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Final Report

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Project Team:

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Key Words

Intermodal connectivity, airport ground access, air passenger mode choice, transportation provider behavior, project evaluation, system performance measures, connectivity performance measures, policy recommendations

Abstract

This report has been prepared as the final deliverable for 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 transportation system performance measurement, an air passenger mode choice model, and a model of transportation provider behavior, and is designed to interface with a traffic network analysis model. The qualitative approach is used to enhance the quantitative analysis to account for factors that are difficult to quantify and to provide recommended policy and planning guidelines.

This report documents the progress on the project over the past three years. It describes the following main tasks:

- Identification of opportunities for improved intermodal connectivity at California airports
- Research into techniques for modeling air passenger mode choice and development of a mode choice model for use in subsequent analysis
- Development of techniques for modeling transportation provider behavior
- Performance measurement definitions and calculations addressing both system performance and connectivity performance
- Design and development of a prototype version of an Intermodal Airport Ground Access Planning Tool
- Use of the prototype IAPT to evaluate selected projects at three Bay Area airports
- Development of policy recommendations and guidelines for project evaluation

IAPT provides a standard way for quantitative project evaluation at an airport level. A user friendly graphical interface makes it easy for a user to define projects for a given airport, input data, select model parameters, choose performance parameters for comparison, run the analysis process, and view the output in different ways. Requirements for further development of the IAPT are discussed and recommendations for future study of airport ground access planning issues are presented.

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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.

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Contents

Appendices

List of Figures and Tables

Figure **Page**

List of Acronyms

ACRP	Airport Cooperative Research Program
ACTT	Access travel time
AGT	Automated guideway transit
AM	*Ante meridiem* (before noon)
APM	Automated people mover
ASC	Alternative-specific constant
AVM	Automated vehicle monitoring
BART	Bay Area Rapid Transit
BRT	Bus rapid transit
CAAA	Clear Air Act Amendments
Caltrans	California Department of Transportation
CMAQ	Congestion Mitigation and Air Quality (program)
CPC	Connectivity production cost
CSV	Comma-separated values
CTPS	Central Transportation Planning Staff (Boston)
FAA	Federal Aviation Administration
FEIR	Final Environmental Impact Report
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GAO	Government Accountability Office
GIS	Geographic information system
GUI	Graphical user interface
HOV	High occupancy vehicle
IAPT	Intermodal Airport Ground Access Planning Tool
IIA	Independence from irrelevant alternatives
ISTEA	Intermodal Surface Transportation Efficiency Act
ITLSS	Intermodal Terminals Location Simulation System
ITS	Intelligent transportation systems
IVTT	In-vehicle travel time
LAWA	Los Angeles World Airports

List of Acronyms (cont.)

LAX	Los Angeles International Airport
Massport	Massachusetts Port Authority
MBTA	Massachusetts Bay Transportation Authority
MNL	Multinomial logit (model)
MOCP	Measure of connectivity performance
MOP	Measure of performance
MOSP	Measure of system performance
MPO	Metropolitan planning organization
MTS	Metropolitan Transit System (San Diego)
MTC	Metropolitan Transportation Commission (San Francisco Bay Area)
MTD	Metropolitan Transit District (Santa Barbara)
OAC	Oakland Airport Connector
OAK	Oakland International Airport
ODBC	Open Database Connectivity
NCIT	National Center for Intermodal Transportation
NL	Nested logit (model)
NO_x	Nitrogen oxides
OD	Origin-destination
PATH	Partners for Advanced Transit and Highways
PDX	Portland International Airport
PFC	Passenger facility charge
PM	Particulate matter
PM	*Post meridiem* (after noon)
PT	Public transportation
PVH	Passengers per vehicle-hour
PVM	Passengers per vehicle-mile
RB	Resident business (trip type)
RCM	Recursive partitioning methodology
RFP	Request for proposals

List of Acronyms (cont.)

RP	Resident personal (trip type)
RP	Revealed preference
RP	Revenue per passenger
RTP	Regional Transportation Plan
SamTrans	San Mateo County Transit District
SAN	San Diego International Airport
SEM	Structural equation modeling
SERAS	South East and East of England Regional Air Service (study)
SFO	San Francisco International Airport
SJC	Mineta San José International Airport
SOV	Single occupancy vehicle
SP	Stated preference
SPSS	Statistical Package for the Social Sciences (computer software)
STP	Surface Transportation Program
TAZ	Transportation analysis zone
TCRP	Transit Cooperative Research Program
TIFIA	Transportation Infrastructure Finance and Innovation Act
UCSB	University of California Santa Barbara
U.K.	United Kingdom
U.S.	United States
VB	Visitor business (trip type)
VHT	Vehicle-hours of travel
VMT	Vehicle-miles of travel
VOC	Volatile organic compounds
VP	Visitor personal (trip type)
VTA	Valley Transportation Authority (Santa Clara)
WT	Waiting time
WTA	Water Transit Authority (San Francisco Bay Area)

Executive Summary

This report describes the work conducted over the past three years for a research project for the California Department of Transportation (Caltrans) that has been exploring planning techniques to support improved intermodal connectivity at California airports. The research has included a literature review, identification of opportunities to improve intermodal connectivity at a wide range of California airports, extensive system modeling and analysis, design and development of an Intermodal Airport Ground Access Planning Tool (IAPT) to evaluate potential airport ground access improvements, definition of potential projects to enhance intermodal connectivity at the three major airports in the San Francisco Bay Area that could serve as case studies to demonstrate the use of the IAPT, and the development of policy recommendations and project evaluation guidelines. The IAPT development included the design of the overall software structure and data flow, definition and implementation of the functionality of each sub-module, design of the supporting databases, and development of a Graphical User Interface (GUI). The IAPT was developed using Microsoft Visual Studio.Net. It is designed to evaluate proposed projects at the airport level as part of intermodal ground access planning for improved connectivity and system performance. Each chapter of the report is summarized in the following sections.

(1) Introduction: The first chapter describes the overall objectives of the project and the scope of this report. It examines the role of modeling in quantitative analysis of strategies to improve intermodal connectivity at airports and discusses the dynamic interactions that arise in airport ground access activities, as well as the capabilities and limitations of such modeling.

The scope of intermodal airport ground access planning for a given airport needs to take into account the following considerations: air passenger mode choice behavior, transportation provider behavior, regional transportation network traffic, and the respective roles of the airport authority and local government agencies. The dynamic interactions between these components of the intermodal airport access system may be unidirectional or bidirectional. Prediction of air passenger mode use must be based on an understanding of the behavioral characteristics of each component and interactions between them. However, since the overall system is very complicated, simplifications are necessary. The main assumptions related to the analytical approach and the simplification of the overall system are:

(a) Evaluation of the comparative performance of project alternatives is usually the most interesting consideration for decision makers. System performance can be described using performance measures such as travel time, vehicle-miles of travel (VMT) or vehicle-hours of travel (VHT), emissions, etc., as well as some composite performance measures quantifying the connectivity within the transportation system. The values of these performance measures for any particular project alternative are determined by the interactions between the air passenger access mode choice, transportation provider behavior and the transportation network traffic.

(b) Competition between modes is assumed to occur collectively rather than between individual providers within a mode; i.e. all the providers in the same mode are considered to compete as one with their counterparts in other modes. Although this joint behavior does not typically occur in practice, the assumption is reasonable in the sense that the behavior of transportation providers for a given mode can be considered as a collective behavior averaged over all the providers within the mode. This simplification is consistent with a mode choice model that predicts the use of different modes rather than specific providers, and also significantly reduces the complexity of modeling transportation provider behavior.

(c) The modeling of airport access can be distinguished from general transit system modeling in that origin and destination patterns and vehicle routing can be greatly simplified for planning purposes and there is no network optimization problem to be faced. An access/egress path can be defined that links each primary airport access mode with any auxiliary modes that provide access to or egress from the primary mode, potentially at both the origin and destination ends of the trip. Examples of such paths and primary modes are: (i) single mode trips such as taxi, shuttle van, pickup/drop-off by private vehicle, or self-driving with airport parking, and (ii) combined mode trips such as rail transit with access by private vehicle parked near the station and a shuttle bus link from the nearest rail station to the airport, or self-driving to an off-airport parking lot with a shuttle van link to the airport, for each of which the primary mode is obvious. The choice of the auxiliary mode(s) may not need to be explicitly considered in modeling air passenger mode choice, although of course their travel times and costs should be considered together with those of the primary mode. If only the primary mode choice 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 avoid the need for modeling 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 agencies is unidirectional, and is reflected through the regulations and policies regarding access to the airport terminal by the transportation providers and the fees charged for that access. These factors affect passengers indirectly through prices and waiting times experienced using different modes.

(2) Literature review: Chapter 2 provides a review of the relevant literature on intermodal ground access to airports, including the broad range of issues in airport ground access planning, general principles of intermodal transportation planning, modeling and analysis of airport traveler access/egress mode choice, and the role of ground access travel information. The chapter also discusses the findings of a recent study by the United States Government Accountability Office on potential strategies that would redefine the Federal role in developing airport intermodal transportation capabilities.

Intermodal airport ground access planning should follow accepted principles of intermodal transportation generally, i.e. convenient connectivity, flexible choices of different modes, coordination between transportation providers, and cooperation and collaboration among transportation providers and governmental agencies at all levels to ensure seamless service. Thus the literature review examined the overall picture: intermodal transportation planning principles, quantitative and qualitative approaches for planning, including airport access planning, passenger mode choice modeling, transportation provider behavior modeling, planning tool development, and addressing California airport ground access needs from a strategic planning perspective.

(3) Opportunities for improving intermodal connectivity at California airports: The third chapter examines a range of opportunities to improve intermodal connectivity at airport in California. Many of the these opportunities leverage existing investments in improved public transportation, particularly rail services, by improving the connections between the airports and nearby rail services or the regional bus route network. These range from extending light rail lines to airports, as currently planned for Sacramento International Airport, to improved bus service to

airports or improved links between airports and nearby rail stations, such as the people-mover connections planned for both Oakland International Airport and San José International Airport.

Many opportunities exist at different levels for improving intermodal connectivity at California airports: a strategic level, a regional level and an airport operational level. The chapter reviews the findings of previous work at a strategic level that addressed the needs for improving the connectivity at California airports for both passenger and commodity movement (Landrum and Brown, 2001). The chapter then identifies and discusses a range of potential projects that could improve intermodal connectivity at a large proportion of California commercial service airports.

<u>(4) IAPT design and implementation</u>: Chapter 4 describes the design and implementation of a computer modeling tool, termed the Intermodal Airport Ground Access Modeling Tool (IAPT), that has been developed as part of the current research in order to support the analysis of projects to improve airport intermodal connectivity.

The IAPT has four major components – regional transportation network traffic data for the different access modes serving the airport, an air passenger mode choice model, which generates predictions of air passenger mode use across the available modes and thus vehicle trips for the given airport; a transportation provider behavior model, which predicts the changes in the service characteristics of the available modes in response to changing traffic levels, and a performance measurement module, which calculates system performance and connectivity performance measures. Iteration between the mode choice and provider models leads to the prediction of vehicle trips and related system performance measures. The performance evaluation module forms the final step of the IAPT analysis process and generates measures of the change in system performance and connectivity offered by different alternative projects. Those components and the underlying database structure are linked with a GUI, which allows users to define airport characteristics and projects, select alternatives, enter and update relevant data, run the analysis, and view the outcome and performance measures for comparison in decision making. The GUI effectively hides the complexities of the modeling and data flow processes and provides the user with a friendly and standardized planning environment for the evaluation and comparison of multiple projects in decision-making.

(5) Passenger mode choice modeling: The following chapter discusses the passenger mode choice modeling approach adopted in the IAPT in more detail, including a review of the relevant literature and the development and estimation of a preliminary airport access mode choice model for Oakland International Airport.

The mode choice model component of the IAPT predicts how air passengers would choose a mode for their airport access trip based on their air party characteristics and the service levels offered by the available access modes. A discrete multinomial logit mode choice model has been adopted in the initial implementation of the IAPT for modeling air passenger mode selection. The perceived attractiveness of each mode is reflected in a utility function that depends on several parameters. The essence of the mode choice modeling approach is to calculate the probability of each air party in a representative sample of air parties choosing each of the available modes. These choices are then factored up to the total number of ground access trips, based on an assumed or known total number of passenger trips to and from the airport. This aggregate demand is obtained from airport traffic statistics or demand forecasts while the mode choice model parameters are determined from air passenger survey data for the given airport.

(6) Transportation provider behavior modeling: Chapter 6 discusses the approach to modeling the behavior of transportation providers serving the airport ground access system within the analytical framework of the IAPT.

Ideally, such a model should represent the competitive behavior of transportation providers within and between modes, but in the current implementation of the IAPT the model only focuses on the collective competition between modes. The most common way of thinking about provider behavior is to focus on the elasticities of demand that can be observed empirically by the providers, considering the ridership changes that result from changing service variables, such as increasing or 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 near-simultaneous actions of multiple providers. A game theory approach, on the other hand, can be applied to capture the dynamic effects of the interactions among decisions by multiple transportation providers. A few researchers have begun to attack the problem using this approach, in which a passenger mode choice model is tightly coupled with a provider behavior model. The chapter examines how such an approach can be applied within the framework of the IAPT and presents a preliminary framework for such an analysis.

(7) Performance measures: Performance measures are critical for the evaluation of projects for decision-making. Traditional methods focus on system performance measures such as VHT, VMT, revenue, travel time, and emissions. Recently, the transportation community has begun to quantify the connectivity in addition to those system performance parameters. It has been suggested that both system performance measurement and connectivity performance measurement be used for project evaluation. Chapter 7 describes the approach to measuring both system and connectivity performance within the IAPT. The connectivity performance measures depend on the following factors:

- Average and variance of walking time (to a service point)
- Average and variance of waiting time (for scheduled/non-scheduled services)
- Average and variance of travel time (on a given mode and path)
- Average and variance of scheduled headway
- Number of transfers required.

Although connectivity measures can be defined based on these factors, the challenge of how to combine those factors in a single performance measure that can effectively reflect the different considerations, particularly for airport ground access planning, is not yet well understood and needs further study in the future.

(8) Guidelines for using IAPT in airport ground access planning practice: Chapter 8 presents guidelines for using the IAPT to analyze airport ground access projects. The overall framework of the IAPT has been developed to provide generic analysis capabilities that could in principle be used for any airport ground access planning study as long as the corresponding data and models are available in the required formats. To use the IAPT for project evaluation it is first necessary to prepare the required data, depending on whether the project involves a new service at an airport for which data has already been assembled, or a new airport or region. What is needed to run the IAPT are:

- A passenger mode choice model for the airport(s) in question

- Data on the trip and party characteristics of a sample of air parties (often the same sample used to develop the mode choice model)
- Regional highway network travel times and distances
- Regional transit system service data
- Other transportation provider service data, including service locations, fares, schedules, and travel times.

These form the essential information that needs to be provided when analyzing a new region or airport, or updated to the same time period in cases in which analysis is being repeated to reflect more recent values for some of the above data (for example, more recent air passenger survey data has become available). Once this has been done, the project evaluation process using the IAPT follows a standard sequence of steps, comprising airport selection, project definition, performance measure definition and selection, data input, performing the analyses, and displaying the results in various ways. The IAPT provides the flexibility to allow the planner to focus on the quantitative comparison of different alternative projects for the selected airport without becoming unduly involved in managing the underlying analytical processes.

<u>(9) Potential Bay Area case studies:</u> Chapter 9 describes five potential projects to improve intermodal connectivity at the three major Bay Area airports that were defined for future analysis using the prototype IAPT in order to demonstrate the use of the performance measures identified in the research and incorporated in the IAPT. The five projects are:

- The Oakland Airport Connector automated people-mover between the Coliseum Bay Area Rapid Transit (BART) and Amtrak stations and Oakland International Airport

- A planned automated people mover at San José International Airport connecting the airport to nearby stations of the Santa Clara Valley Transportation Authority light rail system and the Caltrain commuter rail line serving communities between Santa Clara County and San Francisco

- A proposed ferry service linking a terminal serving San Francisco International Airport with downtown San Francisco and the East Bay

- An off-airport terminal located in the South Peninsula serving Oakland International Airport and potentially San Francisco International and San José International Airports
- An off-airport terminal located to the south of downtown San José providing service between Santa Clara County and both Oakland International Airport and San Francisco International Airport.

Due to the resource constraints of the current phase of the research, detailed analysis of these case studies was deferred to future work.

(10) Policy recommendations: a Chapter 10 presents a number of recommendations that have been developed to help guide future efforts to improve airport ground access planning in California, including both passenger and freight movement, based on the research undertaken in the project.. These address potential opportunities for improving intermodal connectivity at California airports, institutional aspects involved in pursuing these opportunities, the need for additional guidance material and coordination to facilitate funding airport intermodal connectivity projects, and requirements for technical support to airports and regional transportation planning agencies to assist them in analyzing the potential ridership and economic feasibility of proposed projects to improve airport intermodal connectivity.

