35 round trips per day, with an average ridership of 7 passengers per trip in each direction, plus any airport employees who would be attracted to the service.

3.2.2 San Francisco Bay Area

A proposed project to develop an automated people-mover link between Oakland International Airport and the Coliseum BART station is being developed as a collaborative partnership between BART, the Alameda County Transportation Improvement Authority, the Alameda County Congestion Management Agency, the California Transportation Commission, the California Department of Transportation, the City of Oakland, and the Port of Oakland. The BART Board of Directors certified the Final Environmental Impact Report on March 28, 2002. A contact award was expected in 2006 with revenue operation commencing in late 2010. The connector will be about 3.2 miles long and as currently planned will follow the Hegenberger Road corridor, with two intermediate stations, one at Edgewater Road between the Interstate 880 freeway and the airport and one at Doolittle Drive on the northeast boundary of the airport. The total project budget is reported as approximately $232 million in 2001 dollars.

The California *Ground Access to Airports Study* identified two intermodal connection opportunities at San Francisco International Airport: improved regional access from the south and east; and an airport ferry service dock. The opening of the airport BART station with the connection to the Caltrain line at the Millbrae BART station now provides good rail connections to the south, while BART itself provides extensive coverage of the East Bay. There are currently efforts underway to expand ferry service on the Bay, and if a ferry route were to be established from the Ferry Terminal in downtown San Francisco to Peninsula communities to the south of the airport, these ferries could stop at a dock at the airport. This would require a shuttle bus connection to the airport terminals. The ridership potential of such a service is very dependent on the exact nature of the ferry service.

Currently, there exists a shuttle bus service (Airport Flyer) between the San Jose Airport and the Metro/Airport Light Rail station. A proposed project to develop an automated people-mover link between San Jose International Airport and the nearby Valley Transit Authority (VTA) light rail system has been fairly well defined (Lea+Elliott, 1999), ridership estimates have been prepared (Dowling Associates, 2002), and environmental documentation completed (San Jose International Airport, 2003). The project involves an elevated automated people-mover link 0.6 miles in length between the airport terminal complex and a VTA light rail station on North First Street. The project has been estimated to cost $110 million to construct and $1.5 million per year to operate. Average daily ridership in 2010 has been projected at about 2,500, or about 4.3 percent of total air passenger and employee airport trips.

3.2.3 San Diego

The Blue Line of the San Diego Trolley light rail system runs to the north of the airport and links Mission Valley and the Old Town Transit Center to the north of the airport with downtown and communities to the south of downtown, as well as connecting in downtown with the Orange Line serving communities to the east. There is currently no dedicated shuttle bus service between the airport and the Trolley stations on the north side of the airport, although the MTA transit bus Flyer Route 992 provides frequent service between the airport and downtown, including stops at the Amtrak Station and Blue Line and Orange Line Trolley stops. However, Trolley riders on the Blue Line traveling from stops to the north of the airport have to travel past the airport to the downtown in order to connect to the Route 992 bus to reach the airport. Potential connectivity enhancements include a dedicated shuttle between the airport terminals and the Blue Line Middletown station adjacent to the airport.

3.2.4 Sacramento

The California *Ground Access to Airports Study* identified the possibility of a remote terminal with light rail access to the airport as a potential intermodal connection opportunity. The area immediately to the east of the airport is currently being developed as a business park, termed the Metro AirPark, with residential development planned in the area further east of the airport and north of the existing urban boundary of Sacramento. As part of this development, it is envisaged that the Sacramento light rail transit system will be extended to the Metro AirPark and the airport. Presumably the objective of an off-airport terminal serving the airport via the light rail connection would be to provide remote parking closer to the trip ends of air passengers. The off-airport terminal could also provide airline check-in, although this has always been difficult to implement and keep in service, since the airlines are reluctant to bear the staffing costs involved. However, the geography of the region makes selecting a suitable location for a remote terminal difficult. Interstate 80 passes to the north of Sacramento, crossing the Sacramento River about 12 miles to the southeast of the airport. While locating an off-airport terminal in the vicinity of the junction of Interstate 80 and Interstate 5, which provides the access to the airport, would ensure the largest proportion of air passengers who could conveniently access the terminal, this location may be too close to the airport to attract many users. The travel time on the light rail service from this location would be significantly longer than continuing on to the airport. Locating the terminal closer to central Sacramento would mean that many air passengers would have to travel away from the airport in order to reach it. On the other hand, locating a terminal to the east or south of the city, while being more convenient to access by air passengers with trip ends in those areas, would require users to ride the light rail through downtown Sacramento, which would significantly increase the journey time.

3.2.5 Central Valley

Bakersfield Airport is located about 4 miles to the north of the Amtrak station in downtown Bakersfield. The airport is currently served by the Golden Empire Transit District Route 3 bus, which runs between the airport and the downtown transit center. Hourly service is provided from Monday to Saturday between about 7 am and 6:30 pm. Travel time is approximately 30 minutes. In order to get to and from the Bakersfield Amtrak station, it is necessary to transfer at the downtown transit center to Route 5, which provides a 20 minute service headway on weekdays and a 30 minute service headway on weekends. Rather than run a separate shuttle bus, it would be more cost effective to extend the route of Route 3 beyond the transit center to terminate at the Amtrak station. It would also be desirable to increase the service frequency to 30 minutes, and add evening and weekend service. While it is unlikely that the airport traffic alone would justify the full costs of the additional runs, increasing the service frequency would also most likely increase ridership by other users of the route.

Fresno Yosemite International Airport is located about 4 miles to the northeast of the Amtrak station in downtown Fresno. The airport is currently served by the Fresno Area Express transit system Route 26 bus, which runs between the airport and the downtown transit center. It does not however pass the Fresno Amtrak station. Half-hourly service is provided on weekdays from about 6 am to about 10 pm and hourly service is provided on weekends from about 8 am to about 7 pm. Travel time is approximately 30 minutes. In order to travel to the Fresno Amtrak station, it is necessary to transfer to the Route 22 bus at the downtown transit center. This also operates at 30 minute intervals on weekdays and at 50 minute intervals at weekends. Waiting times for the transfer at the transit center vary between about 5 minutes and 15 minutes. Intermodal connection between the airport and the Amtrak station would be greatly enhanced by changing the route of bus Route 26 to reach the downtown transit center via First Street and the Amtrak station on Tulare Street. While this would eliminate service to a small area that is currently served by Route 26, this could be resolved with a minor readjustment to one of the other routes in the area. It would also be desirable to extend the weekend service hours to provide evening service and to increase the weekend service frequency to every half hour.

3.2.6 Central Coast

Santa Barbara Municipal Airport is located about 6 miles to the west of the Amtrak station in downtown Santa Barbara. There is currently no dedicated link between the airport and the station, which provides access to Central Coast communities via the Amtrak Pacific Surfliner and long distance trains. There is also an Amtrak station in Goleta, immediately adjacent to the airport. The airport is currently served by the Santa Barbara Metropolitan Transit District (MTD) Route 11 bus, which links the campus of the University of California Santa Barbara (UCSB) with the downtown transit center on State Street. Service is provided every 30 minutes from about 6 am to about 11:30 pm on weekdays, from about 6:30 am to about 10:30 pm on Saturdays, and from about 7 am to about 10 pm on Sundays. To reach the Santa Barbara Amtrak station, it is necessary to transfer to another route at the downtown transit center. Although the Goleta Amtrak station is immediately north of the airport, there is no bus service to the station itself although two bus routes pass within about 200 yards. Intermodal connection between the airport and the Santa Barbara Amtrak station could be enhanced by extending the route of bus Route 11 down State Street beyond the transit center to terminate at the Amtrak station. Connection between the airport and the Goleta Amtrak station could be enhanced by modifying the Route 11 slightly to stop at the station when leaving the airport for downtown or before arriving at the airport from downtown. Since only a few Amtrak trains stop at the Goleta station each day, it would only be necessary for some runs of Route 11 to make this detour. As a side benefit, this would also provide a bus connection between the Goleta Amtrak station and the UCSB campus.

3.3 Further Analysis of Potential Intermodal Opportunities

In order to expand the preliminary assessment of the feasibility of the potential intermodal opportunities described in the previous section, a more quantitative analysis will be undertaken in the next stage of the research using two approaches: a simplified spreadsheet model and the Intermodal Airport Ground Access Planning Tool. The objective of the spreadsheet analysis is to obtain an approximate estimate of the likely use of the proposed intermodal connectivity enhancement as well as an estimate of associated revenues and costs. Revenue estimates will be derived from the assumed fares and ridership estimates, while cost estimates will be derived from capital and operating cost experience for similar projects that have been implemented at other airports. The IAPT will provide a more detailed analysis capability that will account not only for the use of improved intermodal connections, but also the effect of any particular improvement on the operation and performance of the rest of the airport ground access system.

It is envisaged that the spreadsheet model will be used to perform a screening analysis of a range of intermodal connectivity opportunities identified in the course of the research, while the IAPT will be used for more detailed analysis of a few selected projects.

3.3.1 Spreadsheet Model

The planned spreadsheet model combines a trip generation model and a mode choice model in order to estimate the annual number of air passengers using a proposed intermodal connection. Estimating the use of any proposed intermodal access improvement requires a fairly disaggregate mode choice analysis, since the potential use will depend on the trip origins of air travelers using the airport, the distribution of air party characteristics, and the other airport ground access options available at the airport. Since many of the airports for which the analysis is required may not have recent (or any) air passenger survey information available, the spreadsheet model uses a trip generation model to estimate the number of trips that originate in each analysis zone in the region served by the airport. While any reasonably detailed zone system could be used, the data requirements will be simplified by adopting a zonal system based on postal zip codes, rather than the more detailed traffic analysis zones used by regional planning agencies. This level of resolution is adequate for the type of preliminary analysis that the spreadsheet model is intended to perform and provides a standard approach that can be easily applied in different regions. Population and income data are readily available at the zip code level, and air passenger survey responses often give trip origin information in terms of zip codes. Highway distances and travel times from each zip code to an airport can be obtained from web-based trip planning services (*e.g.* maps.yahoo.com).

The number of air passenger trips that originate in a given zip code depends on the demographics and other characteristics of the zone, such as the population and number of hotels or businesses. For those airports where reasonably detailed air passenger survey data is available, the composition of air party characteristics and the distribution of air passenger origins can be estimated from the survey data. In the case of airports for which air passenger survey data is not available, it will be necessary to develop estimates of both the air party characteristics and the distribution of trip origins. For the purpose of the spreadsheet model, air travelers can be classified into five groups:

- Residents of the area making a business trip
- Residents of the area making a non-business trip
- Visitors to the area making a business trip
- Visitors to the area making a non-business trip and staying in a hotel
- Visitors to the area making a non-business trip and staying with residents.

Residents of the area are assumed to begin their trip to the airport from their home. While in practice a small proportion begin their trip from their place of work or other location, their ground access mode choice decisions are likely to be influenced by similar factors in both cases. Visitors on business trips are assumed to stay in a hotel and begin their ground access trip to the airport from their hotel. In practice, some business visitors may begin their ground access trip from the business location that they are visiting, depending on the time of day of their flight. However, to the extent that they are likely to stay in a hotel near the business they are visiting, assuming that their ground access trip begins from their hotel will not introduce a significant bias in the assumed trip end distribution or ground access mode use. It is further assumed that the trip origins of visitors staying in hotels are distributed according to the distribution of hotel rooms, while the trip origins of visitors staying with residents of the area are distributed according to the distribution of trip origins of resident non-business trips.

For the purposes of the planned spreadsheet model, a simplified trip generation model will be developed using data from an air passenger survey performed at Orange County John Wayne Airport in July 2000 (Applied Management & Planning Group, 2000). Although more extensive surveys have been performed at other airports, it is felt that the pattern of trip generation at John Wayne Airport would be more representative of smaller airports for which air passenger survey data are not available.

A number of airport ground access mode choice models have been reported in the literature over the years, as discussed in Chapter 3 below. However, they vary widely in functional form, the airports for which they have been developed, and the dataset from which they have been estimated and thus the values of the estimated model coefficients are not directly comparable. Furthermore, it is generally accepted that such models are not easily transferable to different airports. Nevertheless, in the absence of a mode choice model specifically developed for a particular airport, there may be no choice other than to utilize a model developed for a different airport.

A recent airport ground access mode choice model has been developed for the San Jose International Airport by Dowling Associates (2002) using data from a 1995 air passenger survey performed for the Metropolitan Transportation Commission. Separate model coefficients were estimated for four types of air passenger trip: resident business trips, resident personal trips, visitor business trips, and visitor personal trips. Since the model was specifically developed to estimate the future ridership on the proposed automated people-mover to connect the airport to the Santa Clara Valley light rail system, the model has separate coefficients for travel times using rail and bus transit, and separate mode-specific constants for transit access using the people-mover and transit access without using the people-mover. This makes it appear particularly appropriate for estimating the use of improved intermodal connections at other airports, although it is unknown how well the model coefficients estimated for ground access trips to San Jose International Airport will explain air traveler behavior at those airports. However, an assessment of the likely accuracy of the model predictions can be made by comparing the use of other modes predicted by the model with data on the actual use of those modes, either from air passenger surveys (where they exist) or airport operational statistics such as the use of airport parking lots.

The general structure of the spreadsheet model will consist of a number of separate worksheets, some of which are common to each application of the model and some of which have to be developed for each airport for which the model is applied. In general, those data that vary by zip code require a specific table to be developed for each application, since obviously the zip codes representing the area served by the airport will be different in each case. Since the model choice model also estimates the use of other modes in the course of estimating the use of the intermodal connection, the use of each of these modes is also presented in the output of the model to assist in assessing the reasonableness of the mode use estimates.

3.3.2 Intermodal Airport Ground Access Planning Tool

The IAPT is a more sophisticated analysis tool that is designed to perform a similar function as the spreadsheet model, but at a much greater level of detail and accounting for additional considerations that are ignored in the spreadsheet model. The most significant of these is the explicit inclusion in the modeling framework of transportation provider service decisions. In addition, the IAPT provides a mechanism to define a range of measures of system performance, including vehicle emissions, and determine the effect on these measures of performance of introducing new services or modes, or changing the service characteristics of existing modes. Unlike the spreadsheet model, which is designed to be readily configured to analyze ground access system changes at a wide range of different airports, use of the IAPT to model different airports will require fairly extensive customization. In addition to distance and travel time data for the regional highway and transit system and detailed service data for the ground access modes serving the airport, the IAPT will require disaggregate air passenger survey data and the development or availability of a ground access mode choice model for the airport.

Chapter 4. Structure of the Intermodal Access Planning Tool

The chapter describes the planned structure of the Intermodal Access Planning Tool (IAPT), including the supporting data requirements and the design of the user interface.

There are several elements that must be considered in planning for intermodal transportation: decision makers (at different levels), users of the system (air passengers, air cargo shippers and airport employees), transportation providers and operating agencies, and the relevant surface transportation networks. The relationships among these four elements is shown in Figure 4-1, together with potential modeling assumptions regarding the decisions being made by the various parties in the process. The structure of the IAPT has been designed to provide an analytical framework that will represent these elements and their relationships.

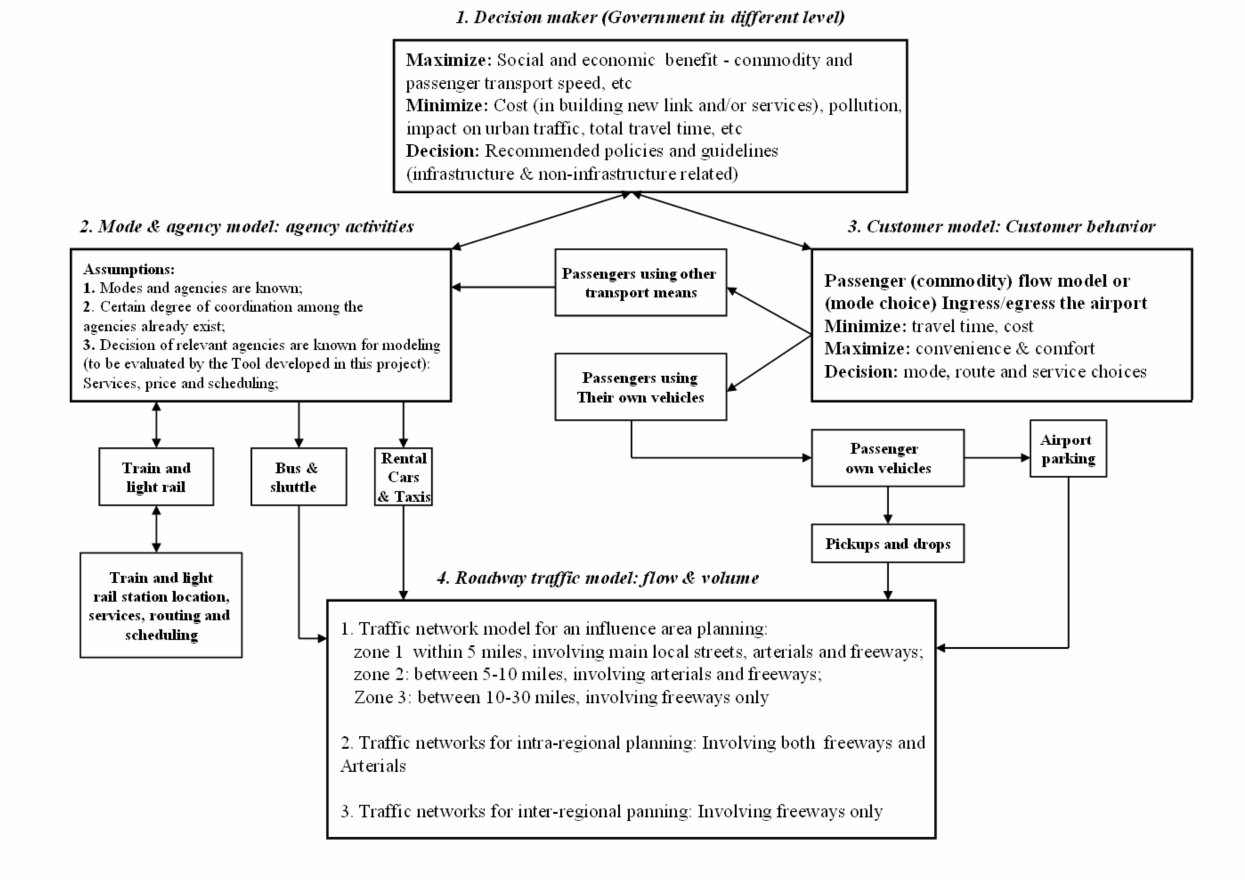


Figure 4-1: Conceptual Modeling Approach

The two primary analytical components of the modeling framework shown in Figure 4-1 address the mode choice behavior of airport travelers and the decision-making behavior of transportation providers. These components are described in more detail in the following two chapters. The remainder of this chapter describes the overall approach to be followed in the design of the IAPT.

4.1 Functional Design

The initial implementation of the IAPT is being developed to model air passenger ground access trips and to analyze the impact on ground access travel patterns of the introduction of a new mode or service or a change in the service characteristics of an existing mode. Because users may wish to compare the effects of several different alternatives, such as varying the technology used for a new access link or varying the fare charged, the IAPT will provide the capability to define a set of ***project alternatives*** and estimate the effect on ground access travel patterns of each of these alternatives compared to a ***baseline alternative***. Typically the baseline alternative will be the current system. The definition of a given project alternative comprises a complete description of the ground access system, including all available ground access services and their associated service characteristics (fares, frequencies, travel times, *etc.*).

Since the use of the different ground access services (or modes) for a given project alternative will depend on the total level of originating air passenger traffic at the airport, it will generally be necessary to analyze the system at different levels of air passenger traffic, corresponding to estimated future growth of traffic at the airport. Thus the IAPT will allow the user to define a set of ***analysis scenarios*** consisting of a given project alternative and a given level of air passenger traffic. In principle there is no limit to the number of analysis scenarios that may need to be analyzed. For a given analysis scenario the IAPT will estimate the number of air parties using each ground access service, use these estimates to compute other measures of system performance, such as fare revenue or vehicle trips, and display, print or save this information in a format that can be used by other programs.

4.1.1 Analysis Functionality

In order to estimate the number of air parties using each ground access service for any analysis scenario, the IAPT applies an air passenger ground access mode choice model to a representative sample of air party trips using the appropriate service characteristics for each ground access service. This requires two other analytical components: a process to generate the representative sample of air party trips for the given level of air passenger traffic and a way to determine the service characteristics for each ground access service. For the initial implementation of the IAPT the representative sample of air party trips is provided as an input file, rather than being generated within the tool. Typically this file will be obtained from the results of an air passenger survey at the airport in question. Any adjustments needed to correspond to the level of air passenger traffic in the analysis scenario will have to be done externally to the IAPT analysis.

As discussed in Chapter 1, the appropriate values of the service characteristics for each ground access service will depend on the response of the transportation providers to the changes in the use of the various ground access modes. This is explicitly modeled in the IAPT through a feedback loop between the mode choice model and the transportation provider behavior model, illustrated in Figure 4-2. The figure also shows the relationship between this analysis cycle and the other components of the analysis.

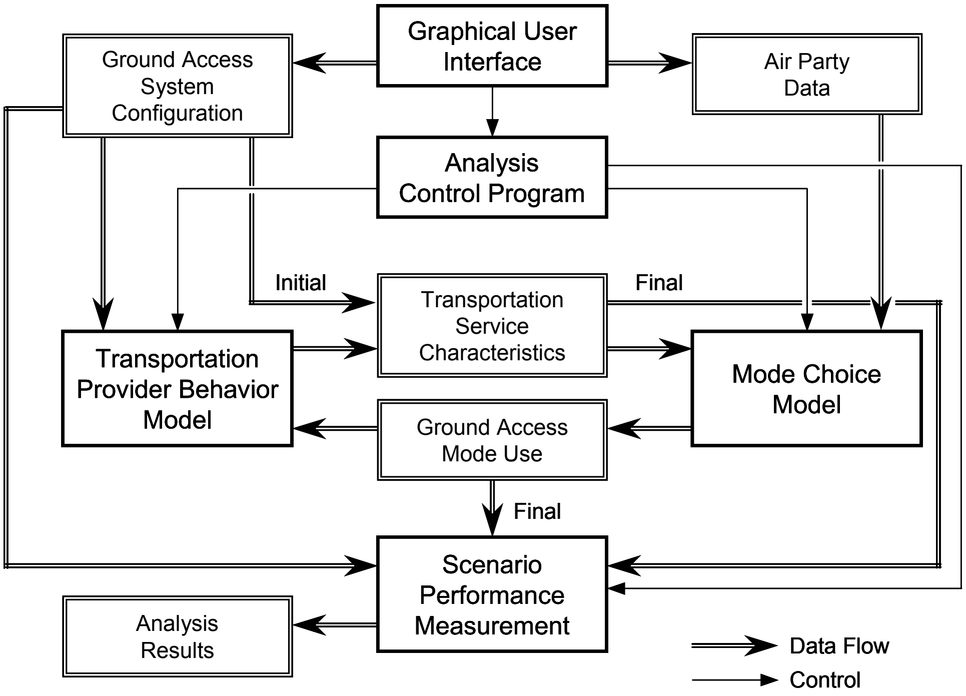


Figure 4-2: Functional Structure of the Analysis

Once the model has generated a set of air party trips by each mode, it is a fairly straightforward calculation to estimate the number of vehicle trips as well as other system performance measures that depend on person-trips or vehicle-trips, such as the total revenue for each service. Other system performance measures that depend on the distance traveled to the airport, such as vehicle-miles of travel or vehicle emissions, can be calculated from the trip origins of each air party. In some cases (such as taxi or private vehicle), vehicle trips and air party trips are the same thing. In other cases, such as scheduled services, the vehicle trips for a given service frequency are independent of the passenger trips, which only affect the load factor (although too high or too low a load factor may result in a change to the schedule).

The initial implementation of the IAPT will not attempt to interface directly with a highway network analysis model. The output of an IAPT run will include a file of estimated vehicle trips from each traffic analysis zone. These trips can be added to a trip table for the non-airport traffic and used in a separate highway network traffic flow analysis to explore the effect of changes in the volume and pattern of airport ground access vehicle trips on traffic levels on the individual links of the local street and highway network near the airport. While these changes could in principle affect ground access travel times, in practice the volume of airport-generated traffic is not usually large enough to have a significant effect on travel times except in the immediate vicinity of the airport, where airport trips may be a large proportion of the total traffic on each link. However, the type of improved intermodal connection envisaged in this research is unlikely to have a major impact on the volume of vehicle trips accessing the airport.

4.1.2 Model Components and Interfaces

As indicated in Figure 4-2, there are five basic components to the IAPT:

1. The graphical user interface
2. The analysis control program
3. The mode choice model
4. The transportation provider behavior model
5. The scenario performance measurement module.

Each of these components interact through the IAPT database. The ***graphical user interface*** allows the user to enter all the necessary data to define a set of analysis scenarios, specify the measures of performance, initiate the analysis, and control the display and output of the analysis results. The ***analysis control program*** manages the interaction between the mode choice model and the transportation provider behavior model to calculate the mode use and change in transportation service characteristics for each analysis scenario. In essence this consists of two iteration loops. The outer loop processes each analysis scenario in turn. The inner loop begins by calling the ***mode choice model*** with the initial values of the transportation service characteristics for the current analysis scenario. The mode choice model calculates the use of each mode for the sample of air party trips defined for the given analysis scenario. The analysis control program then expands this mode use pattern to the total usage of each mode for the associated airport traffic level and calls the ***transportation provider behavior*** model to determine which adjustments, if any, to make to the transportation service characteristics in the light of the mode use. The analysis control program then calls the mode choice model and transportation provider behavior model in turn until a solution is obtained in which the change in mode use on two successive iterations is less than a defined threshold. Finally, the analysis control program calls the ***scenario performance measurement module*** to calculate the defined performance measures for the calculated mode use. This completes the analysis sequence for a given analysis scenario and the graphical user interface provides the functionality to view, print, or export the results.

Each analysis module reads its input data from the IAPT database and writes its output to the database. The graphical user interface obtains its input from user entries or external files and transfers this data to the database. During the iteration between the mode choice model and the transportation provider behavior model, the intermediate values of the transportation service characteristics and resulting mode use are stored in the database to permit subsequent analysis of the convergence process.

Given the complexity of the issues to be addressed by the IAPT, it can be expected that the analytical capabilities of the various components will be enhanced over time and that additional capabilities will be incorporated in the future. Therefore the main model framework and the associated interface links have been designed so that the tool can be easily refined and further developed in the future. Key to this capability is the separation of analytical functions and the underlying data structures.

4.2 Software Structure and Data Flow

The software implementation of the foregoing functional design is fairly straightforward. Each of the IAPT components consists of a separate Visual Basic (VB) module. Starting the IAPT initiates the graphical user interface, which continues to run during the various steps of the data entry and analysis. To analyze a set of defined analysis scenarios, the graphical user interface calls the analysis control program which in turn calls the other three modules as necessary before returning control to the graphical user interface.

Data flow between the modules is handled through reading and writing data from and to the supporting data tables in the IAPT database. These will be implemented as standard relational data tables in an ODBC-compatible database. It is envisaged that. Microsoft Access will be used for the initial implementation of the IAPT, although Visual Basic programs can interface with any ODBC database. Implementing the data tables in a format that is accessible by other software will allow the contents of the data tables to be easily displayed for model development purposes and eventually could allow the data contained in the tables to be utilized by other applications or for the IAPT to be integrated with other analysis software.

4.2.1 Database Design

While the basic unit of analysis for the IAPT is the ***project***, there is a large amount of contextual information that is common to multiple projects, including data specific to the ***airport*** at which the project is located and the ***region*** within which the airport is located. Organizing these data in a hierarchical structure avoids the needs to redefine common data for each project or common data for multiple airports in the same region.

The data tables store the input information that defines analysis regions, airports, and projects together with their associated data, model parameters and structural information, measures of performance, and specifications of the analysis runs to be performed. They also contain the output from the analysis runs. Since it is likely that the input data for any set of projects to be analyzed will evolve over time as the user defines analysis scenarios, performs analysis runs, and modifies the projects in the light of the analysis results, the data table specifications will have provision for change logs to track actions to create and modify the data. This will also facilitate use of the IAPT by multiple users to analyze large or complex projects, allowing each user to identify changes that have been made to the input data by other members of the team.

The underlying data that is required to support the IAPT can be organized into several categories:

- Regional data describing the surface transportation system and other common characteristics of the region within which a specific airport is located;
- Airport data common to all projects at a specific airport, such as air passenger survey data and forecast traffic levels;
- Project data, including available ground access modes and associated service characteristics;
- Parameter values and structural information for the component models of the IAPT;
- Results of model analysis runs.

In order to illustrate the planned database structure, initial specifications for some of the key data tables are shown in Appendix A. Specifications for additional data tables will be defined as development of the IAPT proceeds. To assist in managing the potentially large number of data tables required, it is envisaged that region-specific and airport-specific data tables will be grouped in separate databases.

4.3 Graphical User Interface

The graphical user interface (GUI) is critical to the effective use of the software. It provides the functionality to manage the interfaces between the analytical components and the associated data flows, as well as to allow the user to define the problem to be analyzed and to view the results of the analysis. It is expected that many users of the IAPT will not be concerned with the underlying technical details of the modeling or the internal data flows. In particular, the development and calibration of a mode choice model is a rather complex process and thus this component is probably not something that a typical user will wish to modify. What the users will require is an easy way to enter the necessary data for a given airport and to define the characteristics of the project to be analyzed, such as consideration of alternative service changes (schedule, routing, frequencies, fare, etc.) or undertaking cost and benefit analysis for adding a new mode to improve connectivity.

The GUI is organized as a sequence of screen displays that perform specific functions and provide the user with a logical framework to enter the necessary data. Screen displays make use of data that has been already entered into the database to control the entry of additional data, thereby maintaining consistency of the underlying data. Checks are performed for completeness of the required data before initiating an analysis run. Each screen display contains a set of top-level navigation buttons that allow the user to move between different data entry and model analysis functions, as well as a context-sensitive help button that provides guidance on entering the required information for the current screen.

The initial screen on starting the IAPT is shown in Figure 4-3. This shows the seven navigation buttons that appear on each successive screen. The first button displays a descriptive overview of the IAPT and defines the terminology used in the tool.

Figure 4-3: Initial IAPT Screen

Selecting one of the next five buttons initiates a sequence of screens that guide the user through the relevant data entry or analysis tasks:

- Defining the projects to be analyzed
- Data entry
- Defining measures of performance
- Performing analysis runs
- Viewing, printing or exporting analysis results.

The final button displays a context-sensitive help screen that provides user guidance for the current screen. The following discussion will not attempt to describe every screen, but will illustrate the general approach using representative screens.

4.3.1 Project Definition

The IAPT is designed to analyze a set of defined project alternatives at a given airport, where each project alternative (referred to simply as a ***project***) represents a specified combination of ground access modes and associated service levels. The first step in any analysis is to assign a name to each project and provide a description of the project for later reference. The data for these projects are then entered later using the defined name.

The second navigation button, ***Define Project***, allows the user to define a new project or modify the description of an existing project. Projects are defined in a hierarchical structure for a specific airport. At each level of the hierarchy a project inherits the characteristics of it parent project in order to reduce data entry requirements and simplify analysis of project variants. In order to define a new project or modify an existing project, the user first selects the relevant airport from a list of defined airports in the IAPT database or adds a new airport to the database. Selecting a defined airport displays a list of existing projects for that airport. Selecting one of these projects displays the project description, a text explanation of the project, which can be edited and the changes saved. In order to define a new project, an existing project is selected as its parent in the hierarchy or it is designated as a new top-level project, termed a ***baseline project***. In the case of a new variant (child) of an existing project, the name and description of the existing project are displayed and edited to define the new project, as illustrated by Figure 4-4.

Airport: OAK Oakland International Airport

Project: 1.1.2 BART Connector - $5 fare, 15 min hdw

Project Description:

Automated people mover connection between BART Coliseum station and airport terminal. Elevated guideway with one track in each direction. Each car carries up to 10 people. 3 car max. consist. Four intermediate stations. 15 minute headway. $5 fare between airport and BART, $2.50 to intermediate stations.

Edit text and press **OK** to save changes or **Cancel** to return to previous screen

Figure 4-4: Typical Project Definition Screen

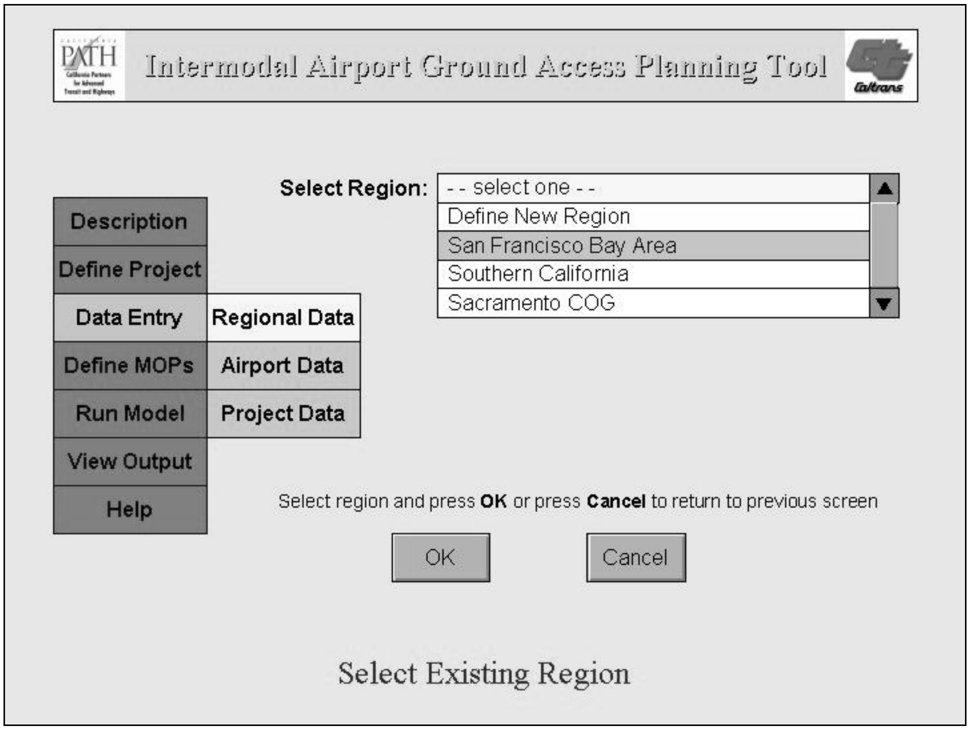
To create the new project variant, the user edits the name and description of the parent project (changed or additional text shown in blue) and presses **OK**. The new project variant is automatically assigned the next number in the hierarchical project number sequence. As with all screens, pressing **Cancel** returns the user to the previous screen in the sequence.

In the case of a new baseline project the name and description are entered in blank fields.

4.3.2 Data Entry

The ***Data Entry*** button provides the user with access to a sequence of screens that are used to enter data for a region, airport or specific project. Selecting the ***Regional Data*** option allows the user to define a new region or select an existing region and enter or edit regional characteristics (currently limited to the number of analysis zones in the region, although this could be expanded to support future capabilities) and import highway or transit network data from external files. Selecting the ***Airport Data*** option allows the user to define or edit an analysis time frame with associated air traffic growth factors, to import representative air passenger data, and to define the existing ground access modes and their associated utility functions and service data. Selecting the ***Project Data*** option allows the user to define the available ground access modes for a selected project and enter or edit the modal service and cost data.

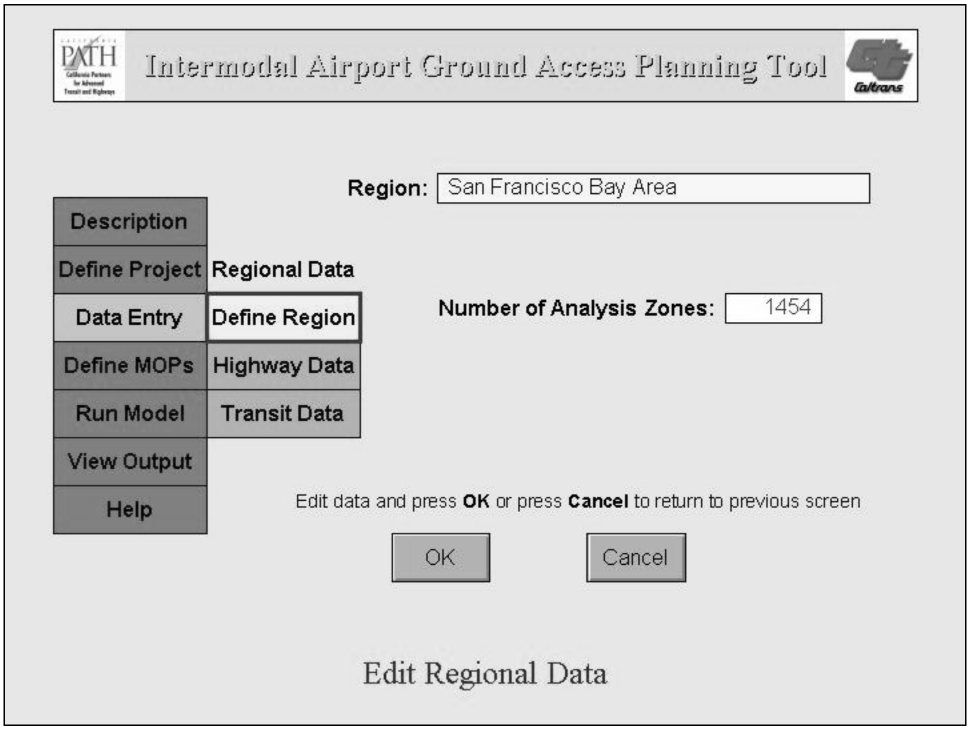
The GUI uses a consistent approach to data entry for the wide range of data that are needed to support the analysis. First, the relevant region, airport or project is selected, as illustrated in Figure 4-5, which shows the selection of an existing region.