(11) Concluding remarks and recommendations for future research: The final chapter presents some concluding remarks from the research undertaken during the project and presents recommendations for future research. Several aspects of the research undertaken in the course of this project require further work and the development of IAPT is only at a preliminary stage. The software itself needs further development. The transportation behavior modeling needs to be refined and the convergence of the Generalized Nash Game process needs further study. In addition, airport employee ground access behavior should be studied so that it can be modeled and incorporated in the IAPT. The IAPT is currently structured for planning ground access projects for a specific airport. In practice, passengers choose among available airports in a region and this choice in influenced by the airport ground access system at each airport. This airport choice behavior affects both airport passenger traffic levels and the associated ground access activities. Future enhancement of the IAPT needs to take airport choice into account to

allow the IAPT to be used in regional-level airport ground access planning. Air freight has been a steadily expanding segment of air transportation and is critical for the U. S. economy in a globalized market. Further research into the characteristics of the air freight market is needed in order to determine how to model the factors affecting ground movement of air freight to and from airports. Including air cargo truck trips in the IAPT would provide important analytical capabilities for Caltrans.

Chapter 1. Introduction

This research report documents the work done under the project titled *A Combined Quantitative and Qualitative Approach to Planning for Improved Intermodal Connectivity at California Airports*. The project was sponsored by California Department of Transportation and undertaken by the Partners for Advanced Transit and Highways (PATH) under task order TO5406-6406 during the period 10/01/2004 to 10/31/2007.

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 involved 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. It is envisaged that this would be supplemented as part of future work 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 has been developed in this research as the main product. The IAPT has been designed to provide an analytical environment that integrates existing data sources and transportation network analysis software with improved models of air passenger travel choice behavior in order to evaluate the costs and benefits of proposed projects to improve intermodal connectivity for airport ground access. 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. Planning guidelines have been developed on how to use the IAPT for implementation-related project evaluation. Based on the results of the qualitative case study analysis, policy recommendations have been developed and reviewed with Caltrans and other stakeholders.

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.

The IAPT has been developed as an analytical tool to support airport-level planning of ground access projects that can enhance intermodal connectivity. Its focus is on the efficient evaluation of a wide range of project alternatives at a specific airport, rather than strategic planning at a regional or statewide level, such as that undertaken in the earlier Caltrans *Ground Access to Airport Study* (Landrum & Brown, 2001).

1.1 Scope of this Report

This report documents all the deliverables of the project, including the structure of the IAPT and the technical details of the various components of the tool. It includes the following elements:

- An extensive literature review on intermodal transportation planning with emphasis on the intermodal airport ground access planning
- Identification of opportunities for improving intermodal airport ground access in California airports
- Development of a modeling framework for analyzing improvements in airport intermodal connectivity, including the design and development of a prototype version of the Intermodal Airport Ground Access Planning Tool (IAPT)
- Systematic consideration of intermodal airport ground access systems performance measurement, including the definition of measures of *systems performance* and *connectivity performance*

- Development of guidelines for project evaluation using IAPT
- Policy recommendations for improving intermodal connectivity at California airports based on the findings of the research
- Recommendations for further development of the IAPT and technical support for intermodal airport ground access planning
- Appendices containing technical details of the mathematical modeling and data specification and preparation for the IAPT

Each of these elements is described in more detail in the following sections.

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, the version of the IAPT described in this report and the focus of the research has been on air passenger trips. It is anticipated that future enhancements to the IAPT would be desirable to address airport employee trips, air passenger airport choice and air cargo truck trips.

1.2 Role of Modeling in Quantitative Analysis

The objective of quantitative analysis in assessing proposed improvements in airport ground access systems, and enhancements to intermodal connectivity in particular, 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 impact 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 a 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 to better understand these complex and interactive 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 that 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 characteristics of the alternative services available. However, for many of these services, their 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 circuity 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 curb-front 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 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 also 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 diagram shown in Figure 1-1 on the following page.

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.

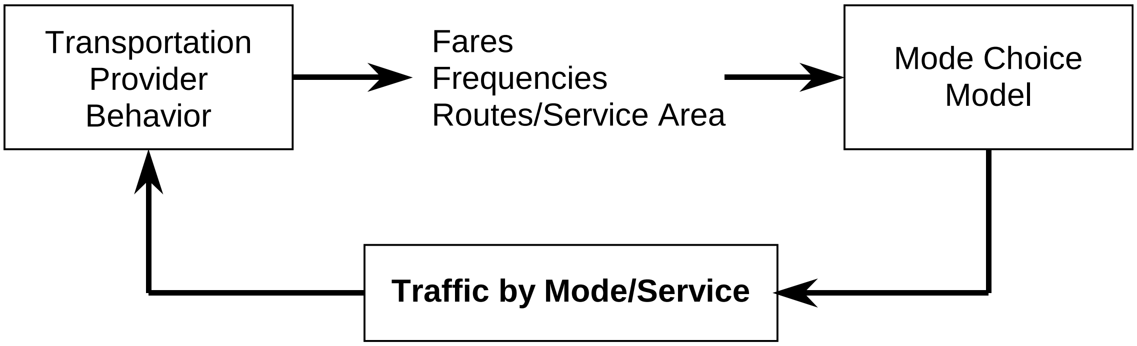


Figure 1-1: Feedback Between Transportation Provider and Airport Traveler Behavior

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. The development of the IAPT as part the current research has been based on an air passenger survey undertaken by the San Francisco Bay Area Metropolitan Transportation Commission (MTC) in 2001 and 2002.

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 is obviously not be possible to include these services or modes in mode 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 those at 5 pm on a Friday afternoon and those at 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 ten more chapters and six appendices. Chapter 2 documents the literature review undertaken as part of the research, while Chapter 3 presents some of the opportunities for improving intermodal airport access in California. Chapter 4 describes the design and implementation of the IAPT, including all the functional components, the software structure and data flow, and the graphical user interface. The following two chapters present the development the two key analysis components of the tool. Chapter 5 describes the air passenger mode choice model development for 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. However, the details of the mathematical modeling have been put in the appendices. Chapter 7 discusses a number of issues involved in measuring airport intermodal connectivity, including how *system performance* measures and intermodal *connectivity performance* measures have 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. The mathematical definitions of the proposed measures of performance and their calculation formulae have been put in an appendix.

Chapter 8 provides guidelines for using the IAPT for intermodal airport ground access project evaluation, using a tutorial approach. Chapter 9 discusses how five potential Bay Area intermodal airport access projects identified in Chapter 3 could be evaluated using the IAPT, including project definition, data preparation and selection of alternative analysis scenarios. Chapter 10 presents a number of policy recommendations for enhancing intermodal connectivity at California airports that were developed in the course of the research. These recommendations should be reviewed and refined in the light of the results of the analysis of the Bay Area case study projects that has been deferred to a later phase of the research. Finally, Chapter 11 offers concluding remarks and recommendations for the future development of the IAPT.

Appendix A documents the technical details of a number of representative airport access mode choice models that have been developed in recent years. Appendix B provides the detailed mathematical derivation of the transportation provider behavior modeling described in Chapter 6.

Appendix C documents the details of the performance measure calculations discussed in Chapter 7. Appendix D documents the structure of the data tables that form the basis of the initial IAPT implementation, while Appendix E provides additional details of the technical aspects of the IAPT. Appendix F presents a number of sample data files used in the development and testing of the IAPT.

Chapter 2. Literature Review on Intermodal Airport Ground Access

This chapter presents a review of recent literature relevant to intermodal airport ground access planning. The objective of this project is to improve intermodal connectivity in airport ground access using a combined qualitative and quantitative approach. This involves a number of different aspects of airport ground access planning. On the qualitative side, it involves institutional issues, political relationships and coordination between planners in different types of organizations, as well as the role of air passenger information systems in air traveler mode choice behavior and understanding and accounting for the relevant decision making behavior of ground transportation providers. On the quantitative side, it involves how to measure the performance of an intermodal transportation system so that those performance measures can be used to guide decision-making at different planning levels. This in turn requires the ability to model the air passenger mode choice and transportation provider decision making behavior, their interactions and the resulting effects on the number of vehicle trips generated by the airport, as well as the impact of these trips on traffic conditions on the street and highway network and air pollution. The review has examined recent literature addressing these aspects of airport ground access planning as well as some principles, viewpoints, analysis methods, and recommendations from the literature on general intermodal transportation that are relevant to the particular case of airport ground access travel. The review also gives particular attention to the distinction between qualitative and quantitative analysis approaches, and includes the application to airport ground access issues of relevant modeling and analysis methods from general urban intermodal transportation.

2.1 A irport Ground Access Planning

There is an extensive literature on the many different aspects of airport ground access planning, particularly the planning and design of specific airport ground access facilities. This section summarizes some of the more recent key documents and studies that are particularly relevant to intermodal aspects of airport ground access planning. All of these documents and reports contain extensive bibliographies, from which the interested reader can obtain more detailed information.

In 1994 the Federal Aviation Administration (FAA) sponsored two workshops on ground access to airports that were organized by the Institute of Transportation Studies at the University of California at Berkeley. These examined the role of off-airport terminals and institutional and funding issues in developing improved airport ground access services and systems (Gosling, 1994). Subsequently, a contract was let by the FAA in association with the Federal Highway Administration (FHWA) to develop a planning guide for intermodal access to airports (Shapiro, *et al.*, 1996). The importance of viewing the airport ground access system as an intermodal interface and the role of such airport ground access systems as rail links and off-airport terminals was further developed in a paper by Gosling (1997).

The growing interest in improving public transportation access to large airports, and in particular proposals to develop very expensive rail links at an increasing number of airports, began to become of concern to the FAA and other Federal transportation agencies. Together with the Federal Transit Administration (FTA) and the Federal Highway Administration, in 1998 the FAA requested the Transit Cooperative Research Program to undertake a comprehensive study of strategies for improving public transport access to large airports (Leigh Fisher Associates, 2000, 2002).

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 this study was primarily interested in methodology, 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 findings of the latter study are discussed in more detail in the following chapter.

2.2 Intermodal Transportation Planning Principles

Since airport ground transportation can be considered as a particular subset of the more general intermodal ground transportation system, airport ground access planning should be guided by generally accepted principles for intermodal transportation planning. The National

Center for Intermodal Transportation (NCIT) has proposed the following four principles for the development of the intermodal transportation system (NCIT, 2001):

Connection: All modes should be well connected with one another to accomplish the convenient, expeditious, and efficient movement of commodities and people. Connecting points should be conveniently located and connections timed to facilitate movements from one mode to another.

Choices: The intermodal network should offer choices, allowing its users to select the mode that can most efficiently satisfy their transportation needs.

Coordination: The transportation infrastructure should be planned, designed, and built in a way that brings the modal networks sufficiently close together so that connections can be made relatively effortlessly. In addition, transportation providers must coordinate their schedules to reduce dwell time between intermodal movements.

Cooperation: There should be cooperation and collaboration among transportation providers and governmental agencies at the federal, state, and local levels to ensure that the needs of the users for seamless service are realized.

One definition of good intermodal connectivity is as follows: ***Advanced and attractive systems that operate reliably, and relatively rapidly, and form part of the passenger and freight door-to door chain with smooth and synchronized transfers.***

However, in order to apply these principles effectively, it is necessary to understand the similarities and differences between planning for intermodal urban transportation in general and airport ground access in particular.

Similarities:

- As an example of intermodal transportation, the principles guiding airport ground access planning are similar to those for intermodal transportation in general;
- Basic requirements for facilities and service follow those identified by Homburger *et al.* (1996): adequacy to handle expected demand, compatibility with existing master plans, environmental compatibility, acceptability to decision makers and the public, and financial feasibility;

- Planning processes in both cases involve institutional issues, political relationships, identification of needs for enhanced facilities and services, and development of recommended changes to policy guidelines;
- Many of the factors influencing passenger mode choice decisions are similar;
- Public and private transportation providers operate in a similar way in serving airport ground access and general urban transportation trips.

Differences:

- Compared to general urban travel, airport ground access travel typically involves many more distinct modes and services;
- Airport ground access and egress trips by air passengers involve considerations not typically addressed in general urban travel, such as the need to carry luggage, round trips involving travel duration of many days, and a significant proportion of trips by visitors to the region;
- Many airport employees have shift patterns involving travel outside the usual commute times and the regular work week;
- Travel purposes for airport ground access trips are limited to airport related activities, which are not as diversified as those involved in general urban transportation;
- The total demand for airport ground access travel can be estimated from the air passenger traffic level at the airport and airport employee counts;
- Airport authorities typically maintain information on available airport ground access services at their airport(s), providing a current and consistent source of information;
- Airport access and egress trips involve travel to or from a single location, which reduces the complexity of travel patterns compared to general urban intermodal transportation;
- Transportation providers are generally subject to airport regulation which makes their behavior more predictable and can provide a source of statistics on operational traffic

and activity levels, which is not always the case for more general urban intermodal transportation;

- Surveys of air passenger and airport employee travel patterns can be performed relatively easily at the airport, since these trips involve a common location.

These differences make some aspects of the modeling and analysis of airport ground access more challenging than that for general urban intermodal transportation while making other aspects easier.

2.3 Quantitative and Qualitative Approaches in Airport Planning

To develop a combined quantitative and qualitative approach for intermodal airport ground access planning, it is necessary to look at quantitative, qualitative and combined approaches used for planning in previous work. This requires a way to distinguish between quantitative and qualitative approaches. For the purpose of this discussion, a quantitative approach is considered to be one that involves modeling for analysis regardless of how simple or how complicated the model may be. Most previous work used either a qualitative or a quantitative approach. Few studies tried to combine them for intermodal transportation planning.

Cunningham and Gerlach (1998) discuss the use of decision support systems for airport ground access planning using both quantitative and qualitative approaches. The approach used in this work included: (1) a literature review to obtain background information concerning the airport ground access problem and analysis of various proposed ground access solutions; (2) telephone interviews with airport and regional transportation officials to clarify issues and identify key transportation officials familiar with airport ground access planning; and (3) 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. Participants were encouraged to provide their opinions as well as factual information regarding the planning process and the extent to which decision makers relied on quantitative models and qualitative information to reach a decision.

However, this study does not discuss how the quantitative approach was conducted in the locations examined. Instead, the main part of the study discusses some practical problems encountered in (or controversial attitudes towards) the use of quantitative analysis in intermodal airport ground access planning. The main findings are the following: (1) on the one hand, decision makers need a decision support system to provide numerical results as references for decision making; (2) on the other hand, using quantitative modeling for strategic decision support is very difficult. This difficulty arises because (a) modelers are not confident about the accuracy of their models and transportation officials believe that the information supplied is flawed by a number of defects that minimize the value for the decision maker, which in turn leads to the situation that decision makers lose confidence in the quantitative method; and (b) modeling is generally believed to be very costly and difficult – human behavior is not sufficiently understood to accurately predict how travelers make individual transportation decisions. To avoid these difficulties, the authors propose the following solution: (i) improve quantitative modeling such that the model can actually reflect passenger mode choice behavior; (ii) use a combined quantitative and qualitative approach for decision making, where the qualitative approach involves 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.

They point out that planning, designing and building a transportation system involves multiple constituencies, as well as multiple decision variables and criteria. This suggests that decision-making at different levels of government needs to consider the interests of the different constituencies at the local, regional, and state level.

Cunningham and Gerlach suggest that decision makers, particularly higher level officials, tend to rely on a qualitative analysis based on a subjective assessment that draws on their background, beliefs, and experience. They might never make use of 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.

Reliance on a vision of how an organization, community or region should evolve is also a widely used tool for decision making in the business and political community. Quantitative information is then often developed to support that vision. In this case, the main information used by the decision makers in practice is derived from the vision with only minor information from quantitative analysis. In consequence, decision makers often choose to rely on models that are consistent with their visions. Where the results of analysis are in conflict with their vision, decision makers often choose to base their decisions on their vision rather than the analysis. This can often arise from a large gap between the quality of the analysis tools and how the decision makers perceive those tools.

The authors also identify a number of concerns and limitations with existing approaches to quantitative analysis:

(a) Small amounts of data often only allow models to provide a general representation of complex phenomena, such as the use of average daily traffic levels;

(b) Models are often too sensitive to key inputs and too easily manipulated;

(c) Models sometimes do not predict what is really happening;

(d) There is often difficulty modeling the effect of new modes or services using models that have been calibrated on data for the existing pattern of services.

The authors propose a number of ways to remedy these modeling limitations in order to win the confidence of decision makers:

(a) Involve the transportation agency decision makers in the modeling process by organizing a committee to oversee the design and use of transportation models;

(b) Ensure that the modelers make clear to decision makers the following aspects:

- What assumptions have been made
- What data are to be used and why
- The methodology to be used, which should be documented in a form that decision makers can understand;

(c) Encourage the decision makers to use the results of model analysis as prudently and conservatively as possible.

Ceder (2004) discusses the major elements and challenges surrounding the introduction of new or improved public transportation (PT) systems or services. The choice between public and private transport is an individual decision that is influenced by government and community decisions. These decisions often send mixed signals to the public transport passengers and potential users while failing to recognize system-wide considerations and integration implications. This paper attempts to summarize the current state of PT practice and to cover issues affecting the use of PT including the willingness of users to pay for improved service, assessment and projection of economic viability, the effectiveness of new initiatives mostly in Europe and North America, and strategies to achieve multi-modal service integration.

Ceder discusses the use of a qualitative analysis approach to address factors which affect the quality of service offered by the intermodal system but are difficult to quantify. These factors could include the introduction of the following intelligent transportation systems (ITS) technologies and other measures to improve user comfort and convenience:

- Automatic vehicle monitoring (AVM)
- Signal priority for public transportation vehicles
- Traveler information systems
- Stability of perception of service
- Ticketing integration
- Improved terminal, interchange and park and ride facilities
- Coordination between different modes to reduce total travel time
- Increased passenger comfort
- Introduction of different modes to increase system capability.