Select region and press **OK** or press **Cancel** to return to previous screen

Figure 4-5: Selection of a Region for Data Entry

Some data is entered or edited directly on the screen, as illustrated by Figure 4-6, which shows a change being made to the number of analysis zones defined for the selected region. As with the project definition screens, new data is entered in blank fields while changes to existing data are shown in blue. More complex data can be imported from external files. Selecting the ***Highway Data*** or ***Transit Data*** options displays a list of the data tables required for each type of data. Selecting a particular data table displays a data management screen which provides the option of importing data form an external file, deleting data tables, or viewing and editing the contents of existing data tables. Figure 4-7 shows a typical data management screen for highway travel time data.



Intermodal Airport Ground Access Planning Tool

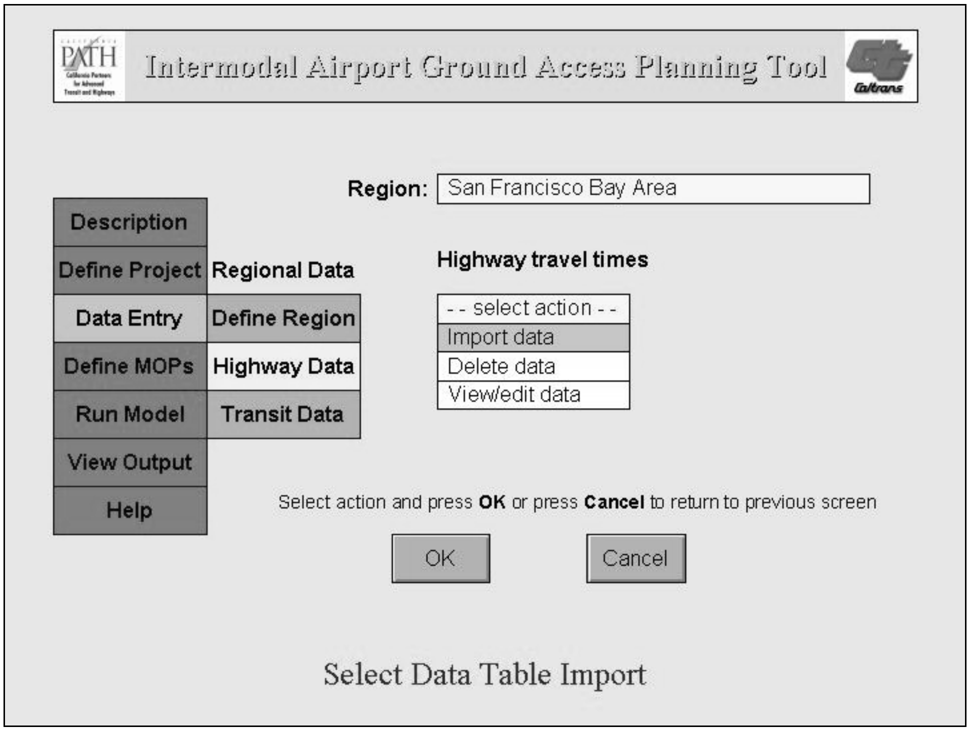
Region: San Francisco Bay Area

Number of Analysis Zones: 1454

Edit data and press **OK** or press **Cancel** to return to previous screen

Edit Regional Data

Figure 4-6: Typical Data Entry or Editing Screen



Intermodal Airport Ground Access Planning Tool

Region: San Francisco Bay Area

Highway travel times

Select action and press **OK** or press **Cancel** to return to previous screen

Select Data Table Import

Figure 4-7: Typical Data Management Screen

Selecting the import data option generates a data import screen, as shown in Figure 4-8, which displays a standard browse window to identify the file to be imported. The user navigates to the correct file, selects it by clicking on its icon, and imports the data by clicking **Open** in the file browse window. Data tables are stored internally in the IAPT database as Microsoft Access tables. If the external file is not already in this format, it is converted to the correct format on import. For initial implementation of the IAPT, valid external file formats consist of Microsoft Excel worksheets and comma separated value (CSV) text files, in addition to Microsoft Access tables. Conversion routines for additional formats may be developed in the future, although most other file formats can be easily converted to Microsoft Excel before being imported.


Intermodal Airport Ground Access Planning Tool

Region: San Francisco Bay Area

Import highway travel time data file

Look in: Network Data

Airport Bus Stops
Highway Data
Regional Rail Stations
TAZ Data
Transit Data
Bay Area TAZ Data.xls
Data Reference Memo.doc
MTC TAZ Map.pdf

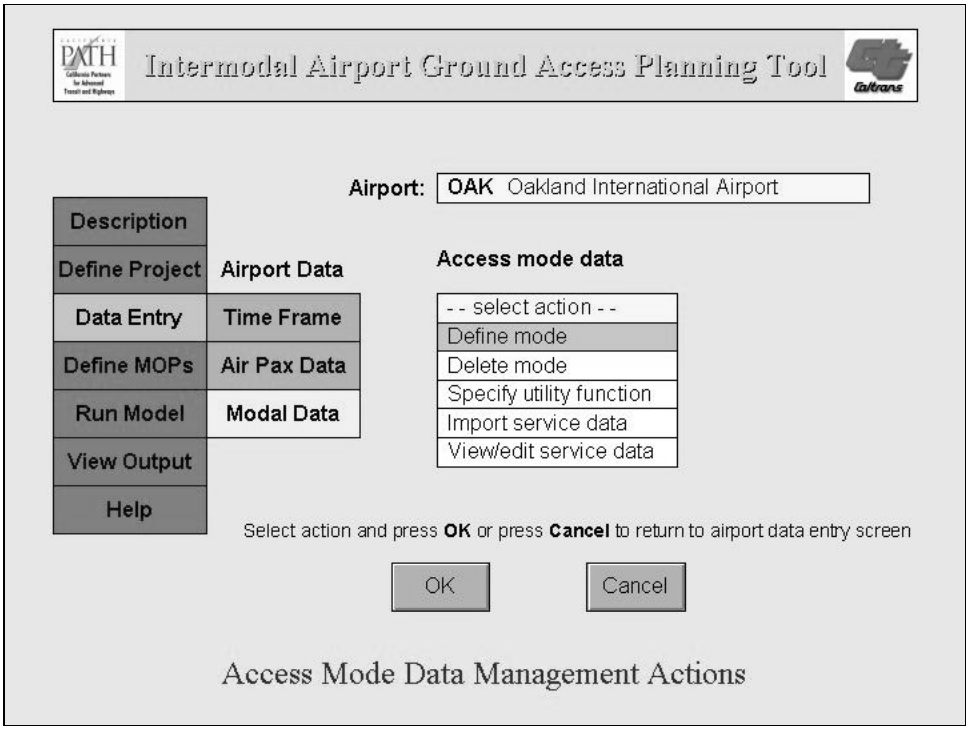
File name:
Files of type: All Files (*.*)

Select File to Import

Figure 4-8: Typical Data Table Import Screen

Selecting the delete data or view/edit data options generates a list of the existing data tables of the relevant type in the IAPT database. Deleting a table is simply a matter of selecting the table and pressing the **Delete** button. Selecting a table and pressing the **View/Edit** button displays the contents of the table in a scrollable window. In general, minor changes to data table contents can be performed directly on the data table display. As with other screens, changes are shown in blue and the changed data can be saved or the changes cancelled. The screen also provides the user with the option of exporting the contents of a data table in CSV format. This allows external data files to be updated with any changes made on the IAPT screens. However, for major changes to data table contents it will usually be easier to modify the source data, delete the existing internal data table and re-import the revised data.

Airport data and project data are entered in a similar way. For airport data, analysis time frames (future years for which the analysis is to be performed and the associated air traffic growth factors) are entered on screen, representative air passenger data tables are imported from external files in the same way as highway and transit network data, and data on the existing modes are entered directly on screen. The access mode data management screen is shown in Figure 4-9 for a representative airport.



Airport: OAK Oakland International Airport

Select action and press **OK** or press **Cancel** to return to airport data entry screen

Figure 4-9: Access Mode Data Management Screen

As with projects, modes are first defined by assigning them a name and then their service attributes (travel times, costs, etc.) are imported from external files. Utility functions for each mode to be used in the mode choice model can also be defined from this screen. Allowing the utility functions to be defined in this way allows users to modify the mode choice model to incorporate the results of new model calibrations or to reflect the introduction of a new mode.

Project data entry allows users to define the set of modes that are available for a given project as well as vary (or enter) the mode service attributes for each mode. Project data also includes operational performance characteristics and unit cost data to enable the cost of deploying and operating a new ground access mode to be calculated.

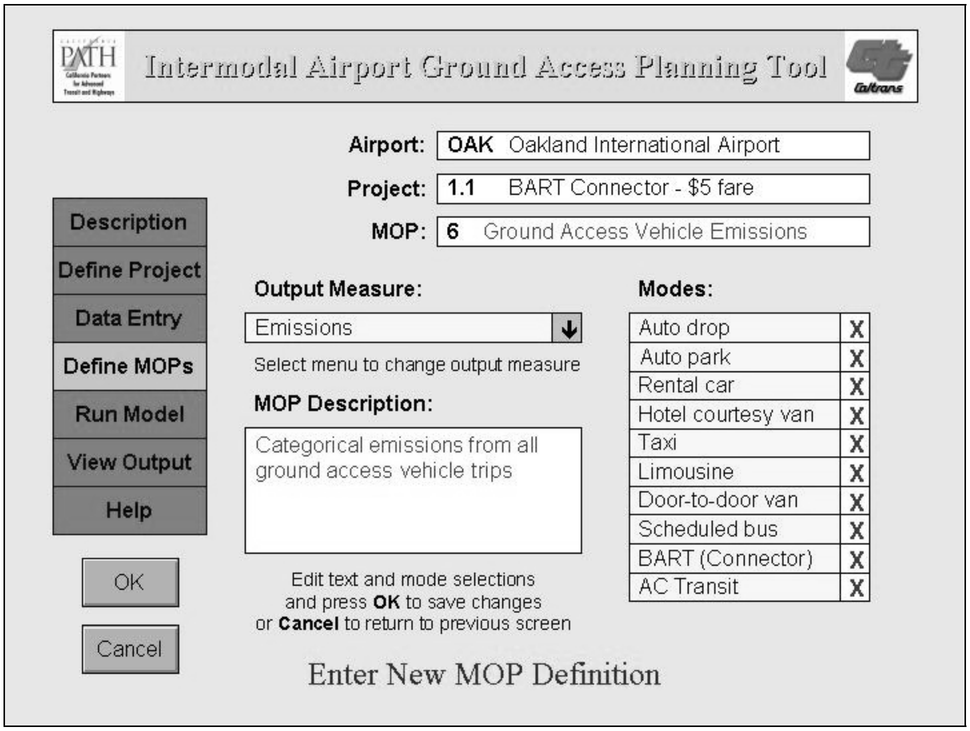
4.3.3 Define Measures of Performance

Measures of system performance are key to the comparative analysis of project alternatives. The IAPT allows users to define measures of performance (MOPs) that are based on a selected output measure applied to a set of ground access modes. The available output measures are limited by the information that can be calculated from the IAPT analysis, but provide a fairly comprehensive set of potential analysis results. The initial implementation of the IAPT will provide the following available output measures for a mode or set of modes:

- Passengers (per year)
- Air parties (per year)
- Total revenue ($ per year)
- Vehicle trips (per year)
- Vehicle-miles of travel (per year)
- Categorical vehicle emissions (tons per year)
- Passenger travel time (person-hours per year)
- Operating costs ($ per year)
- Vehicle fleet size
- Capital costs ($).

The vehicle fleet size and operating and capital cost output measures are intended to support the assessment of the economic viability of a proposed service and the impact of the introduction of a new service on the operating economics of existing modes. Thus these measures do not apply to private vehicles. For the initial implementation of the IAPT, the categorical vehicle emissions (carbon monoxide, hydrocarbons, and oxides of nitrogen) are calculated on the basis of vehicle-miles of travel and average travel speed. This is consistent with the methodology used in the Federal Aviation Administration Emissions and Dispersion Modeling System (FAA, 2004). More sophisticated analysis would be possible in future enhancements of the IAPT that could take into account traffic conditions on individual links of the regional highway system.

MOPs are defined for a specific project, although the definitions are inherited by any child projects in the hierarchy. A typical MOP definition screen is shown in Figure 4-10. The applicable output measure (emissions in this case) is selected from a pull-down menu and the modes to be included in this MOP are indicated by the use of check boxes. This allows the user to define MOPs that apply to a single mode, to several modes, or (as in this case) to all modes.



Airport: OAK Oakland International Airport

Project: 1.1 BART Connector - $5 fare

MOP: 6 Ground Access Vehicle Emissions

Output Measure: Emissions

Select menu to change output measure

MOP Description: Categorical emissions from all ground access vehicle trips

Modes:	
Auto drop	X
Auto park	X
Rental car	X
Hotel courtesy van	X
Taxi	X
Limousine	X
Door-to-door van	X
Scheduled bus	X
BART (Connector)	X
AC Transit	X

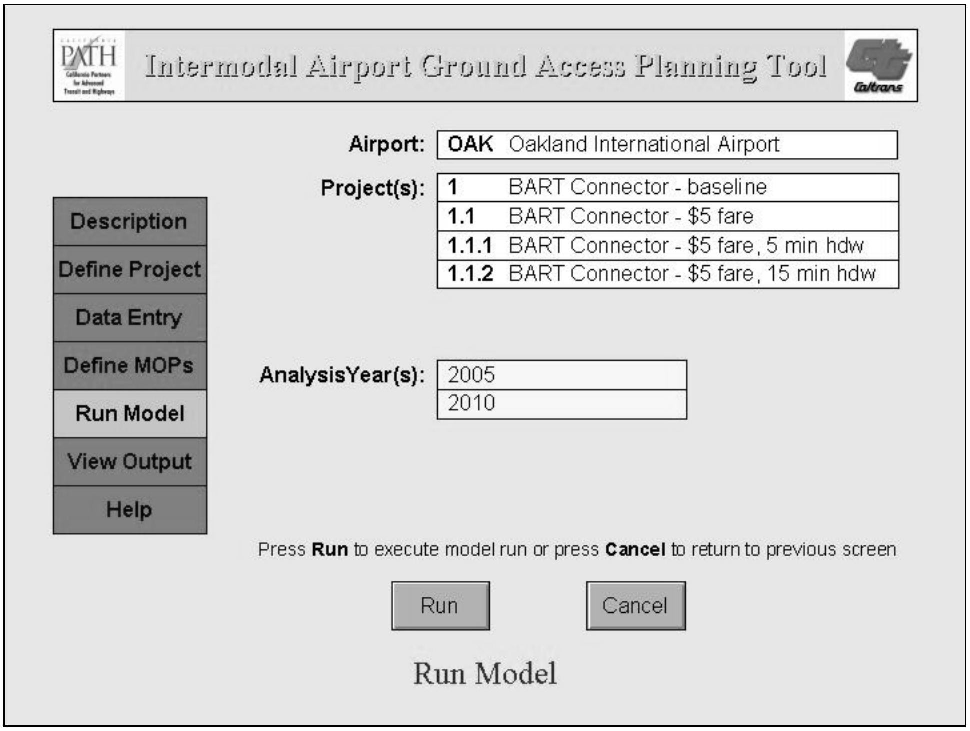
Edit text and mode selections and press **OK** to save changes or **Cancel** to return to previous screen

Enter New MOP Definition

Figure 4-10: Measure of Performance Definition Screen

4.3.4 Perform Analysis

Once the data entry is completed and the MOPs have been defined, the analysis is performed from the ***Run Model*** navigation button. This presents a sequence of screens that allows the user to select an airport, one or more projects, and one or more analysis years, as illustrated in Figure 4-11. The analysis is initiated by pressing the **Run** button. The IAPT analysis control module assigns a sequential number to the analysis run and then performs the analysis for each project and analysis year in order. As the model runs, the project and analysis year being analyzed are displayed and a session log window displays the progress of the analysis.



Airport: **OAK** Oakland International Airport

Project(s):	
1	BART Connector - baseline
1.1	BART Connector - $5 fare
1.1.1	BART Connector - $5 fare, 5 min hdw
1.1.2	BART Connector - $5 fare, 15 min hdw

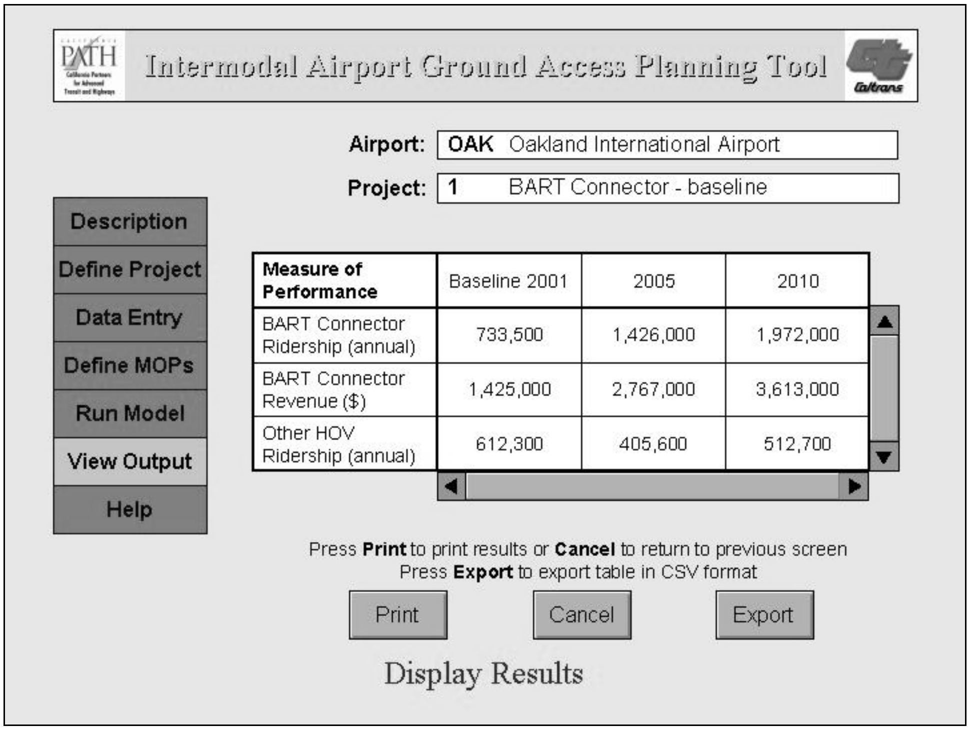
AnalysisYear(s): 2005 2010

Press **Run** to execute model run or press **Cancel** to return to previous screen

Figure 4-11: Representative Model Run Definition Screen

4.3.5 Display or Export Analysis Results

Selecting the ***View Output*** navigation button allows the user to select an airport and displays a list of all the analysis runs performed to date for that airport. The analysis runs are grouped by project and listed in date order, showing the run date/time and the analysis year for each analysis run. The user can select one or more analysis years for a given project and one or more MOPs for that project. The results are then displayed in a scrollable table that shows the value of each selected MOP for each selected analysis year, as illustrated in Figure 4-12. The table can be printed by pressing the **Print** button and exported in CSV format by pressing the **Export** button. The print option generates the standard printer selection window and the export option generates a standard file save window to designate the name and location of the exported file.



Airport: OAK Oakland International Airport

Project: 1 BART Connector - baseline

Measure of Performance	Baseline 2001	2005	2010
BART Connector Ridership (annual)	733,500	1,426,000	1,972,000
BART Connector Revenue ($)	1,425,000	2,767,000	3,613,000
Other HOV Ridership (annual)	612,300	405,600	512,700

Press **Print** to print results or **Cancel** to return to previous screen
Press **Export** to export table in CSV format

Figure 4-12: Typical Model Output Screen

Chapter 5. Passenger Mode Choice Modeling

The modeling of air passenger ground access mode choice forms the primary analytical component of the initial implementation of the Intermodal Access Planning Tool (IAPT). The choice of ground transportation mode by air passengers and airport employees for their airport access and egress trips determine the traffic volumes on airport roadways and the use of airport parking facilities, as well as the ridership on public modes serving the airports and the use of other airport ground transportation facilities. Airport ground access mode choice models (strictly airport ground access/egress mode choice models) therefore provide an essential analytical tool to support airport ground transportation planning, and a key component of the IAPT.

The distinction between access and egress trips is often ignored in airport ground transportation planning and mode choice models are developed to predict access mode choice only with the mode choice process assumed to be symmetrical. This results in part from the available data on ground transportation mode use obtained from air passenger surveys, which typically only survey departing passengers (*i.e.* those enplaning at the airport) and commonly only ask about how the survey respondents got ***to*** the airport. However, recently a number of surveys have also asked visitors to the area how they left the airport when they arrived in the area and residents of the area how they plan to leave the airport on their return trip (of course, since this has not yet occurred at the time they are surveyed, these respondents may not have made this decision or may change their plans). The results of these surveys suggest that the access and egress travel patterns are not in fact symmetrical for many air passengers, as borne out by the experience of anyone who has made many air trips. However, the important question is not whether individual travelers use different modes in the two directions, but whether in the aggregate the mode use pattern is different in the two directions. Even if the total flow using a particular mode over the week is equal in the two directions (and even this may not be true), the time of day and day of the week patterns are likely to be different in the two directions, which would have important implications for ground transportation planning.

Another important distinction is that between air passenger trips and airport employee trips. Although both types of traveler make use of many of the same facilities and services, the factors that influence their mode choice decisions are likely to be quite different. Airport employees have to travel to the airport on a regular basis, typically on a daily basis, although the number of times per week and the times of day for the trip in each direction are determined by their work hours. Since many airport functions operate on a 24-hour basis, seven days per week, the resulting shift patterns can be quite complex. In contrast, most air passengers make a trip to the airport relatively infrequently, perhaps only once or twice a year, often have luggage, and may be less concerned about the cost of the access and egress trip, since it may form a relatively small part of the total cost of their air trip. Furthermore, many air passengers are visiting the area and may not have access to a private vehicle that can be used for the access and egress trip, while residents of the area who do have access to a private vehicle that can be parked at the airport while they are away on their air trip can face a significant cost in doing so if they are away for any length of time.

In spite of the importance of airport employee mode choice decisions to the traffic volumes on airport access roadways and airport employee parking requirements, there has been almost no attention given to airport employee mode choice in the literature. At best, surveys have been conducted of airport employee mode use and estimates have been made of how this might change in response to potential actions that are being considered, such as changing airport employee parking rates or subsidizing employee use of shared-ride or public transport services.

Therefore for the initial implementation of the IAPT, the mode choice model development has focused on air passenger ground ***access*** mode choice. Extension of the resulting models to address air passenger airport egress mode choice, and the development of mode choice models for airport employee trips has been left for a subsequent stage of the research.

5.1 Air Passenger Mode Choice Model Development

In order to provide an introduction to the subsequent discussion of the development of the mode choice modeling component of the IAPT, as well as the following summary of the literature on air passenger ground access mode choice models (hereafter referred to simply as air passenger mode choice models), this section provides an overview of the process of developing air passenger ground access mode choice models as well as the factors that influence air passenger mode choice decisions and the typical mathematical forms of these models.

5.1.1 Mode Choice Model Development Process

In common with other models of transportation mode choice behavior, the development process for a model of airport traveler mode choice behavior involves four distinct steps: model ***specification***, model ***estimation***, model ***calibration***, and model ***validation***.

Model Specification

Model specification refers to the selection of an appropriate mathematical form for the model and selection and definition of the associated explanatory variables. These choices involve both theoretical and practical considerations. A reliable model should be based on a well-tested and accepted theory of human behavior and should include appropriate explanatory variables. There is an extensive literature on the mathematical representation of travel choice behavior, and the state of the art of such models is continually evolving. However, less attention has been given to the choice of appropriate explanatory variables, beyond such obvious considerations as travel cost and time. In particular, how to account for the role of such considerations as household income levels, availability of information on travel choice alternatives, who is paying for the trip, and the perceived convenience of different modes is not well understood. In practice the choice of explanatory variables is also often constrained by data availability.

Model Estimation

Model estimation refers to the process of deriving values for the coefficients of the proposed model such that the model provides the best fit to a dataset of observed traveler choices. This typically utilizes standard statistical model estimation techniques and commercial or publicly available software packages. The model specification and model estimation processes are typically interactive, with the initial model specification being refined in the light of the model estimation results.

Thus in the current context the model estimation process requires the development of a dataset of air party mode choice decisions with the associated air party characteristics and transportation service characteristics (costs, travel times, *etc.*) for a representative sample of air parties. Since the transportation service characteristics are required for all modes considered in the choice set, values for these characteristics have to be obtained for each air party in the dataset for all modes in that party's choice set, not just the mode that the party in fact chose. The air party characteristics and mode chosen are typically obtained from an air passenger survey. Since some time usually elapses between the conduct of the survey and the estimation of a mode choice model using that information, it is necessary to obtain the relevant values of transportation service characteristics for the date of the survey, not the current values. In an ideal world, the organization sponsoring the air passenger survey would assemble the transportation service characteristics at the time the survey was conducted. However, in practice this very rarely happens. Also in an ideal world, airport authorities would archive service information about the transportation modes serving the airport on an on-going basis, so that they would have a time series of this information. Needless to say, in practice this rarely happens either. Therefore the estimation of a mode choice model typically requires a fairly major effort to recreate the historic transportation service information for the period of the air passenger survey. In some cases this requires a considerable amount of detective work to piece together information from multiple sources.

Once the model estimation dataset has been assembled model development usually follows fairly standard econometric principles. Various model functional forms, including both alternative nesting structures and alternative utility function specifications, are estimated and statistical tests performed to determine which model best fits the data. This process is best performed incrementally by starting with fairly simple models and then increasing complexity by adding or redefining variables or changing the nesting structure, in order to see if these changes improve the fit of the model to the data. However, some caution is appropriate in selecting between alternative model specifications. It is generally better to select a model that makes good intuitive sense than one that provides a better fit to the data, but has unreasonable or counter-intuitive properties. The latter situation can be due to problems in the estimation dataset, such as incorrect transportation service values or poorly worded air passenger survey questions. While such counter-intuitive models may provide a better explanation of the apparent behavior of the air parties in the estimation dataset, they are likely to produce unreasonable results when applied in other situations.

Model Calibration

Model calibration refers to the process of adjusting the model to ensure that the model predictions agree with observed travel patterns. This requires a comparison of the predictions of an estimated model with observed traffic levels on the various modes. While this can be done by collecting actual traffic data for the period of the air passenger survey used to estimate the models, this is less satisfactory than applying the model for a different period. Indeed, if traffic data are available for the period of the air passenger survey, it is better to use these data to weight the survey responses to ensure that the sample properly reflects the use of access/egress modes at the airport.

Since use of the different airport ground access modes changes seasonally, due to changing composition of the passenger traffic using the airport, the principal role of model calibration is to ensure that the model predicts the mode use pattern over the year rather than just for the period of the air passenger survey.

However, this then poses the question of how to obtain air passenger characteristics for periods other than those used for the model estimation. One approach, of course, is to perform periodic surveys throughout the year. However this is expensive. An alternative approach is to segment the market using passenger data reported by the airlines and to assume that the mix of passenger characteristics for each of these market segments is the same as in the original survey. Thus a synthetic sample of air party trips can be generated using Monte Carlo sampling techniques and the mode choice model applied to this sample to predict traffic levels on the various modes that can be compared with the observed levels.

Since the comparison typically has to be done at the level of the total traffic using the mode (or sub-mode), due to an absence of more disaggregate data, the only practical adjustments to the model that can be made to calibrate the predictions is to adjust the mode-specific constants. However, this is not an unreasonable approach. The function of the mode-specific constants in the model is to ensure that the probabilities of each party choosing a given mode sum to the number of parties that actually chose that mode. This corrects for missing variables, biased sampling, incorrect data for transportation service values, model misspecification, and similar problems. Since it is likely that the effects of these problems differ between the estimation dataset and the calibration dataset, it is not unreasonable to assume that the calibration errors result from errors in the values of the mode-specific constants.

Model Validation

The final step in the development of an air passenger mode choice model is validating that the model in fact correctly predicts how the air passenger choices will change in response to changes in the system such as changes in the service levels of existing modes (*e.g.* a change in fare or frequency) or the introduction of a new service. While a model may appear to do a reasonable job of predicting the observed choices of air passengers under the current conditions (or more strictly the conditions that pertained when the choices were observed), that does not necessarily mean that it will do an equally good job of predicting how those choices will change under different circumstances. However, this is precisely why such models are needed. Therefore it is highly desirable (although not often done) to validate the model by testing how it performs under different conditions from those for which it was calibrated.

This of course requires a change in circumstances that can be used to perform validation tests. The introduction of a new service or mode, or a significant change to the service levels offered by an existing mode (such as a change in parking rates at the airport), can provide opportunities to validate the performance of the model. However, the introduction of a new mode at an airport raises the technical issue of how to include the new mode in the model, if it was not in operation at the time when the air passenger mode choice data was collected from which the model was estimated. This issue is discussed further later in this chapter.

5.1.2 Factors Influencing Air Passenger Mode Choice

Air passenger travel to and from airports is very different from other types of urban travel, and in consequence the typical mode choice models used for urban transportation planning are useless for predicting air passenger mode choice. This results from two different aspects of air passenger airport ground access travel that interact to influence the mode choice decisions.

The first aspect is the nature of the air party characteristics and the circumstances of the air trip itself. As noted above, many air passengers are visitors to the area, which not only has implications for their access to private vehicles, but their knowledge of travel alternatives. Furthermore, many air passengers are traveling in air parties of two or more individuals, which influences the cost of using different modes. Air passengers travel for a wide variety of trip purposes, which are commonly grouped together as “business” or “non-business” (sometimes referred to as “leisure” or “personal”) trips. Air travelers on business trips may have their travel expenses paid by their employer or another organization, which will influence how they regard the relative costs and convenience of different modes. Other considerations include the duration of the air trip, the time of day that the air party needs to be at the airport, the amount of luggage that the party has, and the income level of the travelers.

The second aspect is the much larger number of potential modes that need to be considered, compared to typical urban travel demand models. These include:

- Private vehicle parked for the duration of the air trip
- Drop off or pick up by private vehicle
- Rental car
- Taxi or hired car
- Shared-ride door-to-door van
- Scheduled airport bus service
- Public transit
- Charter bus
- Courtesy shuttles from nearby hotels.

In addition, there are often numerous sub-modes that need to be considered, such as different parking lots with different rate structures and accessibility to the airport terminals, some of which may require the use of a courtesy shuttle bus, and multiple operators that may have different service characteristics or locations, affecting the resulting traffic patterns on the airport and access roadways. Some public modes may also involve a secondary mode decision on how to access the station or service point used. Since these access decisions are likely to vary by air party, depending on the party characteristics and the availability of different access modes, these factors may also need to be incorporated in the model to properly reflect the likely use of the public mode in question.

Market Segmentation

It is common practice to estimate different mode choice models for different segments of a market, such as different types of trip. This reflects the possibility that travelers forming these different market segments may have different demographic or socio-economic characteristics, which could influence their choice behavior, as well as differences in the modes that may be available or appropriate for trips made by different segments of the market. For example, travelers on business trips may have a different perceived value of time from when the same travelers make personal trips. This can become particularly critical if key factors that can be expected to influence travel choice decisions, such as income, are omitted from the model.

In the case of air passenger mode choice models, it has become common practice to segment the market into four types of trip:

- Business trips by residents of the region
- Non-business trips by residents of the region
- Business trips by visitors to the region
- Non-business trips by visitors to the region.

Some earlier models only used part of this segmentation approach, such as estimating separate models for residents and visitors, but not developing separate models for trip purpose. In some cases, this was due to limitations in the air passenger survey data used to estimate the models.

Some additional segmentation may be necessary to address what may be termed "captive mode use". For example, visitors to the region who decide to rent a car for transportation during their visit other than for their trip to and from the airport will most likely pick up and return this car at the airport, and therefore use it for their airport access and egress trip. Similarly, visitors staying in hotels near the airport that have a courtesy shuttle service are likely to use this mode to travel between the airport and the hotel, unless they have rented a car at the airport. It may therefore be desirable to model the ground access mode use of these air parties differently from that of other air parties that are choosing between a wider range of alternatives.

5.1.3 General Structure of Air Passenger Mode Choice Models

Although there are significant implementation differences between air passenger mode choice models and general urban transportation mode choice models, for the reasons mentioned in the previous section, the underlying behavioral processes are not usually regarded as fundamentally different and thus similar functional forms have been used for both types of model. These generally assume that each traveler (or decision-maker) perceives a utility associated with each potential choice that depends on the characteristics of that alternative (such as the travel time and cost) as well as the characteristics of the traveler. The probability of a traveler choosing a particular alternative then depends on the perceived utilities of each of the alternatives. The various functional forms that have been proposed to model this process differ in how the utility for a given alternative is expressed, as well as how the probability of a traveler choosing a particular alternative is calculated.

The majority of air passenger mode choice models found in the literature comprise one of two types: ***multinomial logit*** models and ***nested logit*** models. The function form of both models is similar. Multinomial logit (MNL) models include all the choice alternatives in a single level (or nest), while nested logit (NL) models group the choice alternatives in two or more levels or nests, as illustrated in Figure 5-1.

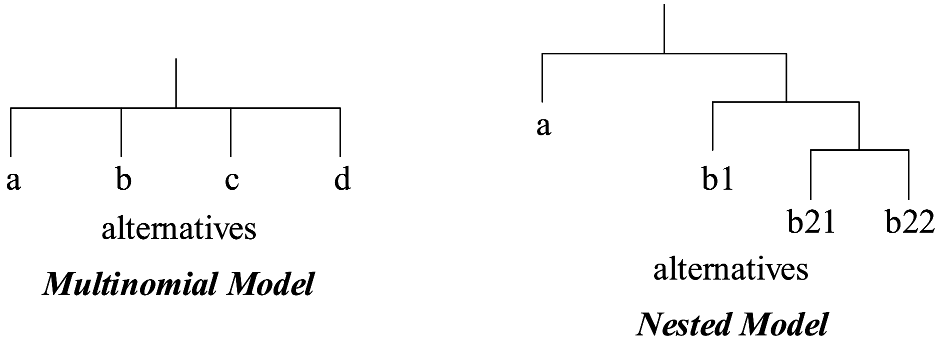


Figure 5-1: Multinomial and Nested Models

In the nested model shown in Figure 5-1, alternative *b* consists of a second-level nest of two sub-alternatives, *b1* and *b2*, the second of which consists of a third-level nest of two further sub-alternatives, *b21* and *b22*. For example, alternative *b* might represent use of private vehicle, with alternative *b1* representing the air party being dropped off at the airport and *b2* representing the use a private vehicle that is parked at the airport for the duration of the air trip, where *b21* represents the use of the short-term parking lot and *b22* represents the use of the long-term parking lot.

Both types of model are typically implemented as ***disaggregate*** models that predict the probability of a given air party choosing a particular alternative. This allows the different characteristics of each air party to be explicitly accounted for in the model. The general form of the MNL model is given by:

$$P(i) = \frac{e^{U(i)}}{\sum_{j=1,n} e^{U(j)}} \tag{5.1}$$

where $P(i)$ is the probability of the air party choosing mode i of n modes and U_j is the perceived utility of mode j. The perceived utility of each mode is typically expressed as a linear function of the explanatory variables, for example:

$$U(j) = a_j + b_1 * \text{cost} + b_2 * \text{wait time} + b_3 * \text{in-vehicle time} + b_4 * \text{walk distance} + \varepsilon \qquad \textbf{(5.2)}$$

where the *a* and *b* terms are parameters to be estimated and *ε* is a random error term that is assumed to be Gumbel distributed with a zero mean and is typically omitted from the description of the utility function. Since a constant amount can be added to each utility expression in a MNL model without affecting the result, one of the mode-specific constants (the a_j terms) is typically set to zero.

The random error term is introduced to account for differences in perceived utility across similar air parties facing the same set of service characteristics (cost, travel time, *etc.*) for a given alternative. In addition, the effect on perceived utility of differences in ***air party*** characteristics is accounted for in three different ways:

1. Through differences in the value of the service characteristics of different modes for air parties with different party characteristics (*e.g.* different costs for air parties of different sizes or for those parking a vehicle for different lengths of time)
2. By including specific variables in the utility functions (*e.g.* a variable for household income or the number of checked bags)
3. By estimating different parameter values for different market segments (*e.g.* travelers on business versus personal trips).

By assuming a Gumbel distribution for the random error term in the logit model it can be shown that the probability of choosing a particular alternative given by the model is also the probability that that alternative has the highest perceived utility for that decision-maker of any of the alternatives. This derivation can be found in any textbook on discrete choice models (e.g. Ben-Akiva & Lerman, 1985). However. it imposes some constraints on the logit model.

The general form of the NL model is similar to the MNL model, with the addition of a scaling parameter μ_m for each nest *m*, as follows:

$$P(i|m) = \frac{\left(e^{U(i)}\right)^{\frac{1}{\mu_m}}}{\sum_{j \in N_m} \left(e^{U(j)}\right)^{\frac{1}{\mu_m}}} \qquad (5.3)$$

$$P(m)=\frac{\left(\sum_{j\in N_m}\left(e^{U(j)}\right)^{\frac{1}{\mu_m}}\right)^{\mu_m}}{\sum_{l\in S}\left(\sum_{k\in N_l}\left(e^{U(k)}\right)^{\frac{1}{\mu_l}}\right)^{\mu_l}} \tag{5.4}$$

where N_m is the set of modes within nest m and S is the set of nests at the same level that contain nest m. If one branch of a nest consists of a discrete mode rather than a lower-level nest, the value for the scaling parameter for that mode $\mu_{m'} = 1$. Thus if there is only one nest, the above equations reduce to the MNL model.

The principal advantage of the NL model is that it is less vulnerable to the effects of a property of the MNL model termed the Independence from Irrelevant Alternatives (IIA). This states that including a new alternative in the choice set (or changing the perceived value of one of the alternatives) should not affect the relative probabilities of choosing any of the other alternatives. It can be seen from the above equation for the MNL model that the ratio of the probability of choosing any two alternatives is determined only by the perceived utilities of those alternatives, thus:

$$P(i)/P(k)=\frac{e^{U(i)}}{\sum_{j=1,n}e^{U(j)}}\Bigg/\frac{e^{U(k)}}{\sum_{j=1,n}e^{U(j)}}=\frac{e^{U(i)}}{e^{U(k)}}=e^{U(i)-U(k)} \tag{5.5}$$

However, in many situations in airport ground access mode choice it is quite unlikely that changing the characteristics of one mode or sub-mode will leave the relative probabilities of choosing all the other modes and sub-modes unchanged. For example, increasing the parking rates in the short-term parking lot is likely to have a greater effect on the probability of an air party choosing to park in the long-term parking lot than on the probability of choosing to use a shared-ride van, since those who would otherwise have parked in the short-term lot are much more likely to choose to park in the long-term lot instead than to use shared-ride van. Similarly, changes in one public transportation service are likely to impact the use of other public transportation services to a greater extent than the use of private vehicles. These effects can be reflected through the appropriate nesting of alternative modes and sub-modes.

5.2 Literature Review on Air Passenger Mode Choice

Although air passenger mode choice models represent a fairly specialized area of the more general study of traveler mode choice, there has been a steady stream of studies and papers addressing this topic over the past 30 years. This section reviews the development of thinking on how best to structure such models and examines a sample of recent models in more detail. It also discusses a number of recent ideas on ways to enhance the traditional logit mode choice models and alternative approaches to modeling mode choice. While there has been very little experience applying these ideas to air passenger mode choice, this is an area that may be worth exploring further in the future stages of the research.

5.2.1 Air Passenger Mode Choice Models

One of the earliest efforts to develop a formal model of air passenger airport ground access mode choice was undertaken in the early 1970s (Ellis, *et al.*, 1974). This study used a multinomial logit model, as did several other studies that developed air passenger ground access mode choice models over the next ten years (Leake & Underwood , 1977; Sobieniak *et al.*, 1979; Spear, 1984; Gosling, 1984; Harvey, 1986). However, by the mid 1980s it was becoming recognized that some of the limitations of the multinomial logit model could be addressed through the use of nested logit models (Ben-Akiva & Lerman, 1985). One of the first applications of nested logit models to airport ground access mode choice was undertaken as part of a study of surface access to London Heathrow Airport (Howard Humphreys and Partners, 1987), followed shortly thereafter by a study by Harvey (1988) that used a nested logit structure to develop an integrated model of airport choice and ground access mode choice for the San Francisco Bay Area. Subsequent air passenger ground access mode choice models developed for Boston, Massachusetts (Harrington *et al.*, 1996), Portland, Oregon (Portland Metro, c1998), and airports in the southeast and east of England (Halcrow Group, 2002) used a nested structure, while other studies continued to use multinomial logit models to represent air passenger ground access mode choice (Tambi &. Falcocchio, 1991; Dowling Associates, 2002; Psaraki & Abacoumkin, 2002). A number of recent studies have used nested logit models to represent air passenger airport choice, with airport ground access mode choice as a lower level nest (Bondzio, 1996; Monteiro & Hansen, 1996; Mandel, 1999; Pels *et al.*, 2003). However, these models generally only include a single-level nest for the airport ground access mode choice process, and thus are equivalent to multinomial logit models from the perspective of ground access mode choice.

The technical details of many of the earlier models have been documented by researchers at the Institute of Transportation Studies in the early 1990s as part of a research project for the California Department of Transportation (Lunsford & Gosling, 1994). This review was recently updated as part of a study for the Southern California Association of Governments to develop a Regional Airport Demand Model (Gosling, *et al.*, 2003). In addition to the studies described in the two literature reviews, a number of other airport ground access mode choice models have been subsequently identified. However, the level of detail reported in the literature for each of the models varies, with some authors only providing partial information on estimated parameter values, or even on the independent variables included in the model. It is common to estimate separate sets of model parameters, or even different model specifications, for different market segments, such as residents of the area versus visitors, or air travelers on business trips versus those on leisure trips. Some published articles describing these models only present the estimated values of the model coefficients for some of the market segments. This makes comparison of the different models difficult. However, detailed results are available for four recent models.

Boston Logan Model

This model was developed by the Central Transportation Planning Staff (CTPS) in Boston using a 1993 air passenger survey performed at Boston Logan International Airport (Harrington *et al.*, 1996). Separate submodels were developed for resident business trips, resident non-business trips, non-resident business trips and non-resident non-business trips. The two resident submodels consist of a nested logit model, with separate nests for door-to-door modes (taxi and limousine) and automobile modes (drop-off, short-term parking, long-term parking, and off-airport parking). There are four shared-ride public modes at the top level (regular transit, scheduled airport bus, the Logan Express service to off-airport terminals in the region, and the Water Shuttle between the airport and the downtown Boston waterfront). The visitor submodels are multinomial logit models and omit the long-term parking alternatives but add a hotel shuttle mode.

This model is particularly relevant to the current project because it includes both a rail access mode, the Metropolitan Boston Transit Authority (MBTA) regional rail transit system, and off-airport terminals, the Logan Express service operated by the Massachusetts Port Authority (Massport), the airport authority for Logan Airport. The MBTA Airport Station is adjacent to the airport and linked to the passenger terminals by a free shuttle bus service operated by Massport. Unlike many other airport access mode choice models, the CTPS model is also interesting in that it treats rental car use as an independent decision and excludes it from the mode choice decision process. Further details of the model are provided in Appendix B.

Portland Ground Access Study Model

Soon after the Boston Logan model was developed, a similar modeling effort was undertaken in Portland, Oregon, as part of a ground access study for Portland International Airport (PDX) jointly undertaken by the Port of Portland and Metro, the regional Metropolitan Planning Organization, with the assistance of Cambridge Systematics, Inc. (Bowman, 1997; Portland Metro, c1998). The primary purpose of the model was to forecast the potential ridership on potential ground access enhancements, including a planned extension of the Portland MAX light rail system to the airport. An air passenger survey was performed at the airport that combined a revealed preference (RP) survey that examined air passengers' actual mode use and a stated preference (SP) survey that was designed to determine travelers' preferences for modes that were not then available, namely light rail, express bus and shared-ride transit (it is unclear from the documentation how this was defined).

An initial model estimation was performed by Cambridge Systematics (Bowman, 1997) that jointly estimated two multinomial logit models using both the RP and SP data, one for business travelers and one for non-business travelers. These models were subsequently revised by Metro staff (Portland Metro, c1998). Separate parameters were estimated for the same four market segments as the Boston Logan model (this resulted in four models, rather than the two estimated by Cambridge Systematics). In addition, separate alternative-specific constants were estimated for each mode for trips originating within the Portland metropolitan area (termed internal trips) and those originating outside the metropolitan area (termed external trips). Two different sets of model parameters were estimated for each market segment, reflecting different assumptions for the alternative-specific constants for the light rail and express bus modes. Details of the final models are provided in Appendix B.

SERAS Model

As part of the South East and East of England Regional Air Service (SERAS) study undertaken for the United Kingdom Department of Transport, Local Government and the Regions, a set of surface access models were developed that included an air passenger mode choice model, an airport employee trip distribution model, and an airport employee mode choice model (Halcrow Group, 2002). The air passenger mode choice model is a nested logit model that covers 12 defined ground access modes and has separate coefficients for six market segments:

- U.K. business passengers on domestic trips
- U.K. business passengers on international trips
- U.K. leisure passengers on domestic trips
- U.K. leisure passengers on international trips
- Non-U.K. passengers on business trips
- Non-U.K. passengers on leisure trips.

The 12 ground access modes consist of several different types of rail link, including a dedicated express rail service (such as the Heathrow Express service from Central London to Heathrow Airport), London Underground, and coach connections to nearby mainline rail stations, as well as private automobile (both drop-off and park), rental car, taxi, local bus, and charter and intercity coach. The model adopted a nested logit structure, with several levels of nest to account for the complex pattern of public modes and alternative rail services. The utility functions for each mode use a generalized cost approach that considers travel time, out of pocket costs and time penalties for interchanges, with all costs converted to equivalent minutes of travel time. Details of the model are provided in Appendix B.

San José International Airport Model

This model was developed by Dowling Associates (2003) to estimate the ridership on a planned automated people-mover to connect the airport to a nearby Santa Clara Valley Transportation Authority light rail line. The model was estimated using data from an air passenger survey performed at the airport for the Bay Area Metropolitan Transportation Commission in 1995 and supplemented with the results of stated preference surveys that were conducted as part of the study to determine how air passenger mode choice might be influenced by the availability of the people-mover and to compensate for the limited number of users of the light rail line in the 1995 survey sample. Four multinomial logit submodels were estimated for the same four market segments used in the Boston model (non-business trips were termed personal trips). Each submodel included the following seven modes: private car, rental car, scheduled airport bus, door-to-door shuttle van, taxi, public transit bus, and light rail access via the people-mover. In addition, the visitor submodels included hotel shuttle. Details of the model are provided in Appendix B.

5.2.2 Alternative Mode Choice Model Approaches

While the nested logit model overcomes some of the inherent limitations of the MNL model, there remain a number of other limitations to the use of this functional form for modeling air passenger mode choice. Perhaps the most significant of these is the assumption that the variance of the error term in the utility function is the same for all air parties and all alternatives. Another limitation can arise where the same alternative appears in different nests, for example if several public transportation alternatives have station or stop access sub-mode nests that will typically involve the same sub-modes. Efforts to explore alternative model formulations to standard nested logit models have taken two approaches. One is to use more advanced logit model formulations that address some of the limitations in the standard model. The other is to use an entirely different conceptual approach to representing the mode choice process.

Advanced Logit Models

Work on advanced forms of the logit mode has explored two formulations. The ***mixed logit model*** (Hensher & Greene, 2003; Hess & Polak, 2005) allows the variance of the error term in the utility function to vary across travel parties and choice alternatives. In this model the variance of the error term is defined as a function of explanatory variables and associated parameters that are estimated. This overcomes a significant limitation of the multinomial and nested logit models that they assume an error term with the same variance for all alternatives and all travel parties. Of course, this also introduces a large number of additional degrees of freedom into the model specification. Since it is far from obvious how the variance of the error term ***ought*** to differ across alternatives or travel parties, considerable exploratory work will be necessary to develop reasonable error term functions that can be estimated. The estimation of mixed logit models is also significantly more computationally intensive than nested logit models and generally requires a simulation approach (Train, 2003).

The ***cross-nested logit model*** (Small, 1997) allows different combinations of elemental alternatives to appear in each choice alternative. This avoids some of the problems that are associated with the hierarchical nesting structure of a nested logit model. For example, in the case of a nested logit airport ground access model with fixed route modes at one level and station or stop access sub-modes (*e.g.* auto drop, taxi, local bus and walk) at a lower level, the variance in the access sub-mode utilities for one fixed route mode are assumed to be uncorrelated with those for the other fixed route modes. However, in reality an air party is likely to view the utility of a given access sub-mode in exactly the same way for access to any of the fixed route modes. The cross-nested logit model overcomes this restriction by defining alternatives that contain a combination of a fixed route mode and an access sub-mode.

While both mixed logit and cross-nested logit models have been used for urban travel mode choice modeling, their application to airport ground access mode choice is very recent and there are to date only a handful of papers that have reported attempts to use these models to study airport ground access mode choice. These models suffer from the disadvantage of being far more computationally intensive to estimate that traditional nested logit models, and to date it is unclear if the improvement in model performance justifies the effort involved. Nonetheless, this appears to be a promising area for future research.

Alternative Approaches to Modeling Mode Choice

Several recent papers have proposed alternative approaches to modeling mode choice that are not based on the use of logit or similar utility-based models.

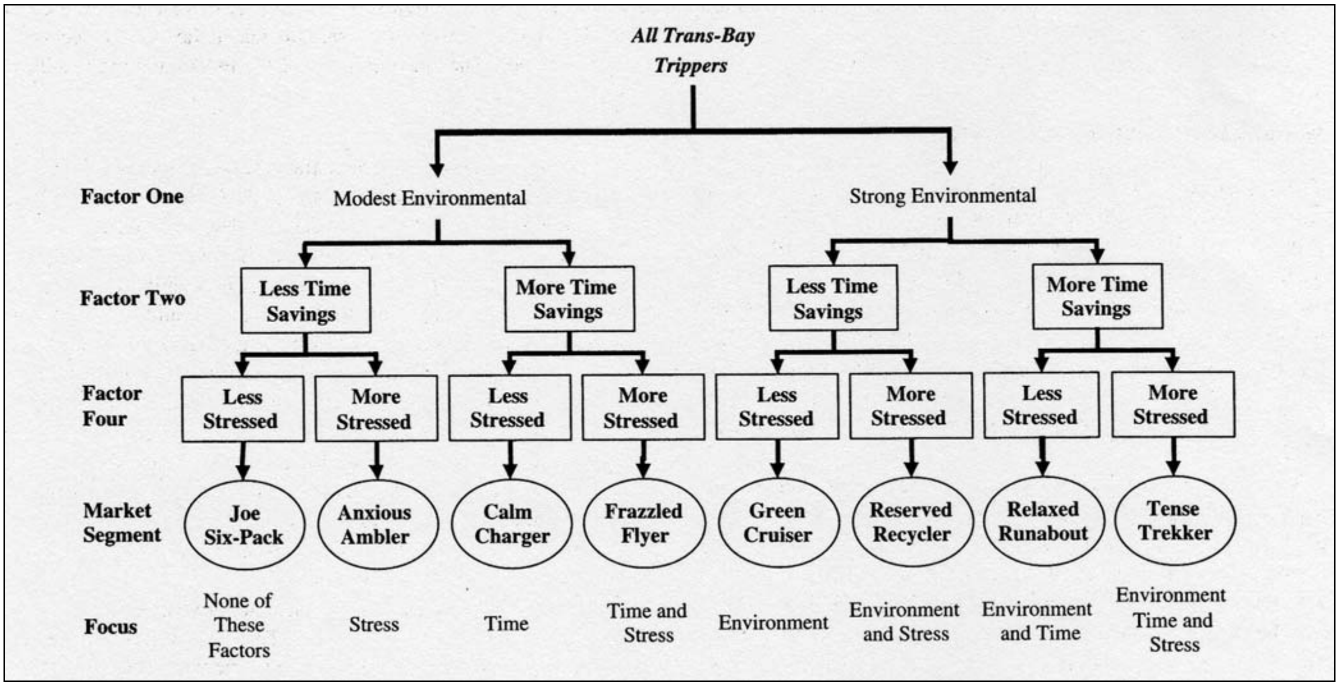
One approach that has been applied to a number of transportation mode choice problems is based on market segmentation by traveler attitude, rather than more objective criteria such as trip purpose or residence location. Proussaloglou and Koppelman (1989) applied this approach to the design of rail services and Golob (2001) developed joint models of attitude and behavior to explain traveler response to the San Diego Interstate 15 Congestion Pricing Project. More recently, Outwater et al. (2003, 2004) applied this approach to forecasting ridership on an expanded ferry system in the San Francisco Bay Area. While none of these studies have addressed airport ground access mode choice, the Bay Area ferry study is particularly relevant to the current research because it addresses the challenge of predicting mode use of an enhanced transportation service that does not currently exist.

In the Bay Area ferry study responses to a set of 30 attitude questions were collected as part of two surveys, a household survey that included a stated preference exercise addressing improved ferry service and an onboard survey of users of existing ferry services. The responses to the attitude questions were then grouped into six different factors using statistical factor analysis. The resulting six factors were classified as:

- Desire to help the environment
- Need for time savings
- Need for flexibility
- Sensitivity to travel stress
- Insensitivity of transport cost
- Sensitivity of personal travel experience.

Structural equation modeling (SEM) techniques were used to estimate functional relationships between each of these six factors and various socio-economic and demographic variables. The attitudinal factors derived from SEM were then used to define eight market segments for trans-Bay travelers using statistical cluster analysis. The resulting market segments were given descriptive names that were chosen to invoke the primary determinants of traveler attitudes in that segment, as shown in Figure 5-2.

In order to understand how mode choice behavior varies across the eight market segments, two sets of multinomial logit mode choice models were estimated, one set using the revealed preference (RP) data from both the household and onboard surveys and the other set using the stated preference (SP) data from the household survey. The mode choice models included market-segment specific constant terms and an additional travel time variable for the time-sensitive market segments. Three models were estimated in each case, one for home-based work trips, one for home-based shopping/other trips and one for home-based recreational trips. The SP models were used to forecast ridership on an enhanced ferry system. The RP models were not used in the forecasts but were developed for comparative purposes with the SP models. The modeling framework was applied by using the market segmentation model to divide the entire Bay Area population into the eight market segments based on zone-level socioeconomic and demographic data for 1998. The mode choice models were then used in conjunction with trip generation estimates by analysis zone and the proportions of different market segments in each zone to forecast ridership.



Source: Outwater, *et al.*, 2003

Figure 5-2: Market Segmentation for Bay Area Ferry Study

A somewhat different approach has been proposed by Karlaftis (2004) that makes use of a technique called recursive partitioning methodology (RCM). In this approach, a dataset is successively divided into a sequence of subsets that forms a binary classification tree (*i.e.* each node in the tree splits into two subnodes). At each node in the tree, the remaining cases in the dataset are split into two subsets on the basis of the values of one of the independent variables using a selected value of the variable as a splitting criterion. The variable used at each node and the splitting criterion value are selected so as to minimize the heterogeneity of the two resulting subsets, where the least heterogeneous subset would consist of cases choosing a single mode and the most heterogeneous subset would contain a mixture of cases choosing the modes in proportion to those in the entire dataset. In the Karlaftis paper, the measure of heterogeneity used to select the splitting criterion at each node is the Gini index of diversity, defined as:

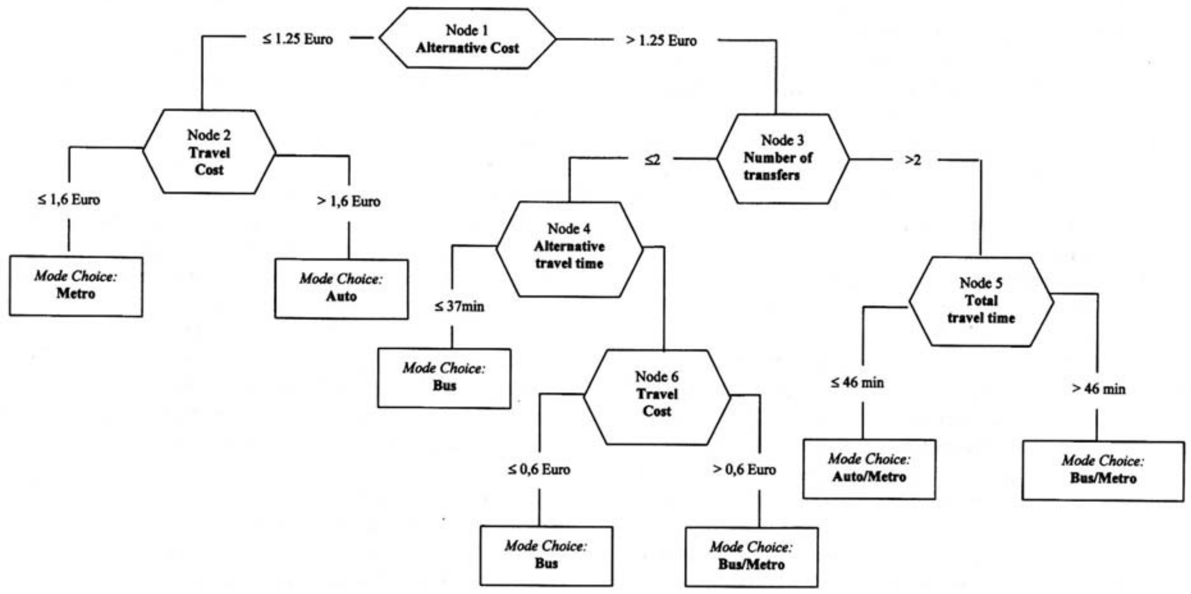
$$h(v) = 1 - \sum_{j=1}^{J} \left(p(j|v)\right)^2$$

where $h(v)$ = heterogenity of subset v (Gini Index of Diversity)

$p(j|v)$ = proportion of cases of class j in subset v

Selection of the variable to be used at each node and the value to be used as the splitting criterion is performed by iteratively testing each variable and selecting the variable and value that gives the greatest decrease in heterogeneity at the node, where the heterogeneity of each of the two resulting subsets are weighted by the proportion of cases in each subset. Each leaf of the resulting tree is assigned to that mode that has the greatest number of cases in the final subset at each leaf node. In order to use the model to predict mode use, the classification criteria at each node are applied to the cases in the dataset for which the prediction is required, and the resulting cases in each of the subsets at the leaves of the tree are assigned to the mode associated with that leaf.

The model was applied to three test cases in the paper, an intercity mode choice dataset from Australia and two urban commuter mode choice datasets, one from Athens, Greece and one from Las Condes, Chile. The resulting classification models were tested by applying them to a hold-out sample of cases from each dataset and comparing the predictions to the modes actually chosen. The predictive ability of the models was found to be very good. In the case of the Athens dataset, which had the largest number of cases of the three test datasets, the percentage of cases for each mode that were correctly predicted varied from 88 to 98 percent. The resulting classification tree for the Athens model is shown in Figure 5-3.



Source: Karlaftis, 2004

Figure 5-3: Classification Tree for Commuter Mode Choice in Athens

One question with the proposed approach is the extent to which it depends on the specific values on the independent variables in the dataset and therefore how stable the classification process will be over time, as the values of the variables change and the composition of the market changes. The models reported in the paper were tested against hold-out samples that were selected randomly from the same dataset, which implies that they had the same characteristics as the dataset on which the model was developed. Therefore one would expect fairly good correspondence between the performance of the model development dataset and the test dataset. Furthermore, the lack of any formal behavioral assumptions underlying the model makes it difficult to predict how the classification logic might change if a new mode is introduced or an existing mode is significantly changed.

However, in spite of these concerns, these non-parametric modeling techniques appear worth further study in the context of airport ground access mode choice models, and this could represent an interesting direction for future research.

5.3 Data Preparation for Modeling

The development of an airport ground access mode choice model requires data on the mode use of a sample of air party trips and the associated service characteristics of each mode. This forms a significant data assembly and management task. The air party data is typically obtained from an air passenger survey. In order to determine the ground access mode service characteristics for each survey respondent, it is usual to divide the region into analysis zones, assign each survey respondent to the appropriate zone, and then assemble the corresponding modal service characteristics for each origin zone.

In principle, the mode choice model estimation and application software requires a data table that provides for each air party (*case*) the values of the relevant air party characteristic variables (*e.g.* party size, trip duration in days, ground origin analysis zone, *etc.*) and the values of the relevant service measures (*e.g.* travel time, cost, *etc.*) for each of the alternative ground access modes. This can be thought of as a rectangular data table where the rows are air parties and the columns are the variables for each of the air party characteristics and ground access mode service measures. The values of each ground access mode service measure in any given row are the relevant value for that air party. In some cases these will depend on the characteristics of the air party (*e.g.* transit fares will depend on both the ground origin and the air party size) and in some cases the value will be the same for all air parties (*e.g.* travel time on a shuttle bus between the airport and a rail station).

The specific variables that will be required in the data table will depend on the specification of the utility functions in the mode choice model. However, since in general it does not matter if variables are included in the data table that are not used in the utility functions for a given model specification, in general it is better to include all potentially relevant variables so that the data table does not need to be revised every time the model specification is changed.

5.3.1 Structure of the Data Tables

Although in principle the required data file can be assembled as a single table, since many of the ground access service variables are the same for groups of air passengers (e.g. the highway travel time for all air parties from the same analysis zone), it is more efficient to organize the data into a set of separate tables that can be cross-referenced in a relational database structure. If any particular model estimation software requires all the variable values for each case in a single input data table, such a table can easily be constructed from the relational database.

Thus the following four tables can be specified:

1. Air party characteristics
2. Ground access mode service measures that are the same for all air parties
3. Ground access mode service measures that vary with the analysis zone
4. Ground access mode service measures that vary with trip duration.

Some ground access mode service measures (*e.g.* transit fares) will depend on both the analysis zone and the air party size. However, the data can be organized by analysis zone and the actual fare cost for a given air party computed in the specification of the utility function or the generation of the model estimation data table (depending on the flexibility to specify utility functions in the model estimation software). Where the fare per person varies with the party size (*e.g.* a lower fare for the second and subsequent persons in a party) it will be necessary to specify more than one fare variable in the data table. Similarly, highway travel times may vary by time of day (an air party characteristic) as well as analysis zone. This can be handled by defining several different travel times for each analysis zone.

5.3.2 Data Sources

Model estimation datasets were assembled for each of the three Bay Area commercial service airports. This allowed the development of separate airport ground access mode choice models for each airport, as well as a common model using pooled data.

Air Passenger Data

The most recent comprehensive survey for the Bay Area airports was undertaken for the Metropolitan Transportation Commission (MTC)[1] in two phases, the first in August and September 2001 and the second a year later in August and September 2002. The first phase ended when the air transportation system shut down on September 11, 2001, and the second phase was performed exactly a year later. This the first phase provides a profile of pre-9/11 traffic while the second phase provides an indication of post-9/11 conditions and behavior. The survey provides detailed information on the air trip, including the air party size and trip purpose and duration, as well as the origin of the ground access trip, the access mode used, and the household composition and income. The survey response data was obtained from the MTC as an SPSS file.[2] It included the respondent trip origin locations, geocoded to latitude and longitude. This allowed each location to be assigned to the appropriate MTC traffic analysis zone (TAZ), based on a TAZ boundary file obtained from the MTC using standard geographic information system (GIS) software. The current MTC system of traffic analysis zones comprises 1,454 zones covering the nine-county Bay Area. These vary in size depending on the density of general urban travel trip ends, but were deemed to be sufficiently small to provide reasonable estimates of ground transportation service characteristics and correspond to the level of analysis of regional travel modeling performed by MTC.

Ground Transportation Service Data

Data files with highway and transit travel times, transit fares, and highway bridge tolls were obtained from the MTC. These data files were generated as part of the regional surface transportation modeling activities undertaken by MTC and give travel times and costs between any two TAZs. The travel time data is generated from the regional surface transportation network modeling system termed Baycast-90 (MTC, 2004). The data used in the model

---

[1] The Metropolitan Transportation Commission is the Metropolitan Planning Organization for transportation issues for the San Francisco Bay Area.

development was derived from travel patterns in 2000. No attempt was made to adjust travel times to 2001 or 2002, although traffic conditions on the regional highway system had changed somewhat over this period. The data files provided two different travel times for each TAZ pair, a morning (AM) peak travel time reflecting average weekday morning commute congestion and a free-flow travel time. The MTC data files do not provide PM peak travel times, although the Baycast-90 documentation indicates that some PM peak analysis runs are performed in response to special requests.

According to the documentation on the Baycast-90 travel demand models, the AM peak is defined as 6:00 am to 9:00 am and the PM peak is defined as 3:30 pm to 6:30 pm. However, since the network models assume steady state conditions, the analysis is performed for a 2-hour and 4-hour AM peak. PM peak analysis (when performed) is based on a 1-hour peak. Therefore the AM peak travel time was assumed to apply to airport access trips that arrived at the airport between 7:00 am and 10:00 am on weekdays. Those trips arriving at the airport between 4:30 pm and 7:30 pm on weekdays were assumed to experience PM peak travel times. Obviously this is something of a simplification since the proportion of the access time that a traveler will spend under peak period highway conditions depends not only on their arrival time at the airport but also the distance that they have to travel. In addition, the MTC peak period travel times assume steady-state conditions, which obviously ignore the temporal dynamics of the flow on the highway network.

Since the MTC data do not include PM peak travel times, these were assumed to be the same as AM peak times. This is a considerable simplification and ignores directional issues in the congestion patterns, but is probably more accurate than assuming free-flow conditions. Airport access trips arriving at other times were assumed to experience free-flow conditions. This too is a considerable simplification and is likely to underestimate travel times, particularly on weekdays between the AM and PM peaks. Future work could explore the effect of introducing adjustments to these travel time assumptions.

The transit travel times and costs were obtained from an analysis of the Bay Area transit network, and thus for trips between any TAZ pair could be (and for longer trips almost certainly was) based on the use of more than one transit system. For example a trip from a TAZ in the East Bay to the San Francisco International Airport TAZ could involve an AC Transit bus ride to

---

[2] Statistical Package for the Social Sciences (SPSS) is a widely used commercial statistical software program.

a BART station, a BART trip to the Colma Station, and a ride on a Samtrans bus to the airport. However, in general it cannot be determined from the travel time and fare data which services were used. Thus these data were used for those trips using transit bus to access the airport, or for transit access to rail stations or schedule airport bus stops, but for those trips using rail systems as the primary access mode, the travel times and costs were calculated separately.

While current schedule, fare and rate information for each of the different ground access services can usually be obtained from the airport web sites or those of each transportation provider, assembling the data for the period of the air passenger surveys required a significant amount of research. Airport parking rates at the time were obtained from airport landside or planning staff. Some information could be obtained from ground transportation information publications that were current at the time and were in the personal files of the research team or were obtained from the airport staff. Efforts to locate back-up copies of airport ground transportation information web pages that had been current at the time of the survey proved unsuccessful. It appears that there is no formal process to archive these for future reference. Telephone enquires to transportation providers or regulatory agencies were able to produce some information, although in some cases this was simply the recollection of the person contacted. With some persistence, the rail system operators (BART, Caltrain and the Valley Transportation Authority) were able to provide schedules and fare tables for the two periods.

This information as assembled into tables for each mode. The stations for each rail system and stop locations for the schedule airport bus services were assigned to TAZs and fares and travel times calculated between each TAZ with a station or stop and the airport station or airport itself. An analysis was undertaken of the TAZ to TAZ highway distance data to identify the closest station or stop to each TAZ for each fixed route service, and the off-peak highway access time obtained. Finally the information was organized into a set of relational database tables that could be used to compute the ground access service characteristics for each mode for every air party in the air passenger survey data.

5.3.3 Adjusting Air Passenger Survey Data

One aspect of the MTC 2001 and 2002 air passenger survey required additional analysis and adjustment before the data can be used to estimate an airport access mode choice model. The survey methodology used a self-completed questionnaire that was distributed to all passengers over 16 in the boarding lounge and collected as passenger boarded or (in a few cases) mailed back by the respondent later. The questionnaire asked how many passengers in the air party completed the survey, as well as how many adults (over 16) were in the air party, and this number was used in the survey analysis performed by the survey contractor to weight the results to take account of multiple responses from the same air party.

However, examination of the survey response data shows that in many cases, the data from a given respondent is not consistent with the information stated on the questionnaires completed by other respondents from what appears to be the same party. There are three different potential problems with the data:

1. A respondent indicated that *p* members of the air party completed the questionnaires, but there are either more or fewer responses in the data that are obviously from the same air party (*e.g.* identical destinations and origin address);
2. There are *p* responses in the data that are obviously from the same air party, but the respondents reported that there were fewer than *p* adults in the air party;
3. Survey responses that are obviously from the same party give conflicting information on other party characteristics (*e.g.* access mode).

In order to identify the extent of these problems and to attempt to correct them, an analysis was undertaken of the air party survey response data to identify multiple records from the same air party and develop a more accurate estimate of the actual air party size. This analysis was based on the following procedure:

1. The survey response data was first sorted by month, day, flight (airline and flight number), air party travel destination, and origin address (city, zip code and street address), in that order. This was intended to group survey response records from the same air party together.
2. Each record was then assigned a Party Sequence Number, with successive records for each group of records apparently in the same air party numbered from 1. Each group of records was also assigned an Actual Response Count equal to the number of records in the group.
3. A check was performed to identify successive records that had a different street address, but the same city and zip code. These were inspected to see

if there were any misspellings or incomplete information in the street address (this was a fairly common problem) and the street address was corrected if necessary and the data resorted.

4. If successive records had insufficient street address information to determine whether or not they formed part of the same air party but had the same origin zip code, other fields were examined, including: air party size, ground access mode, ground access trip departure time and arrival time at airport. If it appeared from this additional information that the records were from the same air party, the street address field was modified (and the data resorted if necessary) to cause the records to be treated as a single party.

Two particular cases needed special treatment. Multiple responses from the same hotel were only considered to be the same air party if they had the same residence zip code, trip duration, arrival time and airport egress mode (where this information was provided). Tour groups or large travel parties that came to the airport by charter bus were considered to be a single air party as long as they had the same final destination, whether or not their ground origin was different. It was assumed that there was only one such party on each flight.

This adjustment process enabled the elimination of multiple responses from the same party and allowed the correction of some response errors (for example three responses that were obviously from the same party but that each reported only one person in the party). In many cases, however, where multiple responses from the same air party gave conflicting information it was impossible to determine which was correct, and thus one of the responses was selected on the basis of which appeared to be the most complete or consistent response.

These difficulties raise the question why survey respondents from the same air party would give different answers to the same question where the answer should be the same for each member of the party. It is possible that some differences are the result of data entry errors (possibly due to difficulty reading respondent handwriting). If they were on the original survey responses, they may reflect different recollection of relevant information or misunderstanding of terms used on the survey questionnaire (*e.g.* what constitutes an “air party”). Finally it is possible that some respondents deliberately gave incorrect information, whether because they somehow found this amusing or out of desire to conceal the correct answer for some reason.

While it is impossible to know the reason for these differences, the large number of them in the dataset does suggest that survey responses where only one response was received for an air party may well involve similar errors, whether of data entry or actual response, but since there is no other response to compare them to, there is nothing that might indicate a problem.

One other interesting aspect that emerged from this analysis is that the usual assumption that each air party travels together to the airport from the same trip origin does not always apply. Examples found in the data include two people traveling together on a business trip from the same firm that began their journey to the airport from their workplace but drove separate cars because they were presumably returning to their respective homes at the end of the trip, or two people from different households taking a trip together and meeting at one of the homes before traveling to the airport together. It is clear from these examples that air passenger surveys need to distinguish between the ***air travel party*** and the ***ground access party***. These are often the same, but not always. Similarly, where the members of a ground access party that arrived at the airport together began their trip to the airport from different locations, additional information on how they reached their final mode would be helpful for modeling their mode choice decisions.

5.4 Model Development and Calibration

Once the model estimation dataset has been finalized, the development of the mode choice model will be undertaken in an iterative process, in which the model formulation will be revised in the light of the estimation results. This exploratory development cycle will examine changes to the model specification as well as the inclusion of additional explanatory variables. As with any model development activity, the objective is not just to obtain a better statistical fit to the data but also to obtain a model that makes sound intuitive sense. Since poor model fit can result as much from trying to explain bad data as from model specification problems, analysis of the underlying estimation dataset to identify suspect data or better understand how specific factors appear to influence mode choice forms an essential component of model development.