2.4 Policy and Institutional Issues

Lacombe (1994) suggests that inadequate ground access facilities may limit airport capacity. This paper examines the requirements in the Clear Air Act Amendments (CAAA) and

Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) 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.

Yevdokimov (2000) examines the use of cost benefit analysis and related techniques to analyze the effect of transportation investment on economic growth. Microeconomic and macroeconomic simulations are used to support the benefit measurement.

2.5 Mode Choice Modeling and Analysis

To date the quantitative approach to air passenger ground access model choice analysis has almost exclusively used a form of logit model (multinomial logit or nested logit). Past model development efforts have been summarized in a recent review of the relevant literature by Gosling *et al.* (2003). A number of subsequent studies and alternative approaches are discussed below.

Tam and Lam (2005) studied the mode choice pattern for ground access travel to Hong Kong International Airport using a survey of air passengers. Their results show that due to very low car ownership and relatively short travel distances to and from the airport, access is mainly by public transport such as bus and train or light-rail. Passengers are divided according to arrival, departure and transit/transfer. The authors conclude that business travelers are less concerned with the cost of service than with travel time and convenience. This paper is primarily focused on the design of the survey and explanation of the results rather than their use for model development.

Arentze and Timmermans (2005) discuss the application of formal decision rules, such as *parametric action decision trees*, to explain travelers' mode choices. According to the authors, using discrete choice models (such as the logit model) could limit the sensitivity of the model to travel time and travel cost. This paper uses a hybrid model to reduce such defects. It is claimed that the hybrid model can reproduce realistic price elasticities of travel demand. The authors assert that decision trees have the advantage of being consistent, exclusive, and complete compared to other methods for formal representation of decision making, such as *belief networks*, *association rules* and *production systems*. However, this paper does not specifically address airport ground access travel.

Two recent papers by Outwater *et al.* (2003, 2004) describe a market segmentation modeling approach to predicting the effect on mode choice of introducing a new mode, in this particular case the introduction of ferry service in markets not currently served by ferries. Two types of models were considered: multinomial logit and nested logit. The authors found that the later did not give any improvement and thus based their analysis on the former. Stated-preference survey data were used to calibrate the model. The calibrated model was then used to analyze three future year alternatives and to test sensitivities to pricing, service changes and alternative modes. According the author, previous mode choice modeling work has tended to emphasize the following factors: trip purpose, geographical location, and travel time. However, the focus of the current paper was to extend this mode choice modeling approach to reflect the effect of passengers' attitudes toward improvement in ferry service and apply this to the forecasting ferry ridership in the San Francisco Bay Area. Six attitudinal factors were identified: desire to help the environment, desire for time saving, need for flexibility, sensitivity to travel stress, insensitivity to transport cost, and sensitivity to personal travel experience. Three of these were used to partition the potential ferry-riding market into eight segments and develop demand estimates for each segment.

Lo, Yip and Wan (2004) incorporated the competitive behavior of transit services in an intermodal planning model using a nested logit approach. However, the competitive behavior between transit providers was considered in a static manner rather than a dynamic interaction between the transportation provider decisions and the passenger travel choices. The effect of the transportation provider behavior on passenger mode choice was reflected through the relationship between fare changes and ridership. Using their model, the authors studied the effect of fare changes on overall network congestion. A case study of travel between Hong Kong International Airport and the Downtown Area was used to illustrate the method.

2.6 Airport Ground Access Travel Information

A key aspect of air passenger choice of travel mode for airport trips is the information available to them about travel options. It is self-evident that travelers will not use transportation options that they are not aware of, but an equally important consideration is whether they can readily obtain the necessary information to decide whether to use a particular service. In the absence of accurate information, their perceptions of travel times or costs may be sufficiently biased to cause them to reject options that in fact might work very well for them. In spite of the importance of this issue, it has received relatively little attention in the literature.

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. These kiosks used a touch-screen display to provide information on alternative travel options and contained a database for all the airports in the demonstration program. Thus air passengers waiting for their flight at one airport could obtain information about ground transportation options at their destination airport. 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). The survey results found that kiosk users generally found the information provided by the kiosks helpful and that they liked being able to obtain information about their destination airport in advance to arriving there.

A similar survey was undertaken a few years later at George Bush Intercontinental Airport in Houston (Burdette & Hickman, 2001). The latter survey only addressed the needs of departing air passengers and included information related to the flight (such as gate information and flight delays) 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 using both static and dynamic paradigms. Although not directly applied to air passenger travel decisions, their approach may offer some insights as to how to better understand the role of travel information systems in airport ground access travel decisions.

2.7 The Government Accountability Office Study

The United States (U.S.) Government Accountability Office (GAO) 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 explored 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 calendar year 2003) and case studies of 16 airports (including Los Angeles International (LAX), San Francisco International (SFO), Oakland International (OAK) and Mineta San José International (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 in the first year of this project 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 were 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. These 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. In order to better understand the factors affecting the feasibility and likely contribution of these alternative strategies, a series of more detailed case studies of potential opportunities for enhancing intermodal connectivity at airports in the San Francisco Bay Area was undertaken. More detailed analysis of the Bay Area case studies is presented in Chapter 9. This analysis examines the likely ridership levels and economic feasibility of the different strategies, and provides 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 California Airport Ground Access Needs

In 2001 the California Department of Transportation (Caltrans) released the findings of an extensive study of airport ground access issues in the state that had been undertaken by a consulting team led by Landrum & Brown (2001). The study report consisted of an Executive Summary and three working papers. A major focus of the work by the Landrum and Brown Team was to identify airport ground access needs and specific problems at a wide range of California airports. This information was then used to develop recommended policies and guidelines to address these problems and needs. These policies and guidelines provide a strategic or high-level approach but do not get into the details of how this could be accomplished in practice. For example, they suggest that improved coordination between airport authorities and ground transportation agencies is needed but do not address how this coordination could be facilitated. The report recommended that the next step for improving the various planning, programming and implementation processes for California airport ground access is for Caltrans to develop a specific improvement plan.

3.1.1 Airport-Identified Issues and Problems

In order to identify the ground access issues and problems at each airport, the study undertook a survey of airport managers throughout the state. The predominant issues identified by the survey respondents are summarized as follows:

- Large and medium sized commercial airports are primarily concerned with major regional mobility issues.
- Small and non-hub commercial airports tend to have more localized problems associated with roadway geometry and immediate terminal area requirements of curbside and parking.
- Issues and needs at general aviation and business airports are also more localized in nature, and are generally related to parking, roadway geometry and roadway conditions.
- Cargo airports are often served by an infrastructure of local roads that are inadequately constructed to meet the truck traffic demands generated by the airports.

3.1.2 Performance Based Needs

The study asked each airport to identify the most significant ground access system deficiencies that they faced and to assess how severe the inadequacy was currently and was expected to be in the future. The specific deficiencies identified by each airport were grouped into the following categories:

- adequacy of alternative modes
- auto access
- curbside
- goods movement
- airport parking.

The study findings presented only those airport needs for which the existing or future conditions were deemed to be moderately to severely inadequate. The specific deficiencies at each airport were listed in the report and then summarized for each airport in terms of the occurrence of deficiencies in each of the five aspects of the airport ground access system described above.

Table 3-1 presents these summary findings for the large and medium hub commercial service airports in California, since it is these airports where intermodal connectivity issues are likely to be most relevant.

Table 3-1: Most Significant Ground Access System Deficiencies at Major California Airports

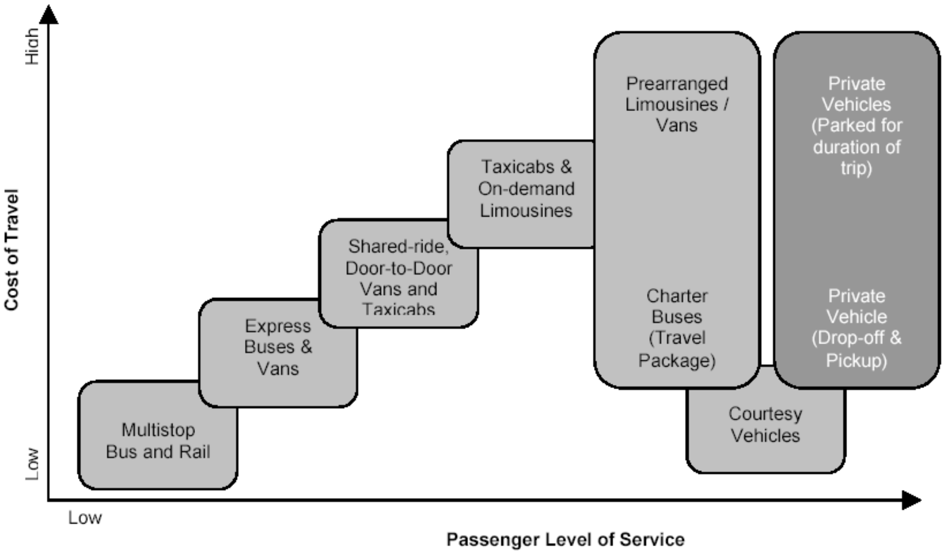
	Adequacy of alternatives		**Auto access**		**Terminal/ curbside**		**Airport parking**		**Goods movement**	
Airport	**2000**	**2020**	**2000**	**2020**	**2000**	**2020**	**2000**	**2020**	**2000**	**2020**
Burbank		*(a)*	●							*(a)*
John Wayne		*(a)*		●	●	●	●	●		*(a)*
Los Angeles	●	*(a)*	●	●	●	●	●	●		*(a)*
Oakland	●	*(a)*		●	●		●	●	●	*(a)*
Ontario		*(a)*	●	●			●	●	●	*(a)*
Sacramento		*(a)*			●		●			*(a)*
San Diego		*(a)*	●	●			●			*(a)*
San Francisco		*(a)*		●	●		●	●	●	*(a)*
San Jose		*(a)*	●				●		●	*(a)*

Source: *California Ground Access to Airports Study*, Working Paper Two: Issues and Problems (Landrum & Brown, 2001), Table 2-4.

Note: (a) Deficiencies not assessed for 2020.

3.1.3 Availability and Use of Public Transportation Modes

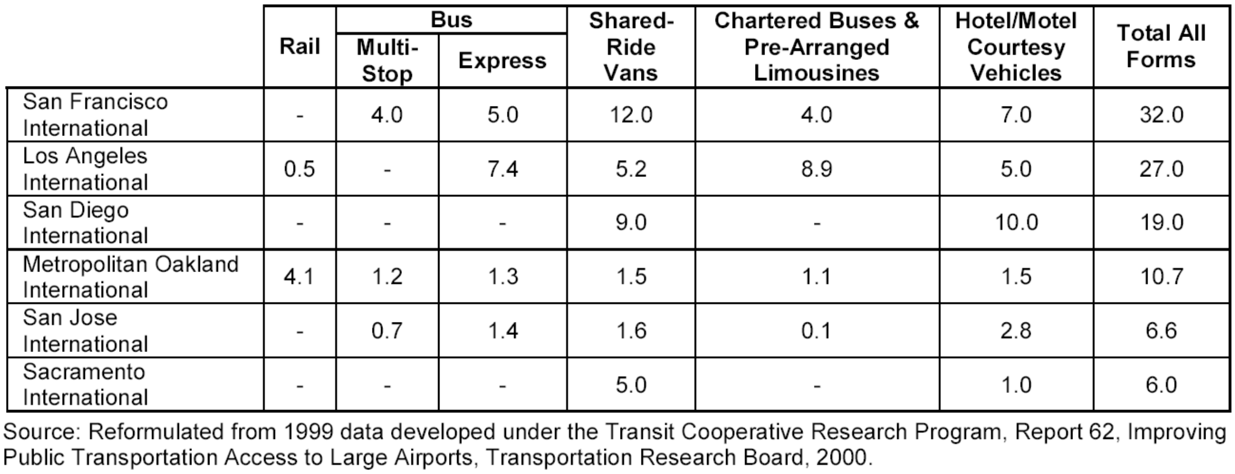
Working Paper Two also discussed the tradeoff between the cost of travel and the level of service offered by different modes, as illustrated in Figure 3-1 and percent market share of different public transportation modes at major California airports shown in Table 3-2. Appropriately reflecting the tradeoff between cost and level of service provided to the users by different modes is obviously critical to accurately modeling of air passenger mode choice and transportation provider behavior in the current project. The data shown in Table 3-2 demonstrate the relatively low market share that has historically been achieved by conventional transit services at California airports, although it should be noted that since the table was prepared the Bay Area Rapid Transit (BART) system has been extended to San Francisco International Airport and use of that service has significantly increased. In addition, use of BART for trips to and from Oakland International Airport has also increased since the data shown in Table 3-2 was assembled by the Transit Cooperative Research Program study from which the data was obtained.



Source: *California Ground Access to Airports Study*, Working Paper Two: Issues and Problems (Landrum & Brown, 2001). Original source: Transit Cooperative Research Program, Report 62, Improving Public Transportation Access to Large Airports, Transportation Research Board, 2000.

Figure 3-1: Comparison of Ground Transportation Options

Table 3-2: Transit Percent Market Share by Mode



	Rail	Bus		Shared-Ride Vans	Chartered Buses & Pre-Arranged Limousines	Hotel/Motel Courtesy Vehicles	Total All Forms
		Multi-Stop	Express				
San Francisco International	-	4.0	5.0	12.0	4.0	7.0	32.0
Los Angeles International	0.5	-	7.4	5.2	8.9	5.0	27.0
San Diego International	-	-	-	9.0	-	10.0	19.0
Metropolitan Oakland International	4.1	1.2	1.3	1.5	1.1	1.5	10.7
San Jose International	-	0.7	1.4	1.6	0.1	2.8	6.6
Sacramento International	-	-	-	5.0	-	1.0	6.0

Source: Reformulated from 1999 data developed under the Transit Cooperative Research Program, Report 62, Improving Public Transportation Access to Large Airports, Transportation Research Board, 2000.

Source: *California Ground Access to Airports Study*, Working Paper Two: Issues and Problems (Landrum & Brown, 2001)

3.1.4 Recommendations

The Landrum and Brown study also made recommendations as how to improve the planning, programming and implementation of airport ground access at a strategic level. In particular, recommended criteria were provided for the selection of ground access projects at different types of airport: commercial (large, medium and small), general aviation, cargo and military. They can be summarized as the following five points:

- Choose cost effective projects;
- Maintain or improve passenger/cargo ground accessibility to airports including road quality and signage and minimize delays at curbside, including providing adequate curbside space;
- Maintain or improve passenger accessibility to local, regional, intra-state, or international air service;
- Mitigate neighborhood, local, and regional highway traffic by maximizing the use of the transit network to decrease vehicle miles of travel and reduce traffic;
- Promote safety.

These criteria can be considered as addressing four different concerns: cost effectiveness, accessibility, environmental impacts, and safety. The recommendations suggested that the project selection should be performance-based and that the performance should be quantifiable, although they did not provide any specific guidance on how to achieve this.

The recommendations of the Landrum & Brown study can be viewed as based on the principle that, since each airport is neither isolated from the larger concerns of society nor from the surface transportation network, it should be viewed as an integral part of the overall transportation system. Thus decisions by each party involved in airport ground access issues affect others directly or indirectly. This requires the decision making in the planning process to consider the problem as a whole and will involve different levels of government. Thus there needs to be effective coordination among decision makers in government agencies and other organizations to address airport ground access planning issues at different levels: airport, regional, state, and federal. There should also be coordination between decision makers involved in planning the aviation system and those involved in planning the ground transportation system.

3.1.1 Need for Planning Guidelines

According to the Landrum & Brown study, many airport managers are frustrated by the lack of guidance from local, regional, state and federal agencies to help them implement ground access projects. Development of planning guidelines based on a combined qualitative and quantitative approach is one of the objectives of the current project. The quantitative approach is reflected in the development of an Intermodal Airport Ground Access Planning Tool (IAPT) that provides the capability to undertake systematic modeling of airport traveler and transportation provider behavior in order to support airport ground access planning and project implementation. The IAPT is designed to generate measures of system performance, which can be used to guide decision-making by planning agencies or decision makers at different levels of government.

3.2 Potential Strategies to Enhance Intermodal Connectivity

The working paper prepared during the first year of the study identified 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 concessions, 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.

3.2.1 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 shuttle bus service between the two locations with a direct-line telephone at the train station that airport travelers can use to call for a shuttle. The 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), with fewer trains serving 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 connects Oakland International Airport (OAK) and the Coliseum BART station as well as the Oakland Coliseum Amtrak station that serves the Capitol Corridor route between San Jose and Sacramento. However, AirBART bus does not serve the Amtrak station directly. An Amtrak passenger has to walk to or from the AirBART bus stop at 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 station on the Caltrain line that that serves communities in the U.S. 101 corridor between Santa Clara County and San Francisco. 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 (U.S. Federal Transit Administration, 2002) and San José International Airport is pursuing an automated people mover link between the airport and the VTA light rail station, with a possible future extension to the Caltrain station (Lea+Elliott, 1999).

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. 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 March 2006 LAWA opened a second FlyAway service from the Patsaouras Transit Plaza adjacent to Union Station in downtown Los Angeles. 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.

3.3 Intermodal Opportunities at Selected California Airports

The working paper identified 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.