5.4.1 General Structure of the Planned Model

The initial formulation of the planed model will use a nested logit structure, with modes with similar characteristics grouped together, as illustrated in Figure 5-3. The proposed structure does not include hotel courtesy van, since this is viewed as a captive mode for those visitors using hotels in the vicinity of the airport that provide this service and that have not rented a car. In the case of visitor trips, rental car is not included in the set of alternative modes shown above, but is a higher-level choice based on trip purpose, trip origin type and duration. Thus for visitor trips, the model might take a three-step sequence:

1. Rent car for duration of trip? *(yes/no)*
2. *(if no)* Starting access trip from hotel with courtesy van service? *(if so, use)*
3. *(if not)* Choose alternative mode using above structure

In general, it can be assumed that air parties choosing scheduled airport bus will choose the most convenient service. While there are a few situations where more than one service is available, the limited data in the air passenger survey will probably not allow a reasonable provider choice model to be developed.

- Private Auto
    - Drop-off *(residents and visitors with residence trip origin only)*
    - Park *(residents only)*
        - On-airport Daily lot
        - On-airport Economy lot
        - Off-airport lot
- Rental Car *(residents only)*
- Exclusive Ride
    - Taxi
    - Limousine
- Shared-Ride Van
- Scheduled Airport Bus
- Public Transit
    - Local bus
    - Regional rail (BART, Caltrain, VTA Light Rail)

Figure 5-4: Initial Mode Choice Model Structure

Rental car will generally only be an attractive option to those residents for whom their trip duration or distance from the airport would make parking a private vehicle or using other modes such as taxi or shared ride van very expensive, or who may not have a private vehicle available. There is a significant additional time involved in picking up and returning a rental car at both ends of the access trip, as well as getting between the car rental facility at the airport and the terminal in cases where this facility is some distance from the terminal.

The foregoing structure does not include an explicit representation of the access mode used to reach the airport bus or regional rail services. Initially this can be assumed based on the distance from the stop or station. A future refinement of the model could include a stop or station access mode nest.

5.4.2 Market Segmentation

Separate models (i.e. different model structure and/or different model parameters) will need to be developed for the following market segments:

- Resident business trips
- Resident non-business trips
- Visitor business trips (residence trip origin)
- Visitor business trips (hotel trip origin)
- Visitor business trips (other trip origin)
- Visitor non-business trips (residence trip origin)
- Visitor non-business trips (hotel trip origin).

While the need to distinguish been resident travelers and visitors and between those on business trips and those on personal or non-business trips is widely recognized in the literature, the role of different trip origin types has been less widely addressed. The principal effect of trip origin type is to constrain the available ground access modes. For example, visitors staying in a hotel will generally not have the option of being taken to the airport by private vehicle, although if they are staying in a hotel near the airport they may have a free courtesy shuttle available. Visitors staying in a hotel may also pay a lower fare for shared-ride van service than travelers with other trip origins, since shared-ride van operators often offer a different fare structure for hotel pick-ups from other locations, in part to offset any cost advantage of several travelers sharing a taxi.

Whether is proves necessary to estimate separate models for each market segment or it is sufficient to constrain the availability of different modes for each air party on the basis of their trip origin type is an aspect that can be explored in the model development.

5.4.3 Mode Utility Specification

The functional specifications for the variables included in the utility function for each mode will take the general form:

$$U_j = a_0 + a_1 * \text{Cost/Inc} + a_2 * \text{IVTT} + a_3 * \text{WT} + a_4 * \text{ACTT} + a_5 * \text{Walk}$$

where U_j = perceived utility of mode *j*

Cost = out of pocket cost ($)

Inc = function of household income *(form to be determined)*

IVTT = in-vehicle travel time (min)

WT = waiting time (min)

ACTT = auto access travel time to primary mode (min) *(where relevant)*

Walk = walking distance (100 feet) *(where relevant)*

a_k = estimated parameters

Previous models have recognized the importance of including household income in the utility functions, although there is no agreement on the appropriate form. The Boston Logan model discussed above distinguished between low-income and high-income travelers and estimated separate travel cost coefficients for each class of traveler for some modes and market segments. While this reflected the limited ability to identify separate coefficients from the data for some modes and market segments, it clearly makes no sense that the perceived value of travel time would vary with income for some modes and not others. The Portland Ground Access Study model expressed all costs as a ratio of the logarithm of household income. This gave an implied value of travel time that increased at a progressively lower rate at higher income levels. Conversely, the ground access model developed for San José International Airport expressed the costs for personal trips as a ratio of the household income raised to the power 1.5. This gave an implied value of travel time that increased at a progressively higher rate at higher income levels.

While it is self-evident that higher-income individuals are likely to have higher implied values of time, the appropriate relationship to household income is less clear. One consideration is that household composition affects the discretionary income per person. A single person making $100,000 per year is not the same thing as a family of four trying to manage on the same household income. Another consideration is the difference between gross income (which is presumably the figure given in response to air passenger survey questions asking about household income) and discretionary income after taxes and fixed monthly spending such as mortgage payments. Thus two individuals with the same per capita household income but with very different monthly housing costs might be expected to have very different perceived values of time. Developing an appropriate transformation for household income to include in the mode choice model will require exploratory analysis.

In the case of those modes where a shuttle bus (or people-mover) ride is required to reach the airport terminal, such as off-airport parking or a rail system where the station is not within walking distance of the terminal, the in-vehicle travel time and waiting time will include the times involved in waiting for and riding the shuttle, as well as the travel time and any waiting time for the primary mode. While the waiting and travel time involved in using a shuttle bus link may be perceived as having a different disutility from waiting and travel time on the primary mode, estimating coefficients for separate variables is generally problematical, due to the lack of variability in the values of the times involved for different air parties. However, to the extent that the perceived disutility is different, the effect of this difference will be picked up by the alternative-specific constant for that mode, since it will generally be a constant value for a given mode. Likewise, it may prove difficult to estimate coefficients for walking distance where these distances are the same for all users of a given mode.

5.5 Model Validation

Since the purpose of the mode choice model is to predict how air passengers will change their ground access travel choice behavior in response to changes in the ground access system, and in particular to improvements in intermodal connectivity, it is important to know that the model not only explains the observed pattern of ground access mode use for the time period for which it was calibrated, but also that it can do a reasonable job of predicting the changes in mode use resulting from subsequent changes in the ground access system. Fortunately, there have been two fairly significant changes in the ground access system at two of the Bay Area airports for which detailed data is available. The first and most significant change was the opening of the BART extension to San Francisco International Airport in June 2003. This provides an ideal test of the ability of the mode choice model to predict the effect of the improvement in accessibility to the airport that this provided.

The other significant change was the reorganization of the on-airport parking lots at Oakland International Airport. This was precipitated by a number of factors, including the need to keep vehicle parking further from the terminal buildings after September 2001, increasing traffic levels at the airport, changes in passenger pick-up and drop-off behavior once greeters and well-wishers were no longer allowed through security to the passenger terminal gate area, and a plan (currently on hold) to construct a multi-level parking structure in place of surface parking in front of the terminals. As a result the economy lot was relocated much further from the terminal, adjacent to the airport access road, and the parking rates revised. This increased the time required to travel between the economy lot and the terminal, due partly to the greater distance and partly to the fact that the lot is now too far to walk to the terminal, so users have to wait for a shuttle bus. Although the previous location was also served by shuttle bus, it was close enough to the terminal that many users chose to walk between the lot and the terminal.

Although these changes in the ground access system at the two airports present potentially useful opportunities to validate the mode choice model, doing so raises some complex data issues. As with any analysis of changes in mode use over time, there is the possibility that observed changes in mode use could be due to changes in the composition of the air passenger market (such as a change in the proportion of business travelers or the split between Bay Area residents and visitors). In the case of the BART extension to San Francisco International Airport, the airport station entry and exit data includes both airport employees as well as air passengers. At Oakland International Airport, the changes in the on-airport parking lots occurred at a time when an improved airport access route on 98th Avenue was completed and several new off-airport parking lot operations opened. In the absence of detailed air passenger survey data for these periods, it will be necessary to undertake a careful analysis of the available time series data on airport access mode use and attempt to make adjustments for these factors.

Chapter 6. Modeling Transportation Provider Behavior

This chapter presents the general framework proposed for the modeling of transportation provider behavior within the IAPT. For the purposes of this modeling the critical transportation provider behaviors that need to be considered are decisions regarding changes in service attributes that affect the air passenger mode choice. These include setting prices and fares, determining service frequencies, and selecting or adjusting routes or service areas. As discussed earlier in this report, the principal objective of modeling these decisions is to determine how these service characteristics will change as a result of the introduction of a new mode or improved service, particularly an enhanced intermodal connection. Since the current values of these service characteristics are known for existing services, it is not necessary to determine what they *should* be under current conditions, but rather to determine how they can be expected to change in the future in response to changes in the airport ground access system.

In general, the transportation providers will respond to changes in their own traffic level as well as the service characteristics (fares, frequencies, etc.) of their competitors. While changes in the service offered by their competitors, if unmatched by changes of their own service characteristics, will of course result in changes in their own traffic level, they may not wait until such changes in their traffic appear but respond immediately by adjusting their own service characteristics. While transportation providers know their own traffic levels, they have much less information about the traffic levels of their competitors. Nonetheless, they will know something about the traffic levels of their competitors, even if only from casual observation or anecdotal information. They may also therefore respond to a perceived (or known) loss of market share. Finally, they may respond to a perceived opportunity to increase their market share or profitability.

Transportation providers may apply different **strategies** of varying degrees of sophistication:

1. Match or undercut their competitors
2. Attempt to maximize their traffic (market share)
3. Attempt to maximize their profit

Profit maximization requires more information than traffic maximization, because it requires an understanding of how costs vary with traffic (i.e. supply side characteristics) in addition to how traffic varies with service characteristics, whereas traffic maximization only requires an understanding of how the traffic varies with service characteristics (i.e. demand side characteristics).

There are four aspects of the system that must be considered in planning for intermodal transportation: decision makers (government at different levels); users of the system (passengers, shippers, and airport employees); transportation providers, and the relevant transportation networks. The relationships among these four system components from the perspective of the transportation providers are shown in Figure 6-1, together with potential modeling assumptions regarding the influence on transportation provider behavior of decisions being made by the other parties in the process and traffic conditions on the highway network. From the point of view of modeling transportation provider decisions, it is necessary to consider the effects that the other parties and traffic conditions have on them.

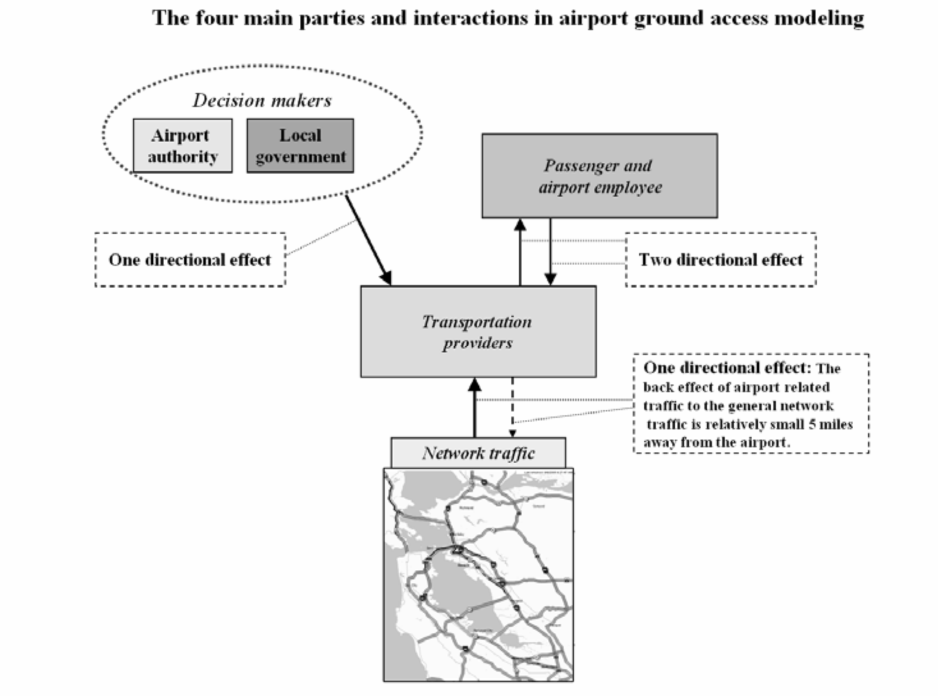


Figure 6-1 Interactions of System Components in Transportation Provider Decisions

6.1 Operational Considerations

The following discussion describes some of the operational considerations that affect decision-making by the various modal organizations. Since public agencies and private firms may have different business goals, they are discussed separately.

6.1.1 Public Agencies

Public agencies include airport authorities and local transit or regional rail agencies. In some cases the same transit agency operates both bus and rail systems. In other cases, bus and rail systems are operated by separate agencies. However, since the characteristics of bus and rail systems are so different, even where both systems are operated by the same agency, they can be considered as a separate decision-making process.

Most airport authorities limit their direct provision of ground transportation services to operating on-airport parking lots. However, the Los Angeles World Airports also operates the Van Nuys FlyAway Service, an express bus service to an off-airport terminal in the San Fernando Valley, and is currently considering providing a similar service to other locations. A number of airports operate (or have operated) shuttle bus or automated people-mover (APM) connections between the airport and nearby rail stations or other ground transportation facilities, such as consolidated rental car facilities. To date, San Francisco International Airport is the only California airport operating an APM (AirTrain) and it operates entirely on airport property, connecting the airport terminals to a consolidated rental car center. However, Los Angeles World Airports, the Port of Oakland (in association with BART), and San Jose International Airport are each planning APM links to nearby rail stations. Many of these airport-provided services are actually operated by private firms under contract to the airport (for example APCOA Airport Parking). However, since the airport authority can (and typically does) determine the details of the service provided, including rates and fares, this is considered to be a public agency decision.

On-Airport Parking

Most airports view on-airport parking as an important revenue source. Thus, maximizing revenue is a key policy goal. At the same time there may be a need to balance the use of different parking lots so that spaces are available at all times at each lot. Typical airport pricing policy charges a fairly high rate per hour (or shorter period) with a daily maximum. This results in a situation where spaces being used by vehicles parked for a short term (less than 6 hours) generate more revenue than spaces being used by vehicles parked for a day or more. Therefore airports typically designate separate areas (or lots) for short-term and long-term parking, and adjust the rate difference to discourage those parking for more than a few hours from occupying the more convenient short-term spaces that are located closer to the terminals. Some airports have a three-tier system, with short-term, medium-term (often termed daily parking), and longer-term (often called economy) areas or lots.

Although an airport might wish to adjust the parking rates to maximize revenue, there are a number of factors that complicate determining what these rates should be. The first is that raising the rates too high may divert potential users to other modes, particularly drop-off and pick-up by private vehicles, which typically generates no revenue for the airport. The second factor is the presence of privately operated off-airport parking lots in competition with the airport lots. Too large a rate differential will divert parking to those lots, also resulting in a loss of that revenue. However, those operators may decide to adjust their rates when the airport changes the on-airport rates, as discussed later. The third factor is that shuttle buses may be required to transport passengers to and from more distant lots. Diverting vehicles from close-in lots where passengers can walk between the lot and the terminals to these more distant lots may increase the number of shuttle bus trips required, with a consequent increase in operating cost for the lots.

A fourth factor has emerged in recent years with the changes in security requirements that prevent greeters and well wishers from going to the airline gates to meet or see air passengers off. This has increased the amount of drop-off and pick-up traffic and led to severe terminal curbfront congestion at many airports. This congestion is worsened by traffic recirculation resulting from the prohibition of vehicles waiting at the curb. Some airports have attempted to address this by providing free parking for a limited time, or developing free “cell-phone lots” where those picking up air passengers can wait until the air passengers call them to indicate that they are ready to be picked up from the terminal curb. However, this is likely to reduce the revenue from short-term parking, since some greeters who might otherwise have paid to park for a short time will now use the free lot. When a free initial period is provided in the regular lot, there is no way to restrict the use of this to those picking up air passengers and there will also be a loss of revenue from those dropping off air passengers (who would not use a cell-phone lot anyway).

Another consideration for on-airport parking is that the provision of parking facilities is not costless. Structured parking is very expensive compared to surface lots, but surface lots require a large area that the airport may need for other facilities. Thus in addition to short-term decisions about parking rates, there are longer-term planning decisions about how much parking to provide and in what form to provide it.

Off-Airport Terminals

In contrast to on-airport parking, the primary motivation for an airport to establish an off-airport terminal service is to reduce the vehicle trips to and from the airport, whether to address highway congestion, airport roadway congestion, or air quality concerns. Depending on the pricing structure, the service may make money or it may require a subsidy. Parking is typically provided at the off-airport terminal at lower rates than at the airport, in part to attract patrons to the service, and this may well generate more revenue than it costs to provide the parking.

In addition to decisions about where to locate the off-airport terminals, how much parking to provide, and what fare to charge for the bus service to and from the airport, the patronage attracted to the service will depend on the frequency of the bus service. At periods of peak demand for the service, the frequency is likely to be largely influenced by the traffic volume and indeed it may be necessary to run additional buses to carry all the traffic. However, at off-peak periods the frequency is likely to be determined more by waiting-time considerations. The directionality of the traffic flows (the peak demand in one direction is likely to occur at a different time of day from the peak demand in the other) and extent of peaking will result in many buses running with low load factors. There is also the operational consideration that once a bus is dispatched in one direction, it will generally have to return to be available for a subsequent run. Since the round trip travel time is not likely to vary widely from run to run (particularly if the buses can use high-occupancy vehicle lanes or exclusive bus lanes to avoid the worst of any highway congestion), productive use of the vehicles and drivers is likely to require a fairly constant headway throughout the day, irrespective of changing levels of demand.

Shuttle Bus and Automated People-Mover Links

Shuttle buses or APM links to nearby rail stations or other transportation facilities are not a primary ground access or egress mode, but can influence the attractiveness of those other modes. A key decision for the airport authority or operator of the links is whether to charge for the service and if so how much, while a related decision is how often to run the service. At busy periods, the frequency may be determined by vehicle capacity considerations, while at other times the frequency is a policy decision that will influence the attractiveness of the transportation modes being served. If a fare is charged, there is an obvious relationship between the fare and the service frequency. A higher fare may be justified for a more frequent service and will generate more revenue per passenger carried. However, whether an increased frequency at a higher fare will generate more or less riders will depend not only on the fare and frequency involved, but also on the attractiveness of the transportation mode being served and the relative attractiveness of the competing ground transportation services. In general, it is likely that the cost of operating an increased frequency will not be matched by the increase in revenue from the additional riders attracted by the higher frequency.

Another consideration in service frequency is the round-trip travel time on the shuttle bus route. The number of vehicles required to operate the service depends directly on the headway and round-trip travel time. The calculation of round-trip travel time needs to take account of any breaks required by the drivers, slack time required to allow the vehicles to make up for any delays due to traffic congestion or passenger loading and unloading, and any time out of service for refueling.

Waiting times with APM systems will depend on the number of cars in service. At busy periods the waiting times will be determined by the maximum number of cars available, while at less busy periods the number of cars put in service involves a trade-off between the maximum expected wait and the cost of operating the cars. Although the size of the cars will determine the capacity of the system at peak times, this is a design decision that involves trade-offs between frequency and load factor at busy periods. Larger cars will generally imply a higher operating cost per car mile, which will tend to act as a disincentive to maintaining high frequency at less busy times. This problem can be partly offset by the use of small cars that can operate in short trains at busy periods.

Bus Transit

Airport service is generally a very minor part of most bus transit agency systems. Typically only one or two routes serve an airport, and those routes usually serve large numbers of passengers who are not traveling to and from the airport. The design of the routes that serve an airport is generally determined more by the travel needs of the non-airport patrons than those traveling to or from the airport. Which routes serve the airport thus tends to be more a factor of which routes happen to go past (or near) the airport for other reasons. For example, the Samtrans 7F route provides express bus service between Palo Alto and downtown San Francisco via the U.S. 101 freeway. Since the route goes right past San Francisco International Airport, it makes sense to include a stop at the airport terminal, thus linking the airport with both downtown San Francisco and the stops served by the route in southern San Mateo County.

Fares are usually set on a systemwide basis, with no premium for airport travelers. Frequency tends to be determined on the basis of the other demands on the route. Vehicle type and size is largely a reflection of the composition of the entire vehicle fleet, which tends to be determined more by overall traffic volumes on the network than on particular routes.

Most bus transit systems only recover part of their operating costs from fares, and thus require subsidies from a variety of public funding sources. The justification for the use of public funds to support these services is partly to provide transportation alternatives for those who do not have access to or cannot use private vehicles (children, the elderly and disabled, the poor, and those unable to drive for whatever reason) and partly to provide an alternative to private vehicles as a way to reduce traffic congestion and vehicle emissions. This has important implications for the attitude of bus transit agencies to providing service to airports, where other alternatives exist and travelers are generally perceived as being able to afford to use them.

Rail Systems

Rail systems include metropolitan light and heavy rail (e.g. the Santa Clara Valley light rail system and BART), regional commuter rail (e.g. Caltrain in the Bay Area and Metrolink in Southern California), and intercity rail services (e.g. the Capitol Corridor Amtrak trains). While the technology differs, the nature of the service and the factors affecting agency decision making are sufficiently similar to be treated as the same. A major characteristic of these systems is that they require large operating subsidies, and any new service (such as new equipment or new lines) requires capital grants, typically from Federal and state funds, although bonds financed through local taxes are also used. The argument for the use of public funds to subsidize these services is generally the same as for bus transit systems, with perhaps more emphasis on reducing highway congestion and improving air quality.

In contrast to bus transit systems, fares are generally set on a station-pair basis and vary by station. Thus where a rail station is located at an airport and only serves riders traveling to and from the airport, the operator has the option of charging a premium fare for airport trips. However, where the station serving the airport also serves other patrons, then the issue is more complicated and it may be more difficult to justify a premium fare. The operator may also have a policy of treating all users equally, irrespective of the nature of their trip. Because of the large capital investment and operating subsidies required, operators have a strong incentive to increase ridership, thereby both helping the farebox recovery ratio (the proportion of operating costs paid by the riders) and justifying the capital investment. For these reasons, operators may view airport service as an opportunity to attract additional riders and build public support for the expansion or continued operation of the system. Rail systems tend to attract higher income riders compared to bus transit services, and airport services may attract riders who would not otherwise use public transportation at all.

Where airport stations are located on a line that serves other stations, the proportion of riders on any train who are traveling to and from the airport is likely to quite small, and train frequencies are largely determined by the needs of these other riders. One exception to this arises where a regional rail service predominantly serves highly directional commute travel, such as the Metrolink services to downtown Los Angeles. Train frequencies in this situation are typically much lower in the non-commute direction, during the middle of the day, and at weekends (indeed there may not be any service in the non-commute direction or at weekends). However, these may be precisely the times and directions when air passengers and airport employees would like to use the service to get to the airport. In particular air passengers from the downtown or traveling through the downtown are likely to require outbound morning service to the airport and Sunday evening service as they return from weekend trips or arrive for meetings or activities during the week. Because of shift work, airport employees also may be traveling at non-commute times, and in the non-commute direction depending on where they live. This may require additional trains that primarily serve airport trips. The operator will have to decide if the airport riders are enough to justify the costs of the running the additional trains.

In the uncommon situation where a dedicated line serves the airport (this is presently the case in California only at San Francisco International Airport), there is the issue of which trains from other lines in the network to route to the airport line. This reduces the number of transfers for passengers on lines with trains that provide direct airport service, but may involve additional waiting time if not all trains on those lines serve the airport. The provision of coordinated, cross-platform or same-platform transfer can significantly reduce the inconvenience of not having direct airport service, and increase the efficiency of train operation.

6.1.2 Private Firms

In contrast to public agencies, the objective of private firms is generally to maximize profit. However, while public agencies are not usually directly in competition with similar agencies providing the same service (there may be multiple transit agencies in a region, but they typically have distinct service areas or routes), it is quite common to have several different firms providing the same ground transportation service and competing for the same passengers or customers. Therefore inter-firm competition is as important as inter-mode competition in how these firms establish their service characteristics.

Off-Airport Parking

Operators of off-airport parking lots are in competition with the on-airport parking lots as well as each other. Thus they are likely to adjust their parking rates in response to rate changes either for the on-airport lots or by other off-airport parking operators. An important competitive service characteristic is the frequency with which they operate their shuttle vans between the lot and the airport. The frequency will be determined by the number of vans that they have in service. During busy periods this may be constrained by the number of vans they have in their fleet, while during less busy periods they may establish a maximum waiting time for a customer and dispatch a van with only one party on it if necessary.

Since it will generally take their customers longer to get to the airport using an off-airport lot than parking in an on-airport lot (although not necessarily), they will generally charge lower rates than the on-airport lots. Airport staff have suggested in discussions about parking rates that off-airport parking lot operators tend to set their rates at a constant margin below the on-airport long-term rates, although this margin may vary across the different operators, depending on their location and how frequently they provide shuttle van service. Some operators offer discounted rates for advance reservations through the Internet or issue discount coupons through various means, such as travel agents, direct mail or travel publications. They may also offer other discounts on their daily rate, such as every fourth day free. This can make comparing rates at different lots quite complex.

Rental Car

Rental cars are typically rented for the duration of a visitor's stay in the region, which complicates the discussion of the cost of using a rental car for airport access and egress trips. This is further complicated by the fact that most rental car companies offer both daily and weekly rates, so that the cost of renting a car for an additional day may be zero (or the cost of an additional day's insurance fee). In any event, visitors renting a car are likely to do so at the airport anyway, and so they necessarily use the car for their airport egress and access trip. Car rental rates vary widely by rental company and car model, and the companies may well apply some form of yield management, in which the rate that they will charge for a particular vehicle will vary with the demand for that size of vehicle. Furthermore, customers may choose to rent a larger, more expensive car for reasons of comfort or prestige, while the choice of rental car company may be based on perceptions of reliability or the availability of special corporate rates.

A major decision faced by a rental car company is whether to locate on or off the airport. On-airport companies pay higher concession fees to the airport, but have the advantage that their facilities are more accessible and they can typically have a customer service counter in the baggage claim area. Off-airport companies have to provide a shuttle bus service to transport their customers to and from the airport. This is not only an additional expense, but can add significantly to the time required to rent and return a car. As with off-airport parking lot operators, there are decisions about how frequently to operate the shuttle bus.

The development of consolidated rental car facilities at many airports, which typically require customers to ride a shuttle bus to reach the facility (or an APM in the case of San Francisco International Airport), has reduced some of the advantage of an on-airport location. In an attempt to preserve an advantage for on-airport companies, airports with a consolidated rental car facility beyond walking distance from the terminal typically require off-airport companies to pick up and drop off their customers at the facility, making everyone ride the shuttle bus. Airport staff at San Jose International Airport have noted that when they opened their consolidated rental car facility that required a shuttle bus ride instead of the short walk to the prior rental car pick-up and return areas, rental car use went down and taxi use went up. This suggests that for at least some air travelers, the decision of whether to rent a car takes into account the time and cost involved in alternative ways of getting around during the visit.

The development of consolidated rental car facilities impacts the cost of renting a car in another important way. The costs incurred by the airport in constructing these facilities and operating the shuttle buses are typically recovered from the rental car companies through airport fees that the rental car companies add to each rental contract. These often appear as "below the line" charges in addition to the rental rates that the companies advertise. This can significantly increase the cost of renting a car, particularly for a short time.

While most rental car use is by visitors to the region, for obvious reasons, there may be some situations in which residents of the region who live a long way from the airport find it cost effective to rent a car each way for their trip to and from the airport, rather than driving and parking for the duration of their air trip, imposing on a friend or family members to take them to the airport and pick them up on their return, or using some other mode of ground transportation. The cost and convenience of such an approach will depend on whether there are any drop-off or other fees for a one-way rental and how easy it is to pick up and return a rental car near their home.

Taxi

Taxi rates in most urban areas are set by the local cities, often by a special-purpose body such as a taxicab commission, and the taxis are metered. The rates are generally based on distance or time (when the travel speed is slower than a specified speed or for time spent waiting). There may also be a fixed charge ("flag drop fee") and additional fees for bulky luggage or additional passengers. Airports typically charge taxis a fee for picking up a passenger and this is usually recovered from the passenger through the additional fees. Airports may also restrict taxis picking up passengers to those from the local jurisdiction (or in the case of San Francisco International Airport, the City and County of San Francisco). Taxis from other jurisdictions may drop off passengers and typically may pick up passengers by prior arrangement. However they will typically charge an additional fee to cover their round trip, since they are unlikely to be able to pick up a fare for the other direction.

Cities generally limit the number of taxis that are licensed to operate in the city, and the number of licenses and taxi rates are adjusted from time to time to ensure that sufficient taxi service is available. Because of the higher fares typically involved, taxi drivers are usually keen to get trips to the airport, and once at the airport will generally wait for a return trip. Because of the directional imbalance in air passenger trips by time of day, these waits can often be quite long. However, even an hour wait for a fare may still be a better option than deadheading back to the city to cruise for another fare. The deadhead trip could easily take a half-hour and the taxi may have to cruise for some time before picking up a fare, which may anyway be a fairly short trip. When there is a shortage of taxis at the airport, the taxi dispatcher at the airport will typically call the taxi companies and ask for more taxis to be deadheaded to the airport. Because of the higher fares involved and the prospect that there will be little or no wait at the airport, the taxi companies and drivers are usually happy to comply.

Many taxi companies hold the licenses and own the taxis but lease them to the drivers for a daily "gate fee". The driver pays for fuel and keeps any fare revenue in excess of the gate fee. Dispatchers at the taxi companies take telephone reservations for taxi service and dispatch the closest vehicle (or sometimes the most appropriate vehicle) by radio. Drivers however are free to cruise in search of fares or deadhead to the airport and wait for a fare there.

Thus decisions on taxi rates and availability of taxis are generally outside the direct control of either the airport or the taxi companies, and certainly outside the control of the drivers, although taxi companies frequently use the political process to lobby for more favorable treatment. The airport may lobby for more licenses to be issued if there are times when an insufficient number of taxis are available.

Limousine

Limousines (also known as hire cars) provide on-demand door-to-door service, much like taxis, but at set rates rather than metered rates. They typically use more luxurious vehicles than taxis. Although in California they are licensed by the state Public Utilities Commission, they are free to set their own rates within certain limits, and thus compete on price with each other. However, they generally do not publish their current rates in advance, but quote them to potential customers in response to a specific enquiry. This makes it difficult for potential customers to compare rates or know whether a particular quote is reasonable or not.

Some limousine companies may have a counter at the airport and provide on-demand service to arriving passengers who have not made an advance reservation. Other companies may only provide service in response to a reservation, and may only serve a particular area within the region. Thus limousine company service decisions involve which areas to serve, whether to have a presence at the airport (this could involve a staffed counter or simply a counter with a telephone), and the rate schedule for their service area. Many limousine companies are quite small (some may only have one vehicle), which may affect their ability to accept a given reservation. Thus another service decision is how many vehicles to have.

Shared-Ride Van

Shared-ride van services provide door-to-door service in defined geographical areas. A given operator may serve several such areas, but the logistics of picking up or dropping off several air parties tends to restrict each van trip to a fairly small geographic area. The larger the area served in relation to the volume of traffic carried by the operator, the less likely it will be that several reservations will occur within a reasonable proximity and time frame. Thus the operator will either have a very circuitous pick-up or drop-off route, which will make the first passengers to be picked up or the last passengers to be dropped off very unhappy, or will have to assign a pick up time to passengers well before their flight departure time in the hope that a later reservation will come in for a pick-up in same general area that can be served with the same run. This will also make the passengers very unhappy, and in fact if the lead time is too long the passengers may decide to use another service or mode. In the worst case, the operator will only get one travel party for each run and will in effect be operating a taxi service, but at shared-ride fares.

The situation at the airport is a little easier because all the potential passengers are in one place. The dispatcher can group people by general destination, and passengers have the option of selecting the operator that has a van going to the general area of their destination, whereas when they call up to make a reservation for a trip to the airport they have no idea what other trips the van that picks them up will have to serve. Even so, the operator cannot expect passengers to wait for very long in the hope that another party appears that is going to the same general area, and at some point will have to serve the passengers that are there.

Although shared-ride van operators do not usually operate to a published schedule, the practicalities of accepting reservations mean that they usually operate an implied schedule. When the first passenger calls up to request a pick-up, they have to be given a pick-up time, even though the operator does not know the flight departure times of the next passengers to call. Also, the operator needs to have a vehicle available to perform the pickup. Therefore pickups in a given area are generally scheduled at set times past the hour so that a series of pickups in adjacent areas can be linked into a reasonable sequence. When a passenger calls to make a reservation, they are assigned to one of these times based on the time required to get them to the airport in time for their flight. Trips from the airport are dispatched to ensure that there is a vehicle that has completed its drop-off run in time to perform the pickups when required.

Therefore the most fundamental decision faced by an operator is what geographical area to serve. Once a service area has been defined, then fares need to be established for each fare zone. Typically cities or groups of zip codes are used to define fare zones for convenience in determining the correct fare to quote. Then based on the rate at which passengers request service in each area, the frequency at which to dispatch vans needs to be determined. As the service request rate drops, so the circuity in picking up multiple parties increases and travel times increase, or service frequency has to be reduced. This results in a trade-off between load factor and the travel time for the first passenger to be picked up, which affects both the time it takes the van to serve the run as well as the satisfaction of the passengers with the service. Thus there are limits on how much circuity is tolerable, just as there are limits on how long before flight departure passengers are willing to arrive at the airport. Reducing fares will increase ridership, which will reduce circuity and permit more frequent service, but the increased ridership may not be enough to offset the lower fares, resulting in a reduction in revenue. Even if revenue increases, so do the operating costs of any increased frequency required to handle the additional passengers. Thus profit may decline.

Unlike taxis and limousines, which typically do not charge extra for additional passengers, shared-ride vans typically charge one fare for the first passenger in a party and a lower fare for additional passengers traveling together. This makes the service more attractive for parties of more than one person and generates additional revenue by increasing the load factor. As a practical matter there is a limit to how many stops can be made to pick up passengers without the time spent picking up passengers becoming excessive and some operators have a defined policy on this, such as no more than three stops after the first pick-up. Since the vans generally seat at least seven passengers, it is desirable to attract a reasonable number of multi-person parties. Some operators have different fares for passengers picked up from or dropped off at hotels, since these may be unrelated individuals although traveling on the same van. Rather than a fairly high fare for the first passenger in a party and a lower fare for subsequent passengers, they have a fare somewhere between the two rates that applies to all passengers picked up or dropped off at a hotel. This avoids disputes about whether these passengers are the same travel party or not. In addition discounts can be offered for round-trip tickets as a way to discourage travelers from using other modes or services for their return trip. Thus decisions need to be made about the fare structure as well as the average fare level.

Scheduled Airport Bus

Scheduled airport bus operators face many of the same operational issues described for off-airport terminals above, namely balancing fare and frequency, and choosing which routes to operate and stops to serve. However, unlike airport-sponsored off-airport terminal services, they do not have the option of operating at a deficit (at least not intentionally and not for long). Although most scheduled airport bus services locate their stops at hotels, transit centers or other establishments that provide somewhere for passengers to wait and short-term parking facilities, they may operate their own off-airport terminals with on-site parking. In the Bay Area, Marin Airporter operates two off-airport terminals in Marin County at Larkspur Landing and Ignacio.

Service decisions involve which routes to operate, where to locate stops on those routes and whether to provide any facilities at those stops, what size equipment to use, how frequently to operate and what fares to charge. These decisions all interact. Service frequency is influenced by the geography of the route as well as the size of the equipment and the traffic loads to be carried. Larger equipment reduces the cost per seat, which could allow lower fares that might attract more traffic, but at the price of reducing frequency. For marketing purposes it is desirable for departures from a given stop to be at regular and consistent times, such as every half hour at ten minutes and forty minutes after the hour, but this is influenced by the round-trip travel time to and from the airport.

Scheduled airport bus services typically charge the same fare to all passengers, although they may have a reduced fare for children or a discount for a round-trip fare. One operator has offered a “greeter/wellwisher” fare that allows a return trip within a defined time period for the one-way fare.

Hotel Courtesy Vans

Hotels located near an airport may provide a courtesy shuttle to and from the airport for their customers. The service is generally provided at no charge. Therefore the only service characteristic of relevance to the decision of an air passenger whether to use the courtesy shuttle is the waiting time involved. These services are generally provided on an as-needed basis, although at busy times they may effectively operate on a fixed headway, due to the limited number of vehicles in service (often only one). Operator decisions are therefore restricted to whether to provide the service at all and how many vehicles to put in service at different times of day. At less busy times, a customer who calls the hotel to request a pick-up from the airport may have to wait while a van is dispatched from the hotel and drives to the airport. In the worst case, there may be a single van in service that has just left the airport for the hotel and the patron may have to wait while the van proceeds to the hotel and then returns to the airport.