3.3.1 Southern California

Burbank/Bob Hope Airport is currently served by Metrolink and Amtrak trains, although these are relatively infrequent. However, 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 Canoga Park in the San Fernando Valley using buses on a dedicated guideway, termed the Orange Line, opened in October 2005. The Red Line 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. Since October 31, 2005 Burbank Bus, the local transit system for the City of Burbank, has operated its NoHo-Emprire route between the North Hollywood station and the area immediately to the east of Bob Hope Airport. The closest bus stop to the airport is on North Hollywood Way and Thornton Avenue at the entrance to the airport, a short walk from the terminal building. However, the bus route makes a one-way loop in the area to the east of the airport, and travelers from the North Hollywood station to the airport have a somewhat longer ride than travelers from the airport to the station. The service operates weekdays with departures from North Hollywood station between 6 am and 10 am and from 2:45 pm to 7:23 pm.

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. An improved link to the North Hollywood station would enhance service to 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. 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 would serve a significant share of the Burbank Airport market. A transit advocacy group in the San Fernando valley, The Transit

Coalition (www.thetransitcoalition.us), has proposed extending the Orange Line north from its current terminus at North Hollywood station to Burbank Airport along Vineland Avenue, using arterial streets rather than a dedicated guideway.

John Wayne Orange County Airport currently has no dedicated link to any regional rail system. The Orange County Transportation Authority has plans to implement a bus rapid transit (BRT) route between the Irvine Station to the east of the airport and the City of Brea to the north (http://www.octa.net/brt.aspx). It is anticipated that service would commence by 2010 and the planned route includes the airport and the Santa Ana Depot transportation center that would provide access to Metrolink and Amtrak 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. An alternative, and more direct, connection would be provided by establishing a shuttle bus link between the airport and the Tustin Metrolink and Amtrak station about 4 miles to the northeast of the airport. 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 with trip ends outside Orange County. 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 a 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 and the FlyAway service from Union Station commenced in March 2006. 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 recent LAX master plan update 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 other 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 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.

3.3.2 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 (U.S. Federal Transit Administration, 2002) and issued a Request for Qualification for a planned public private partnership for a design-build, finance and operate contract in February 2006. In September 2006 three teams were prequalified to submit proposals in response to a Request for Proposals (RFP) that was anticipated to be issued later in 2006, with a contact award expected in

2007 and revenue operation commencing in 2011. However, as of October 2007, the planned RFP had not yet been issued. 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. As of late 2006, the total project budget was reported to be approximately $254 million in 2001 dollars (http://www.bart.gov/about/projects/airport.asp).

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 a new ferry route has been proposed linking the Ferry Terminal in downtown San Francisco with a new terminal at Oyster Point just to the north of SFO and Harbor Bay Isle adjacent to OAK (http://www.watertransit.org/newferryroutes.shtml). This would require a shuttle bus connection between the Oyster Point ferry terminal and the passenger terminals at SFO. 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.

3.3.3 San Diego

The Blue Line of the San Diego Trolley light rail system runs to the north of San Diego International Airport (SAN) and links Mission Valley and the Old Town Transit Center to the north of the airport with the downtown and communities to the south of downtown, as well as connecting in downtown with the San Diego Trolley 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 Metropolitan Transit System (MTS) bus 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.

In 2005 the San Diego Regional Airport Authority, the operator of San Diego International Airport, commenced work on an Airport Transit Plan to improve public transit access to the airport (http://www.san.org/airport_authority/airport_master_plan/transit_plan.asp). The Airport Transit Plan was prepared under the oversight of an Airport Transit/Roadway Committee with staff representative of all the regional transportation agencies. The draft plan identified a range of potential improvement alternatives, including measures to increase the attractiveness of the existing services, improved marketing and route changes, and new services. These were then assigned to one of three tiers, depending on whether they could be implemented immediately, required further study and cost analysis, or depended on increased transit ridership or airport development before they could be implemented. They were also classified as having an implementation timeframe in the near-term (1 to 3 years), mid-term (3 to 5 years) or long-term. The alternatives considered included an express bus to the Old Town Transit Center and several potential off-airport terminal locations, as well as a direct Trolley connection to the airport terminals in the long term. While requiring a longer travel time than a direct shuttle bus connection to the Middletown Trolley station, service to the Old Town Transit Center would connect to other bus routes serving the Transit Center without requiring an intermediate transfer to the Trolley.

3.3.4 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, planning is underway to extend the Sacramento light rail transit system to the Metro AirPark and the airport (Sacramento Area Council of Governments, 2000; Parsons Brinckerhoff Quade & Douglas, 2003). Presumably the objective of the proposed off-airport terminal serving the airport via the light rail connection was 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.

3.3.5 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.

3.3.6 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.

3.4 Further Analysis of Potential Intermodal Opportunities

In order to better understand the factors affecting the feasibility and likely contribution of alternative strategies for enhancing intermodal connectivity and demonstrate the application of the Intermodal Airport Ground Access Planning Tool (IAPT), a series of more detailed case studies of potential opportunities at airports in the San Francisco Bay Area was defined. Five potential access projects for the three Bay Area airports were selected for case study analysis. The results of this analysis will address three objectives of the current project:

- Illustrate the application of the IAPT to evaluate airport ground access projects
- Validate the practical application of the IAPT by comparing the results of the IAPT analysis to those of other studies
- Explore the effectiveness of alternative strategies to improve intermodal connectivity for airport ground access.

The five selected case studies consist of:

(1) The Oakland Airport Connector automated people-mover between the Coliseum BART and Amtrak stations and Oakland International Airport

(2) A planned automated people mover at San José International Airport connecting the airport to nearby stations of the Santa Clara Valley Transportation Authority light rail system and the Caltrain commuter rail line serving communities between Santa Clara County and San Francisco

(3) A proposed ferry service linking a terminal serving San Francisco International Airport with downtown San Francisco and the East Bay

(4) An off-airport terminal located in the South Peninsula serving Oakland International Airport and potentially San Francisco International and San José International Airports

(5) An off-airport terminal located to the south of downtown San José providing service between Santa Clara County and both Oakland International Airport and San Francisco International Airport.

These five case studies have been selected based on prior studies of project feasibility and inclusion in the case studies of a range of different high-occupancy airport access modes. Among the selected case studies, the Oakland Airport Connector (OAC) and the automated people mover at San José International Airport (SJC) are both pending projects that have already undergone a considerable amount of planning and design. The ferry terminal at San Francisco International Airport (SFO) is a conceptual project derived from the currently planned expansion of ferry services in the Bay Area. The proposed off-airport terminals represent potential solution to the current inadequate public transit options for air passengers between the South Peninsula or Santa Clara County and Oakland International Airport (OAK) as well as between Santa Clara County and SFO.

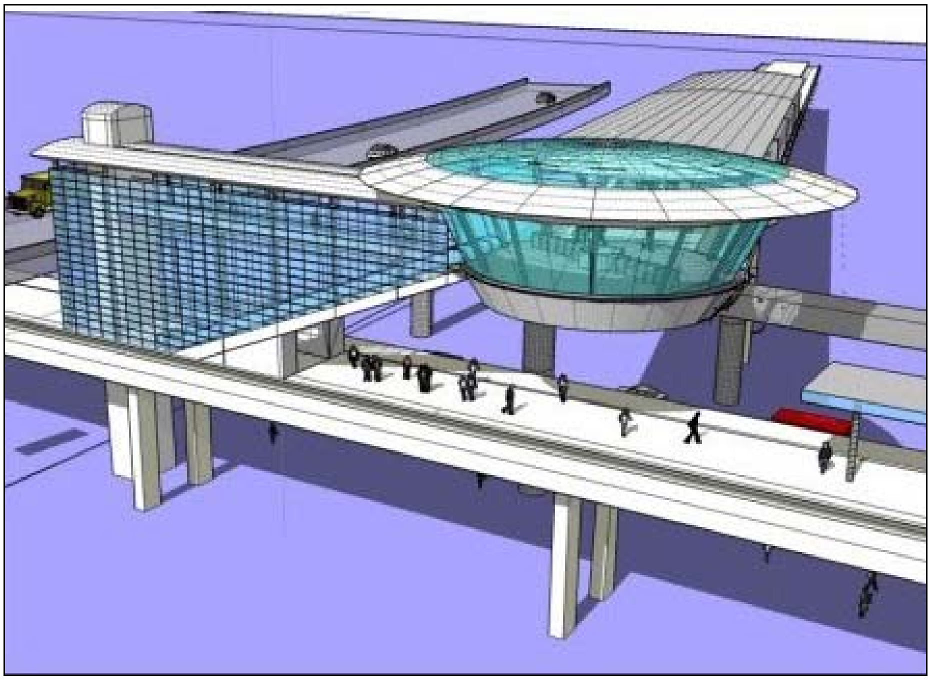
The current version of IAPT has the capability to define three types of new project:

- Adjustment to the service levels and fares for an existing service
- Introduction of a new service for an existing mode
- Implementation of a new mode not currently available in the system.

The first two case study projects involve the implementation of a new mode as a replacement for an existing service. The Oakland Airport Connector and the SJC people mover will replace existing shuttle bus services that provide connections between the airports and the regional rail transit system. The third case study project, the proposed South San Francisco ferry terminal, involves the implementation of a new service that makes use of a new mode that is not currently used to provide airport ground access service. The South Peninsula and Santa Clara County off-airport terminals are new services, but utilizing a mode that is currently serving other parts of the region. Each project would first be evaluated based on the proposed service characteristics assumed in prior studies or adopted for similar services elsewhere in the region. A sensitivity analysis would then be performed by evaluating each project with a range of service levels (*i.e.* higher or lower fares and frequencies). Each case study is described in more detail in the following sections.

3.4.1 The Oakland Airport Connector

The San Francisco Bay Area Rapid Transit District (BART) is currently pursuing implementation of the proposed BART-Oakland Airport Connector, connecting the BART Coliseum Station to a new station at the Oakland International Airport via an elevated automated guideway transit (AGT) system. The 3.2-mile connector is intended to maximize BART ridership by providing a more reliable and convenient airport connection than the current shuttle bus alternative. Conceptual designs of the two stations at either end of the AGT system are illustrated in Figures 3-2 and 3-3.



Source: BART website (http://www.bart.gov), The Oakland Airport Connector Project

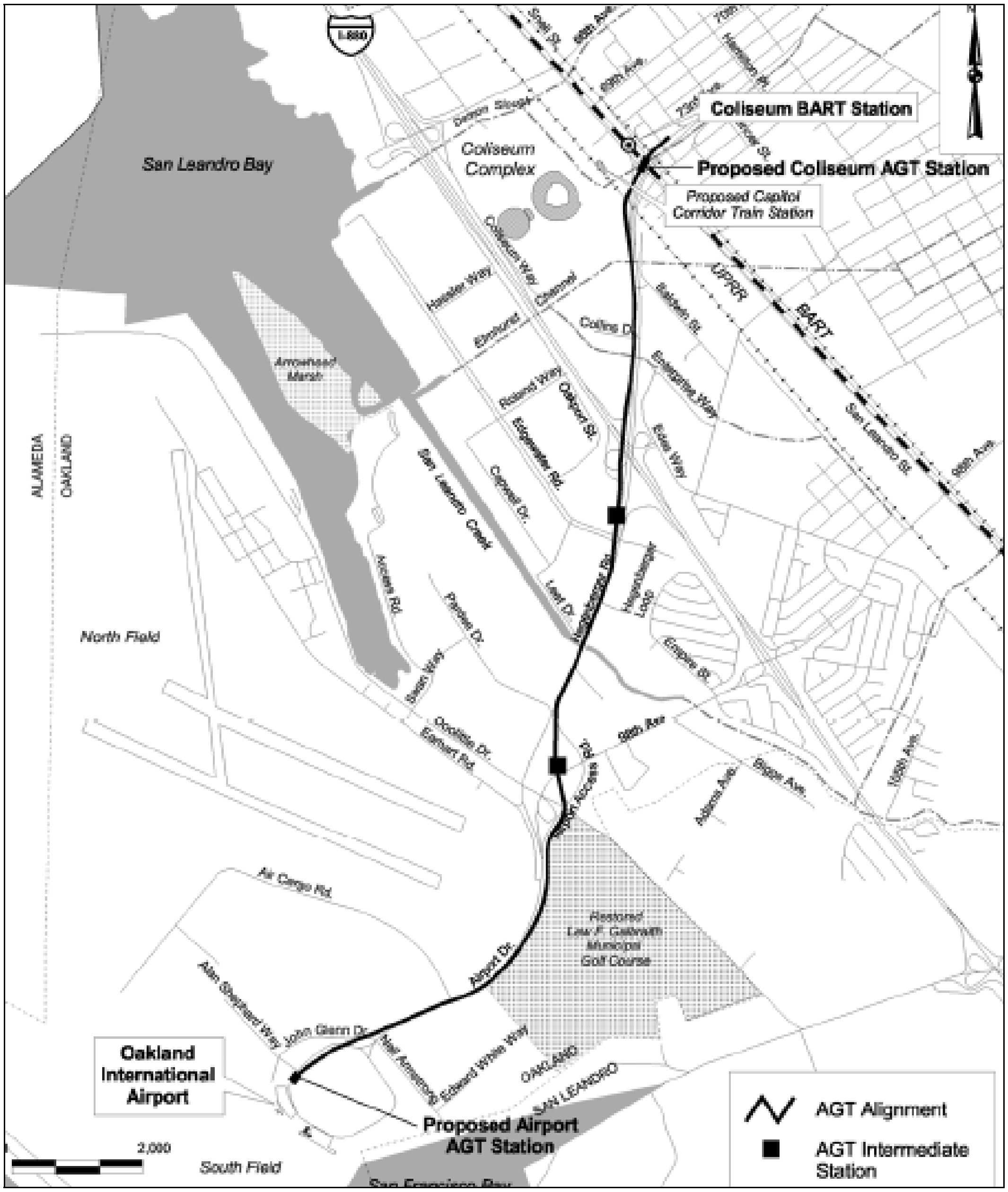
Figure 3-2: Coliseum Station Rendering

Source: BART website (http://www.bart.gov), The Oakland Airport Connector Project

Figure 3-3: Oakland Airport Station Rendering

The new OAC link will have a total of four stations including two terminal stations and two intermediate stations: one at Edgewater Road between the Interstate 880 and the airport and one at Doolittle Drive on the northeast boundary of the airport, as shown in Figure 3-4. The proposed OAC is expected to enhance level of service and reliability over the existing AirBART shuttle at similar monetary cost to the users. Transit ridership is estimated to capture a mode share of approximately 20 percent of OAK air passengers by 2020 (Dunscombe & Cartwright, 2004).

The Oakland Airport Connector (OAC), upon projected completion in year 2011, will replace the current AirBART shuttle providing connection between the BART Coliseum station and the airport terminals following the route shown in Figure 3-5. The AirBART shuttle currently captures approximately an 8 percent airport access mode share and ridership is predicted to grow at an annual rate of 12.4 percent as air travel demand grows at the Oakland Airport. AirBART has a frequency of approximately 10 minutes and trip times that vary between 12 to 17 minutes depending on the traffic conditions at the airport terminals and on the neighborhood arterials.



Source: U.S. FTA & BART, Oakland International Airport Connector FEIR, 2002.

Figure 3-4: Alignment of Oakland Airport Connector Preferred Alternative

The design and operating parameters for the OAC are summarized in Table 3-3. In order to model the OAC using the IAPT, it will also be necessary to define the associated service data for the other ground access modes and the air traffic growth rate at OAK for the analysis time frame.

Source: Base map –Google Maps, 2007; AirBART route – U.S. FTA & BART, Oakland International Airport Connector FEIR, 2002.

Figure 3-5: AirBART Roundtrip Route

Table 3-3: Operating and Patronage Assumptions for the OAC Preferred Alternative

	2005
Stations	4
Vehicles	
Capacity (passenger w/ luggage)	60 passengers
Peak Operating Fleet	8
Total Fleet	10
System Capacity (persons/hr/direction)	1,895
Average Travel Times	
One-way in-vehicle time	6.4 min
Dwell time (end station)	40 sec
Dwell time (intermediate station)	20 sec
Headway (6am - 8pm)	3.5 min
Total passenger walk time	3 min
One-way trip time (in-vehicle time + wait time)	8.2 min
Average total trip time (wait + in-vehicle travel + walk time)	11.2 min
Cost	
Capital (in 2000 $)	229.6 million
Annual O&M (in 2000 $)	7.6 million
Revenue	
Fare	$2/trip

Source: U.S. FTA & BART, Oakland International Airport Connector FEIR, 2002.

3.4.2 SJC Automated People Mover Link

The Mineta San José International Airport has proposed an automated people mover (APM) connecting the Santa Clara Valley Transportation Authority (VTA) light rail transit Metro/Airport Station on North First Street to the San José International Airport (SJC). The 0.6 mile APM system would consist of automated, electric-powered vehicles running along a separate guideway on a dedicated right-of-way, as shown in Figure 3-6. In addition, there is a possible extension under consideration that would connect the airport terminals with the Santa Clara Caltrain station to the west of the airport. There are two alignments under consideration: a 2.5-mile surface route or a 1.2-mile tunnel route under the airfield (Dowling Associates, 2002).

The proposed APM system at SJC will replace the Airport Flyer (VTA line 10 bus) that currently provides connection between the Metro light rail station and the airport terminals, as well as the Santa Clara Caltrain station following the route shown in Figure 3-7. The Airport Flyer currently captures about a 2 percent airport access mode share and operates at a frequency of approximately 10 minutes with a one-way trip time ranging between 8 to 10 minutes.

Source: Base map –Google Maps, 2007; APM route – San Jose International Airport, Master Plan Update FEIR, 2003.

Figure 3-6: SJC Automated People Mover Preferred Alignment

Source: Base map –Google Maps, 2007; Airport Flyer route – Valley Transportation Authority website, Airport Flyer Route Map.

Figure 3-7: Airport Flyer (VTA Line 10) Route

The proposed APM is expected to reduce vehicle traffic on local roadways and at the airport, which in turn would improve local air quality. The VTA light rail transit services are estimated to capture approximately 5 percent of air passenger mode share by 2010. Table 3-4 compares the key service characteristics for the current Airport Flyer service as well as the designed parameters for the proposed APM.

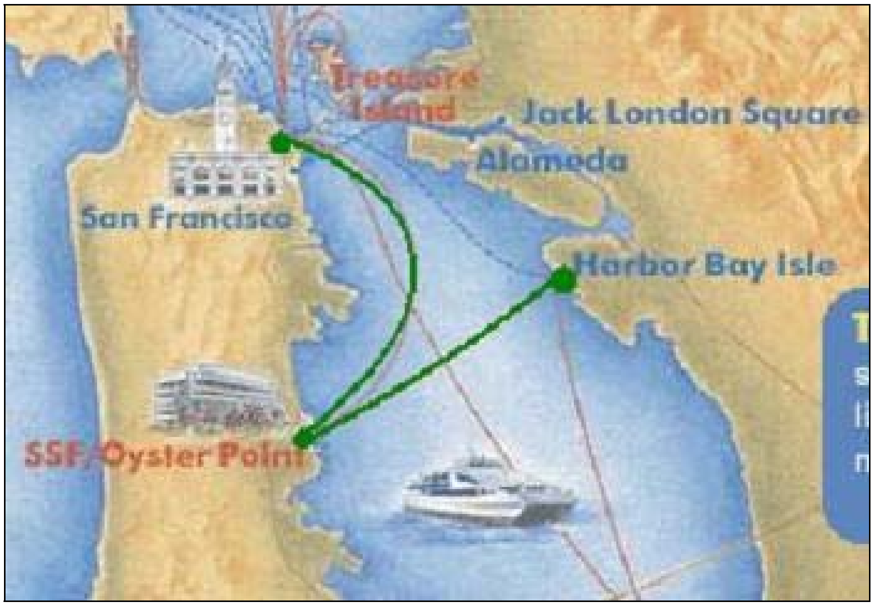
Table 3-4: Operating Assumptions for the SJC Automated People Mover

	APM	Airport Flyer
Average Travel Times		
One-way in-vehicle time	1.8 min	9 min
Headway (6am - 8pm)	5 min	10 min
Total passenger walk time	3.6 min	4 min
One-way trip time (in-vehicle time + wait time)	4.3 min	14 min
Average total trip time (wait + in-vehicle travel + walk time)	7.9 min	18 min
Revenue		
Fare	Free	Free

Source: Dowling Associates, San Jose International Airport Transit Connection Ridership, Final Report, 2002.

3.4.3 SFO Ferry Service

The San Francisco Bay Area Water Transit Authority (WTA) is currently in the process of adding eight new routes on the existing Bay Area ferry system as part of the proposed expansion of ferry service. The objectives of the proposed expansion are to help relieve roadway congestion on the transbay bridges and Bay Area highways as well as providing a more pleasant traveling experience. As part of the expansion, a new ferry terminal at Oyster Point in South San Francisco will be built to provide service from the East Bay and San Francisco Ferry Building to South San Francisco, as shown in Figure 3-8. The project is currently in the planning and design phase and is proposed to begin initial service by late 2008. The WTA anticipates nearly 1,000 daily passenger trips to and from South San Francisco by the year 2025 (San Francisco Bay Area WTA, 2007).



Source: San Francisco Bay Area Water Transit Authority website, Proposed Ferry Routes (At http://www.watertransit.org, accessed March 2007). South San Francisco routes highlighted.

Figure 3-8: Proposed Ferry Service Routes to South San Francisco

The new terminal at Oyster Point will be located approximately 4 miles north of San Francisco International Airport (SFO) and could serve as an alternative access mode for trips to SFO from downtown San Francisco or East Bay communities in the vicinity of the Harbor Bay Isle ferry terminal. The WTA plans to work with the San Mateo County Transit District

(SamTrans) and the Peninsula Congestion Relief Alliance to provide feeder service for more convenient access to the Oyster Point terminal. It would be a logical extension of these arrangements to provide a direct shuttle service between the ferry terminal and the airport terminals, as shown in Figure 3-9.

Source: Base map –Google Maps, 2007.

Figure 3-9: Potential Shuttle Bus Route Between Oyster Point Ferry Terminal and SFO

The proposed East Bay ferry terminal would be located at Harbor Bay Isle adjacent to Oakland Airport. If the Port of Oakland were to operate a shuttle bus service between the airport and the Harbor Bay Isle terminal, travelers from South San Francisco could use the ferry service to access Oakland Airport. This would also allow air passengers to use the ferry service and connecting shuttle bus services to transfer between OAK and SFO.

The current ferry service on the existing route between Oakland and San Francisco runs on a varying headway between an hour and over two hours on weekdays (weekend service is more limited) and charge a fare of $5.50 for a one-way trip. The airport ridership share that such a service might attract is very dependent on the exact nature of the ferry and its connecting services. The preliminary assumptions for the capital and operating characteristics for the route between the East Bay, Downtown San Francisco and South San Francisco are summarized in Table 3-5 below.

Table 3-5: Operating Assumptions for the Proposed South San Francisco Ferry Route

Vessels	
Capacity	149 passenger
Total Fleet	2 fast ferry
Average Travel Times	
One-way ferry travel time	30 min
Shuttle Transfer[1]	10 min
Cost	
Capital (in 2000 $)	38 million
Annual O&M (in 2000 $)	22 million
Revenue	
Fare ($)	5

Note: 1. Based on auto travel time between Oyster Point and SFO

Source: San Francisco Bay Area Water Transit Authority website (http://www.watertransit.org, accessed March 2007).

3.4.4 South Peninsula Off-Airport Terminal

Current public transportation services at Oakland International Airport (OAK), including BART, Alameda-Contra Costa Transit District (AC Transit), and Amtrak, provide direct airport access to most air passengers from Alameda County, Contra Costa County, and San Francisco County. However, passengers from South Peninsula communities wishing to utilize public transit to access OAK can either take Caltrain and transfer to BART at Millbrae station or take a transbay bus across the Dumbarton Bridge and connect to BART at Fremont station. These alternatives are both inconvenient and time consuming. One possible solution is to implement an off-airport terminal in the South Peninsula at a reasonably accessible location. From the off-airport terminal, regularly scheduled bus services would provide passengers with express transfer to OAK.

Marin Airporter currently provides scheduled airport bus service to SFO from two off-airport terminals in Marin County, at Larkspur Landing and North Hamilton Parkway in Ignacio. Both facilities provide long-term parking at lower rates than the airport (currently $3.00 per day at Hamilton and $4.00 per day at Larkspur Landing). The Larkspur Landing terminal is shown in Figure 3-10. Off-airport terminals have been implemented in a number of other regions, including Los Angeles and Boston. Los Angeles World Airports (LAWA) operates FlyAway bus services to Los Angeles International Airport from two terminals, one in Van Nuys and one at Union Station in downtown Los Angeles. LAWA has recently modernized the FyAway terminal in Van Nuys, including construction of a parking garage, and opened its second FlyAway terminal at Union Station. Baggage check-in is currently available at both terminals for six major domestic airlines for a fee of $5. Airline check-in services are not currently available at the Marin Airporter terminals, although both American Airlines and United Airlines have offered these services at the Larkspur Landing terminal in the past.

Figure 3-10: Marin Airporter Larkspur Landing Terminal

Given that the purpose of introducing an off-airport terminal is to increase airport accessibility for travelers who have inconvenient transit access to the East Bay, the location of the off-airport terminal should be chosen to maximize accessibility for those passengers. The off-airport terminal should provide short term and long term parking, passenger pick-up and drop-off areas, and be fairly accessible by local and regional transit services. Some of the Caltrain stations in the south Peninsula could fulfill these requirements and would be good candidates for an off-airport terminal site. The locations of the Caltrain stations relative to the two bridges crossing the South Bay are shown in Figure 3-11.

The Caltrain Station at Palo Alto could be a suitable potential location for an off-airport terminal in the South Peninsula. The station is located just south of the Dumbarton Bridge, which is the major Bay crossing between the south Peninsula and the East Bay, as shown in Figure 3-11.

Figure 3-11: Caltrain System Map

Palo Alto is one of the major stops serving the heavily utilized Baby Bullet (express) trains. Due to the popularity of the Baby Bullet service, parking is often scarce at the stations serving these trains. If an off-airport terminal were to be implemented at the Palo Alto station, additional parking would have to be incorporated in the project. For the purpose of the case study analysis, the assumed values for the operational characteristics of the off-airport terminal service shown in Table 3-6 are based on the existing Marin Airporter scheduled bus service to SFO. Travel times are based on typical auto travel time between the off-airport terminal location and the respective airports.

Table 3-6: Operating Assumptions for the Proposed South Peninsula Off-Airport Terminal

Travel Time	60 minutes
Waiting Time	15 minutes (assume 30 min headway)
Parking Rate	$4/day
Fare	$18 one-way

Although air travelers to SFO from the South Peninsula are fairly well served by Caltrain, if an off-airport terminal is to established near the Palo Alto Caltrain station with affordable long-term parking for air travelers, it may be worth exploring whether a large enough market would exist to support express bus service to SFO and SJC in addition to the service to OAK. Service to SFO and SJC could also serve any travelers needing to transfer between the two airports. The Baby Bullet trains are fairly infrequent outside of commute periods and an express bus service to SFO from Palo Alto would be significantly quicker than regular Caltrain service. Although air travelers from the South Peninsula using SJC would not experience any travel time advantage using the off-airport terminal compared to driving to the airport, the shorter driving distance to the terminal would be attractive to those dropping off or picking up air passengers, while lower cost parking might be attractive to those who would otherwise park at the airport. The net effect of service to the two airports would help reduce vehicle trips to and from both SFO and SJC in the congested U.S. 101 corridor.

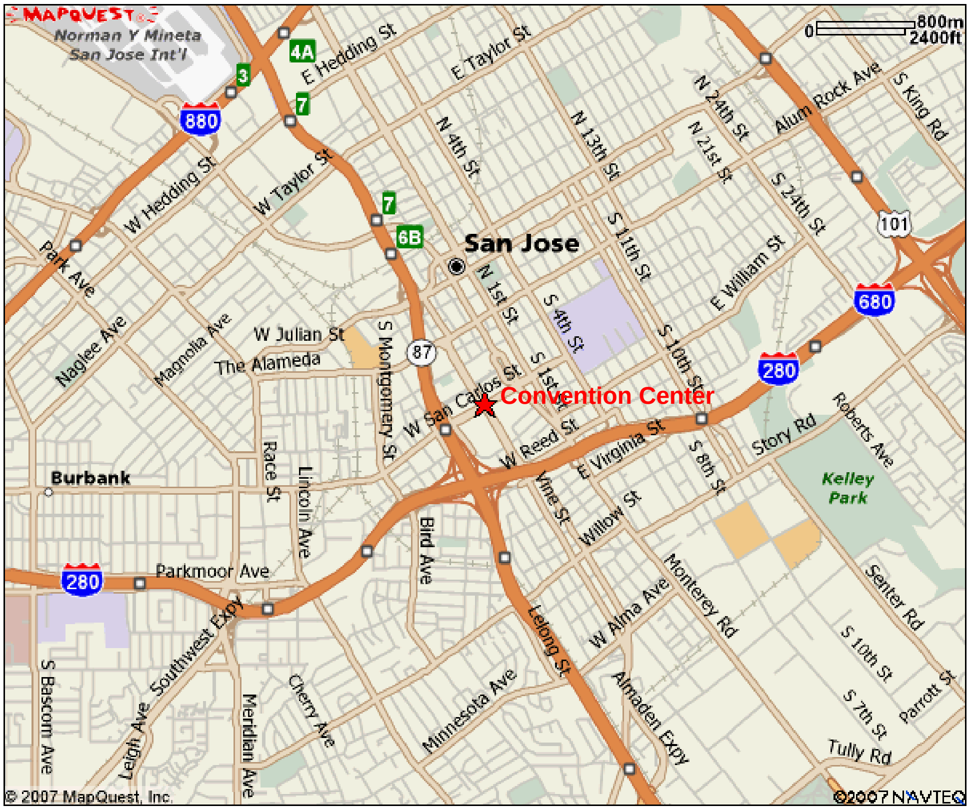
3.4.5 Santa Clara County Off-Airport Terminal

A similar off-airport terminal strategy could be applied to improve connection between communities in Santa Clara County and both SFO and OAK. Although the majority of air travelers from Santa Clara County use SJC for domestic flights, international service from SJC is very limited and Caltrain service from stations south of San José is infrequent outside of commuter hours. An off-airport terminal in central Santa Clara County may be a viable way to improve the current public transportation connectivity to SFO offered by Caltrain. Such a terminal may also be able to support service to OAK from Santa Clara County for those air travelers from the county using that airport. Although the Capitol Corridor trains serve OAK from the San José Diridon station, service is fairly infrequent.

An ideal location for an off-airport terminal should provide convenient freeway access, particularly from the U.S, 101 corridor serving the South County communities, as well as be accessible by the VTA light rail system. A location in the vicinity of the I-280 and SR 87 freeway junction, as shown in Figure 3-12, would be fairly easily accessible by auto to communities to the south and west of downtown San José, as well as by the VTA light rail system. The Convention Center VTA light rail station (shown in Figure 3-12) is served by both the VTA Mountain View–Winchester and Alum Rock–Santa Teresa light rail lines.

For the purpose of the case study analysis, assumed values for the operational characteristics of the off-airport terminal service are similar to those adopted for the South Peninsula off-airport terminal, as shown in Table 3-7. Travel times to SFO and OAK would also be about an hour via U.S. 101 or I-880 respectively.

Since the route from the off-airport terminal to SFO would pass SJC, it may be worth serving SJC airport en-route to SFO. Although a stop at SJC would add travel time to the service to SFO, this might be offset by additional ridership that would be attracted to the service. Service to SFO could also be provided by extending the route between the South Peninsula off-airport terminal and SJC to terminate at the Santa Clara County off-airport terminal, thus effectively serving both SJC and SFO from the off-airport terminal. Although this would further increase the travel time between the off-airport terminal and SFO, the reduction in the number of bus trips needed could make such a service economically viable when it would not otherwise attract enough ridership. Analysis will need to explore the trade-offs between operating costs, fares and the travel time disadvantage of multi-stop service.



Source: Base map – Mapquest (www.mapquest.com), 2007.

Figure 3-12: Potential Santa Clara County Off-Airport Terminal Location

Table 3-7: Operating Assumptions for the Proposed Santa Clara County Off-Airport Terminal

Travel Time	60 minutes
Waiting Time	15 minutes (assume 30 min headway)
Parking Rate	$4
Fare	$18 one-way

One potential difficulty with locating an off-airport terminal in the vicinity of the I-280 and SR 87 interchange is the relatively high land value. This may make the provision of parking at the rates encountered at the other off-airport terminals not economically viable. Analysis will need to examine the implications of higher parking rates on terminal patronage and whether a location further away from the downtown core might be a more viable project, even through it would be more difficult to access by transit.

3.5 Intermodal Air Cargo Considerations

The California *Ground Access to Airports Study* (Landrum & Brown, 2001) gave only limited attention to air cargo needs. However, at large airports, truck traffic generated by air cargo activities can have a significant impact on traffic levels on airport access and egress routes. The efficiency of air cargo operations is reduced when trucks are delayed by highway and roadway congestion in the vicinity of the airport. Although air cargo movements at airports are inherently intermodal, since they involve a transfer between aircraft and surface modes (typically truck), there is a growing interest in exploring the potential application of improved connections between different surface modes in order to facilitate the movement of air cargo and to reduce the impact of air cargo related truck trips on the local street and highway system.

This chapter provides an overview of the air cargo industry and an introduction to intermodal planning issues in handling air cargo. It also discusses opportunities for improving intermodal connections to better serve air cargo activity.

The air cargo industry is generally considered to comprise three components: air express, air freight, and air mail. Traditionally air express consisted of high priority shipments that were carried on passenger flights, while air freight consisted of heavier shipments that were moved using a combination of dedicated cargo aircraft and the belly holds of passenger aircraft. The evolution of the integrated carriers, such as Federal Express and UPS, which provide door-to-door shipment services using fleets of ground vehicles and aircraft, has blurred the distinctions between the different types of cargo. Indeed, the integrated carriers have recently begun to carry airmail for the Post Office as well as the packages and freight that they pick up and deliver themselves. They have also developed second- and third-day delivery services that have allowed them to attract larger amounts of heavier freight and have moved into the provision of contract logistics services in which they operate warehouses or other functions on behalf of their customers and handle the distribution through their intermodal network of trucks and aircraft.

The development of second- and third-day products has also allowed the integrated carriers to operate their fleets of trucks and aircraft as an intermodal network, with some shipments moving long distances by truck and some not even being put on an aircraft at all. Since sorting facilities are often located at or near airports, this can result in an increase in truck traffic to and from the airport carrying freight that is not moved by aircraft at all and has begun to also blur the distinction between air freight and surface freight.