Some airports have encouraged several hotels located near each other to provide a shared courtesy shuttle service. This reduces the number of vans using the terminal curbfront and airport roadways and can provide more frequent service to customers. However, more distant hotels can have concerns that such an arrangement may favor those hotels closer to the airport, since the intermediate stops involved increase the time required to reach the more distant hotels. One solution to this problem is a circular route that results in every customer having the same total time for the round trip from and to the airport.

Charter Bus

Charter buses are generally associated with large travel groups such as sports teams, school groups, and organized tour groups. As such, the decision whether to use a charter bus is taken by the group organizer in the light of the cost of chartering the bus and alternative ways of getting the group to and from the airport. It is likely that considerations of keeping the group together play a larger role in the decision than the cost of chartering the bus (although of course differences in charter rates will influence which bus company is used). These factors are not really amenable to being modeled within the normal air passenger ground access mode choice process and use of charter bus by any given group can be viewed as an exogenous decision.

6.2 Literature Review

The research in passenger behavior has been conducted extensively using mode choice models (Train, 2002). The basic idea of the mode choice model is to provide the probability distribution of the ridership among all the available modes. It catches the behavior of the passenger at the time period the survey data is obtained. Airport ground transportation system can be considered similarly (Gosling, 1984).

In contrast to passenger behavior, transportation provider behavior is a relatively new research area. This may be due to several reasons:

(a) The behavior of transportation providers is intrinsically competitive and dynamic under the circumstances of the market economy. How to model the competitiveness dynamically is a great challenge.

(b) Among many factors relevant to transportation provider behavior, there are four closely related parties interacting with each other in a non-deterministic manner. Those parties are: transportation providers, passengers, local government and airport authority, and traffic networks. Among those relationships, institutional issues, political issues and human behavior are involved, which are difficult to quantify.

(c) Transportation providers usually to do not provide information about their operation approach and management strategies for research, but usually consider them proprietary.

6.2.1 Indirect Approach through Passenger Behavior

Lo *et al.* (2004) studied the modeling of multi-modal transit services using a three-level Nested Logit (NL) choice model to deal with the complex and inter-related decisions in a multi-modal network: the first level focuses on combined-mode choice, the second on transfer location choice, and the third on route choice. Using this NL network as a platform, the authors examined the effect of fare competition on company profitability as well as on overall network congestion. Mathematically, using multiple levels in NL is reasonable to deal with multiple factors. However, as one can see later, transfer location choice and route choice are not a problem in airport ground transportation. This paper considered transfer behaviors and nonlinear fare structure. The nonlinearity means that fare is not simply distance based. i.e. not a linear function of distance. This approach basically hoped to investigate the providers' behavior through passengers' mode choices. It is thus an *indirect approach*. This approach addressed the response of the passenger mode choice to fare changes, network traffic variations and transfers needed. However, it did not address the competitive behavior of the transportation providers directly. It is thus still a static model. Besides, as shown in Figure 6-1, transportation providers are in the center of the picture for the interactions of all the parties involved in airport ground access in the sense that the interactions between the other parties are through the transportation providers.

6.2.2 Elasticity Approach

Elasticity is a simplified description (TCRP, 1995) of the relationship between fare or other service changes by the providers and the ridership changes due to the responses of passengers. Roughly speaking, the elasticity can be described as the ratio of the ridership change to changes in explanatory variables such as the fare. Statistically, this approach can reflect to some extent the effect of fare changes for one mode or several modes, for example, vanpool (Concas et al. 2005; Winters, 2000). It shows that the ridership is relatively inelastic, particularly for passengers with travel distance above 30 miles. For trips below 30 miles, the individual elasticities are equivalent to the aggregate estimate. Most importantly, it is a static approach and cannot capture the dynamic property of the interaction between providers and passenger.

To support transit agencies seeking innovative pricing and funding strategies to attract more passengers to transit, TCRP (1997) sponsored a study of the elasticity of fare for multiple modes/providers. As the outcome of the research, coordinated intermodal pricing was a suggested approach which could potentially generate new revenues, increase transit ridership and help to achieve regional transportation goals. This research looked at the current pricing strategies of transit systems and practical price changes and then investigated the outcome of the new price strategy. This research is the most extensive one so far on transit fare elasticity. It considered the problem from different aspects.

(a) Multiple regions in North America including five areas in LA, one in Washington D. C. and Ontario which showed the representativeness of this research;
(b) Regional agency goals: reducing VMT or reducing SOVs, maintaining regional access and mobility, and supporting economic development, which were considered as the evaluation principles for this project.
(c) Transit agencies' goals: maintaining a simplified fare structure and increasing ridership and revenue;
(d) Transportation costs and their effects on revenues:
    (i) Direct cost: variable-out-of-pocket cost such as fuel and vehicle maintenance, and fixed-out-of-pocket cost such as vehicle purchase;

(ii) Social costs and externalities: costs for road construction and maintenance, transit capital expansion, traffic enforcement, accident response, and mitigating air and noise pollution;

(e) Ridership change as the price of one mode changes;

(f) Ridership shift as the prices of multiple competing modes change – *cross price elasticity*;

(g) Price changes for certain modes were evaluated to see their effects on reducing VMT and SOV usage.

The study results show that changing of transit pricing will have relatively small effects on solo drivers. Specifically, lowering transit fares is not likely to attract significant numbers of SOV users. The impacts of changing auto-related costs (primarily through tolls and parking rates) can be substantial. Since auto driver is considered as one of the main modes in our study, it is necessary to see if this is also true for airport passengers and employees. This may imply that the change of fare and operation frequency by transportation providers may have effects on ridership shift among the total transit user demand (of all the airport passenger demand), but it may have limited effect on the choice of using transit or auto.

Litman (2004) also studied transit elasticity extensively from the following aspects with the corresponding findings:

(a) *User type*: Transit dependent riders (low income, non-car-owners, non-drivers, people with disabilities, elderly, and college and high school students) are generally less price sensitive than *choice* or *discretionary* riders (people who have the option of using an automobile for that trip).

(b) *Trip type*: Non-commute trips tend to be more price sensitive than commute trips. Elasticities for off-peak transit travel are typically 1.5 to 2 times higher than peak-period elasticities, because peak-period travel largely consists of commute trips.

(c) *Geography:* Large cities tend to have lower price elasticities than suburbs and smaller cities, because they have a greater proportion of transit-dependent users.

(d) *Type of price change:* Transit fares, service quality (service speed, frequency, coverage, and comfort), and parking pricing tend to have the greatest impact on transit ridership. Elasticities appear to increase somewhat as fare levels increase (i.e., when the starting point of a fare increase is relatively high).

(e) *Direction of price change*: The changing directions are not symmetrical. Fare increases tend to cause a greater reduction in ridership than the same size fare reduction will increase ridership.

This research has been conducted for single fare elasticity and cross elasticity with the above segments taken into consideration. The findings suggest that the transit elasticity is affected by many factors, which makes the modeling of such relationship very difficult because some factors are even difficult to quantify such as geographic factors. This situation is aggravated if multi-agency fare changes are taken into consideration. To account for the effect of those factors, a promising approach from our point of view is to deduce the ridership shift from the mode choice model, as described below.

Another way to model the elasticity is to find a functional relationship between the price changes and the ridership shift. There are two possible ways to do this:

Method 1: Zhou et al (2005) proposed a functional relationship between fare and ridership for a single transit provider. The relationship between passenger line flow (the number of persons using the service line in a unit time interval) v and price p can be modeled as an exponential function:

$$v = v_0 e^{\alpha p} \tag{6.1}$$

where v_0, α are constant, which can be estimated from observed data using the least squares method. The relationship between ridership R and the price of a single mode can be modeled as a dynamic relationship as:

$$\frac{dR}{dp} = v_0 e^{\alpha P}\left(1 + \alpha P\right)$$

which provides the rate for the ridership increase or a dynamic relationship between the ridership and the price. This can be used as a first order approximation:

$$\Delta R = v_0 e^{\alpha p}\left(1 + \alpha p\right)\Delta p$$

which is the relationship between the increments of price and of the ridership.

Method 2: If the mode choice model, such as any type of logit model, is calibrated from survey data, one can similarly deduce such a relationship by replacing the equation (6.1) with the line flow function from the mode choice model. Mathematically, one can prove that it is equivalent to use the mode choice model and the ridership shift deduced from the model based on the above argument.

From the previous work, the following observation can be obtained: Elasticity is an approximate approach to model the relationship between price changes and ridership shift among the available modes. However, it is difficult to use this concept to forecast ridership in cases where a new mode is introduced. Besides, the relationships among transportation providers and between the providers and passengers are dynamic in nature like a micro-economic system (Katzner, 1989). To capture those dynamic relationships, alternative modeling approaches are necessary. The elasticity study also provides some useful information that can be used for our future research, for example to check if our approach could provide a similar outcome with respect to a given fare strategy in a similar situation.

6.2.3 Game Theory Approach

The Game Theory approach directly looks at the competitive behaviors of the transportation providers under the effect of other factors such the impact of network traffic and passenger mode choice behaviors. The following studies are in this direction, which is closely related to our approach.

It was recognized that fierce competition exists between the transportation providers wherever their service routes or destinations overlap. Particularly, the decentralization of the bus service in UK caused such full competition between bus service providers as studied in Evans (1987, 1990). This research began to recognize the most important parties and their interactions as shown in Figure 6-1, *i.e.* the transit providers, the passengers and the interaction between them and among the transportation providers.

The function of those parties and their interactions were emphasized further by Zubieta (1998) who presented a model for a deregulated transportation system with full representation of the urban network. It was assumed that a few private bus companies provide the totality of the urban transportation services. Each private company was assumed to have exclusive rights to operate a particular transit line. The transit network with a small number of private transit agencies provided the urban mass transportation service. Full competition among the providers was based solely on the frequency of service, as the model considered a fixed origin-destination matrix of demand and fares were assumed constant parameter. The solution was the Nash equilibrium point at which bus operators seek their individual profit maximization, whereas passengers minimized their individual expected travel time including in-vehicle time and waiting time. At equilibrium, marginal revenue should equal marginal cost for each operating company and, for each origin-destination pair, travel 'strategies' for passengers should be optimal. The effect of passenger response was considered with a typical transit assignment model, which is a transit network model with a stochastic user equilibrium assignment with elastic OD demand, instead of from a mode choice model as in our approach. In the formulation of the performance index, the operation cost per unit time was taken into consideration.

The work of Zhou *et al.* (2005) is the most sophisticated mathematical model for three of the four parties and their interactions (Figure 6-1) for a transit system so far in the literature. The only party dropped is the decision maker. This approach emphasizes the dynamic interactions among the three parties:

(1) The relationship between transportation providers and passengers: Two methods are proposed for this relationship. One is the mode choice model and the other is the Stackelberg leader-follower game, although only the former is used for analysis and algorithm development. Both approaches are different from that used in Zubieta (1998) for modeling the feedback (or response) from passengers. Using Stackelberg's leader-follower game, on the other hand, will overemphasize the function of the transportation providers. This is not a fair game in the sense that, for only one player in each party (leader or follower), the leader can influence the decision making of the follower but not the other way around, which is not allowed in Nash game. In fact, except in the case of monopoly, passengers should have at least the same capability or freedom to affect the market share as the transportation provider in a customer driven market economy framework. It is thus assumed that transportation providers can affect the behavior of passengers but cannot control it.

(2) The relationships among transportation providers: Price competitive behaviors among all the transit providers and fixed operation frequencies for all the providers are assumed. This competition happens over the transit network concerned.

Correspondingly, passengers are also assumed to make a service choice among all the providers for the given OD pair. A change in fare is used as the main factor for the transportation providers to affect the mode choice behavior of the passengers. Mathematically, the competition among the transportation providers is modeled as a Nash Game among all the providers involved in the given transit network. This implies that the revenue function for each provider is calculated on a link basis and added overall the network served. The feedback effect of the passengers is modeled using a multinomial logit model, which determines the probability distribution of the transit market share of each service. The equilibrium point of the Nash Game coupled with the logit model is assumed to be the result of competition. Correspondingly, the optimal fare is determined at the Nash Equilibrium point. At the Nash equilibrium, no transportation provider can increase its revenue by unilaterally changing the fare. For problem simplification, it is assumed currently that the operational costs are fixed. However, this assumption is unrealistic in practice. Next year's enhancements will remove this assumption and consider profit maximization, as well as the effects of capital investment needs.

(3) The relationship between transportation providers and network traffic: The regional transit network is much larger than the network related to airport access. For the transit network, two-directional interactions between the transit providers and network traffic are significant. For airport access, the effect is one direction only: the network traffic situation affects the providers' behavior through travel time etc, but traffic generated by the transportation providers from the airport has little effect on network traffic beyond 3 ~5 miles away from the airport.

Research in this direction has laid down the foundation for the approach in our research. Our approach is mainly based on the work of Zhou *et al.* (2005). In our approach, we mainly take the fare as the decision parameter for the operation strategy of the transportation providers, but consider the effect of service frequency as a fixed but changeable factor in practical implementation in IAPT. The network assignment problem has been greatly simplified as mode choice at the airport without network optimization, considering the special characteristics of the airport ground access problem.

6.3 Interaction between Passenger and Transportation Provider Decisions

The contributions of this research are in several aspects compared to previous work:

1. A simpler system compared to a transportation network system
    - (a) The airport access trip has a unique destination and the egress trip has a unique origin, which is the airport.
    - (b) The network in consideration is simplified in the sense that we do not consider all the possible links between OD pairs over a network. Instead, for a given OD pair, we only consider one service path, which will be discussed in detail later.
2. The total passenger demand for each OD pair can be determined from airport survey data. This is different from the assumption in Zhou *et al.* (2005) where it is assumed that the transit demand is sensitive to the fare changes.
3. In the work of Zhou *et al.*, the operation frequency of the transportation providers is assumed fixed. In our work, we assume that both fare changes and operation frequency are decision parameters for the providers to affect the mode choice behavior of the passengers.

6.3.1 Characteristics of Transportation Providers

To understand the common factor of all the providers, it is necessary to understand the characteristics of each provider, how they deal with the three fundamental relationships, and what are the main factors they take into consideration for their operation. Although the following discussion, which is summarized from Section 6.1, uses examples from Bay Area airports, it is applicable to other airports with the corresponding available modes and providers.

Public Providers

Public providers include three typical types:

(1) Public transportation providers: BART or other rail plus shuttle bus, APM link, or transit bus

Airport authorities can (and typically do) determine the details of the service provided, , including operation frequencies, rates and fares.

- High capital and operating cost
- Stable schedule/time table and infrequent fare changes

- Stable service levels
- Strategy: To maximize the revenue or profit – It is not clear that public transit systems attempt either to minimize cost (they could obviously do this by stopping service) or to maximize revenue (this would require an increase in service frequency which they could not afford, since their subsidy is limited and their revenues generally do not cover their operating costs). This point needs further investigation.
- Decision parameters: Fares, service frequency, and facilitating connections.

(2) On-Airport Parking:

- Most airports view on-airport parking as an important revenue source but there are limiting factors
  - Trade-off between price and number of users
  - Competition from private off-airport parking`
  - Possible need for a shuttle bus to transfer passengers between parking lots and the terminal – increasing operating cost (constraint)
  - Capital cost for parking lot
- The operation strategy is to maximize revenue through pricing as key policy goal. There is a trade-off in pricing for short term and long term parking.

Private Providers

Private transportation providers may apply fare and service frequency **strategies** of varying degrees of sophistication:

a) Match or undercut their competitors
b) Attempt to maximize their traffic (market share)
c) Attempt to maximize their profit

In our modeling, we can ignore strategy (a) at this stage. (b) can be considered as equivalent to the strategy for revenue maximization in the long run. Different private providers have their own characteristics.

- Rental car: Prices are flexible for different programs. frequency to operate shuttle buses to/from airport; used mostly by visitors to the region
- Off-Airport Parking: Prices are usually lower compared to on-airport parking. Shuttle van service is available between the lot and the airport, the frequency of which is an important service parameter.
- Taxi: Fare is determined by a local jurisdiction and distance metered (not by the company or the airport). Drivers prefer long distance trips. Pickups may be restricted outside the relevant jurisdiction, which can be a severe limit to taxi drivers. Capacity is controlled by the number of licenses available from the local regulatory jurisdiction.
- Limousine: Pre-set rates are used rather than metered rates. Door-to-door service in defined geographical areas through reservation is the main operation logistics.
- Shared-Ride Van: It provides door-to-door service in defined geographical areas. The logistics of picking up or dropping off are limited by proximity and desired time window of passengers. There is a trade-off between fare, number of passengers, routing, and satisfaction of passengers. Fare is usually determined by zip code. They are not operating to a published schedule. The practicalities of accepting reservations means that they usually operate an implied schedule. Routing for pick-ups is planned at the reservation stage depending on the locations of passengers. There is a complex relationship between operating frequency, number of passengers picked up, revenue and profit. The profit estimation needs to account for those factors;
- Scheduled Airport Bus: The operation logistics are to balance fare, frequency, routing and stop selection;
- Hotel Courtesy Van: Some hotels provide free service to hotel customers. A factor in air passenger decisions whether to use the courtesy shuttle is the waiting time involved. It is normally operated at a fixed headway. Several close-by hotels sharing such a service is an example of cooperation in this mode;

- Charter bus: This mode is typically associated with large travel groups such as school groups and organized tour groups. It is not considered in modeling.

Common factors affecting operations for most transportation providers are:

- Service area and routing are usually fixed except for shared ride van, taxi and limousine
- Fares or rates are changed and each mode changes its price by a common percentage or fixed increment for all zones served
- The trade-off among operating frequency, fare or rates, and profit or operating cost recovery.

Operating frequency and schedule are used as strategy by providers such as public bus and rail transit, shared ride van and scheduled bus.

6.3.2 Passenger Response to Service Changes

It is assumed that passenger behavior is modeled using a nested logit model as discussed in Chapter 5. The passenger response to transportation provider service decisions assumed by the transportation provider behavior modeling should be compatible with that produced by the mode choice model. This implies a close coupling between the provider behavior model and the passenger behavior model: the revenue or profit which a provider wishes to maximize is generated from the ridership projected by the mode choice model, which takes pricing and operating frequency into account.

It is implicitly assumed in mode choice modeling that those passengers not using autos tend to choose modes that have fewer transfers to reach the airport or destination. This means that it unlikely that a passenger will change to another mode at some point if the mode chosen at the origin will bring him/her directly to the destination. This also means that mode choice and routing are determined at the same time. Such a choice results in an airport ground access/egress path. Examples of such access/egress paths are:

- Parking and BART/Train
- Bus and BART
- Rental car and rental car shuttle
- Shuttle van

- Taxi
- Direct Bus
- Driving and parking at or near the airport
- Hotel shuttle van

6.3.3 Dynamic Interactions

The main factors affecting transportation provider operational decisions and passenger mode choice decisions are different, although transportation providers have to take into account passenger behavior in assessing the likely effect of their service decisions. This interaction can be modeled as a Generalized Nash game in which the transportation providers compete for market share. A Nash game assumes that each competitor knows all others' strategies (Osborne, 2004). A Nash Equilibrium is a set of mixed strategies for finite, non-cooperative games between two or more players whereby no player can improve his or her payoff by changing their strategy. Each player's strategy is an 'optimal' response (cf. optimality) based on the anticipated rational strategy of the other player(s) in the game. Traditional Nash games do not allow constraints/interaction between players' strategy sets. Generalized Nash games, however, allow some constraints/interaction of players' strategy sets. The passenger response to the provider decisions can be modeled by directly incorporating the mode choice model in the Generalized Nash game analysis.

Preliminary consideration indicates that the following factors are crucial for the modeling of transportation providers' behavior: (1) the relationship with passengers; (2) the relationship with other transportation providers in the same mode and other modes; (3) the relationship with the network traffic; (4) airport and local government policy on airport regulation, revenue collection, and etc.

(1) Relationship between providers and passengers: The factors that providers and passengers take into consideration are slightly different. However, since the providers' behavior is driven by the market, the providers have to consider the passengers' interests. The factors which affect passenger mode choice include:

    - Price
    - The number of transfers

- Walking time (to service point)
- Waiting time (for service)
- Travel time (between two points)
- Variance of travel time (travel time reliability)
- Scheduled frequency
- Ride comfort.

(2) Relationship with other transportation providers: Providers are treated as an aggregated entity for a given mode. They know the service (for example, service area, stations, fare and frequency) of other providers in other modes, which determine the decision parameter value and range or *strategy set* in Game Theory terminology. There is full competition among the modes available to passengers from a given zone or a few connected zones such as those served by a BART station. A generalized Nash game method can be used to model the competition among modes (Harker, 1991). A fundamental assumption in a Nash game is that each competitor knows the strategy of all other providers. This is reasonable because the pricing, frequency and schedule of a provider are usually public information to attract passengers.

(3) Network traffic effect: Traffic conditions on the highway network affect the providers and passengers through the travel time that they experience. Initially this will be assumed to be independent of the passenger mode choice decisions, since the proportion of the regional highway travel contributed by airport ground transportation travel is quite small, except in the immediate vicinity of the airport. Feedback from the mode choice decisions to local traffic conditions will be incorporated in modeling later.

(4) Relationship between transportation providers and airport authority and local government: Airport authorities and local government control the behavior of transportation providers to some extent but leave them flexibility in schedule and pricing changes. The means for such control include regulation of airport ground transportation providers, requirements for permits to pick up passengers at the airport, limitations on access to the terminal curbfront, and various airport use or concession

fees. Those factors and their effects will be addressed in the qualitative approach, but will not be explicitly considered in the modeling of transportation provider behavior.

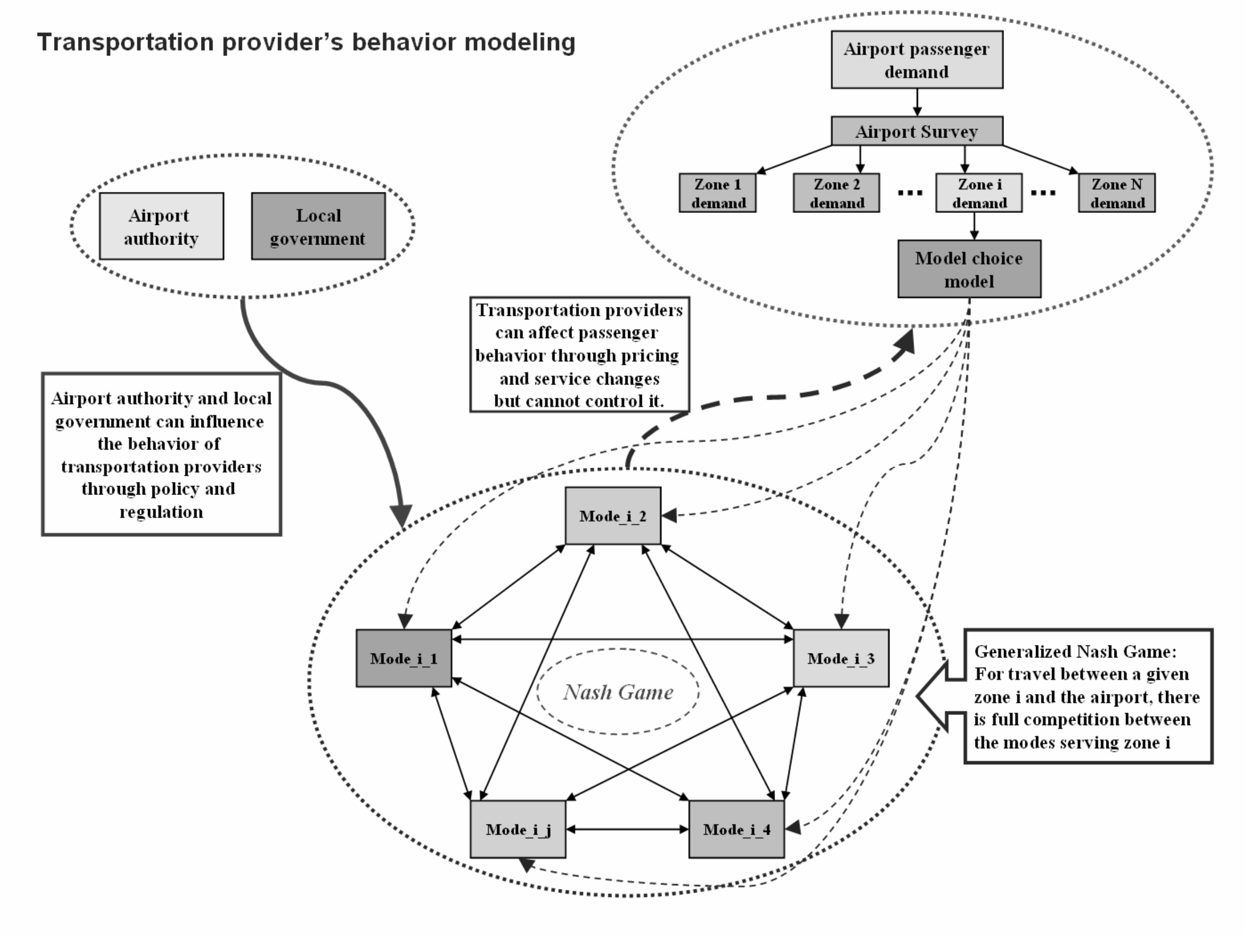


Figure 6-2: Transportation Provider Modeling

6.4 Simplified System Representation and Justification of Assumptions

The following discussion and mathematical modeling and analysis apply to both air passenger and airport employees and to both access and egress trips. However, due to practical data limits, the IAPT development of this project is restricted to airport access trips of air passengers only. This point is understood throughout the rest of the report. To simplify the problem for easier mathematical modeling, the following assumptions have been made and their justification is discussed below.

Assumption 1: Total and zonal (or OD) demand is known. Total passenger demand for the airport for any given time period is known from airport traffic statistics and forecasts. Zonal demand (the demand for passenger trips from or to each origin or destination zone) can thus be determined from airport survey data.

Assumption 2: (about Competition)

- All the providers within a mode collectively compete with other modes;
- Only pricing and operating frequency are changed;
- Each mode knows the service levels of other modes;
- If one mode changes its pricing or service level, other modes make changes immediately in response;
- The set of modes in competition is known and fixed.

Assumption 3: A zone is abstracted as a node in the transportation network, termed the zone centroid. The links within a zone are ignored at this stage although some zones may be geographically large.

This assumption is reasonable if a large zone has a low population density, which is usually the case. Under this assumption, the routing of passengers within a zone is ignored, which means that, as far as airport access/egress is concerned, a ground access or egress path connects the zone centroid to the airport.

Assumption 4: Air passengers information about the available modes and services and will make a decision which access/egress path to be used before they travel.

Access/egress path: An access/egress path links each OD pair (linking each zone centroid with the airport), and may use more than one service from more than one mode (including a single mode as a special case) such as:

- Shuttle, off-airport parking, private car
- Shuttle and rental car
- BART and private car
- BART and bus
- Private car parking at airport
- Taxi

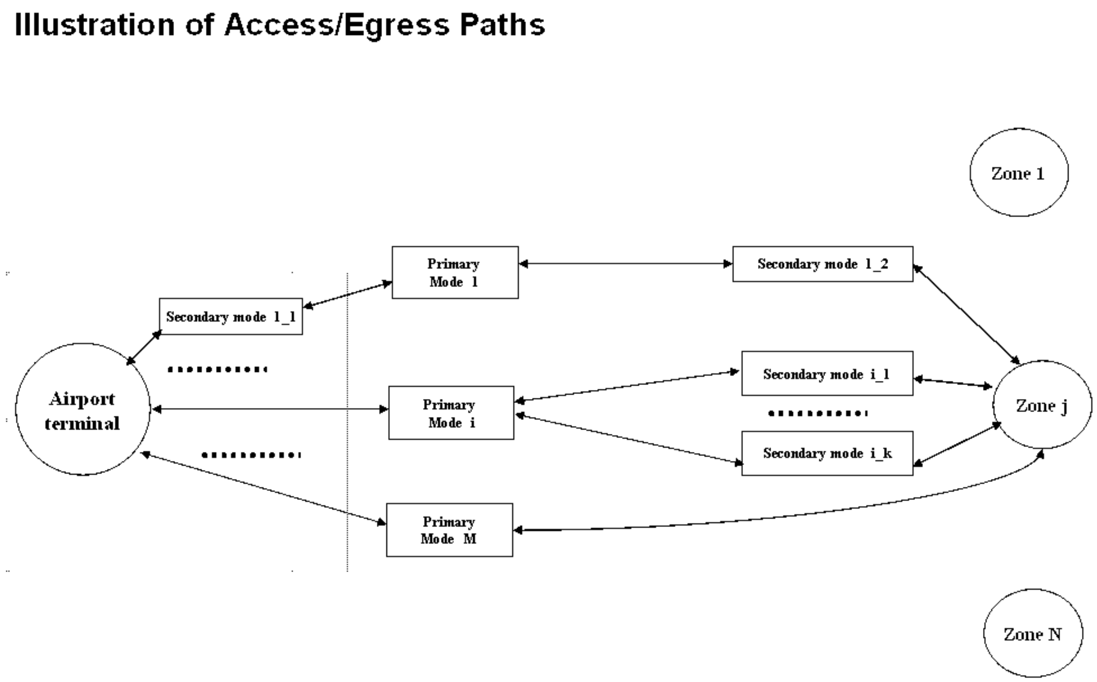


Illustration of Access/Egress Paths

Figure 6-3 Path Choice is Equivalent to Primary (Representative) and Secondary Mode Choice

An access/egress service path may connect several stations (Figure 6-3). There may be several access/egress service paths serving an OD pair. We designate a ***primary mode*** for each access/egress service path at the airport. Other modes linking a zone or the airport to the primary mode are called ***secondary modes***. For example, air passengers may use private car or bus (secondary modes) to access the nearest BART station to take BART to SFO. In each case, BART is considered as the primary mode for these two different access paths. In practical implementation in IAPT, the difference between the behaviors of secondary modes with respect to a primary mode will be ignored by averaging the fares and services levels of those secondary modes. Essentially, a one-to-one correspondence between primary mode and access/egress path is implicitly assumed in the implementation.

The travel time for each access/egress service path can be obtained from a highway traffic network model for highway users or from other calculations, such as published schedules for fixed route systems. Shuttle vans, private cars and rental cars are assumed to use the access/egress path with the least travel time.

With this concept, for a given primary mode and OD pair, there may be several access/egress service paths, with each corresponding to a different secondary mode. In most cases, in considering the competition behavior of transportation providers, it is only necessary to consider the primary mode and ignore the secondary modes. However, the fare of all the secondary modes will be represented by a weighted fare over the number of users in the calculation of the fare along the entire access/egress path. This simplification is equivalent to saying that there is a one-to-one correspondence between primary modes and access/egress paths in the analysis. This discussion results in the following assumption for analysis:

Assumption 5: Although origin and destination are opposite for access and egress trips, it is assumed that the competition is among the primary modes serving the given OD pair.

Assumptions 4 and 5 greatly simplify the problem: optimization for competition at each node in the network is avoided. Instead, the competition can be considered among the primary modes serving the OD pair, in which the airport is either origin or destination. For the passenger mode choice considered in Chapter 5, a passenger choosing mode i is equivalent to saying that the passenger chooses the access/egress path with primary mode i. With this consideration, in mathematical modeling, one does not need to distinguish the access trip and egress trip. However, in practical parameter identification using real data, it is necessary to distinguish those two trips and identify separately.

Assumption 6: The capital cost for each mode is fixed.

Under this assumption, profit of a transportation provider is mainly determined by the revenue and operating cost, where vehicle purchase costs can be represented by their amortized contributions to overall operating costs. Capital costs of capital intensive modes such as BART are exogenous to the model, but must be considered in the overall evaluations by the model user.

Assumption 7: No limit on transportation provider capacity.

Each mode has enough vehicles for operation and its capacity is always above the demand. This means that there are adequate services provided for each zone with capacity greater than the demand for that zone. This is reasonable because if a transportation provider serves several areas, the supply (area capacity) for several areas can adjusted to meet the demand. It is also reasonable from a market economy viewpoint: there are always providers looking for business opportunities.

Assumption 8: (About fare changes) A transportation provider/mode changes fare by a fixed percentage or a fixed increment for all zones.

Based on an initial fare for each zone, this assumption greatly simplifies the problem. Otherwise, if we consider the optimization of revenue/profit of a mode which serves 500 zones, for example, then we would need 500 times as many decision parameters as used for optimization in a single zone, which will cause a huge burden in computation.

Under these assumptions, the mathematical modeling and analysis have been conducted as described in Appendix C. Several points are emphasized to help to understand the assumptions and mathematical mechanism in later discussions.

(1) The decision parameters of transportation providers are the main factors which can be quantified and controlled by providers to affect the outcome;

(2) The decision set is the allowed range of values for the decision parameters. This range may in practice be subject to several constraints. For example, the price is not allowed too low because of local government or airport regulation, or because the provider needs to keep the business to operate in the long run.

(3) Strategy in Generalized Nash Game is the way a competitor chooses the value of decision parameter(s) to achieve expected outcome based on their information about their competitors;

Chapter 7. Measuring Airport Intermodal Connectivity

Since the current research addresses ways to improve intermodal connectivity at airports, this naturally raises the question of how connectivity can be measured in transportation systems in general and airport ground transportation systems in particular. Once suitable measures have been developed, they can be used to identify aspects of the system that contribute to an inadequate level of connectivity and in turn focus attention on where improvements need to be made. This chapter explores the question of how to measure intermodal connectivity in the context of airport ground transportation and how those measures could be used to analyze the performance of the airport access/egress system and identify needed improvements.

Improvements in airport accessibility usually involve large investments, but the actual effects of these improvements are often not easy to measure. The lack of well-defined connectivity measures impedes efforts to quantify the effectiveness of such improvements. This chapter introduces a proposed conceptual and methodological framework for (i) developing quantifiable airport access/egress connectivity measures, and (ii) detecting segments of the airport access/egress system where the level of connectivity needs improving. Prior work on measuring transportation connectivity has largely addressed conventional public transit operations serving primarily local work trips rather than airport access/egress travel, so it will be necessary to adapt that thinking to address the more specialized topic of airport ground transportation.

A well-connected airport access/egress system can be defined as having two major characteristics: (a) convenience, and (b) availability (over both space and time). An essential attribute of a well-connected airport access/egress system is to have good integration between different services that form a single access/egress path, which needs to address the following considerations: (i) good information about the available options, (ii) stability of service patterns, and (iii) well-coordinated interchanges.

Good information on the travelers' options should cover all transportation modes and available services and should be designed to address the particular needs of air travelers. The information should be clear and accurate, and provide detailed instructions on the full path between the airport and the traveler's origin or destination. *Stability of service patterns* implies infrequent service changes, since frequent changes are likely to introduce confusion among the travelers and make it difficult to provide effective and current information. *Well-coordinated interchanges* implies easy transfers between routes on a given access/egress path and comfortable interchange facilities, regardless of whether the connecting routes are provided by different modes or operators.

A well-connected airport access/egress network provides an integrated approach to public transportation, private vehicles, and pedestrian connections at the airport terminal as well as interchange facilities. Physical integration is attained by means of easy accessibility to all transportation services and transfers (where relevant) between providers, including access/egress travel between the trip origin or destination and public modes, which can involve parking private vehicles, being dropped off or picked up by others, or use of secondary connecting modes such as local bus or taxi. Interconnections among different types of transportation providers (*e.g.* rail, bus, taxi, van, and rental car) can be provided in a wide variety of physical facilities. However, for airport access/egress trips, consideration has to be given to the need to accommodate passengers with baggage. The widespread use of wheeled bags means that airport travelers can more easily use services that involve significant walking distances, while on the other hand level changes involving stairs (or escalators that are out of order) are a significant inconvenience. When service headways are fairly short waiting facilities can be limited to provision of seating and shelter from rain and wind. However, when waiting times are longer, as is often the case with longer distance rail systems, then more comfortable waiting facilities may be needed.

7.1 Planning Considerations

Planning for intermodal connectivity in airport access/egress systems has to give particular consideration to the needs of passengers who are likely to be carrying luggage or escorting children, while many air passengers are likely to be unfamiliar with the local region and its transportation system. The need to transfer between transportation modes or between routes (of a given mode) is a major source of inconvenience and stress for airport access/egress travel. Designing schedules with a minimum amount of waiting time during transfers can decrease the level of inconvenience, while providing cross-platform or same-level connections can improve the ease of transfer. However, there are significant limitations to the ability to do this in the case of airport access/egress systems. Airport travelers are likely to be a small proportion of the ridership on general urban transit systems, and therefore operators are unlikely to be willing to adjust schedules of routes serving a much larger number of other passengers simply to improve the service to airport travelers. Furthermore, scheduling connections with very little transfer time runs the risk that if the inbound service is at all delayed, the travelers may miss the connection and spend even more time waiting than if the connection had been scheduled with more time for the transfer. Timed transfers, in which each service waits for any connecting services, avoid this problem, but run into the issue of how much schedule disruption can be tolerated to improve service for relatively few riders.

7.1.1 Review of Public Transit Connectivity and Coordination Studies

The following studies have addressed general transit connectivity issues, since those issues have received much more attention in the literature than airport access connectivity problems. The focus of these studies has been on improving the operational efficiencies for the transit operators and on reducing the waiting times for passengers, which are key issues for both general urban transit systems and airport access/egress services.

Kyte *et al.* (1982) present the process of building a route network in which a main trunk line passes through a series of transit centers. The process includes a determination of clock headways that provide the same departure times every hour, with the objective of coordinating transfer times at the transit centers. Schneider *et al.* (1984) provide a detailed list of criteria for choosing a proper site for the location of a timed-transfer transit center. Hall (1985) develops a model for schedule coordination at a single transit terminal between a set of feeder routes and the line that they feed. The travel time on each of the routes is assumed to include a random delay, while the optimized variable is the slack time between feeder arrivals and the main-line departure. Ceder and Wilson (1986), in a study of transit route design at the network level, emphasize the importance of eliminating a large number of transfer points because of their adverse effect on the user. However, the operators have to trade off user convenience against the operating efficiency of the transit route network.

These studies have tended to focus on the challenge of developing a service network that minimizes the travel time of users in the aggregate, rather than how individual users perceive the connectivity of the system for the particular trips that they wish to make. Thus they tend to provide measures of network connectivity, rather than connectivity between a particular origin and destination. Measures of airport ground access/egress connectivity need to address both the extent to which all airport trips are served by a particular mode or combination of modes, as well as how well those access/egress paths compare to travel by private automobile or direct service by such modes as taxi, limousine or rental car.

7.2 Developing Measures of Airport Connectivity

A suggested definition of a well-connected airport access/egress path is: *An attractive sequence of modes or services that operates reliably and relatively rapidly, with convenient and coordinated transfers.* The factors influencing each component in this definition are as follows:

Attractiveness: The attractiveness of a service will be influenced by the design of the vehicles and facilities, the ease of purchasing tickets (including use of electronic ticketing, credit cards, pre-payment and common-use tickets), on-board services, ride comfort and ease of boarding/alighting, particularly for passengers with luggage or disabilities, arrangements for meeting arriving travelers (including clear signs and directions), and readily available information (telephone number, Internet and posted signs).

Reliability: Service reliability is of particular concern to airport-bound travelers, due to the consequences of missing a flight. Service measures of concern to passengers include the variance in total travel time, waiting time, and seat availability, as well as timely information about service delays or other problems. There are two aspects to reliability. The first is the adherence to published departure and travel times. The second is the consistency of service availability at different times of day or days of the week. A particular issue of concern with public transportation modes is the availability of late night, early morning or weekend service.

Rapidity: From the perspective of the traveler, services should provide a fast travel time with a minimum of intermediate stops. However, this objective has to be balanced against reasonable coverage of the service area and efficient operation of the vehicles. A key measure of the overall rapidity of an intermodal service path is the total travel time compared to that by private automobile or other direct door-to-door services, such as taxi or limousine.

Convenience of transfers: Transfers between modes and services should occur in a comfortable setting that minimizes the walking distance and level changes involved, with clear signing and announcements to allow users to easily locate their outbound service.

***Coordination**:* Coordination of schedules at transfer points should be designed to reduce waiting times while minimizing the risk of missed connections. This can be enhanced through on-line communication between the transportation providers (with on-board vehicle information) or timed-transfer strategies in which vehicles wait for connecting services.

Each access/egress path choice (sequence of modes or services that a passenger traverses between a particular origin or destination and the airport terminal) can be characterized by the same quality-of-service attributes for each mode:

- Average walking distance (to service point)
- Variance of walking distance (across different trip end locations)
- Average waiting time (for scheduled or non-scheduled services)
- Variance of waiting time (measure of uncertainty for scheduled or non-scheduled services)
- Average travel time (on a given mode and path)
- Variance of travel time (reliability)
- Average headway of scheduled modes
- Variance of headway of scheduled modes.

These eight attributes can be measured directly and will therefore be termed *quantitative attributes*. However there are also other important attributes that cannot be easily quantified and measured. Three of the latter are:

- Convenience of transfers
- Comfort of vehicles and ability to accommodate luggage
- Availability of clear and understandable information.

These less easily quantified attributes will be termed *qualitative attributes.* Of course, the value of all eleven attributes may be perceived differently by different passengers or by the same passenger in different situations. These different perceptions can be captured by a relative weighting of each attribute. These weights can be based on the results of traveler attitude surveys or mode or path choice modeling. The analysis framework should distinguish between quantitative and qualitative attributes in order to assist decision makers in evaluating improvements and changes to specific services or facilities, although for some purposes it may be useful to combine both types of factor to obtain an overall assessment.

7.3 Detecting Weaknesses in Intermodal Access Trip Chains

The overall performance of an intermodal trip chain will be strongly influenced by the attributes of its weakest link. It is therefore important to be able to detect the more critical weaknesses in airport intermodal connectivity chains, because these are likely to be the most significant impediments to travelers' use of those modes. Although consideration of potential weaknesses can draw on past research addressing the conventional urban transit experience, it is important to advance beyond that to address the specific concerns that could deter air travelers from relying on a particular access mode or chain. These could include such issues as:

- unassisted level changes or excessive walking distances at transfer locations
- insufficient seating at waiting locations
- waiting locations exposed to adverse weather
- lack of cleanliness of facilities or vehicles
- situations where personal safety or security is perceived to be threatened
- insufficient information to enable travelers to easily locate connecting services and to reassure them that they are waiting at the right location
- uncooperative or unaccommodating employee attitudes.

Any of these factors, or combinations of these factors, could have at least as large an effect on an air traveler's choice of airport ground access mode as the quantitative attributes introduced in the previous section, but conventional mode choice models are not well-equipped to address their effects directly. Such models typically account for these effects through the mode-specific constant, making it difficult to identify the contribution of different factors, or indeed where those factors occur. More insight into these issues can be gained through such techniques as focus groups, stated preference surveys, or more targeted traveler attitude surveys that attempt to assess perceptions of service quality. There is an urgent need for research to better understand the influence of these qualitative factors on the perceived utility of different services and modes.

7.4 Capacity Issues in the Airport Ground Transportation System

Even though large hub airports are major activity centers attracting large numbers of travelers, the only access modes that typically encounter capacity constraints are those associated with automobile access (curbside space for pick-up and drop-off, access roads and ramps, and parking facilities). Air travelers who need to access the airport during a commuting peak period are likely to encounter capacity problems on the highway network and possibly on a public transit vehicle as well, but these are primarily peak period capacity problems of the region as a whole rather than problems peculiar to the airport. These regional transportation system capacity constraints influence congestion and travel times on the different modes, and hence airport traveler mode choice. However their solution transcends airport ground transportation system planning and will depend on investments in the larger regional transportation system.

Localized capacity constraints on the airport roadways, parking facilities, and passenger circulation system are another matter, and their identification and solution are very much a focus of airport ground transportation planning. These are clearly dependent on the proportion of airport travelers using each mode, and thus their solution can be approached through a combination of expansion of facilities to serve the capacity constrained modes, as well as measures to encourage travelers to use those modes with available capacity. Once airport traveler mode choice has been determined, it is fairly simple matter to convert this to passenger and vehicle flows over the various links of the airport ground transportation system and determine where bottlenecks can be expected to arise.

There are two aspects to this type of analysis that need to be given careful consideration. The first is that congestion resulting from inadequate capacity of airport facilities typically only accounts for a fairly small part of the overall travel time to or from the airport. Thus, even quite severe capacity constraints on particular links of the system are not likely to have a major influence on airport traveler mode choice by themselves. Efforts to relieve congestion by encouraging mode shifts to less constrained parts of the system will therefore need to use price or similar incentives rather than simply relying on the congestion itself to cause travelers to seek other modes. The second aspect is that the overall traffic level at an airport is highly variable over the course of a week and seasonally, with the highest traffic levels typically occurring around the major holiday periods such as Thanksgiving and Christmas. Thus any capacity limitations are likely to manifest themselves first during a limited number of peak periods during the year, or at particular times of the week. Since the delays associated with these peak periods do not occur very often or typically last very long, this can make it difficult to justify making large capital investments to resolve the capacity constraints, particularly where options exist to reduce the congestion through temporary operational means, such as opening overflow parking facilities or additional passenger pick-up and drop-off locations at peak times.

7.5 Implementation in the Intermodal Airport Ground Access Planning Tool

Once a measure of intermodal airport ground access connectivity has been defined, it can be implemented as one of the measures of performance calculated by the Intermodal Airport Ground Access Planning Tool (IAPT). This can then be used as part of the evaluation of proposed projects to improve airport intermodal connectivity, as well as to generate performance measures for the airport system as a whole by determining connectivity measures for each airport in the system. During the second year of the study the approach presented in this chapter will be refined and one or more specific connectivity measures defined in terms of the output measures to be generated by the IAPT, including travel time and cost by each mode. These measures can then be calculated for each analysis run of the IAPT as part of the calculation of all the measures of performance.

Chapter 8. Future Plans for Intermodal Access Planning Tool Development

This report has described the planned structure of the Intermodal Access Planning Tool (IAPT) and discussed some of the implementation details. The next stage of the project will involve completion of the model calibration work for the air passenger mode choice and transportation provider modules and programming and testing of the model components. Once a preliminary version of the IAPT is operational, its application will be demonstrated by analyzing a selection of potential projects to improve intermodal connectivity at the Bay Area airports. This demonstration will serve two purposes. The first purpose is to test the functionality of the tool and ensure that the various components are able to handle the range of data associated with representative projects. The second purpose is to illustrate the application of the tool to a range of different types of potential project and to provide an opportunity to validate the operation of the tool by generating results that can be compared to past experience with the impacts of similar changes in the airport ground access system or the results of other studies. It is likely that the initial application tests will reveal combinations of conditions that cause the model to generate inappropriate results, or even to fail to generate any results at all, and that this will help identify aspects of the model components that need to be corrected or improved.

8.1 Validation Tests

The identification of suitable validation tests is important to ensuring that the IAPT is capable of producing reasonable results. These tests require a clearly identified change in the ground access system at a particular airport, the effect of which can be observed in the subsequent operational data for the airport. One obvious example is the opening of the BART extension to San Francisco International Airport (SFO). In addition to the change in the number of air passengers using the improved service, BART in this case, to access the airport, there were also associated changes in the use of other modes and changes in the service characteristics of some of those modes as the transportation service providers reacted to the changes in use. Some of these effects are likely to be fairly subtle and possibly difficult to identify due to the effect of other changes in the air passenger market that were occurring at or about the same time. This will require careful analysis of the changes in the use of the ground access system, not only at the airport in question, but also at the other two Bay Area airports in order to determine whether observed changes appear to be the result of the identified change in the ground access system or more general changes in the travel market.

In the case of the BART extension to SFO, there is a further complication that will require some careful analysis. Although the BART system collects detailed ridership data, these data do not distinguish between air passengers, airport employees, and other users. Fortunately, the BART ridership data identifies the station of entry and exit, and the pattern of trip origins and destinations of air passengers are not likely to be the same as those of airport employees. Survey data is available that provides information on the distribution of both air passenger and airport employee trip ends, and this information can be used to estimate the proportion of BART riders to and from each station that are air passengers or airport employees.

Another potential set of validation tests arise from the changes in airport parking rates that have been implemented from time to time. Although in these cases there is detailed data on the resulting changes in airport parking use and no difficulty in identifying air passenger use of parking facilities, since airport employees generally use different facilities, it is likely that there will be some lag in the behavioral response, since it will take some time for air passengers to become aware of the changes. It is unlikely that many air passengers check the airport parking rates before setting out for the airport and instead base their access mode decisions on a general impression of the parking rates from previous experience. Thus it may take one or two air trips for which the parking facilities were used before a change in rates translates into a change in behavior. Given the average frequency at which air trips are made, this could take quite some time.

8.2 Further Functional Development

Beyond the planned functionality of the initial implementation of the IAPT, there are a large number of potential functional enhancements that could be implemented as part of future development of the tool. These enhancements fall into two broad categories: improvement of the functional operation of the various IAPT modules and the addition of new capabilities.

Continued efforts to refine and improve the mode choice model or transportation provider behavior model incorporated in the IAPT can be expected to result in improvement in the predictive reliability of these components and the overall tool. While some improvement can be expected from the model refinement activities in the course of the second year of the current project, the extent of these improvements are likely to be limited by currently available data. New data collection and research activities will most likely be required to support further development of these aspects of the IAPT.

The development of new IAPT capabilities is clearly an open-ended process, and subject to both need and available resources. Planned additional capabilities during the second year of the research will be limited to better integration between the IAPT and a highway network analysis module, in order to explicitly model the feedback between airport ground access mode use and traffic levels and travel times on the adjacent street and highway system, as well as improved representation of the resulting vehicle emissions.

Other desirable capabilities that will require significantly more time and resources to implement include the development of an airport employee access travel module, extension of the air passenger mode choice module to explicitly model egress as well as access travel decisions, and the development of a capability to model air cargo ground access vehicle trips. The latter will require a completely different modeling framework, since the relevant decisions depend on entirely different considerations and data. However, many of the data management activities may be able to take advantage of the basic IAPT framework and user interface, and of course the resulting vehicle trips from air cargo activities share the same highway infrastructure as the air passenger and airport employee trips and all three types of trip contribute to traffic levels and associated travel times.

Chapter 9. Concluding Remarks and Recommendations

The first year of the research has identified a wide range of potential opportunities to improve intermodal connectivity at California airports and developed the detailed structure of a modeling framework to assess the feasibility and potential benefits of these projects. The second year of the research will pursue the detailed implementation of this analytical capability and demonstrate its application to selected projects. Based on the results of this analysis, some preliminary recommendations will be developed to help Caltrans formulate appropriate policies and programs to improve the intermodal connections at the state's airports.

9.1 Potential Follow-on Research

The research undertaken during the first year has identified a number of research topics that will not be addressed during the second year of the research but that it would be useful to explore in future follow-on research projects. Additional topics may well be identified in the course of the second year of the project.

The first three of the following topics describe potential enhancements to the version of the Intermodal Airport Ground Access Planning Tool (IAPT) being developed under the current research. The following topic would lay the groundwork for an extension of the IAPT to address travel by airport employees, while the fifth topic would commence the research necessary to extend the IAPT to analyze air passenger airport choice in addition to airport ground access/egress mode choice. The final two topics would examine issues related to intermodal airport connectivity for goods movement.

9.1.1 Role of Traveler Information and Service Quality in Air Passenger Mode Choice

Most air passenger ground access mode choice models, including those used in the IAPT, assume that air travelers have complete and accurate information about the service characteristics of the available ground access modes, or at least that misperceptions of those characteristics are common to all travelers in a given market segment. However, this is quite unlikely to be true, and failure to explicitly account for this in the models prevents the use of the models to study the effects of different strategies to improve traveler information or market ground transportation services. A related issue arises with regard to subjective issues of service quality, such as crowding, comfort, and ease of handling baggage. Existing models do not easily allow users to analyze the likely impacts of investments or programs to improve these characteristics of specific systems. Part of the difficulty lies in the absence of naturally occurring experiments where the contributions of these factors to passenger decisions can be easily separated out from those of other, more tangible, factors such as cost and travel time. One way that this issue has been addressed in the past is through the combination of stated preference and revealed preference surveys. The proposed research would examine and summarize past experience attempting to address these issues, both for airport ground access systems as well as other transportation systems such as high-speed rail or urban transit, and then build on this experience to design and conduct a combined stated preference and revealed preference experiment, analyze the resulting data, and attempt to identify the contribution of information and service quality factors to travelers' airport ground access decisions. The cost of performing the necessary surveys could be greatly reduced by undertaking the research in partnership with regional transportation planning agencies or airport authorities that are planning to perform air passenger surveys anyway and thereby take advantage of the data collection opportunities presented by those surveys.

9.1.2 Development of Synthetic Air Party Characteristics Data Files

The application of disaggregate mode choice models in the IAPT (or any other application) requires a data file of air party characteristics, including such attributes as the ground origin, the party size, the trip duration, and so forth. For model estimation these data are typically obtained from air passenger surveys. However, two problems arise in applying the resulting models. First, in order to apply the model for a future year (or indeed any year for which air passenger survey data is not available) it is necessary to develop a data file of representative air party characteristics for that period. While it is possible to simply use an existing data file from an air passenger survey and factor the results up or down to adjust for the expected (or actual) change in total traffic, this ignores the very likely possibility that the composition of the travel market will be different from the period when the survey was performed. The second problem arises in applying the IAPT at an airport for which recent air passenger survey data are not available, or do not contain all the variables required by the model. In both cases, it would be desirable to be able to use a utility routine that could generate a data file of synthetic air passenger survey characteristics based on data that are readily available for most airports. These data would include airport traffic statistics, airline traffic data reported to the U.S. Department of Transportation, and demographic and socioeconomic data available from the U.S. Bureau of the Census. The proposed research would define the necessary procedures, develop software to implement these, and evaluate the effectiveness of the procedures by comparing synthetically generated data files for selected airports with actual data for the same airports and time periods obtained from air passenger surveys.

9.1.3 Development of Air Passenger Trip Generation Models

While air passenger surveys provide information on the distribution of air party ground origins, these typically suffer from limitations of relatively small sample sizes. For example, the most recent air passenger survey performed in the San Francisco Bay Area by the Metropolitan Transportation Commission (MTC) obtained about 5,300 responses from different air parties in the first of two survey periods a year apart. In comparison, the MTC currently divides the Bay Area into 1,454 traffic analysis zones for transportation modeling. Thus on average there were less than four responses from each analysis zone. Given the uneven distribution of air party trip origins in the region, the inherent variation of statistical sampling, and that about 15 percent of the responses gave insufficient information to identify their origin zone, some 25 percent of analysis zones had no responses at all. Therefore it would be very useful to develop trip generation models that can predict the number of air party trip originations from a given analysis zone on the basis of zonal demographic and socio-economic characteristics, as well as other relevant factors such as the number of hotel rooms and employment in different sectors of the economy. These models could be used to expand air passenger survey results as well as to predict the distribution of air party trip origins in situations where survey data are not available. The proposed research would review prior research on air passenger trip generation rates, analyze air passenger trip generation patterns from selected air passenger surveys, develop trip generation models, and evaluate the reliability and transferability of these models by comparing the trip generation rates predicted by the models when applied to other regions with actual data on air passenger travel in those regions from air passenger surveys.

9.1.4 Airport Employee Access Mode Choice

The current research has focused on air passenger travel. However airport access travel by airport employees forms another important component of airport ground access travel. While surveys have been performed at a number of airports of employee journey to work travel mode, there has been no known attempts to develop specific access mode choice models for this class of traveler. Typically for airport ground transportation planning studies, standard urban travel journey-to-work mode choice models are used for airport employees. However, airport employees have unique constraints and travel patterns, including shift work and multi-day duty periods in the case of airline flight and cabin crew. The proposed research would assemble data on airport employee mode use from prior surveys, develop airport employee mode choice models, and evaluate the reliability and transferability of these models by using them to predict airport employee mode choice at other airports for which suitable data are available, from which the actual mode use can be compared to that predicted by the model.

9.1.5 Development of Air Passenger Airport Choice Models

The current research project will not address the role of the airport ground access system in air passenger choice of airports. However, improvements in intermodal connectivity could influence which airports travelers choose to use, and in fact represent a potential strategy to influence this choice. Improved connections to secondary airports in a multi-airport region could encourage more travelers to use those airports and in turn encourage airlines to expand service at those airports. There have been a number of past studies that have developed airport choice models for different regions, including the San Francisco Bay Area, and for the past few years there has been a study in progress to develop a regional airport demand model for the Southern California region that is planned to include an airport choice component as well as an airport ground access mode choice component. However, many of the past models have significant weaknesses, including an inability to adequately reflect the influence of airfare differences in airport choice and limited representation of the role of airport ground access in the choice process. In particular, the representation of the airport ground access system does not allow a reliable analysis of the contribution of improved intermodal connectivity to the airport choice process. Furthermore, many of the models were developed using air passenger survey data that are now significantly out of date or for regions outside California. The proposed research would review recent developments in modeling air passenger airport choice, including the status of the model development activities for the Southern California region, and develop an airport choice model for the San Francisco Bay Area based on the airport ground access modeling capabilities being developed in the current project.

9.1.6 Air Cargo Truck Activity at Airports

The number of truck trips generated by airports depends on the weight of air cargo handled at the airport as well as the presence at the airport of cargo handling facilities, such as regional sorting centers. However, the relationship between the weight of air cargo handled at the airport and the number of truck trips generated by the cargo handling activities is not well understood. There are also no readily available models to predict the regional origins and destinations of the truck trips generated by the airport. The proposed research would review the available data on air cargo truck movements and previous studies on air cargo activity and truck trips at airports, and would identify gaps in the available information and develop a research plan to assemble the necessary data to better understand the volume and pattern of truck traffic generated by air cargo activity.

9.1.7 New Air Freight Collection and Distribution Alternative Using BART

In order to address the impact of highway congestion on the timely movement of air freight within the San Francisco Bay Area, planning staff at the Bay Area Rapid Transit (BART) District have expressed an interest in exploring the feasibility of moving air freight on BART trains. The potential advantages of such a system from the perspective of air freight carriers are a reduction in travel time and improvement in reliability through reducing the use of congested highways in transporting freight to and from the airports. There may also be cost savings to the air freight carriers, depending on the fees that BART would charge for this service. The reduced level of truck movement on the regional highway system could possibly contribute to reducing highway congestion, particularly at peak times, and provide air quality benefits. The proposed system could also financially benefit BART if the revenues from moving air freight exceeded the additional costs of doing so. However, there are a number of operational and economic aspects that would need to be explored further before it can be determined whether such a service is even remotely feasible. These include how the freight would be transported on the BART system, the likely magnitude of any time savings, given the time required to transfer the freight to and from the BART trains, and the capital and operating costs involved. The proposed research would define and evaluate operational concepts for handling air freight on BART, including required modifications to the cars, design of loading and unloading facilities, operating cost and staffing requirements, train operating issues, and safety, liability and insurance considerations. Based on the results of this evaluation, the research would undertake an economic evaluation to assess the rates required to enable BART to recover its costs, the potential travel time savings to the air cargo carriers and other highway users that could result, and the extent of any cost savings to the air cargo carriers.

References

Bazaraa, M. S., Sherali, H. D. and Shetty, C. M., Nonlinear Programming Theory and Algorithms, John Wiely & Sons, Inc., 1993.

Becker, A.J., and F. Spielberg, “Implementation of a Timed Transfer Network at Norfolk, Virginia,” Transportation Research Record, No. 1666, 1999.

Ben-Akiva, Moshe, and Steven R. Lerman, Discrete Choice Analysis: Theory and Applications to Travel Demand, The MIT Press, Cambridge, Massachusetts, 1985.

Bondzio, Lothar, “Study of Airport Choice and Airport Access Mode Choice in Southern Germany,” Airport Planning Issues, Proceedings of Seminar K, held at the PTRC European Transport Forum, Brunel University, England, September 2-6, 1996, Vol. P 409, Planning and Transportation Research and Computation International Association, 1996.

Bowman, John L., Portland PDX Airport Access Project Mode Choice Models, Memorandum to Keith Lawton, Metro, Cambridge Systematics, Inc., July 28, 1997.

Burdette, Debra, and Mark Hickman, “Investigating the Information Needs of Departing Air Passengers,” Transportation Research Record, No. 1744, July 2001.

Ceder, A., Network Theory and Selected Topics in Dynamic Programming (in Hebrew), Dekel Academic Press, Israel, April 1978.

Ceder, A., B. Golany and O. Tal, “Creating Bus Timetables with Maximal Synchronization,” Transportation Research, Vol. 35A, No. 10, 2001.

Ceder, A. and O. Tal, “Designing Synchronization into Bus Timetables,” Transportation Research Record, No. 1760, 2001.

Ceder, A., and N.H.M. Wilson, “Bus Network Design,” Transportation Research, Vol. 20B, No. 4, 1986.

Ceder, A, and Y.B. Yim, Integrated Smart Feeder/Shuttle Bus Service, California PATH Report, Institute of Transportation Studies, University of California, Berkeley, August 2002.

Clever, R., “Integrated Timed Transfer: A European Perspective,” Transportation Research Record, No. 1571, 1997.

Concas, S., Winters, P. L., Wambalaba, F. W., Fare pricing elasticity, subsidies and the demand for vanpool services, TRB 2005 Annual Meeting

Cunningham, Lawrence F., and James H. Gerlach, "Transportation Agencies' Experiences with Decision Support Systems for Airport Ground Access Planning," Transportation, Vol. 25, No. 1, February 1998.

Daduna, J.R. and S. Voss, "Practical Experiences in Schedule Synchronization," *in* J.R. Daduna, I. Branco and J.M.P. Paixao *(eds.)*, Computer-Aided Transit Scheduling, Lecture Notes in Economics and Mathematical Systems, No. 430, Springer-Verlag, Berlin, 1993.

Desilets, A., and J.-M. Rousseau, "SYNCHRO: A Computer-assisted Tool for the Synchronization of Transfers in Public Transit Networks," *in* M. Desrochers and J.-M. Rousseau (*eds.*), Computer-Aided Transit Scheduling, Lecture Notes in Economics and Mathematical Systems, No. 386, Springer-Verlag, Berlin, 1990.

Dowling Associates, Inc., San Jose International Airport Transit Connection Ridership, Final Report, Prepared for San Jose International Airport, Lea+Elliott and Walker Parking, Oakland, California, June 2002.

Du, Yafeng, and Geoffrey D. Gosling, Airport Ground Transportation Information Systems: State of the Art and Technology Opportunities, Research Report UCB-ITS-RR-94-13, Institute of Transportation Studies, University of California, Berkeley, December 1994.

Ellis, R.H., J.C. Bennett and P.R. Rassam, "Approaches for Improving Airport Access," Transportation Engineering Journal, Vol. 100, No. TE3, August 1974.

Evans, A., A theoretical comparison of competition with other economic regimes for bus services, Journal of Transport Economics and Policy 21, p7-36, 1987

Evans, A., Competition and the structure of local bus markets, Journal of Transport Economics and Policy 24, p255-281, 1990

Ford, L.R. Jr., and D.R. Fulkerson, Flows in Networks, Princeton University Press, Princeton, New Jersey, 1962.

Golob, Thomas F., "Joint Models of Attitudes and Behavior in Evaluation of the San Diego I-15 Congestion Pricing Project," Transportation Research, Part A: Policy and Practice, Vol. 35, 2001.

Gosling, Geoffrey D., An Airport Ground Access Mode Choice Model, Technical Document UCB-ITS-TD-84-6, Institute of Transportation Studies, University of California, Berkeley, July 1984.

Gosling, Geoffrey D., *(ed.)*, Ground Access to Airports, Proceedings of Two Workshops Sponsored by the Federal Aviation Administration, Berkeley, California, October 31 - November 2, 1994, Proceedings UCB-ITS-P-94-1, Institute of Transportation Studies, University of California, Berkeley, December 1994.

Gosling, Geoffrey D., with Cambridge Systematics, Inc., and SH&E, Inc., SCAG Regional Airport Demand Model: Literature Review, Prepared for the Southern California Association of Governments, Los Angeles, California, June 2003.

Gosling, Geoffrey D., and Samuel W. Lau, Evaluation of a California Demonstration of an Automated Airport Ground Transportation Information System, Research Report UCB-ITS-RR-95-3, Institute of Transportation Studies, University of California, Berkeley, May 1995.

Halcrow Group Ltd., SERAS Surface Access Modelling, Prepared for the Department of Transport, Local Government and the Regions, South East and East of England Regional Air Services Study, London, England, July 2002.

Hall, R.W., "Vehicle Scheduling at a Transportation Terminal with Random Delay En Route," Transportation Science, Vol. 19, pp. 308-320, 1985.

Harker, P.T., 1984. A variational inequality approach for the determination of oligopolistic market equilibrium. Mathematical Programming 30, 105–111.

Harker, P.T., 1988. Private market participation in urban mass transportation: application of computable equilibrium models of network competition. Transportation Science 22, 96–111.

Harker, P.T., 1990. Finite-dimensional variational inequality and nonlinear complementarity problems: a survey of theory, algorithms and applications. Mathematical Programming Research 48, 161–220.

Harker, P.T., 1991. Generalized Nash games and quasi-variational inequalities. European Journal of Operational Research 54, 81–94.

Harrington, Ian E., *et al.*, Summary of People Mover Study Passenger Mode Choice Models, Draft Memorandum, Central Transportation Planning Staff, Boston, Massachusetts, May 17, 1996.

Harvey, Greig, "A Study of Airport Access Mode Choice," Journal of Transportation Engineering, Vol. 112, No. 5, September 1986.

Harvey, Greig, ACCESS: Models of Airport Access and Airport Choice for the San Francisco Bay Region – Version 1.2., Report prepared for the Metropolitan Transportation Commission, Berkeley, California, December 1988.

Hensher, David A., and W.H. Greene, "The Mixed Logit Model: The State of Practice," Transportation, Vol. 30, No. 2, May 2003.

Hess, Stephane, and John W. Polak, "Mixed Logit Modeling of Airport Choice in Multi-Airport Regions," Journal of Air Transport Management, Vol. 11, No. 2, 2005.

Howard Humphreys and Partners, Heathrow Surface Access Study, Report prepared for the U.K. Department of Transport, Leatherhead, Surrey, England, June 1987.

Karlaftis, Matthew G., "Predicting Mode Choice through Multivariate Recursive Partitioning," Journal of Transportation Engineering, Vol. 130, No, 2, March/April 2004.

Katzner, Donald W., Walrasian Microeconomics: An Introduction to the Economic Theory of Market Behavior, Addison-Wesley, 1988

Katzner, D. W., The Walrasian of the Microeconomy, An Elementary Exosition of the Structure of Modern General Equilibrium Theory, The Univ. of Michigan Press, Ann Arbor, 1989

Klemt, W.D., and W. Stemme, "Schedule Synchronization for Public Transit Networks," *in* J.R. Daduna and A. Wren (*eds.*), Computer-Aided Transit Scheduling, Lecture Notes in Economics and Mathematical Systems, No. 308, Springer-Verlag, Berlin, 1988.

Kottenhoff, K., "Passenger Train Design for Increased Competitiveness," Transportation Research Record, No. 1623*,* 1998.

Kyte, M., K. Stanley and E. Gleason, "Planning, Implementing and Evaluating a Timed-transfer System in Portland, Oregon," Transportation Research Record, No. 877, 1982.

Lacombe, A., "Ground Access to Airports: Prospects for Intermodalism," Transportation Quarterly, Vol. 48, No. 4, Autumn 1994.

Landrum & Brown (with Booz Allen & Hamilton, Planning Company Associates, and Nelson/Nygaard), Ground Access to Airport Study, Prepared for the California Department of Transportation, Division of Aeronautics, Sacramento, August 2001. Executive Summary; Working Paper One: Roles and Responsibilities; Working Paper Two: Issues and Problems; Working Paper Three: Recommendations.

Lea+Elliott, Inc., APM Alternatives Refinement Analysis, Prepared for San Jose International Airport in association with PB Aviation, Skidmore, Owings and Merrill, CCS Planning and Engineering, and Hanscomb, San Francisco, California, Draft, October 1999.

Leake, G.R., and J.R. Underwood, "An Inter-City Terminal Access Modal Choice Model, Transportation Planning and Technology, Vol. 4, No. 1, September 1977.

Lee, K.K.T., and P. Schonfeld, "Optimal Slack Time for Timed Transfers at a Transit Terminal," Journal of Advanced Transportation, Vol. 25, No. 3, 1991.

Leigh Fisher Associates, in association with Matthew A. Coogan and MarketSense, Improving Public Transportation Access to Large Airports, Transit Cooperative Research Program Report 62, Transportation Research Board, National Academy Press, Washington, D.C., 2000.

Leigh Fisher Associates, Remote Terminal Market Analysis - Los Angeles International Airport, Prepared for Los Angeles World Airports, San Mateo, California, October 2001.

Leigh Fisher Associates, in association with Matthew A. Coogan and MarketSense, Strategies for Improving Public Transportation Access to Large Airports, Transit Cooperative Research Program Report 83, Transportation Research Board, National Academy Press, Washington, D.C., 2002.

Litman, T., Transit Price Elasticities and Cross-Elasticities, Journal of Public Transportation, Vol. 7, No. 2, 2004, p37-58

Lo, Hong K., Chun-Wing Yip and Quentin K. Wan, "Modeling Competitive Multi-modal Transit Services: A Nested Logit Approach," Transportation Research, Part C, Emerging Technologies, Vol. 12C, No. 3-4, June-August 2004, pp. 251-272.

Lo, Hong K., and W.Y. Szeto, "Modeling Advanced Traveler Information Services: Static versus Dynamic Paradigms," Transportation Research, Part B, Vol. 38, 2004.

Lunsford, Mark E., and Geoffrey D. Gosling, Airport Choice and Ground Access Mode Choice Models: A review and Analysis of Selected Literature, Working Paper UCB-ITS-WP-94-5, Institute of Transportation Studies, University of California, Berkeley, June 1994.

Mahmassani, Hani S., *et al.*, Synthesis of Literature and Application to Texas Airports, Research Report 1849-1, Center for Transportation Research, University of Texas at Austin, June 2000.

Mahmassani, Hani S., *et al.*, Domestic and International Best Practice Case Studies, Research Report 1849-2, Center for Transportation Research, University of Texas at Austin, February 2001.

Mahmassani, Hani S., *et al.*, Assessment of Intermodal Strategies, Research Report 1849-3, Center for Transportation Research, University of Texas at Austin, April 2002.

Mahmassani, Hani S., *et al.*, Strategies for Airport Accessibility, Project Summary Report 1849-S, Center for Transportation Research, University of Texas at Austin, December 2002.

Mandel, Benedikt N., "The Interdependency of Airport Choice and Travel Demand," Chapter 13 *in* Gaudry, M., and R. Mayes *(eds.)*, Taking Stock of Air Liberalization, Kluwer Academic, Boston, Massachusetts, 1999.

Maxwell, R.R., "Intercity Rail Fixed-interval, Timed-transfer, Multihub System: Applicability of the "Integraler Taktfahrplan" Strategy to North America," Transportation Research Record, No. 1691, 1999.

Metropolitan Transportation Commission, Baycast-90 Users Guide: San Francisco Bay Area Travel Demand Model System (Cube/Voyager Version), Planning Section, Oakland, California, August 2004.

Monteiro, Ana B., and Mark Hansen, "Improvements to Airport Ground Access and the Behavior of a Multiple Airport System: BART Extension to San Francisco International Airport," Transportation Research Record, No. 1562, 1996.

Osborne, Martin J., An Introduction to Game Theory, Oxford University Press, New York, 2004

Outwater, Maren L., Steve Castleberry, Yoram Shiftan, Moshe Ben-Akiva, Yu Shuang Zhou and Arun Kuppam, "Attitudinal Market Segmentation Approach to Mode Choice and Ridership Forecasting: Structural Equation Modeling," Transportation Research Record, No. 1854, 2003.

Outwater, Maren L., Vamsec Modugula, Steve Castleberry and Pratyush Bhatia, "Market Segmentation Approach to Mode Choice and Ferry Ridership Forecasting," Transportation Research Record, No. 1872, 2004.

Pels, Eric, Peter Nijkamp and Piet Rietveld, "Access to and Competition between Airports: A Case Study for the San Francisco Bay Area," Transportation Research, Vol. 37A, No. 1, January 2003.

Portland Metro, PDX Ground Access Study Model Summary, Prepared by the Travel Forecasting Staff, Portland, Oregon, undated.

Press, W. H., Teukosky, S. A., Vetterling, W. T., and Flannery, B. P., Numerical Recipes in C, The rt of Scientific Comuting, 2nd Ed., Cambridge University Press, 1992

Proussaloglou, Kimon E., and Frank S. Koppelman, "Use of Travelers' Attitudes in Rail Service Design," Transportation Research Record, No. 1221, 1989.

Psaraki, Voula, and Costas Abacoumkin, "Access Mode Choice for Relocated Airports: The New Athens International Airport," Journal of Air Transport Management, Vol. 8, 2002.

San Jose International Airport, Norman Y. Mineta San Jose International Airport Master Plan Update: Final Supplemental Environmental Impact Report, State Clearinghouse Number SCH# 1999073066, January 2003.

Schneider, J.B., C. Deffebach and K. Cushman, "The Timed-transfer/Transit Center Concept as Applied in Tacoma/Pierce County, Washington," Transportation Quarterly, Vol. 38, No. 3, 1984.

Shapiro, Phillip S., *et al.*, Intermodal Ground Access to Airports: A Planning Guide, Prepared for the Federal Highway Administration and the Federal Aviation Administration, Report. No. DOT/FAA/PP/96-3, Bellomo-McGee, Inc., Vienna, Virginia, December 1996.