3.5.1 Intermodal Air Freight Planning

Intermodal freight transportation has evolved in two stages. In the first stage, the introduction of containerization greatly increased the ease of loading and unloading for delivery and mode changes, and has been widely adopted for many years. The second stage, which is still evolving, involves the development of a seamless transportation chain to provide intermodal door-to-door service. The structure and composition of the intermodal freight industry has been documented by Muller (1995) and Wegmann *et al.* (1995).

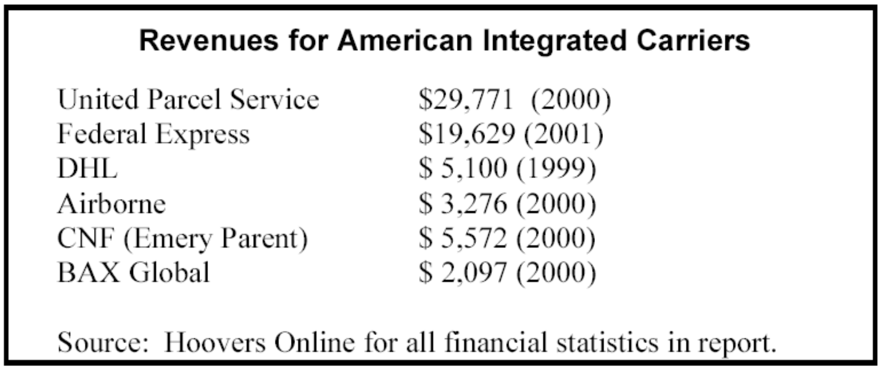
These general intermodal freight transportation trends also apply to air cargo although the latter has some distinct characteristics (Hall, 2002). In recent years, air cargo has been the fastest growing segment of the goods movement industry in the United States, placing increasing demands both on airports and ground transportation to and from airports. Air cargo shipments are inherently intermodal, as few shippers and receivers are located at airports.

Hall (2002) undertook a study of ground access trips handling air cargo in Southern California. More trucks need to be on the road during peak periods to meet start-of-day delivery commitments, particularly in the evenings in the West Cost according to FedEx. Truck movements experience significant roadway congestion on the way to or from, and in the vicinity of, major airports. However, it should be mentioned that although air cargo is a fast growing segment of the freight transportation sector, it accounts for only a relatively small proportion of truck movements in any given region.

The so-called integrated carriers, such as Federal Express (FedEx) and UPS (formerly United Parcel Service), provide an integrated door-to-door service, merging four principal elements: (1) a ground fleet of pickup/delivery trucks, (2) terminals for sorting and processing freight, (3) a long-haul truck fleet for moving freight between terminals, and (4) an aircraft fleet for moving freight between airports. UPS and Federal Express dominate the integrated air cargo market in the U.S., as indicated in Table 3-8.

Both carriers have extensive ground freight transportation networks, particularly UPS, and the revenue data shown in Table 3-8 covers both their air and ground operations. Federal Express has been steadily increasing the proportion of its cargo which is moved by truck.

Table 3-8: Integrated Air Freight Carriers



Revenues for American Integrated Carriers

United Parcel Service	$29,771 (2000)
Federal Express	$19,629 (2001)
DHL	$ 5,100 (1999)
Airborne	$ 3,276 (2000)
CNF (Emery Parent)	$ 5,572 (2000)
BAX Global	$ 2,097 (2000)

Source: Hoovers Online for all financial statistics in report.

Source: Hall (2002). (Revenues shown in millions)

In addition to serving passengers, most airlines also provide freight and mail services. International passenger airlines carry well over half of the world's air freight. To handle this freight, airlines typically form partnering arrangements with freight forwarders, trucking companies, postal services and couriers.

A key aspect of airport access/egress requirements for air cargo is the location of consolidation and sorting facilities relative to the airport. Currently there are two approaches to consolidation and sorting. One is to fill aircraft containers at the local pickup/delivery terminals and move these on tractor-trailers to the airport. The containers are typically pre-sorted, so that they can be moved directly to the aircraft. The alternative approach is to use smaller shuttle trucks, which are bulk loaded during the pick-up cycle and then proceed directly to the airport where their contents are sorted and loaded into containers for loading on to the aircraft.

In common with all freight transportation planning, there are two major problems that need to be addressed in planning intermodal air cargo operations: vehicle routing and facility/terminal locations. Vehicle routing has been extensively studied and algorithms developed to optimize the routing of pick-up and delivery vehicles (see for example Magnanti, 1984). Arnold (2004) studied the problem of optimal location of intermodal terminals involving transfer of freight between rail and road. For this special case, a combined quantitative and qualitative approach was adopted to develop a planning decision making tool, the ITLSS (Intermodal Terminals Location Simulation System), and planning decisions based on the use of the tool have been implemented. This approach could potentially be adapted for intermodal facility location planning for airport ground access by considering the airport as a node on the regional intermodal transportation network.

For air freight ground access planning, it is necessary to understand the characteristics of the system, including how it is operated.

(1) The characteristics of air freight (in contrast to air passenger) intermodal connectivity can be summarized as:

- Customer mode choice criteria: delivery time and affordable price
- The time-definite nature of intermodal service results in a major concern with ***traffic congestion***
- End-to-end delivery chains are increasingly operated by single integrated carriers that perform pickup and delivery, forwarding and transportation functions: allowing them to optimize the flow over their network.

(2) Characteristics of the door-to-door service chain are:

- National and regional sorting sites that allow the integrated carriers to route shipments between their local dispatching centers throughout their service network
- Local dispatching centers for shipment consolidation and breakdown for transportation to and from the nearest airport or sorting site
- Hub-and-spoke network configuration: related to the locations of sorting sites and dispatch centers
- Centralized control of dispatching through real-time tracking of the location of each truck or van, allowing monitoring of system performance and traffic conditions
- An aircraft fleet for moving freight between airports with extensive use of night-time flights
- A long-haul truck fleet for moving freight between terminals
- Terminals for sorting and processing freight
- A ground fleet of local pickup/delivery trucks.

(3) The evolution of time-definite intermodal services progressed through the following stages:

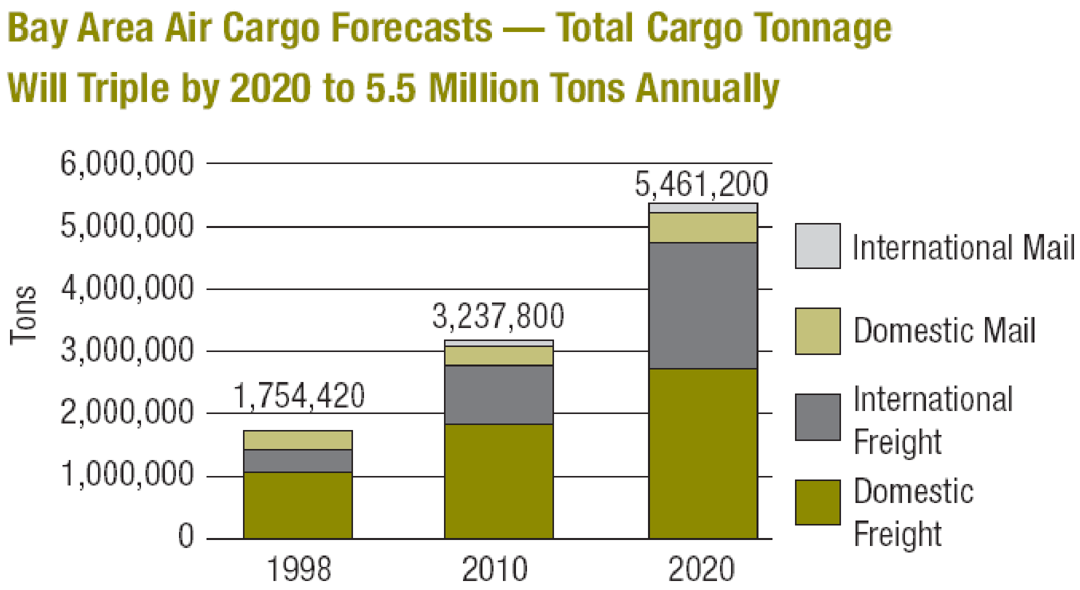
- Conventional independent modal services including end-to-end forwarding (connecting multiple services to achieve end-to-end transportation)
- Integrated (or single-control) forwarding (coordinating multiple services to achieve time-definite deliveries at an economical cost)
- Single company (or single alliance) integrated forwarding, allowing optimized network flows.

(4) There are dynamic interactions between the integrated air cargo industry and customer needs. The economics of the overall system is affected by many factors:

- Characteristics of the demand and supply chain
- Origins and destinations of the packages determined by customer and producer locations
- Time definite delivery commitments
- Traffic conditions on the highway network
- Relationship between demand and capacity of the integrated and non-integrated air freight services
- Routing and scheduling as one of the main strategies in competition
- Independent or cooperative operations.

3.5.2 Air Freight Development in California

As indicated in the recent summary report of the Regional Goods Movement Study for the San Francisco Bay Area undertaken by the Metropolitan Transportation Commission (MTC, 2004), air cargo activity is forecast to increase dramatically in the next 10 to 20 years with the growth of the U.S. and global economy, as shown in Figure 3-13. The current traffic situation is already severe in some corridors that are particularly affected by trucks involved in air cargo movement. With the projected increase in the Bay Area air cargo traffic, truck activity related to air cargo will have an increasing impact on the traffic network and contribute to increased levels of traffic congestion and air pollution.



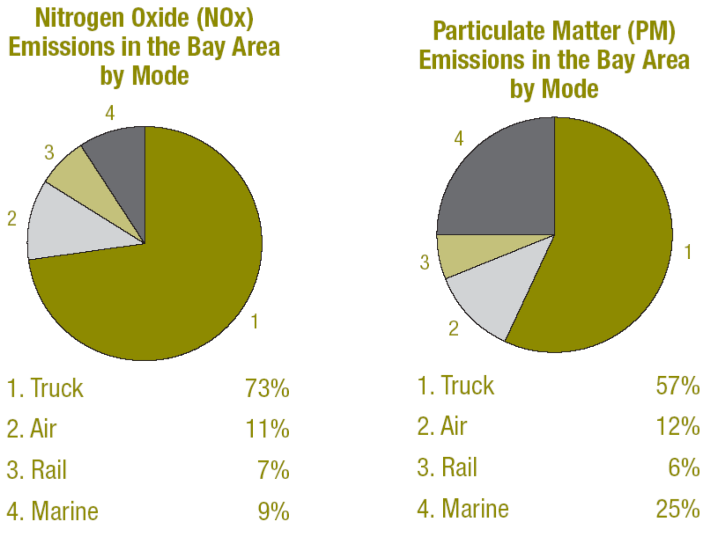
Source: Bay Area Seaport Plan 2003, reported in MTC Regional Goods Movement Study, Final Summary Report, 2004

Figure 3-13: Bay Area Air Cargo Forecast

Traffic Congestion: Traffic congestion presents two difficulties for time-definite intermodal service:

- Overall time limit to meet delivery commitments – if trucks spend longer getting to their local delivery areas, it may be necessary to dispatch additional vehicles in order to reduce the number of deliveries that each truck has to make;
- Limited time window at each step of the whole delivery chain – missing one time window may cause shipments to miss the following time windows in the chain, leading to what may be viewed as a "domino effect."

Air Pollution: Goods movement has a significant impact on air quality. Truck emissions contribute to ground level ozone, the main ingredient of smog, through the complex chemical reactions between volatile organic compounds (VOC) and nitrogen oxides (NO_x) in the presence of heat and sunlight. Particulate matter (PM), a significant emission from diesel engines, is easily inhaled and remains in the lungs where it can be carcinogenic. Goods movement generates emissions both during on-road activity (truck driving) and off-road activity (truck idling and cargo loading and unloading), as well as from aircraft, rail and marine operations, as shown in Figure 3-14.



Source: Bay Area Air Quality Management District, reported in MTC Regional Goods Movement Study, Final Summary Report, 2004

Figure 3-14: Air Pollution Caused by Goods Movement Activities

In order to facilitate the continued expansion of air cargo activity, it may become necessary to develop alternative pickup and distribution modes that generate less air pollution and have less impact on street and highway traffic congestion to replace or at least partly replace trucks in the door-to-door service delivery chain.

3.5.3 Opportunities for Improved Intermodal Connections for Handling Air Cargo

Alternative strategies that have been proposed to improve intermodal connectivity to handle air cargo include dedicated truck lanes, accommodating freight on maglev or high-speed rail systems providing access to airports, and conventional rail transportation. Some of these potential strategies would present significant operational problems that would have to overcome, quite apart from the cost of the necessary infrastructure. However, it may be useful to perform a preliminary evaluation of selected concepts in order to better understand the issues involved.

Possible ways to improve intermodal air freight transportation include the following:

- Expanding the capacity of existing facilities or introducing new services or modes
    - ➢ Freeway capacity expansion
    - ➢ Dedicated truck lanes
    - ➢ Introducing other modes in the delivery chain: e.g. rail, hovercraft, or ferries;
- Deployment of new technology or other operational improvements to make more efficient use of existing facilities
    - ➢ Real-time network traffic information for dispatching and routing
    - ➢ Advanced traveler information systems for traffic prediction
    - ➢ Use of high occupancy vehicle lanes for freight delivery
    - ➢ Truck flow management systems near airports or sorting sites.

3.5.4. Possible Intermodal Air Freight Delivery System in the Bay Area

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 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 would also reduce 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. Two different approaches have been suggested. The first would use dedicated trains to move freight between dedicated facilities located at off-line yards, either existing maintenance and storage yards or new yards constructed specifically to handle freight. This would of course require running additional trains, which would have to be interleaved with regular passenger trains and might encounter track capacity problems at critical points in the system. The second approach would involve adding dedicated freight cars to regular passenger trains. This would require modifying stations to accommodate freight containers and would limit the volume of freight that could be carried on a single train without unduly increasing station dwell times. As a practical matter, only one or two containers could be loaded or unloaded at each door of a freight car per stop and the process of loading and unloading the containers could be very labor intensive. During peak travel periods, when the advantage of such a system would be greatest, many trains already operate at their maximum length and so adding cars to the trains would not be feasible without lengthening the station platforms or reducing the passenger carrying capacity of the trains.

Although these problems may not be technically insuperable, they could be very costly to overcome. Without further analysis, it is unclear whether the travel time savings for the air freight carriers (if any) would be sufficient to justify the rates that BART would need to charge to cover its costs of providing the service. This analysis would need to address the following issues:

(1) Design and size of cargo containers to be used on the BART cars;

(2) Feasibility of loading and unloading containers at BART stations or yards:

    (a) Design of the necessary facilities

    (b) Impact of loading and unloading times on BART schedules

    (c) Staffing levels and responsibilities for loading and unloading the containers;

(3) Potential freight capacity of the system;

(4) Total time required to move containers to BART, load, transport, and unload containers on BART, and move containers to their destination, in comparison with the time required to transport the freight directly by highway;

(5) Rate structure required to cover BART capital and operating costs;

(6) Impact of dedicated freight trains on passenger train schedules;

(7) Safety, liability and insurance considerations.

3.6 Institutional Issues

The first working paper produced by the Landrum & Brown (2001) study, *Working Paper One: Roles and Responsibilities*, examined the institutional setting within which airport ground access planning is conducted and the respective roles and responsibilities of the airport operator and tenants, transportation providers, and local, state and federal government. The working paper reviewed existing funding sources that are available to support airport ground access projects, and the planning and programming process used to prioritize and allocate those funds. The working paper also presented a number of case studies of funding strategies that have been used to finance airport ground access projects in California and other states.

The working paper includes several appendices that provide a detailed description of the institutional setting for each of the 47 airports included in the study (a 48th airport was included in the study after the working paper was prepared), as well as a summary of various local, state and federal programs that provide funds that could potentially be used to support airport ground access projects and the type of project that might be eligible for those programs.

The study included interviews with state, regional, and local agency officials and staff to identify their perceptions regarding their agency's approach to addressing airport ground access issues. In general these discussions suggested that there was a lack of a clear strategic approach to funding and implementing airport ground access projects. Many of those interviewed did not feel that there was a specific state, regional or local process for addressing airport ground access needs, and suggested that both the state and federal government should play a larger role in addressing policy and funding issues. In particular, there was widespread support for greater flexibility in the use of federal airport development funds for airport ground access projects outside the airport boundary. Concern was expressed by many of those interviewed that airport ground access funding needs are relatively minor compared to overall statewide surface transportation infrastructure needs, and that without a specific statewide airport ground access funding and implementation policy and associated funding sources, development of airport ground access projects will not keep pace with growth in aviation passenger and cargo activity.

Chapter 4. Design and Development of the Intermodal Airport Ground Access Planning Tool

The chapter presents the design and development of the Intermodal Airport Ground Access Planning Tool (IAPT), including main components, interactions between them, their functionalities, corresponding supporting data requirements and the Graphical User Interface (GUI). The objectives for design and development is to provide a systematic and standard way for planners to conveniently and quantitatively evaluate multiple alternatives of a project for comparison in decision-making.

4.1 Overview of the IAPT

There are several elements that must be taken into account in intermodal transportation planning at a certain level: decision makers, 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 are 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, and link the requirements/changes of the planner through interaction with those elements using GUI.

Considering convenience for use by intermodal airport ground access planners, the following design principle has been used for design and development of the necessary components and their interactions:

- Generality: Although the system is primarily developed for three Bay Area airports due to availability of data and model, the frame designed and developed allow one to add any other airports in any regions as long as the corresponding data are available;
- User friendly GUI: It is used to (a) to input information required define a different alternatives of a project; (b) to make any changes of system or modeling parameters such as transportation provider service data (growth factor, fare and operation frequencies); and to hide complicated analysis procedures with GUI wherever possible.

- Flexible data entry: For most data related to the tool, there are two ways for input – either from file or from the screen using GUI. Data entered from the screen can be saved to file for future use.
- Flexible for viewing output: The planner may need to view intermediate parameters, such as the probability the passenger choose a particular mode, as well as performance parameters as discussed in Chapter 7. The latter may be viewed from a mode level or from a project level.
- Flexible to run several projects in parallel for comparison: For convenience of comparing different potential alternatives of a project, the system has been developed such that one can define/select several alternatives, related or independent, and view their performance parameters for easy comparison for decision making.
- Scalability: Since the IAPT is for air passenger ground access planning project evaluation for a given airport, future development will be necessary to incorporate airport employee into the system. It I also necessary to integrate air cargo ground access planning into it.
- Towards an integrated planning tool: Although it has been developed for passenger airport ground access only, it can also be expended to an integrated airport ground access planning tool involving both people access and air freight ground access.

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 and development of the IAPT.

4.2 Functionality of Main Components

The initial implementation of the IAPT has been 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 operation frequency and/or the fare charged, the IAPT is designed to 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 characteristics (fares, frequencies, travel times, *etc.*).

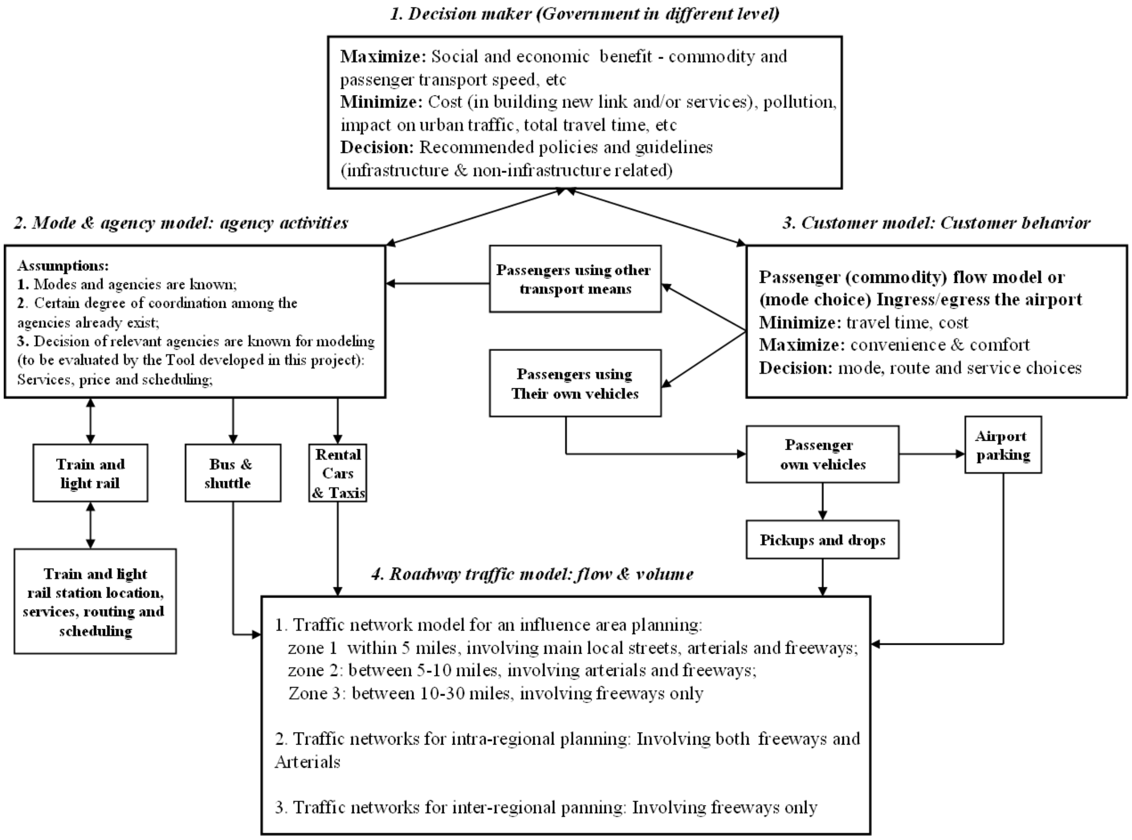


Figure 4-1: Conceptual Modeling of the Intermodal Airport Ground Access System

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 allows 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 system performance measures, such as fare revenue or vehicle trips, and display, print or save this information in a format that can be used for analysis or by other programs.

4.2.1 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. However, as long as the file is in a proper format, it can be directly selected from the GUI in practical run.

As discussed in Chapter 1, the appropriate values of the 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.

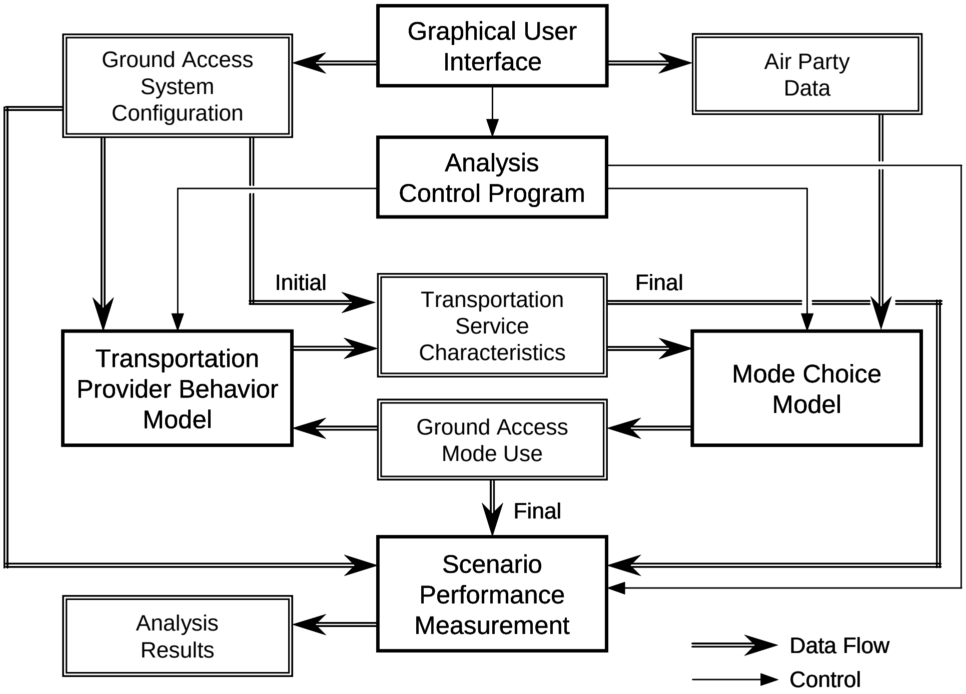


Figure 4-2: Functional Structure of the Analysis

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 implementation of the IAPT did not attempt to interface directly with a highway network analysis model. Instead, travel time for a given transportation analysis zone (TAZ) to/from the specified airport is picked up from a table which is considered as a regional traffic data. Obviously, all the airports within the region use the TAZ division and the same travel time table. However, it is possible to link to network traffic information to obtain updated historical data in future development.

4.2.2 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 interacts with the IAPT database. The ***graphical user interface*** allows the user to enter all the necessary data, to define a set of analysis scenarios, to specify the measures of performance, to initiate the analysis, to select the way for the performance parameter the display, to run the analysis procedure and to 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 finally, 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.

4.3 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 C++ 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.

4.3.1 Overall Software Structure

IAPT is developed with managed C++ running on the Microsoft Visual Studio.NET platform. The system underneath is divided into modules, each responsible for a major function. The modules diagram is depicted as the following (Figure 4-3):

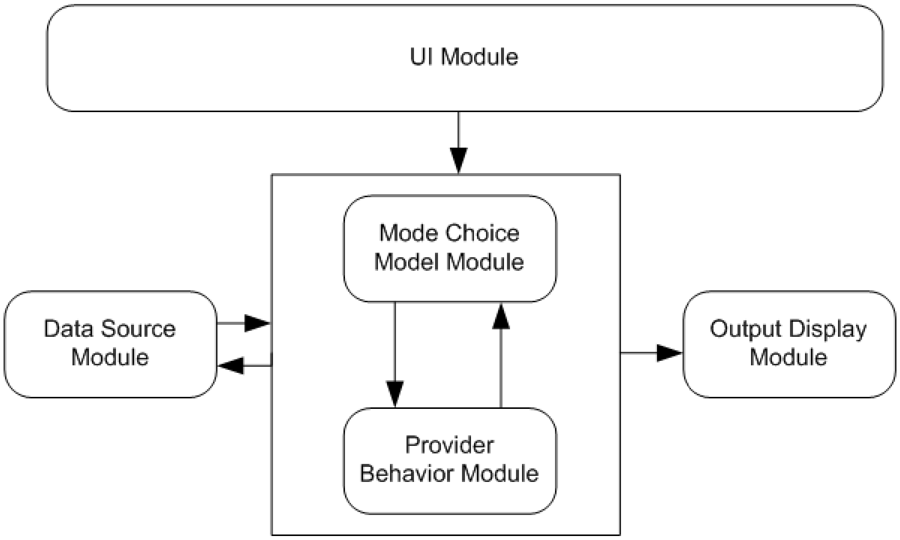


Figure 4-3: Overall Picture of Software Structure

The main modules are briefly described as follows:

(1) The user interface module:

The module is responsible for all the interaction with the users. It is displayed as windows with cascaded tabs and sub-tabs. The function of each tab is self-evident by name.

(2) The data source module:

The module is responsible for reading data files into the system and updating data files. Those options can be conveniently controlled by the user.

(3) The mode choice model module:

The mode choice model is the core of IAPT, which responsible for analyzing the passenger distribution for each mode. Essentially, it calculates the probability for passengers to choose a specific mode.

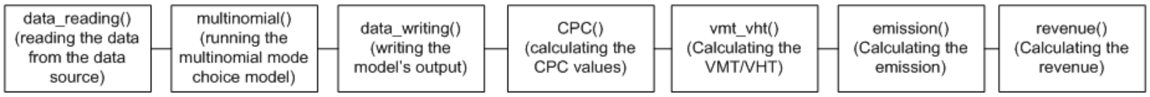


Figure 4-4: Flow-Chart of the Mode Choice Model Module Data Flow

(4) The provider behavior module:

This module implements the behavior of transportation providers modeled in Chapter 6. It models the collective competition behavior between modes to respond to the market changes, which are usually reflected as service changes, including fare and frequency increases or decreases and adding or dropping service points.

(5) The output display module:

The module is responsible for displaying different outputs for evaluation, which are quantitative measure of performance. It also allows future software developers to add or modify measures easily.

4.3.2 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 such as traffic and transit 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 the following categories:

- Regional data describing the surface transportation system and other common characteristics of the region within which a specific airport is located; the main information includes zonal division of the region, travel time/distance from each zone to/from airport;

- Airport data are the airport survey data and forecast traffic levels, which have been cleaned and formatted; they are related to a specific airport and common to all projects; they are also used for the calibration of the passenger mode choice model;
- Project data, including available ground access modes and associated service characteristics; this data table is linked to the corresponding ones used by related alternatives of a project with respect to the baseline project; such a table can be created manually or modified from the baseline project data table from GUI;
- Parameter values and structural information for the component models of the IAPT; those parameters include the coefficients of the utility function in the mode choice model, years of analysis, growth factor, service related parameters (fare and wait time changes by a net amount or percentage);
- Results of model analysis runs.

In order to illustrate the planned database structure, some of the key data table specifications are shown in Appendix D. To assist in managing a potentially large number of data tables required, region-specific and airport-specific data tables have been grouped in separate databases.

Data flow between the modules is handled through reading and writing data from and to the supporting data tables in the IAPT database. These have been implemented as standard relational data tables in text format or in an Open Database Connectivity (ODBC)-compatible database. Microsoft Access has been used for the initial implementation of the ODBC-compatible database. Implemented 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 in the tables to be utilized by other applications or for the IAPT to be integrated with other analysis software.

4.4 Graphical User Interface and Functionality

4.4.1 Hierarchical Structure of the Graphical Use 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 already been 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 (tabs) 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. Figure 4-5 shows the hierarchical structure of those tabs and sub-tabs.

The initial screen on starting the IAPT is shown in Figure 4-6. This shows the 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. All the Level 1 components are represented by six tabs.

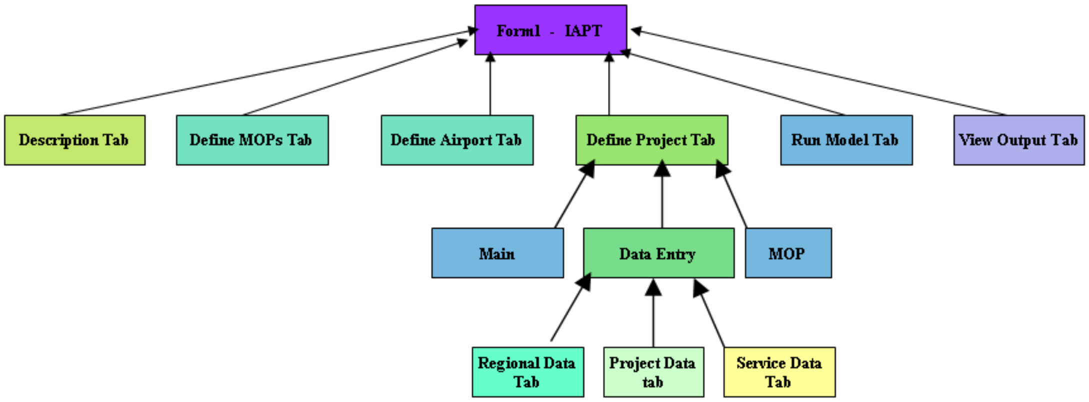


Figure 4-5: Hierarchical Structure of GUI: Each Tab Represents a Major Functional Component

The following initial screen (Figure 4-6) contains the six Level 1 tabs and a brief description of the IAPT.

Intermodal Airport Ground Access Planning Tool

The Intermodal Airport Ground Access Planning Tool (IAPT) provides a user-friendly analysis environment to support the definition and evaluation of a range of alternative potential projects to improve airport ground access. The IAPT contains an analysis model that projects the use of available ground access/egress modes defined for each project and that takes into account the response of transportation service providers to the changing use of the available modes.

IAPT Initialized

Figure 4-6: 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 following discussion will not attempt to describe every screen, but will illustrate the general approach using representative screens.

4.4.2 Measure of Performance Definition and Selection

Measures of system performance are keys 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. Although the information for IAPT calculation is limited, it provides a fairly comprehensive set of potential analysis results to users. The initial implementation of the IAPT provides the following available output measures for a mode or set of modes as shown in the left sub-window of Figure 4-7:

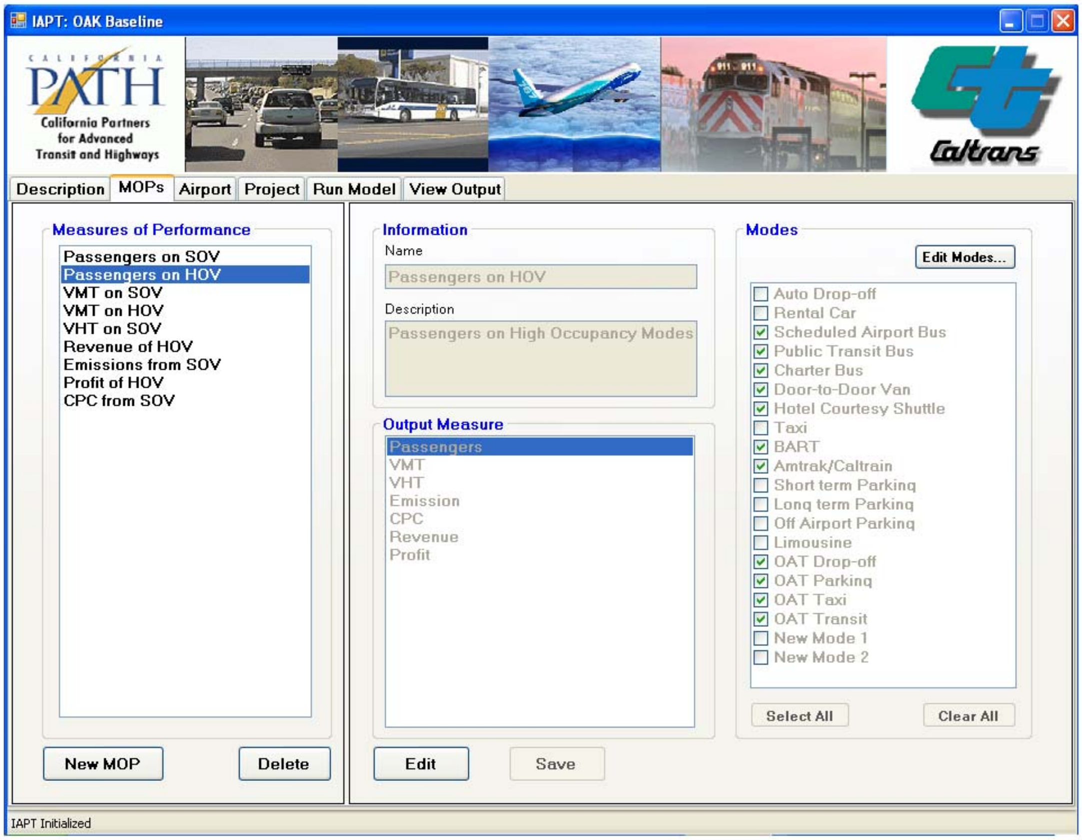
- Passengers on single occupancy vehicle (SOV) per year
- Passengers on high occupancy vehicle (HOV) per year
- VMT on SOV
- VMT on HOV
- VHT on SOV
- Revenue on HOV ($ per year)
- Emissions from SOV (per year)
- Passenger travel time (person-hours per year)
- Profit of HOV ($ per year)
- Connectivity Performance on SOV

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 4-7. This allows the user to define MOPs that apply to a single mode, to several modes, or (as in this case) to all modes (on the right sub-window of Figure 4-7).