Shih, M.C., H.S. Mahmassani and M.H. Baaj, "Planning and Design Model for Transit Route Networks with Coordinated Operations," Transportation Research Record, No. 1623, 1998.

Small, Kenneth A., “A Discrete Choice Model for Ordered Alternatives,” Econometrica, Vol. 55, No. 2, 1987.

Sobieniak, J., R. Westin, T. Rosapep and T. Shin, “Choice of Access Mode to Intercity Terminals,” Transportation Research Record, No. 728, 1979.

Spear, Bruce D., An Analysis of the Demand for Airport Bus Services at Washington National and Dulles Airports, Report DOT-TSC-FAA-84-2, U.S. Department of Transportation, Transportation Systems Center, Cambridge, Massachusetts, May 1984.

Tambi, John E., and John Falcocchio, Implications of Parking Policy for Airport Access Mode Choice, Paper presented at the 70th Annual Meeting of the Transportation Research Board, Washington, D.C., January 1991.

TCRP, 1995, Transit Cooperative Research Program. Transit Fare Pricing in Regional Intermodal Systems. TRB, National Research Council, Washington, D. C.

TCRP, 1997, Coordinated Intermodal Transportation Pricing and Funding Strategies, RESEARCH RESULTS DIGEST, Oct. No. 14

Train, Kenneth E., Discrete Choice Methods with Simulation, Cambridge University Press, Cambridge, England, 2003.

U.S. Federal Aviation Administration, Emissions and Dispersion Modeling System (EDMS) User’s Manual, Prepared for the FAA Office of Environment and Energy by CSSI, Inc., Washington, DC, Revision 1, October 8, 2004.

U.S. Government Accountability Office, Intermodal Transportation: Potential Strategies Would Redefine Federal Role in Developing Airport Intermodal Capabilities, Report GAO-05-727, Washington, D.C., July 2005.

Voss, S., “Network Design Formulations in Schedule Synchronization,” *in* M. Desrochers and J.-M. Rousseau (*eds.*), Computer-Aided Transit Scheduling, Lecture Notes in Economics and Mathematical Systems, No. 386, Springer-Verlag, Berlin, 1990.

Winters, P. L., F. A., Cleland, *Vanpool Pricing and Financing Guide.* University of South Florida, Center for Urban Transportation Research, FL., 2000

Zhou, J. William H.K. Lam, Benjamin and G. Heydecker , The generalized Nash equilibrium model for oligopolistic transit market with elastic demand, *Transportation Research Part B* 39 (2005) 519–544

Zubieta, L., A network equilibrium model got oligopolistic competition in city bus services, Transportation Res.-B, Vol. 32, No. 6, pp. 413-422, 1998

Appendix A

INTERMODAL ACCESS PLANNING TOOL INITIAL DATA TABLE SPECIFICATIONS

The codes following the variable names for each table indicate the variable type. T*n* is a text variable of width *n* characters, M is a memo field (text of variable length), I is an integer, N*d* is a single-precision number with *d* decimal places, N is a single precision number with the decimal places unspecified, and D is a date.

Master Database Name: IAPT

Data Table	Name:	**Regions**		
	Description:	Region names		
	Rows:	Regions		
	Variables:	RegionID	I	Regional ID number (sequential)
		RegionCode	T10	Regional code (10 characters max)
		Name	T50	Region name
		Zones	I	Number of analysis zones
		Changes	M	Change log

Data Table	Name:	**Airports**		
	Description:	Airport characteristics		
	Rows:	Airports		
	Variables:	Code	T3	Three-letter code for airport
		Name	T50	Airport name
		RegionID	I	Regional ID number
		RegionCode	T10	Regional code
		BaseYear	I	Analysis baseline year
		Changes	M	Change log

Data Table	Name:	**Output**		
	Description:	Analysis output measures		
	Rows:	Output measures		
	Variables:	OutputID	I	Output measure ID number
		Name	T30	Output name
		Units	T20	Output measure units
	Note:	Predefined reference table		

Region Database Name: XXXX (Region code)

Data Table	Name:	**HTIME_xxxx** (user-defined)		
	Description:	Highway travel time		
	Rows:	Analysis zones		
	Variables:	Zone	I	Analysis zone number
		xxxx	N1	(User-defined variable name)
		etc.		(Additional variables as necessary)

Data Table	Name:	**HDIST_xxxx** (user-defined)		
	Description:	Highway distance		
	Rows:	Analysis zones		
	Variables:	Zone	I	Analysis zone number
		xxxx	N2	(User-defined variable name)
		etc.		(Additional variables as necessary)

Data Table	Name:	**HTOLL_xxxx** (user-defined)		
	Description:	Highway tolls		
	Rows:	Analysis zones		
	Variables:	Zone	I	Analysis zone number
		xxxx	N2	(User-defined variable name)
		etc.		(Additional variables as necessary)

Data Table	Name:	**TTIME_xxxx** (user-defined)		
	Description:	Transit network travel time		
	Rows:	Analysis zones		
	Variables:	Zone	I	Analysis zone number
		xxxx	N1	(User-defined variable name)
		etc.		(Additional variables as necessary)

Data Table	Name:	**TWAIT_xxxx** (user-defined)		
	Description:	Transit network wait time		
	Rows:	Analysis zones		
	Variables:	Zone	I	Analysis zone number
		xxxx	N1	(User-defined variable name)
		etc.		(Additional variables as necessary)

Data Table	Name:	**TFARE_xxxx** (user-defined)		
	Description:	Transit network fare		
	Rows:	Analysis zones		
	Variables:	Zone	I	Analysis zone number
		xxxx	N2	(User-defined variable name)
		etc.		(Additional variables as necessary)

Data Table	Name:	**Changes**		
	Description:	Data table change log		
	Rows:	Tables		
	Variables:	Name	T50	Data table name
		Date	D	Date created/modified
		Action	T1	Action code (Upload/Modify/Delete)

Airport Database Name: XXX (Airport code)

Data Table	Name:	**Projects**		
	Description:	Project definition for airport XXX		
	Rows:	Projects		
	Variables:	ProjectID	I	Project ID number (sequential)
		ProjectCode	T15	Hierarchical project code
		Name	T50	Project name
		Desc	M	Project description
		Changes	M	Change log

Data Table	Name:	**Time Frame**		
	Description:	Analysis time frame for airport XXX		
	Rows:	Analysis years		
	Variables:	Year	I	Analysis year
		Growth	N5	Air traffic growth factor
	Note:	Changes noted in **Airports** table		

Data Table	Name:	**AIRPAX_xxxx** (user-defined)		
	Description:	Air passenger data for airport XXX		
	Rows:	Air parties		
	Variables:	PartyID	I	Air party case ID number
		xxxx	T/N	(User-defined variable name)
		etc.		(Additional variables as necessary)

Data Table	Name:	**Changes**		
	Description:	Air passenger data table change log		
	Rows:	Tables		
	Variables:	Name	T50	Data table name
		Date	D	Date created/modified
		Action	T1	Action code (Upload/Modify/Delete)

Data Table	Name:	**Modes**		
	Description:	Ground access modes for airport XXX		
	Rows:	Modes		
	Variables:	ModeID	I	Mode sequence number
		Name	T20	Mode name
		Desc	T100	Description
	Note:	Changes noted in **Airports** table		

Data Table	Name:	**Project_Modes**		
	Description:	Project mode specification for airport XXX		
	Rows:	Projects/modes		
	Variables:	ProjectID	I	Project ID number
		ModeID	I	Mode sequence number
		FirstYear	I	First analysis year mode in operation
		LastYear	I	Last analysis year mode in operation
	Note:	Changes noted in **Projects** table		

Data Table	Name:	**Project_MOPs**		
	Description:	Project MOP specification for airport XXX		
	Rows:	Projects		
	Variables:	ProjectID	I	Project ID number
		MOP	I	MOP ID number
		Name	T20	MOP name
		OutputID	I	Output measure ID
		Desc	M	MOP description
	Note:	Changes noted in **Projects** table		

Data Table	Name:	**Project_MOP_Modes**		
	Description:	Modes included in project MOPs for airport XXX		
	Rows:	Projects/MOPs		
	Variables:	ProjectID	I	Project ID number
		MOP	I	MOP ID number
		ModeID	I	Mode sequence number
	Note:	Changes noted in **Projects** table		

Data Table

Name: **Project_Data**

Description: Project modal service data for airport XXX

Rows: Projects/modes/years

Variables:

ProjectID	I	Project ID number
ModeID	I	Mode sequence number
Year	I	Analysis year
FixedTime	N1	Fixed travel time (min)
WaitTime	N1	Average wait time (min)
Walk	I	Walk distance (feet)
PartyCost	N2	Fixed air party travel cost ($)
PaxCost	N2	Fixed air passenger travel cost ($)
DayCost	N2	Fixed daily trip cost ($)
TravTime	T50	Zonal travel time data table name
AM_Time	T20	AM peak travel time variable name
PM_Time	T20	PM peak travel time variable name
Off_Time	T20	Off-peak travel time variable name
Acc_Time	T20	Access travel time variable name
WaitTime	T50	Zonal wait time data table name
AM_Wait	T20	AM peak wait time variable name
PM_Wait	T20	PM peak wait time variable name
Off_Wait	T20	Off-peak wait time variable name
Acc_Time	T20	Access wait time variable name
TravCost	T50	Zonal travel cost data table name
Zone_Party	T20	Air party travel cost variable name
Zone_Pax	T20	Air passenger travel cost variable name
Acc_Party	T20	Air party access cost variable name
Acc_Pax	T20	Air passenger access cost variable name
Acc_Day	T20	Daily access trip cost variable name
TravDist	T50	Zonal travel distance data table name
Zone_Dist	T20	Travel distance variable name
Acc_Dist	T20	Access distance variable name

Note: Changes noted in **Projects** table

Data Table Name: **Project_Eval**

Description: Project evaluation data for airport XXX

Rows: Projects/modes

Variables:

ProjectID	I	Project ID number
ModeID	I	Mode sequence number
VehOcc	N1	Average vehicle occupancy (persons)
TripTime	N1	Round trip travel time (min)
Speed	I	Average speed (mph)
Route	N2	Route length (miles)
Fleet	I	Fleet size (veh)
CostYear	I	Cost estimates in constant (year) dollars
RouteCost	N	Capital cost per route mile ($)
VehCost	N	Capital cost per vehicle ($)
AnnCost	N	Fixed annual operating cost ($)
VMCost	N	Operating cost per vehicle-mile ($)

Note: Changes noted in **Projects** table

Appendix B
DETAILS OF RECENT AIR PASSENGER MODE CHOICE MODELS

This appendix provides a detailed summary of the structure and estimated coefficients for four recent air passenger mode choice models.

Boston Logan Model

This model was developed by the Central Transportation Planning Staff (CTPS) in Boston using a 1993 air passenger survey performed at Boston Logan International Airport.[4] Separate submodels were developed for resident business trips, resident non-business trips, non-resident business trips and non-resident non-business trips. The two resident submodels consist of a two-level nested logit model, with separate second-level nests for door-to-door modes (taxi and limousine) and automobile modes (drop-off, short-term parking, long-term parking, and off-airport parking). There are four shared-ride public modes at the top level (regular transit, scheduled airport bus, the Logan Express service to off-airport terminals in the region, and the Water Shuttle between the airport and the downtown Boston waterfront). The visitor submodels are multinomial logit models and omit the long-term parking alternatives but add a hotel shuttle mode.

This model includes both a rail access mode, the Metropolitan Boston Transit Authority (MBTA) regional rail transit system, and off-airport terminals, the Logan Express service operated by the Massachusetts Port Authority (Massport), the airport authority for Logan Airport. The MBTA Airport Station is adjacent to the airport and linked to the passenger terminals by a free shuttle bus service operated by Massport. Unlike many other airport access mode choice models, the CTPS model treats rental car use as an independent decision and excludes it from the mode choice decision process.

Independent variables include both in-vehicle and out-of-vehicle travel time, automobile access time to the public modes, the number of transfers, travel costs, and dummy variables for the type of trip origin (residence or not), the amount of luggage, air party size, number of air trips in past year, and whether an employer was paying travel expenses. Not all variables are included in all models, and various combinations of the independent variables were estimated. For some

---

[4] Harrington, Ian E., *et al.*, Summary of People Mover Study Passenger Mode Choice Models, Draft Memorandum, Central Transportation Planning Staff, Boston, Massachusetts, May 17, 1996.

model variations, separate travel cost coefficients were estimated for low-income and high-income travelers or for those for whom their travel costs were paid by their employer. However, the definition of low-income and high-income travelers was not defined in the model documentation. Travel times were measured in minutes and costs in dollars, based on 1993 rates.

Tables B-1 to B-4 show the estimated model coefficients for the four market segment models. Values in parentheses are the t-statistics of the estimates. With a few exceptions, most of the estimated coefficients are statistically significant at the 95% level or better. The t-statistics for the alternative-specific constants for the non-resident, non-business model (Table B-4) are as reported in the model documentation, but appear to be incorrect. They are identical to those shown for the resident non-business model (Table B-3), which would be surprising, and three have incorrect signs (t-statistics are generally reported with the same sign as the coefficient), suggesting that the wrong values were reported in the model documentation.

As can be seen from Tables B-1 to B-4, separate travel time and cost coefficients were estimated from groups of modes. This of course has the effect of giving different implied values of travel time for different modes, as shown in Table B-5. While it can be expected that travelers choosing different modes will on average tend to have different values of time (for example travelers choosing taxi will tend to have a higher value of time than those using the MBTA), that is an entirely different issue from assuming that a ***given*** traveler will have a different implied value of travel time when considering alternative modes (as implied by the models).

It makes no sense at all to assume that given travelers will value their time at one amount when considering a high-priced mode and a different amount when considering a less expensive, but more time consuming, mode. The fact that the CTPS modelers were able to obtain a statistically significant difference in the model coefficients for different modes suggests that this is a result of specification problems with the models or problems with the model estimation data. In particular, the omission of any air party size information in the utility functions for most modes would ignore the distinction between costs that are incurred on a per person basis from those costs that are incurred once per air party. Similarly, the use of the same travel cost coefficient for all air parties irrespective of income is likely to lead to differences in the estimated coefficients for modes with widely different costs.

Table B-1 Boston Logan Resident Business Model Coefficients

			Travel Time Coefficients			Travel Cost Coefficients			Dummy Variable Coefficients			
Mode	Const	Tree Coeff	IVTT	OVTT	Auto access	Self pay low-inc	Self pay high-inc	Empl pays	Non-res origin	Empl pays	Luggage >2 bags	>6 flts in year
MBTA rail	-1.471 *(-1.7)*		-0.034 *(-4.9)*	-0.034	-0.072 *(-5.7)*	-0.080 *(-0.8)*	-0.080	-0.080			-1.175 *(-2.2)*	
Scheduled bus/limo	0.437 *(0.8)*		-0.034	-0.034	-0.072	-0.080	-0.080	-0.080				
Logan Express	-0.126 *(0.4)*		-0.034	-0.034	-0.072	-0.080	-0.080	-0.080				
Water Shuttle	-2.851 *(-2.6)*		-0.034	-0.034	-0.072	-0.080	-0.080	-0.080				
Door-to-Door nest		0.361 *(2.9)*							-0.503 *(-2.5)*	1.337 *(4.3)*		
Taxi	-1.279 *(-3.4)*		-0.173 *(-2.0)*	-0.173		-0.295 *(-2.2)*	-0.101 *(-7.5)*	-0.101				
Limousine			-0.173	-0.173		-0.295	-0.101	-0.101				
Automobile nest	-0.290 *(-0.9)*	0.72 *(5.6)*										
Long-term park on airport	0.897 *(2.4)*		-0.036 *(-2.2)*	-0.171 *(-2.9)*		-0.370 *(-3.4)*	-0.193 *(-6.1)*	-0.102 *(-6.1)*				0.850 *(3.7)*
Long-term park off airport	0.527 *(0.8)*		-0.036	-0.171		-0.370	-0.193	-0.102				0.850
Short-term park at airport	-1.491 *(-4.0)*		-0.070 *(-3.8)*	-0.171		-0.370	-0.193	-0.102	-0.794 *(-2.6)*			
Drop-off			-0.070	-0.171		-0.370	-0.193	-0.102	-0.794			

Note: t-statistics shown in parentheses (omitted for repeated values)

Table B-2 Boston Logan Resident Non-Business Model Coefficients

			Travel Time Coefficients				Travel Cost Coefficients			Dummy Variable Coefficients			
Mode	Const	Tree Coeff	IVTT	OVTT	Auto access	No of transfers	Self pay low-inc	Self pay high- inc	Empl pays	Non-res origin	Luggage >2 bags	>2 flts in year	Party size >1
MBTA rail	0.926 *(2.9)*		-0.027 *(-4.7)*	-0.027	-0.092 *(-8.1)*	-0.150 *(-0.9)*	-0.232 *(-2.9)*	-0.232	-0.232		-1.805 *(-5.2)*		
Scheduled bus/limo	3.799 *(4.4)*		-0.027	-0.027	-0.092	-0.150	-0.232	-0.232	-0.232				
Logan Express	2.781 *(5.1)*		-0.027	-0.027	-0.092	-0.150	-0.232	-0.232	-0.232				
Water Shuttle	-0.213 *(-0.0)*		-0.027	-0.027	-0.092	-0.150	-0.232	-0.232	-0.232				
Door-to-Door nest	-0.401 *(-0.4)*	0.470 *(3.2)*											
Taxi	-0.957 *(0.3)*		-0.057 *(-1.7)*	-0.057			-0.093 *(-4.6)*	-0.073 *(-4.1)*	-0.073	1.118 *(2.2)*			
Limousine			-0.057	-0.057			-0.093	-0.073	-0.073				2.452 *(4.3)*
Automobile nest		0.631 *(4.7)*											
Long-term park on airport	0.115 *(1.4)*		-0.036 *(-1.8)*	-0.066 *(-1.0)*			-0.259 *(-6.5)*	-0.118 *(-5.4)*	-0.118			1.139 *(4.0)*	
Long-term park off airport	-0.075 *(0.1)*		-0.036	-0.066			-0.259	-0.118	-0.118			1.139	
Short-term park at airport			-0.074 *(-3.6)*	-0.066			-0.259	-0.118	-0.118	-1.153 *(-3.5)*			
Drop-off	0.604 *(3.4)*		-0.074	-0.066			-0.259	-0.118	-0.118	-1.153			1.109 *(4.1)*

Note: t-statistics shown in parentheses (omitted for repeated values)

Table B-3 Boston Logan Non-Resident Business Model Coefficients

		Travel Time Coefficients				Travel Cost Coefficients			Dummy Coefficients		
Mode	Const	IVTT	OVTT	Auto access	No of transfers	Self pay low-inc	Self pay high-inc	Empl pays	Non-res origin	Luggage >2 bags	Party size >1
MBTA rail	-1.855 *(-3.7)*	-0.022 *(-4.2)*	-0.022	-0.039 *(-4.3)*	-0.286 *(-1.8)*	-0.091 *(-7.9)*	-0.091	-0.058 *(-6.9)*		-0.508 *(-1.9)*	
Scheduled bus/limo	-1.564 *(-3.8)*	-0.022	-0.022	-0.039	-0.286	-0.091	-0.091	-0.058			
Logan Express	-2.856 *(-4.7)*	-0.022	-0.022	-0.039	-0.286	-0.091	-0.091	-0.058			
Water Shuttle	-1.620 *(-4.8)*	-0.022	-0.022	-0.039	-0.286	-0.091	-0.091	-0.058			
Taxi		-0.039 *(-4.3)*	-0.039			-0.091	-0.091	-0.058			
Limousine	-0.275 *(-1.4)*	-0.039	-0.039			-0.091	-0.091	-0.058			
Hotel shuttle	-2.187 *(-11.4)*	-0.039	-0.039								
Short-term park at airport	-1.586 *(-2.1)*	-0.039	-0.152 *(-2.4)*			-0.058 *(-6.9)*	-0.058	-0.058	-2.105 *(-9.6)*		
Drop-off	0.376 *(-1.2)*	-0.039	-0.152			-0.058	-0.058	-0.058	-2.105		0.377 *(1.6)*

Note: t-statistics shown in parentheses (omitted for repeated values)

Table B-4 Boston Logan Non-Resident Non-Business Model Coefficients

		Travel Time Coefficients				Travel Cost Coefficients			Dummy Coefficients		
Mode	Const	IVTT	OVTT	Auto access	No of transfers	Self pay low-inc	Self pay high-inc	Empl pays	Non-res origin	Luggage >2 bags	Party size >1
MBTA rail	-1.066 *(-3.7)*	-0.013 *(-2.5)*	-0.013 *(-2.5)*	-0.013 *(-2.2)*	-0.213 *(-1.2)*	-0.091 *(-7.9)*	-0.091	-0.058 *(-6.9)*		-0.508 *(-1.9)*	
Scheduled bus/limo	0.155 *(-3.8)*	-0.013	-0.013	-0.013	-0.213	-0.091	-0.091	-0.058			
Logan Express	-2.020 *(-4.7)*	-0.013	-0.013	-0.013	-0.213	-0.091	-0.091	-0.058			
Water Shuttle	-2.352 *(-4.8)*	-0.013	-0.013	-0.013	-0.213	-0.091	-0.091	-0.058			
Taxi		-0.013 *(-2.2)*	-0.013 *(-2.2)*			-0.091	-0.091	-0.058			
Limousine	0.812 *(-1.4)*	-0.013	-0.013			-0.091	-0.091	-0.058			
Hotel shuttle	-0.021 *(-11.4)*	-0.013	-0.013								
Short-term park at airport	-0.229 *(-2.1)*	-0.013	-0.152 *(-2.4)*			-0.058 *(-6.9)*	-0.058	-0.058	-2.105 *(-9.6)*		
Drop-off	0.376 *(-1.2)*	-0.013	-0.152			-0.058	-0.058	-0.058	-2.105		0.377 *(1.6)*

Note: t-statistics shown in parentheses (omitted for repeated values)

Table B-5 Implied Values of Boston Logan Model Parameters

Variable	Resident Business	Resident Non-business	Non-resident Business	Non-resident Non-business
TRAVEL TIME ($/hour)				
In-vehicle				
Shared-ride modes[a]				
Self-pay/Employer pays	26	7	15/23	9/13
Taxi/limousine				
Low-income	35	37	26	9
High-income/Employer pays	103	47	26/40	9/13
Auto park				
Low-income	6	8	n/a	n/a
High-income/Employer pays	11/21	18	n/a	n/a
Auto drop or park short-term				
Low-income	11	17	40	13
High-income/Employer pays	22/41	38	40	13
Auto access (shared-ride modes)				
Self-pay/Employer pays	54	24	26/40	9/13
CONSTANTS (minutes of IVT)[b]				
MBTA	43	-34	84	82
Scheduled bus/limo	-13	-141	71	-12
Logan Express	4	-103	130	155
Water Shuttle	84	8	74	181
Taxi	7	24	--	--
Limousine	--	7	7	-62
Hotel shuttle	n/a	n/a	56	2
Automobile				
Park long-term on airport	-17	-3	n/a	n/a
Park long-term off airport	-7	2	n/a	n/a
Park short-term at airport	25	--	41	-29
Drop off	4	-8	-10	18

Notes: a) MBTA, Scheduled bus/limo, Logan Express, Water Shuttle
b) Equivalent minutes of in-vehicle time

Given these problems with the data and the conceptual difficulty with having different implied values of time for different modes, there is no reason to expect any particular relationship between the implied values of time for different market segments or different income levels. However, in fact the implied values of time for higher income travelers or those for whom their employer is paying their travel costs are generally higher than those for lower income travelers, as could be expected. Similarly, for non-resident travelers the implied values of time for business travelers are higher than the corresponding values of time for non-business travelers. While this is also true for some modes for resident travelers, business travelers have a lower implied value of time than non-business travelers for automobile users paying their own travel expenses.

The implied value of the alternative-specific constants, expressed as equivalent minutes of in-vehicle time, where a positive value indicates that the mode has a relative perceived disutility that would be offset by reducing the travel time by that amount, show no obvious pattern and no consistent relationship across the different market segments. For some market segments a given mode is significantly more attractive than another mode while for other market segments the reverse is true. It is quite likely that these values are so distorted by the model specification problems that they have no intrinsic interpretation.

Portland Ground Access Study Model

Soon after the Boston Logan model was developed, a similar model was developed for Portland, Oregon, as part of a ground access study for Portland International Airport (PDX) that was jointly undertaken by the Port of Portland and Metro, the regional Metropolitan Planning Organization, with the assistance of Cambridge Systematics, Inc.[2] The primary purpose of the model was to forecast the potential ridership on a planned extension of the Portland MAX light rail system to the airport, as well as other ground access enhancements. An air passenger survey was performed at the airport that consisted of a revealed preference (RP) survey that examined air passengers' actual mode use and a stated preference (SP) survey that was designed to determine travelers' preferences for modes that were not then available, namely light rail, express bus and shared-ride transit (it is unclear from the documentation how this was defined).

An initial model estimation by Cambridge Systematics jointly estimated two multinomial logit models using both the RP and SP data, one for business travelers and one for non-business travelers.[3] These models were subsequently revised by Metro staff. The documentation does not explain why it was decided to revise the models, or how this was done.

---

[2] Portland Metro, PDX Ground Access Study Model Summary, Prepared by the Travel Forecasting Staff, Portland, Oregon, May 1998.

[3] Bowman, John L., Portland PDX Airport Access Project Mode Choice Models, Memorandum to Keith Lawton, Metro, Cambridge Systematics, Inc., July 28, 1997.

The final model parameters are given in Tables B-6 to B-9. Separate parameters were estimated for the same four market segments as the Boston Logan model (this resulted in four models, rather than the two estimated by Cambridge Systematics). In addition, separate alternative-specific constants were estimated for each mode for trips originating within the Portland metropolitan area (termed internal trips) and those originating outside the metropolitan area (termed external trips). Two different sets of model parameters were estimated for each market segment. The first set (termed Model 1) assumed that the alternative-specific constants for the light rail and express bus modes would be the same as those for shared-ride van and RAZ bus (a scheduled bus service between the airport and downtown Portland locations operated by RAZ Transportation, a Gray Line affiliate). The second set (termed Model 2) used the SP data to estimated separate alternative-specific constants for the light rail and express bus modes. The documentation on the initial model estimation by Cambridge Systematics provides t-statistics for the parameter estimates, but the documentation of the final model does not.

The resident models included private automobile parked at the airport for the trip duration (termed auto park) as a possible mode choice while the non-resident models included rental car as a possible mode choice in place of auto park mode. In the case of the light rail and express bus alternatives it was assumed that travelers would be dropped off at the station or stop by private automobile. For the drop-off alternatives, including air passengers dropped off at the airport by private automobile (termed auto drop off), the time of the driver (termed the chauffeur in the model documentation) was assigned a value of $20 per hour for business travelers and $10 per hour for non-business travelers according to the model documentation (tables giving the final model parameters indicate that $20 per hour was used for all trip purposes, but this is assumed to be a typographic error). Automobile operating costs were assumed to be 12 cents per mile.

The direct costs of each mode (but not the operating costs and value of driver time of automobiles dropping off air passengers) were divided by the logarithm of the average household income for the trip origin zone (in thousands of dollars per year). This gives values of time that vary with household income, as is to be expected, but that have a non-linear relationship that increases at a declining rate at higher income levels. The average household income for the zone was presumably used because the household income of the survey respondents was not obtained in the air passenger survey, although this obviously fails to account for the effect of variation in household income across survey respondents from a given zone.

Table B-6 Portland Ground Access Study Resident Business Model Parameters

	Model 1	Model 2
CONSTANTS (auto park base)		
Internal trips		
Auto drop off	0.85	0.85
Taxi and limousine	-1.162	-1.272
Van, RAZ bus and hotel shuttle	-0.988	-1.258
Light rail (auto drop off)	-0.988	-1.258
Express bus (auto drop off)	-0.988	-1.258
External trips		
Auto drop off	-0.85	-0.85
Taxi and limousine	n/a	n/a
Van, RAZ bus and hotel shuttle	2.312	0.742
Light rail (auto drop off)	2.312	0.742
Express bus (auto drop off)	2.312	0.742
VARIABLES		
Drop off cost ($)	-0.0195	-0.0195
Travel time (minutes)	-0.0176	-0.0176
Cost/ln(income) $/ln($K)	-0.2185	-0.2185

Table B-7 Portland Ground Access Study Resident Non-Business Model Parameters

	Model 1	Model 2
CONSTANTS (auto park base)		
Internal trips		
Auto drop off	-0.30	-0.30
Taxi and limousine	-2.068	-1.538
Van, RAZ bus and hotel shuttle	-1.632	-1.362
Light rail (auto drop off)	-1.632	-0.365
Express bus (auto drop off)	-1.632	-1.528
External trips		
Auto drop off	-0.80	-0.80
Taxi and limousine	-2.188	-2.188
Van, RAZ bus and hotel shuttle	2.368	-0.652
Light rail (auto drop off)	2.368	-2.345
Express bus (auto drop off)	2.368	-3.887
VARIABLES		
Drop off cost ($)	-0.0235	-0.0235
Travel time (minutes)	-0.0264	-0.0264
Cost/ln(income) $/ln($K)	-0.2170	-0.2170

Table B-8 Portland Ground Access Study Non-Resident Business Model Parameters

	Model 1	Model 2
CONSTANTS (rental car base)		
Internal trips		
Auto drop off	-0.50	-0.50
Taxi and limousine	-0.914	-1.234
Hotel shuttle	-0.887	-0.997
Van and RAZ bus	-0.937	-1.397
Light rail (auto drop off)	-0.937	-0.801
Express bus (auto drop off)	-0.937	-0.996
External trips		
Auto drop off	-0.30	-0.30
Taxi and limousine	-1.064	-2.214
Van and RAZ bus	n/a	n/a
Light rail (auto drop off)	-1.287	-1.467
Express bus (auto drop off)	-1.287	-2.417
VARIABLES		
Drop off cost ($)	-0.0082	-0.0082
Travel time (minutes)	-0.0073	-0.0073
Cost/ln(income) $/ln($K)	-0.0913	-0.0913

Table B-9 Portland Ground Access Study Non-Resident Non-Business Model Parameters

	Model 1	Model 2
CONSTANTS (rental car base)		
Internal trips		
Auto drop off	0.10	0.10
Taxi and limousine	-1.754	-1.574
Hotel shuttle	-0.246	-0.046
Van and RAZ bus	-0.596	-0.956
Light rail (auto drop off)	-0.596	-0.914
Express bus (auto drop off)	-0.596	-0.935
External trips		
Auto drop off	-0.50	-0.50
Taxi and limousine	-1.304	-2.054
Van and RAZ bus	-0.346	-1.206
Light rail (auto drop off)	-0.346	-1.206
Express bus (auto drop off)	-0.346	-0.686
VARIABLES		
Drop off cost ($)	-0.0082	-0.0082
Travel time (minutes)	-0.0092	-0.0092
Cost/ln(income) $/ln($K)	-0.0716	-0.0716

The model documentation does not explain why alternative-specific constants were not determined for taxi and limousine use for resident business trips from external origins or for shared-ride van and RAZ bus use for non-resident business trips from external zones, but were determined for the other three market segments in each case. In fact, it is not clear why RAZ bus was included as an option for external trips at all, or why hotel shuttle was considered as an option for resident trips. There are a number of counter-intuitive or surprising values for the alternative-specific constants. The fact that the alternative specific constants for taxi and limousine have a generally higher disutility than auto drop off suggests that the perceived cost of taxi and limousine fares have been underestimated. Also, it is not clear why the perceived relative disutility of existing modes should change between Model 1 and Model 2 when the values for the light rail and express bus were adjusted using the SP data. The large positive value of the alternative-specific constant for shared-ride van and RAZ bus for resident trips from external zones seems inconsistent with the values for internal trips.

The implied values of the model parameters for Model 2 are shown in Table B-10. Because the inclusion of household income in the cost term results in implied values of time that vary with average household income, these values have been calculated for average annual household incomes of $50,000 and $150,000. While the resulting values of time seem consistent for resident and non-resident travelers for each trip purpose, this is a consequence of the way the model was estimated, and the lower value of time for business trips compared to non-business trips is counter-intuitive. The relatively small change in the value of time between a zone with an average annual household income of $50,000 and one with an average annual household income of $150,000 per year is a consequence of the use of the logarithmic transform. For comparison with the implied values shown in Table B-10, a household with one worker and an annual income of $50,000 would have a wage rate of $25 per hour, while a household with two workers and an annual income of $150,000 would have an average wage rate of $37.50 per hour. Thus the implied values appear to be in the general range of the wage rate.

The implied values of the alternative specific constants, expressed as equivalent minutes of travel time, appear implausibly large for many modes. For example, the relative disutility of most public modes for non-resident trips compared to auto drop off, apart from any differences in cost and travel time, is equivalent to well over an hour of travel time and over three hours of travel time in the case of taxi or limousine use for non-business trips from internal zones, or taxi, limousine or express bus use for business trips from external zones. The large differences in the auto drop off constant compared to auto park (for resident trips) and rental car (for non-resident trips) between business and non-business trips suggests that these constants are accounting for more than just the inherent differences in the comfort and convenience of the various modes.

Table B-10 Implied Values of Portland Ground Access Study Parameters

	Resident Business	Resident Non-business	Non-resident Business	Non-resident Non-business
CONSTANTS (minutes)				
Internal trips				
Auto drop off	-48	11	68	-11
Taxi and limousine	72	58	169	171
Hotel shuttle	71	52	137	5
Van and RAZ bus	71	52	191	104
Light rail (auto drop off)	71	14	110	99
Express bus (auto drop off)	71	58	136	102
External trips				
Auto drop off	48	30	41	54
Taxi and limousine	n/a	83	303	223
Van and RAZ bus	-42	25	n/a	131
Light rail (auto drop off)	-42	89	201	131
Express bus (auto drop off)	-42	147	331	75
TRAVEL TIME ($/hour)				
$50,000 avg. h/h income	19	29	19	30
$150,000 avg. h/h income	24	37	24	39
AUTO DROP OFF COST RATIO				
$50,000 avg. h/h income	0.35	0.42	0.35	0.45
$150,000 avg. h/h income	0.45	0.54	0.45	0.57

The ratio of the auto drop-off cost parameter to the cost parameter for all other costs suggests that the auto drop-off costs (primarily the time of the driver) are valued at between about a third and a half of the other costs. This is not unreasonable, since some air travelers may consider being taken to the airport by others as essentially costless to them. However, it is worth noting that the assumed values of time for the drivers (twice as high for business trips as for non-business trips) are inconsistent with the estimated values of time for the air passengers, which are about half again higher for non-business trips than business trips.

SERAS Model

As part of the South East and East of England Regional Air Service (SERAS) study undertaken for the United Kingdom Department of Transport, Local Government and the Regions, a set of surface access models were developed that included an air passenger mode choice model, as well as an airport employee trip distribution model, and an airport employee mode choice model.[4]

The structure of the passenger mode choice model is stated to be the same as the Heathrow Surface Access Model (HSAM) developed by the MVA Consultancy for the British Airports Authority. This is a nested logit model that covers 12 defined ground access modes and has separate coefficients for six market segments:

- U.K. business passengers on domestic trips
- U.K. business passengers on international trips
- U.K. leisure passengers on domestic trips
- U.K. leisure passengers on international trips
- Non-U.K. passengers on business trips
- Non-U.K. passengers on leisure trips.

The 12 ground access modes consist of:

- Drop off by private automobile (termed Kiss & Fly)
- Private automobile parked at airport (termed Park & Fly)
- Rental car (termed Hire Car)
- Taxi
- Local bus and intercity coach
- London Underground
- Coach links to British Rail stations (BR Coach)
- Dedicated premium rail service (Heathrow Express)
- New standard British Rail services
- Alternative premium rail service
- Charter coach (including hotel bus)
- Inter-airport transfer coach.

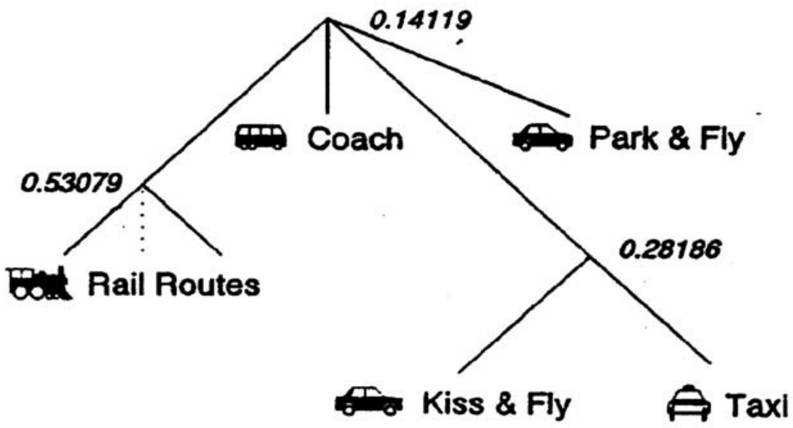
---

[4] Halcrow Group Ltd., SERAS Surface Access Modelling, Prepared for the Department of Transport, Local Government and the Regions, South East and East of England Regional Air Services Study, London, England, July 2002.

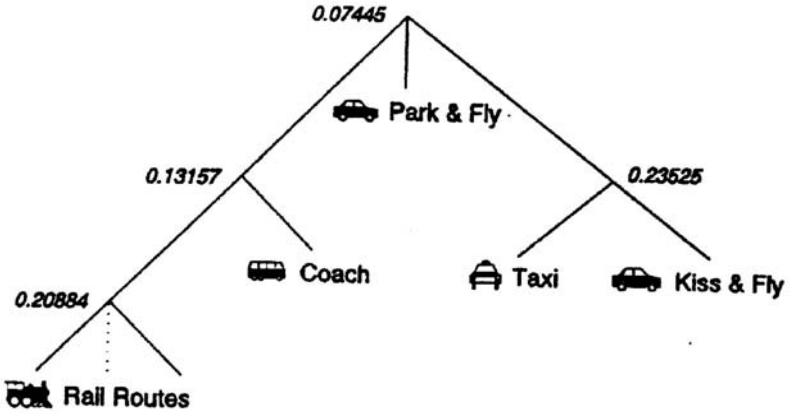
Although the term British Rail is used in the model documentation, these services are now provided by private companies (e.g. Great Western Trains) and British Rail as such no longer exists. The Park & Fly mode was assumed to only be available to U.K. passengers and was substituted by the Hire Car mode for non-U.K. passengers. The Heathrow Express is a dedicated non-stop service between London Paddington Station and Heathrow Airport. The alternative premium rail service was assumed to be a similar service from another London station, while the new standard British Rail service would provide direct rail service to the airport using conventional rail equipment with intermediate stops. The hotel bus service refers to a system of shuttle buses that serve local hotels near Heathrow Airport. However the use of charter coach, hotel bus and inter-airport transfer coach was not explicitly represented in the model, but instead the use of these services was determined independently and the resulting vehicle trips added to those determined using the mode choice model. Thus the mode choice model for each market segment consisted of nine modes.

The nesting structure of the model is shown in Figure B-1. There are several levels of nest, particularly for the different rail modes. The utility functions for each mode use a generalized cost approach that considers the travel time and out of pocket costs (fares, parking, and private automobile operating costs), as well as time penalties for interchanges on public modes, and converts all costs to equivalent minutes of travel time. The utility function divides the generalized cost for the mode by the square root of the direct driving distance to the airport. There are no calibration parameters as such, although different values of time are assumed for each market segment and different weights are applied to waiting time for some market segments. Different automobile operating costs (in pence per kilometer) are assumed for U.K. business and U.K. leisure passengers. Since the models are applied to estimates of air passenger trips that originate in each analysis zone, an average air party size and average trip duration are assumed for each market segment.

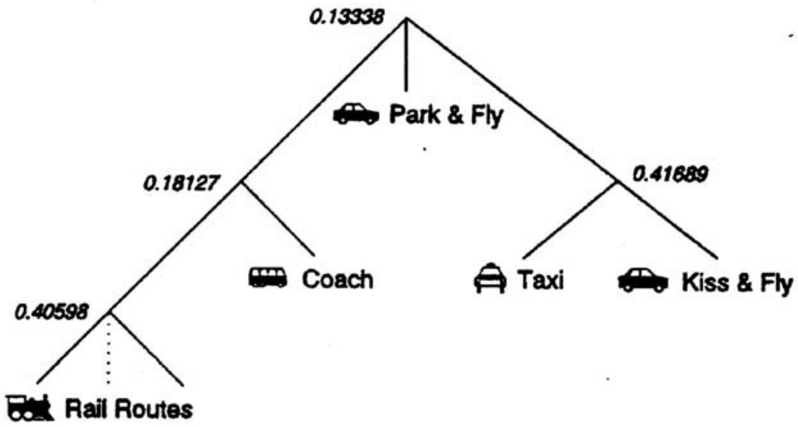
Segment 1 – UK Business Domestic Mode Choice Structure



Segment 3 – UK Leisure Domestic Mode Choice Structure



Segment 2 – UK Business International Mode Choice Structure



Segment 4 – UK Leisure International Mode Choice Structure

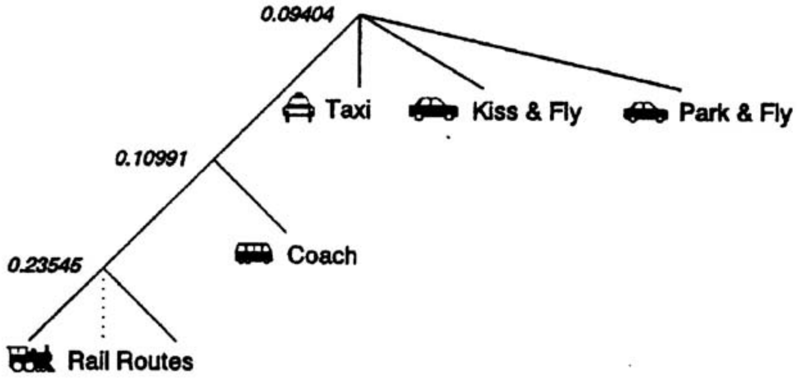
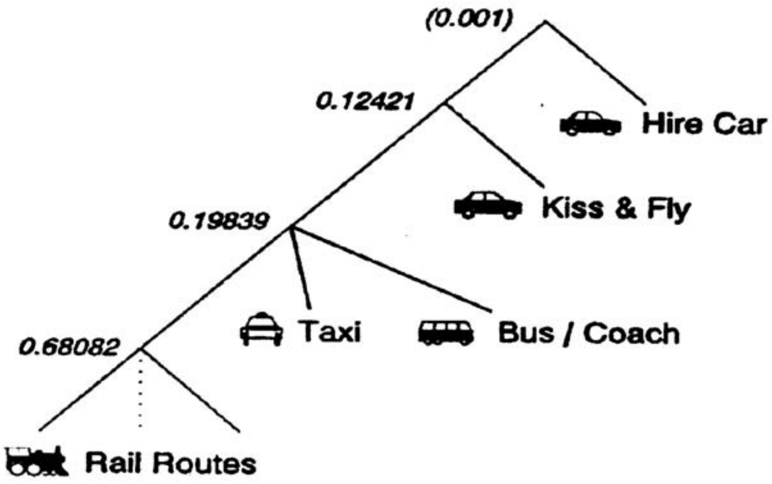
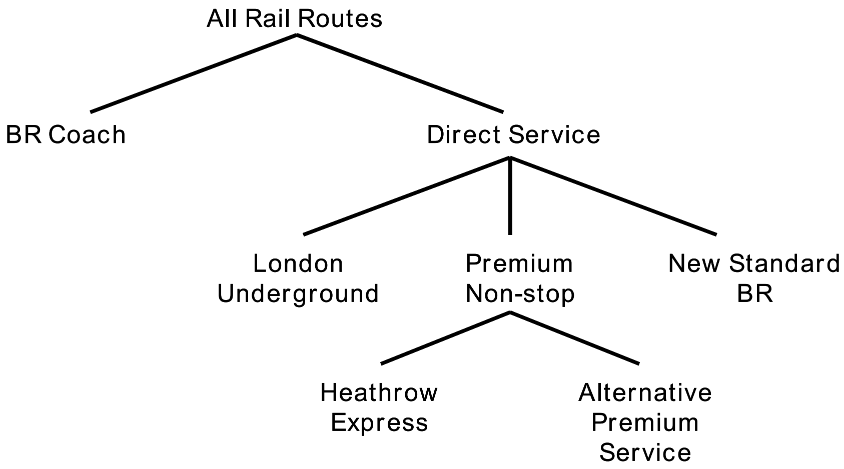


Figure B-1: SERAS Mode Choice Model Nesting Structure

Segment 5 – Non UK Business Mode Choice Structure



Rail Routes Mode Choice Structure



Segment 6 – Non UK Leisure Mode Choice Structure

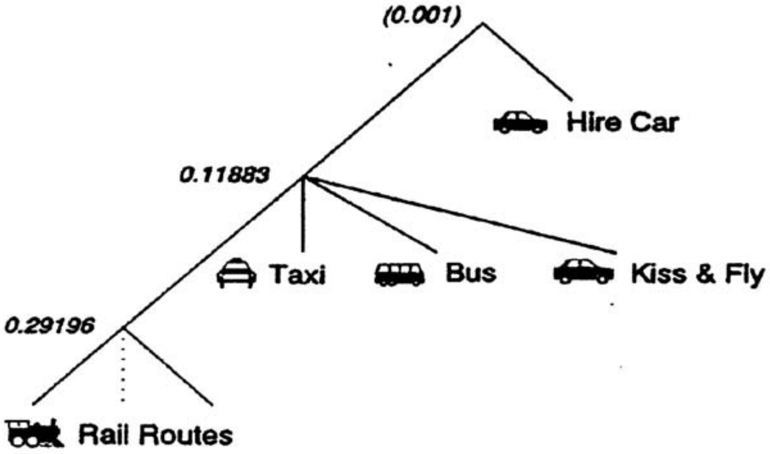


Figure B-1 (cont.): SERAS Mode Choice Model Nesting Structure

The utility functions for each mode are as follows:

$$U_{K\&F} = \frac{T_{car} + \frac{c}{gv}D}{\sqrt{D}}$$

$$U_{P\&F} = \frac{T_{car} + \frac{c}{gv}D + \frac{pd}{gv}}{\sqrt{D}}$$

$$U_{taxi} = \frac{T_{car} + \frac{1}{gv}F_{taxi}}{\sqrt{D}}$$

$$U_{bus} = \frac{T_{bus} + \alpha W_{bus} + \frac{1}{v}F_{bus}}{\sqrt{D}} + \tau_1 I1$$

$$U_{rail} = \frac{T_{rail} + \alpha W_{rail} + \frac{1}{v}F_{rail}}{\sqrt{D}} + \tau_x X1 + \tau_1 I1 + \tau_2 I2 + \theta$$

where T_m = in-vehicle time plus access walk time for mode *m* (minutes)
D = direct driving distance to airport (kilometers)
c = perceived private car fuel cost (pence/km)
v = value of travel time (pence per minute)
g = air party size
p = parking rate (pence per day)
F_m = fare for mode *m* (pence)
W_m = wait time for mode *m* (minutes)
X1 = number of cross-platform interchanges
I1 = number of full intra-modal interchanges
I2 = number of intermodal interchanges
α = weighting of wait time relative to in-vehicle time
τ_x = cross platform transfer penalty (minutes)
τ_1 = intra-modal interchange penalty (minutes)
τ_2 = intermodal interchange penalty (minutes)
θ = direct rail constant (minutes/sq km)

The values for the various model parameters that were used in the SERAS study are shown in Table B-11. Air passenger value of time and vehicle operating costs are given in 1998 pence. Most of the parameter values were adopted unchanged from the 1991 version of the Heathrow Surface Access Model.

Table B-11 SERAS Mode Choice Model Parameters

	U.K. Business Domestic	U.K. Business Int'l	U.K. Leisure Domestic	U.K. Leisure Int'l	Non-U.K. Business	Non-U.K. Leisure
Value of time (£/hr)	28.5	46.3	4.7	6.6	47.8	5.6
Veh. operating cost (p/km)	9.40	9.40	8.14	8.14	n/a	n/a
Average air party size	1.36	1.36	1.99	1.99	1.56	2.08
Average trip duration (days)	2.57	8.50	6.43	18.66	n/a	n/a
Wait time weighting factor	1.0	1.0	1.0	1.9	1.0	1.35
Parking adjustments	2.0	2.5	2.5	4.0	n/a	n/a
Interchange penalty (min)						
Cross-platform	0.43	0.50	0.77	0.90	0.30	0.69
Intra-modal	2.13	2.52	3.86	4.48	1.48	3.45
Intermodal	2.48	2.52	3.86	5.40	1.48	4.19
HEX constant (min/sqrt km)						
Central London	6.70	9.10	17.93	15.54	5.88	16.90
Outer London	3.20	4.09	5.10	7.84	2.99	9.41

Notes: n/a not applicable
HEX Heathrow Express

The values of time for business travelers appear reasonable, although those for leisure travelers appear surprisingly low (in 1998 the pound was worth about 1.66 dollars). The interchange penalties appear too low, particularly for cross-platform connections. In general travelers will experience a wait of about half the headway of the outbound service at an interchange, in addition to any walking time involved. However, it is not clear from the documentation whether these penalties are in addition to any waiting time or are intended to account for it. The Heathrow Express constant (θ) reflects the higher quality of service relative to the London Underground. The difference in value between central and outer London presumably results from the need for a longer journey on the Underground to reach the Heathrow Express terminal at Paddington Station. However, since the ride on the Heathrow Express is the same duration for all travelers, any measure of the higher utility of the Heathrow Express service should be a constant for all travelers. Since these interchange penalties and direct rail constants have been estimated from air passenger survey data, this suggests that the model estimation has underestimated the perceived disutility of the access journey to Paddington Station, possibly due to underestimated interchange penalties (from most parts of London, reaching Paddington Station by Underground involves several changes of line or even changes of mode).

Perhaps the two most questionable aspects of the SERAS model is the use of an average value of time for each market segment. While this is a consequence of the use of aggregate trip generation data rather than applying the model to disaggregate air passenger survey data, it will tend to under-predict the use of public transport modes by lower income travelers and over-predict their use by higher-income travelers. To the extent that higher and lower income travelers are not uniformly distributed geographically, this will result in biased estimates of public transport mode use from any given zone, and hence for any particular service.

An unusual feature of the SERAS model is the division of the computed generalized cost by the square root of the distance in computing the utilities. To the extent that the same distance is used in computing the utilities for each air party from a given origin zone, this simply scales the utility values, which implicitly assumes that the variance of the error term in the utility functions increases with distance from the airport, albeit at a declining rate. While it is likely that the uncertainty in highway travel times increases with distance from the airport, this is not true for out of pocket costs (such as public transport fares and parking costs) or for travel times on rail or intercity bus modes, which operate to a published schedule (while intercity buses may in fact get delayed in traffic congestion, passengers are likely to base their mode choice decisions on the published schedule). Therefore the effect of travel time uncertainty should play a greater role for private car, rental car and taxi modes than for public transport modes. Another concern with this approach is that the scaling effect changes most rapidly at short distances. However, it is precisely at these distances that travel times are most predictable. What would therefore provide a better reflection of uncertainty in travel times is an S-shaped distance function that is asymptotic to one at short distances and would only be applied to private car, rental car and taxi modes.

San José International Airport Model

This model was developed by Dowling Associates to estimate the ridership on a planned automated people-mover to connect the airport to a nearby Santa Clara Valley Transportation Authority light rail line.[5] The model was estimated using data from an air passenger survey performed at the airport for the Bay Area Metropolitan Transportation Commission in 1995 and supplemented with the results of stated preference surveys that were conducted as part of the study to determine how air passenger mode choice might be influenced by the availability of the people-mover, as well as to overcome the problem that there were very few users of the light rail line in the 1995 survey sample. Four multinomial logit submodels were estimated for the same four market segments used in the Boston model (non-business trips were termed personal trips). Each submodel included the following seven modes: private car, rental car, scheduled airport bus, door-to-door shuttle van, taxi, public transit bus, and light rail access via the people-mover. In addition, the visitor submodels included hotel shuttle.

Independent variables consisted of the automobile travel time, transit travel time by rail, transit travel time by bus, waiting time, walking distance, and cost. The cost variable for personal trips was divided by the annual household income raised to the power 1.5. Only one set of alternative-specific constants for private car was presented in the report, making no distinction between air parties being dropped off and those parking for the duration of the air trip. This resulted from a limitation in the 1995 air passenger survey, which also did not make this distinction. It was assumed in the model estimation that residents using private car parked at the airport while visitors were dropped off. The parking cost was included in the parking utility function for resident trips, while a "drop-off" factor was included in the private car utility function for visitor trips to account for the inconvenience for drivers dropping off air passengers (the details of this factor are not given in the report). It is of course possible to use the estimated model to predict the choice of resident air passengers being dropped off by including both modes in the model and assuming that the alternative-specific constant is the same for both drop-off and park.

The estimated model parameters presented in the study report are shown in Table B-12. No goodness-of-fit statistics were provided in the report.

---

[5] Dowling Associates, Inc., San Jose International Airport Transit Connection Ridership, Final Report, Prepared for San Jose International Airport, Lea+Elliott and Walker Parking, Oakland, California, June 2002.

Table B-12 San José International Airport Model Parameters

Variable	Resident Business	Resident Personal	Visitor Business	Visitor Personal
COEFFICIENTS				
Auto Time (minutes)	-0.071	-0.044	-0.068	-0.039
Rail Transit Time (minutes)	-0.053	-0.031	-0.050	-0.029
Bus Transit Time (minutes)	-0.093	-0.051	-0.089	-0.045
Walk Distance (miles)	-5.17	-3.28	-4.69	-2.94
Wait Time (minutes)	-0.107	-0.077	-0.096	-0.071
Cost (cents)	-0.00277	$-1.04/(\mathrm{HHINC})^{1.5}$	-0.00256	$-0.973/(\mathrm{HHINC})^{1.5}$
CONSTANTS				
Private Car	0.0	0.0	0.0	0.0
Rental Car	-2.9	-4.1	+3.9	+1.0
Scheduled Bus	-2.3	-2.7	+1.2	-0.8
Transit (does not use APM)	-1.3	-2.0	+0.9	-0.4
Transit (uses APM)	-1.2	-1.8	+0.8	-0.3
Door-to-Door Shuttle	-1.2	-1.4	+0.6	-0.1
Hotel Shuttle	n/a	n/a	0.0	-3.1
Taxi	-1.4	-1.3	+1.1	+0.1

Notes: HHINC = Annual household income in thousands of dollars
n/a = Mode is not available for this market segment
APM = Automated people-mover

The implied values of the estimated parameters are shown in Table B-13. The implied values of the alternative-specific constants are expressed in dollars and represent the reduction in cost (or increase in cost for negative values) that would be required for the mode to be perceived as having the same intrinsic utility as private car after allowing for any differences in costs and travel times. Since the implied values for personal trips depend on the household income, the values have been calculated for a household income of $55,000, which is stated in the study report to be the average annual household income for potential transit users at San José International Airport based on data from the Association of Bay Area Governments for Santa Clara County (it is unclear what "potential transit users" means in this context, or how the Association of Bay Area Governments could determine the household income of such users, but the value provides a reasonable point of comparison).

Table B-13 Implied Values of San José International Airport Model Parameters

Variable	Resident Business	Resident Personal	Visitor Business	Visitor Personal
ACCESS TIMES ($/hour)				
Auto Time	15	10	15	10
Rail Transit Time	11	7	11	7
Bus Transit Time	20	12	19	11
Walk Time	56	39	55	37
Wait Time	23	18	21	18
CONSTANTS (dollars)				
Rental Car	10.5	16.1	-15.2	-4.2
Scheduled Bus	8.3	10.6	-4.7	3.4
Transit (does not use APM)	4.7	7.8	-3.5	1.7
Transit (uses APM)	4.3	7.1	-3.1	1.3
Door-to-Door Shuttle	4.3	5.5	-2.3	0.4
Hotel Shuttle	n/a	n/a	0.0	13.0
Taxi	5.1	5.1	-4.3	-0.4

Notes: Implied values of personal trips calculated for an annual household income of $55,000 per year.
Implied value of walk time based on a walking speed of 3 mph.

The implied values of the access times are quite low by comparison with the values typically found in air passenger ground access mode choice models (and air travel models generally). The fact that the implied value of rail transit travel time is lower than travel time by private auto is surprising. While the higher implied value for bus transit travel time is consistent with typical experience in urban travel models, the difference from travel time by private auto is surprisingly small, particularly for visitor personal trips. Similarly the implied values of the mode specific constants are quite low compared to those typically found in air passenger ground access mode choice models and the differences between the values for different modes are surprisingly small and in several cases intuitively unreasonable. For example, it makes no sense that the implied value of the alternative-specific constant for taxi for resident business trips would be greater than that for door-to-door shuttle van or transit, which provide significantly lower comfort and convenience. Similarly, it seems quite implausible that schedule bus, transit, or door-to-door shuttle vans would be viewed by visitors on business trips as more attractive than being dropped off at the airport by private car.

What is probably distorting the values of the estimated coefficients is a failure to control for the availability of different modes for different air parties. Visitors who are not staying with residents of the area may not have anyone who can take them to the airport and therefore either rent a car to meet their local transportation needs or use public modes. In order to explain these choices in a situation when the model has assumed that being dropped off by private vehicle is a option that is available, the values of the alternative-specific constants have to be increased.

Appendix C: Modeling Competition between Transportation Providers

C-1 Modeling Principles

Problem formulation, including defining the performance index and decision parameters in the modeling, needs to conform to the following principles:

- Reflect the competition between transportation providers
- Reflect the demand and supply relationship between providers and passengers
- Compatibility with the passenger mode choice model in the IAPT framework
- Compatibility with the traffic network model in the IAPT framework
- Compatibility with the cost and benefit analysis in the IAPT framework.

Predictive capability is the primary and fundamental requirement for any modeling approach. In general, prediction can attempt to address two aspects: changes over time and over space. Prediction over time implies that a model based on the data obtained for a certain time period should be extendable to a longer time period with acceptable prediction error even if service frequencies or pricing may be subject to changes. Prediction implies that, in the case of airport ground access, the model should be able to predict the effect if some new mode becomes available. It is expected that the proposed modeling approach for transportation providers can reasonably predict the ridership for some alternatives which include service and fare changes and the addition of a new mode or service.

Chapter 5 described the modeling of passenger behavior using a mode choice model. As discussed there, the generally adopted form of such models is either a multinomial logit or nested logit model. To apply the model to accommodate differences in the availability of modes for given airport and given zone, nomenclature is used as defined below.

C-2 Nomenclature

i	mode index
W	the set of OD pairs for a give airport, known
$w \in W$	is an OD pair, known

$W_w^{(i)}$	the set of all the OD pairs w connected to airport by primary mode i
$W_e \subset W$	is the set of extreme OD pairs, known
M	the set of modes available at the airport, known
m	the nest at an airport, defined in Chapter 5
N_m	the set of modes in nest m of a nested logit model
M_w	the set of primary modes available for OD w, known
m_w	The nest for a given OD w
$P_w^{(i)}$	the probability that a passenger will choose mode i in a multinomial logit model for a given OD w
P	A matrix with elements $P_w^{(i)}$
$P_w^{(m)}$	the probability that a passenger will choose a mode in nest m in a nested logit model for a given OD w (*i.e.* the probability that the chosen mode will be in nest m)
$P_w^{(i\|m)}$	The probability for a passenger to choose mode i given that the passenger has chosen nest m
D	demand for the given airport in unit time (e.g. hourly), known
D_w	demand for OD pair w in unit time (e.g. hourly), known
$o_w^{(i)}$	vehicle occupancy (passenger number per vehicle) for primary mode given OD w
$p_w^{(i)}$	fare for primary mode i with respect to OD w, decision parameter of transportation provider
p	a matrix of all transportation providers corresponding to primary modes and all OD pairs w
p_w	the price matrix of all modes for given OD pair w
$h_w^{(i)}$	headway for primary mode i with respect to OD w, decision parameter of transportation providers; Wait time is proportional to headway.

$\underline{H}_w^{(i)} > 0$, $\overline{H}_w^{(i)} > 0$ lower and upper bound for headway of primary mode i for given OD w

h the service headway matrix of all primary modes and for all OD pairs w

h_w the service vector of all modes for a given OD pair w

$f_w^{(i)}$ average operation frequency for primary mode i with respect to OD w

There is a simple relationship:

$\underline{F}_w^{(i)} > 0$, $\overline{F}_w^{(i)} > 0$ lower and upper bound for operation frequency for primary mode i for given OD w

$$f_w^{(i)} = \frac{1}{h_w^{(i)}}$$
$$\underline{F}_w^{(i)} = 1/\overline{H}_w^{(i)}$$
$$\overline{F}_w^{(i)} = 1/\underline{H}_w^{(i)}$$

$\underline{p}_w^{(i)}$, $\overline{p}_w^{(i)}$ lower and upper bound of fare fro primary mode i for given OD w

$\Delta p^{(i)}$ - fare increment for given mode *I* which is uniform with respect to all the zones the mode *i* serves

$\zeta^{(i)}$ - fare change in percentage for a given mode with respect to all the zones, $\zeta^{(i)} \geq 0$

$a_w^{(i)} \geq 0$ coefficient of travel time of primary mode i in passenger mode choice utility function, known constant or obtained from mode choice modeling

$b_w^{(i)} \geq 0$ coefficient of operation headway for primary mode i in passenger mode choice utility function, known constant or obtained from mode choice modeling

$d_w^{(i)} \geq 0$ coefficient of operation fare for primary mode i in passenger mode choice utility function, known constant or obtained from mode choice modeling

$\xi_w^{(i)} \geq 0$ comfort factor for primary mode i in passenger mode choice utility function, known constant or obtained from mode choice modeling

$R^{(i)}$ average ridership for primary mode i

$T_w^{(i)}$	travel time for primary mode i for given OD w, known from traffic model
$U_w^{(i)}$	the utility function of primary mode i for given OD w
$u_w^{(i)}$	the performance index (utility function) for primary mode i for given OD w
$u^{(i)}$	the performance index (utility function) of primary mode i

C-3 Ridership From Mode Choice Model

The utility function for passenger mode choice of mode i for given OD pair w is

$$U_w^{(i)} = a_w^{(i)} T_w^{(i)} + b_w^{(i)} h_w^{(i)} + d_w^{(i)} p_w^{(i)} - \xi_w^{(i)} \tag{C.1}$$

The values of the all the coefficients are either constant or can be obtained from the mode choice model.

The probability that passengers choose the composed line is determined by the following nested logit model (Chapter 5 of this report). The probability of a passenger choosing mode i among nest m for a given OD w is

$$P_w^{(i|m)} = \frac{\left(e^{U(i)}\right)}{\sum_{k \in m} \left(e^{U(k)}\right)} \tag{C.2}$$

which is basically a multinomial logit model within a nest m. Suppose the alternatives are divided into disjoint nests $N_1, \ldots, N_s$. According to Chapter 5, the probability of a mode chosen by a passenger being in nest m in a nested logit model is

$$P_w^{(m)} = \frac{\left(\sum_{j \in N_m} \left(e^{U(j)}\right)^{\frac{1}{\mu_m}} \right)}{\sum_{l \in M} \left(\sum_{k \in N_l} \left(e^{U(k)}\right)^{\frac{1}{\mu_l}} \right)} \tag{C.3}$$

For nested logit model, by Bayesian formula, we have

$$P_w^{(i)} = P_w^{(i|m)} P_w^{(m)} \tag{C.4}$$

There are several possibilities to formulate the performance index (utility function) for the transportation providers. Utility functions for modes operated by public and private providers will most likely have different parameter values although we may choose a unified mathematical formula.

C-4 Revenue Function for Transportation Providers

Revenue Function: We have a choice in how to formulate a *revenue function* if we do not know capital and operating costs. There are two ways to formulate the problem: (a) transportation providers are competing for each given OD demand D_w; and (b) they are competing over all OD pairs with their service area. Thus there may be two revenue functions:

(a) Revenue function for mode i for given OD w directly from the hourly demand

$$\begin{aligned} u_w^{(i)} &= u_w^{(i)}\left(P_w, p_w\right) \\ &= p_w^{(i)} D_w P_w^{(i)} \end{aligned} \tag{C.5}$$

where $P_w^{(i)}$ is from (C.4).

In this model, the operating frequency affects the performance measure through the passenger mode choice behavior. This formulation does not emphasize the role of operating frequency.

(b) Alternatively, the provider may attempt to maximize the revenue for each access/egress service path.

This is the approach adopted by Zhou *et al.* (2005). The authors attempted to maximize the revenue for each section of the route.

(c) Total revenue function for mode i

$$\begin{aligned} u^{(i)} &= u^{(i)}\left(P, p\right) \\ &= \sum_{w \in W} p_w^{(i)} D_w P_w^{(i)} \end{aligned} \tag{C.6}$$

We can similarly include frequency as the second formulation above (C.6).

The following discussion only considers approach (a), and will also hold for approach (b).

(d) If we set

$$p_w^{(i)} = p_w^{(i,0)} + \Delta p^{(i)}$$

$p_w^{(i,0)}$ is the base value of the fare, which is supposed to be known or can be calculated from averaged fare for a given mode and OD. $\Delta p^{(i)}$ is the pure increment of the fare change for a given mode, which is invariant with respect from zone to zone. Now (C.6) becomes

$$\begin{aligned} u^{(i)} &= u^{(i)}\left(P, p\right) \\ &= \sum_{w \in W} (p_w^{(i,0)} + \Delta p^{(i)}) D_w P_w^{(i)} = \sum_{w \in W} p_w^{(i,0)} D_w P_w^{(i)} + \Delta p^{(i)} \sum_{w \in W} D_w P_w^{(i)} \end{aligned}$$

Now for each mode, there is only one decision parameter of fare for al the zones. Now let

$$\begin{aligned} & x^{(i)} = \Delta p^{(i)} \\ & x = [x^{(1)}, \ldots, x^{(M)}]^T \\ & x^{(i)} \geq 0 \end{aligned}$$

then

$$u^{(i)} = u^{(i)}\left(P, x\right) = \sum_{w \in W} p_w^{(i,0)} D_w P_w^{(i)} + x^{(i)} \sum_{w \in W} D_w P_w^{(i)}$$

Similarly, if we assume that the fare change is a percent for each mode with respect to all the zones served, then

$$\begin{aligned} u^{(i)} &= u^{(i)}\left(P, \zeta\right) \\ &= \sum_{w \in W} p_w^{(i,0)} (1 + \zeta^{(i)}) D_w P_w^{(i)} = \sum_{w \in W} p_w^{(i,0)} D_w P_w^{(i)} + \zeta^{(i)} \sum_{w \in W} D_w P_w^{(i)} \end{aligned}$$

where $\zeta = [\zeta^{(1)}, \ldots, \zeta^{(M)}]^T$ is the decision parameter,

Net profit function: We have another choice to formulate a net profit function for each mode. This gives the profit for a provider with given capital and operating costs.

C-5 About Decision Parameters

Although, in principle, transportation providers takes operation frequency as decision parameter, this parameter does not change very often. For airport ground access, within around 10 modes, only shared ride van and scheduled bus has the problem of operation frequency. Besides, we can find the hourly demand D_w from airport survey data for a given OD. There is a relationship between OD demand, operation frequency and occupancy:

$$D_w = \sum_{i \in M_w} f_w^{(i)} o_w^{(i)}$$

This relationship can be used for the analysis the behaviors of shared ride van and scheduled bus. It also brings some difficulties for using the frequency as a decision parameter for each mode because the problem is likely non-convex and thus there is no mathematical solution.

C-6 Nash Game Formulation for Complete Competition of Transportation Providers

Find (h_w^*, p_w^*) subject to the constraints on the fare variation and service headway variation such that

$$\begin{aligned} & u^{(i)}(h_w^{(i)}, h_w^{(M_w \backslash i)^*}, p_w^{(i)}, p_w^{(M_w \backslash i)*}) \\ & \leq u^{(i)}\left(h_w^{(i)*}, h_w^{(M_w \backslash i)*}, p_w^{(i)*}, p_w^{(M_w \backslash i)*}\right) \end{aligned} \tag{C.7}$$

holds for all $j \in M_w$. $M_w \backslash j$ means to exclude j from the set M_w. The strategy set is a polyhedron determined by the following inequality:

$$\begin{aligned} & \underline{F}_w^{(i)} \leq f_w^{(i)} \leq \overline{F}_w^{(i)} \\ & \underline{P}_w^{(i)} \leq p_w^{(i)} \leq \overline{P}_w^{(i)} \end{aligned} \tag{C.8}$$

which is a compact and convex set. Compact can be understood as finite in size. A convex set can be understood as the interpolation of any two points in the set is keeps to be in the set.

C-7 Compatibility with Mode Choice Model

To use the parameters of model choice model in IAPT, the transportation provider's behavior model has to be compatible with the mode choice model to adopted in IAPT. The provider's behavior has incorporated the passenger mode choice in the passenger flow calculation, which forms a feedback loop as shown in Figure 1. However, the following issues will need to be solved to make the mode choice model and the provider behavior model compatible. The relationship between cost, revenue and profit:

Transportation costs and their effects on revenue and profit:

- (i) Passenger cost: variable-out-of-pocket cost such as fuel and vehicle maintenance, and fixed-out-of-pocket cost such as vehicle cost
- (ii) Provider cost:
  - Capital cost: Vehicle cost, site, and other facilities
  - Operational cost: Fuel, labor costs, maintenance costs

C-8 Existence of Solutions

As we discussed above, if we consider fix the operation frequency change to some known discrete value and taken into consideration in Assumption 8, then each mode has only one decision parameter which is the fare change percentage of increment. This is uniform for al the served zones. According to the work of Haker (1991), the existence of a solution is guaranteed if the following three conditions hold:

1. the compactness of the feasible strategy set
2. the continuation of the objective function
3. the concavity of the objective function

The above conditions are discussed as follows: (1) is clearly true if we restrict the lower and upper bound for fare change in percentage/increment. (2) is true because the revenue function is continuous regardless of using Multinomial of Nested Logit model for mode choice. As for (3), if we adopt Multinomial model for mode choice, the concavity is ready proved in Zhou *et al (2005).* However, if nested logit model is adopted, strictly speaking, the concavity of the revenue function needs reconsideration, which will be conducted in second year research.

C-9 Algorithm Structure

In the following discussion, the decision parameter $x = [x^{(1)},...,x^{(|M|)}]^T$ is partitioned into two parts $x^{(i)}$ and $x^{-(i)} = [x^{(i)},...,x^{(i-1)}, x^{(i+1)},...,x^{(|M|)}]^T$ to decouple the optimization with respect to mode i from other modes, where $x^{(i)}$ is the decision parameter for mode i and $x^{-(i)}$ are the vector of decision parameters of all modes other than mode i.

Step 1: Set up the initial transportation provider fare structure

$$x^{(i)}(k): k = 0, \quad i \in M$$

Step 2: Solve the following nonlinear programming problem using Frank- Wolfe method as described in next section. It is noted that the zonal demand is known for any given zone:

$$\begin{aligned}
&\max_{x^{(i)}(k) \in \Omega^{(k)}(x^{-(i)}(k))} u^{(i)}\left(P, x^{(i)}(k), x^{-(i)}(k)\right) \\
&u^{(i)} = u^{(i)}\left(P, x^{(i)}(k), x^{-(i)}(k)\right) = \sum_{w \in W} p_w^{(i,0)} D_w P_w^{(i)} + x^{(i)} \sum_{w \in W} D_w P_w^{(i)} \\
&i \in M
\end{aligned}$$

where $\Omega^{(k)}(x^{-(i)}(k))$ is the decision set for all the mode other than mode i fixed at the value of step k. It is noted that this set is determined by the constraints among all the decision parameters.

Step 3: $\left\| x^{(k)} - x^{(k-1)} \right\| < \varepsilon$ then stop. Else, set $k := k+1$ and go to Step 2. Here $\varepsilon > 0$ is a pre-specified threshold to control the convergence of the iteration.

C-10 Frank Wolfe Method

The Frank Wolfe method (Bazaraa, 1993) is used for solving the nonlinear programming problem for each mode considering all the other modes as fixed. This method can be described as follows.

Step 2.1 Consider the nonlinear optimization problem

$$\begin{aligned}
&\min_X f(X) \\
&AX \le b
\end{aligned} \tag{C.9}$$

where the region is bounded. Suppose that X_k is a feasible point, and let Y_k solve the following optimization problem

$$\begin{aligned} &\min_{Y} \nabla f(X_k)^T Y \\ &AY \le b \end{aligned} \tag{C.10}$$

Step 2.2 Let λ_k be an optimal solution to the following optimization problem

$$\begin{aligned} &\min_{\lambda} f[\lambda X_k + (1-\lambda)Y_k] \\ &0 \le \lambda \le 1 \end{aligned} \tag{C.11}$$

Step 2.3 Let

$$X_{k+1} = \lambda_k X_k + (1-\lambda_k)Y_k \tag{C.12}$$

To use this algorithm for our optimization process, the following points are emphasized:

(1) $f(X)$ is objective function with $X = x^{(i)}$ and $x^{-(i)}$ is fixed. The constraint $x^{(i)} \in \Omega^{(k)}(x^{-(i)}(k))$ needs to be written in the form AX which is always doable because the constrains are linear in our case;

(2) The gradient in (C.10) is evaluated at step k with Y to be an auxiliary variable; Step 2.1 is to search the maximum decent direction in the feasible set. To implement those methods in ANSI C code, some software modules developed in (Press et al, 1992) are used: (a) to solve a linear programming using simplex method ;

(3) (C.11) is a single variable nonlinear constrained optimization problem with respect to $\lambda : 0 \le \lambda \le 1$.