Users can define their own Measure of Performance in this tab, edit any existing one, and link the relevant modes to it.



Measures of Performance

- Passengers on SOV
- Passengers on HOV
- VMT on SOV
- VMT on HOV
- VHT on SOV
- Revenue of HOV
- Emissions from SOV
- Profit of HOV
- CPC from SOV

Information

Name: Passengers on HOV

Description: Passengers on High Occupancy Modes

Output Measure

- Passengers
- VMT
- VHT
- Emission
- CPC
- Revenue
- Profit

Modes

☐ Auto Drop-off
☐ Rental Car
☑ Scheduled Airport Bus
☑ Public Transit Bus
☑ Charter Bus
☑ Door-to-Door Van
☑ Hotel Courtesy Shuttle
☐ Taxi
☑ BART
☑ Amtrak/Caltrain
☐ Short term Parking
☐ Long term Parking
☐ Off Airport Parking
☐ Limousine
☑ OAT Drop-off
☑ OAT Parking
☑ OAT Taxi
☑ OAT Transit
☐ New Mode 1
☐ New Mode 2

IAPT Initialized

Figure 4-7: MOP Definition, Editing and Selection Screen

(1) Adding a new MOP:

Clicking the "New MOP" button will create a new MOP named "New MOP" under the list of Measure of Performance. The newly-created MOP comes with default values and is not ready to use yet. The user should modify the details of the MOP by following the procedure of "Editing an existing MOP".

(2) Editing an existing MOP:

Users should select the MOP they wish to edit and then click the "Edit" button. Users can then change the MOP's name, description, the output measure that it associated to, and the modes that the MOP would apply to. After users are satisfied with their choices, they need to click the "Save" button to save the changes. The saved MOPs can be used later.

(3) Deleting an existing MOP:

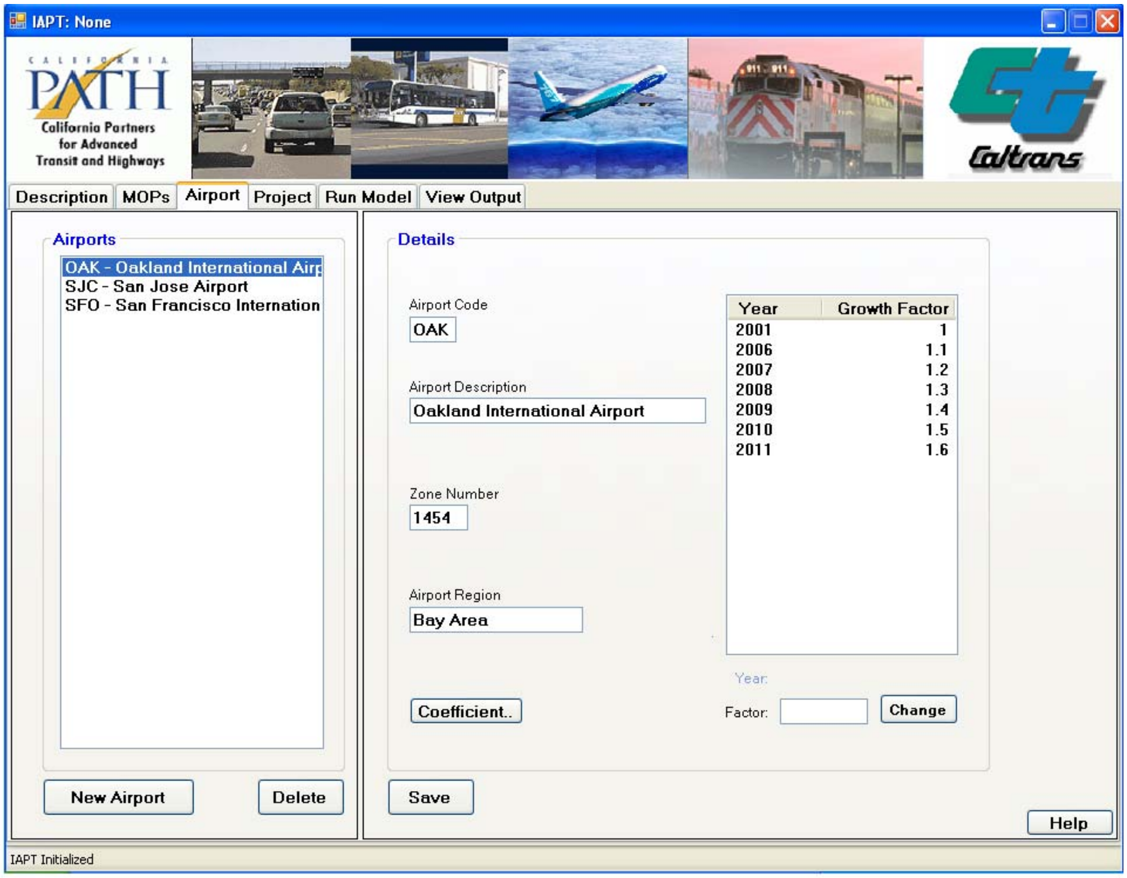
If users wish to delete an MOP should select the MOP first, and then click the "Delete" button. The MOP will be removed from the system.

(4) Editing the modes' names:

Users can also change the names of the modes by clicking the "Edit Modes" button. A table will show up with all the modes' names on it. To change a mode's name, users can select the mode's current name, and then type the new name. When users are satisfied with the modes' names, they need to click "Save" to save the new names. To abort the changes, users can click the "Cancel" button.

4.4.3 Airport

The pane contains all the information related to an airport implemented in the system for analysis: Airport code, airport related region, zone number related to the region, and air passenger growth factor by year (Figure 4-8). Implicitly, once an airport is selected, corresponding airport data, regional traffic and transit data are linked underneath. Users can add or modify the coefficients of a multinomial mode choice models related to the airports, that are available to the system. This makes it flexible in mode choice model calibration and update.



Airports:
OAK - Oakland International Airp
SJC - San Jose Airport
SFO - San Francisco Internation

Airport Code: OAK

Airport Description: Oakland International Airport

Zone Number: 1454

Airport Region: Bay Area

Factor:

Year	Growth Factor
2001	1
2006	1.1
2007	1.2
2008	1.3
2009	1.4
2010	1.5
2011	1.6

Figure 4-8: Airport Definition and Relevant Parameter Input Screen

(1) Adding a new airport:

Clicking the "New Airport" button will create a new Airport named "NEW – New Airport" under the list of airports. The newly-created airport comes with default values and is not ready to use yet; user should modify the details of the MOP by following the procedure laid out in "Editing an existing airport".

(2) Editing an existing airport:

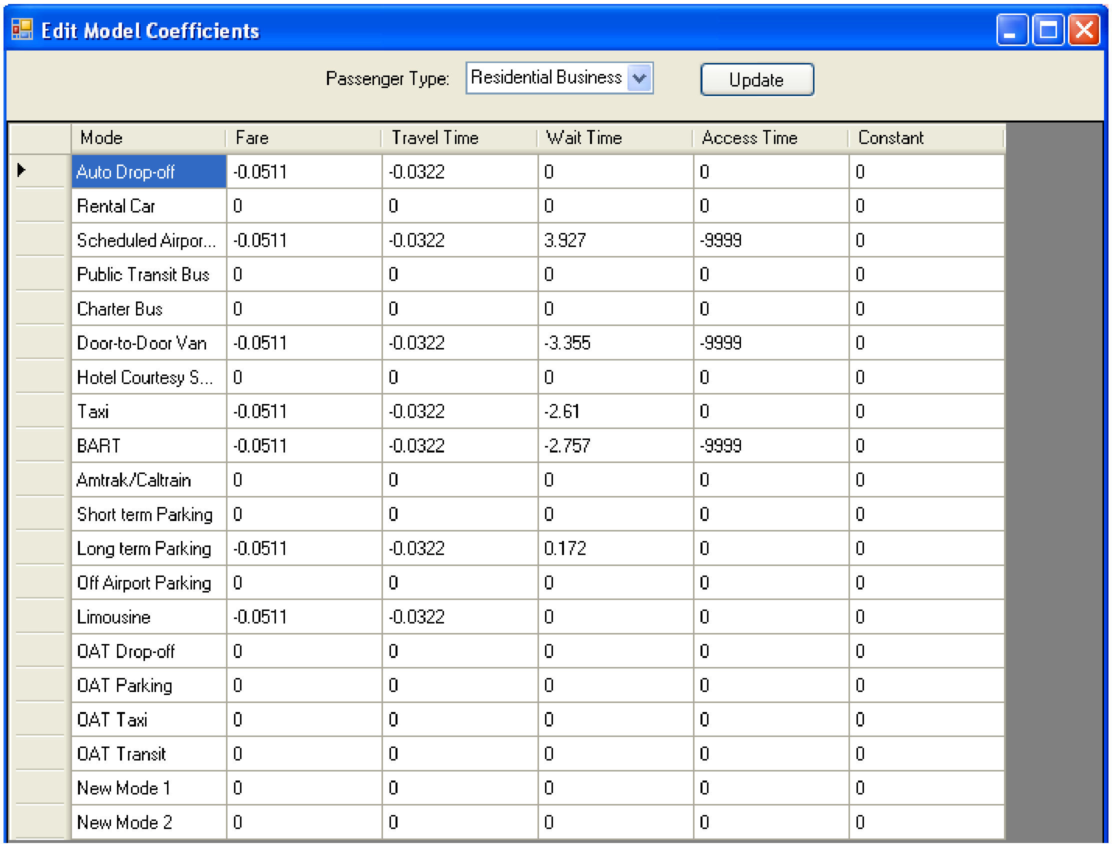
Users should select the airport they wish to edit and the details of the airport will show up on the "Details" section. Users can then change the airport's code, description, zone number, region, and the (projected) growth factors of the airport. To change the growth factor of a year, users should click on the year, and the default growth factor will appear; after setting it to an appropriate value, users need to click "Change" to confirm the change made. After users are satisfied with the airport's detail, they need to click the "Save" button to save the changes.

(3) Deleting an existing airport:

Users wish to delete an airport should select the airport first, and then click the "Delete" button. The airport will be removed from the system.

(4) Changing the coefficients of the mode choice model:

Since the mode choice model is related to airport selected. It is thus reasonable to imbed the mode choice mode coefficient modification sub-module in the airport related information screen. When an airport is selected, users can click the "Coefficient…" button and a new window will be shown as in Figure 4-9:



Passenger Type: Residential Business

Mode	Fare	Travel Time	Wait Time	Access Time	Constant
Auto Drop-off	-0.0511	-0.0322	0	0	0
Rental Car	0	0	0	0	0
Scheduled Airpor...	-0.0511	-0.0322	3.927	-9999	0
Public Transit Bus	0	0	0	0	0
Charter Bus	0	0	0	0	0
Door-to-Door Van	-0.0511	-0.0322	-3.355	-9999	0
Hotel Courtesy S...	0	0	0	0	0
Taxi	-0.0511	-0.0322	-2.61	0	0
BART	-0.0511	-0.0322	-2.757	-9999	0
Amtrak/Caltrain	0	0	0	0	0
Short term Parking	0	0	0	0	0
Long term Parking	-0.0511	-0.0322	0.172	0	0
Off Airport Parking	0	0	0	0	0
Limousine	-0.0511	-0.0322	0	0	0
OAT Drop-off	0	0	0	0	0
OAT Parking	0	0	0	0	0
OAT Taxi	0	0	0	0	0
OAT Transit	0	0	0	0	0
New Mode 1	0	0	0	0	0
New Mode 2	0	0	0	0	0

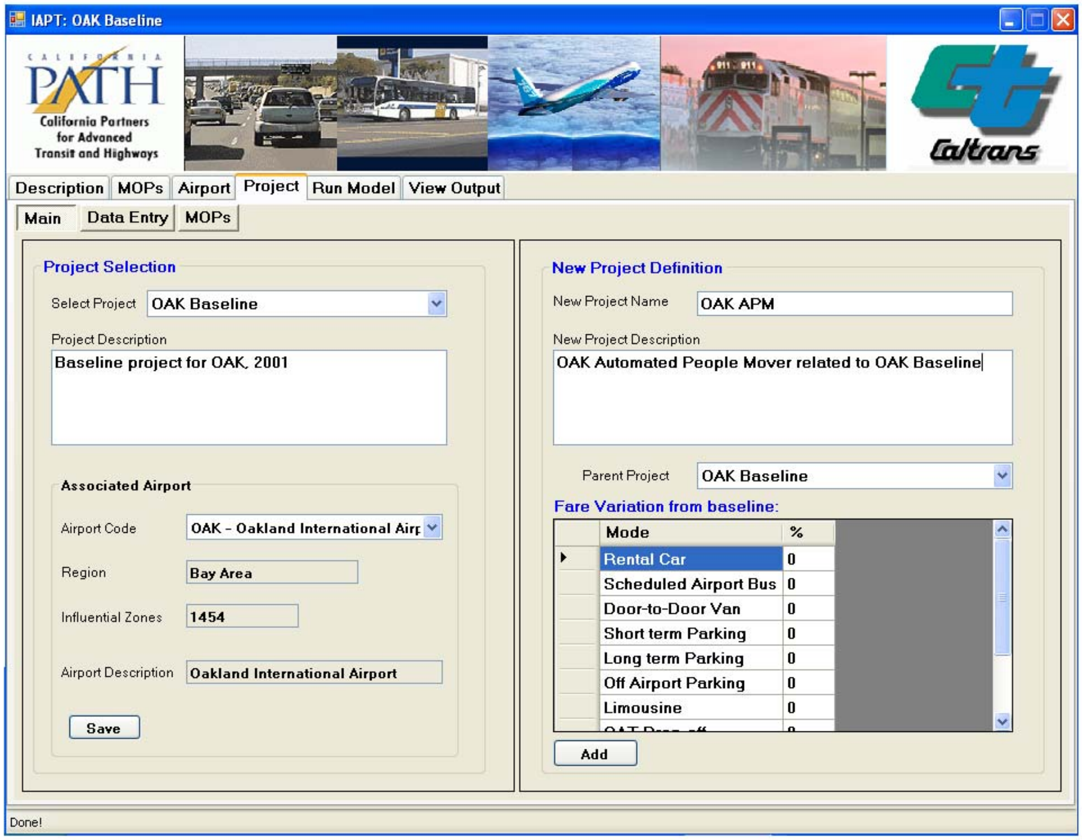
Figure 4-9: Mode Choice Model Coefficient Input Screen

To change the mode-choice model coefficients, users should first select the passenger type. There are four passenger types: Residential business (personnel), Visitor business (personnel), which corresponds to the passenger classification in mode choice model coefficient calibration. Then the user can edit the appropriate coefficients and click "Update" to save the changes before continuing to another passenger type or leaving the window.

4.4.4 Project Definition

The IAPT has been 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 before the data for these projects are entered.

The 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 its parent project in order to reduce data entry requirements and to simplify analysis of project variants. 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 with 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 4-10.



Project Selection

Select Project: OAK Baseline

Project Description: Baseline project for OAK. 2001

Associated Airport

Airport Code: OAK - Oakland International Airp

Region: Bay Area

Influential Zones: 1454

Airport Description: Oakland International Airport

New Project Definition

New Project Name: OAK APM

New Project Description: OAK Automated People Mover related to OAK Baseline

Parent Project: OAK Baseline

Fare Variation from baseline:

Mode	%
Rental Car	0
Scheduled Airport Bus	0
Door-to-Door Van	0
Short term Parking	0
Long term Parking	0
Off Airport Parking	0
Limousine	0

Figure 4-10: Typical Project Definition Screen

<u>*Adding a new project:*</u>

In the "Main" screen, users can enter the details of the new project in the "New Project Definition" section. Specifically, users can enter the follow basic details about the project:

New Project Name: the name of the new project

New Project Description: a brief description of the new project

Parent Project: a project from which the new project will inherit all its attributes and data.

Fare Variation from Baseline: User can change the fares of the modes in the new project by a certain percentage with respect to those in the parent project.

After the inputs of basics of the new project, users must click "Add" to add the project to the system. After adding the new project to the system, users can vary the project's parameters and service data. The procedure is detailed in the following section, "Editing the details of the project".

Editing the details of a project:

To edit the details of any project, users must first select the project in the “Project Selection” section in the “Main” screen. To edit is to modify all the information of the project including its name, attributes and parameters.

Changing the basics of the project:

With the project selected, users can modify the project’s description and its associated airport in the “Project Selection” section in the “Main” screen. Click “Save” to save the changes.

4.4.5 Data Entry

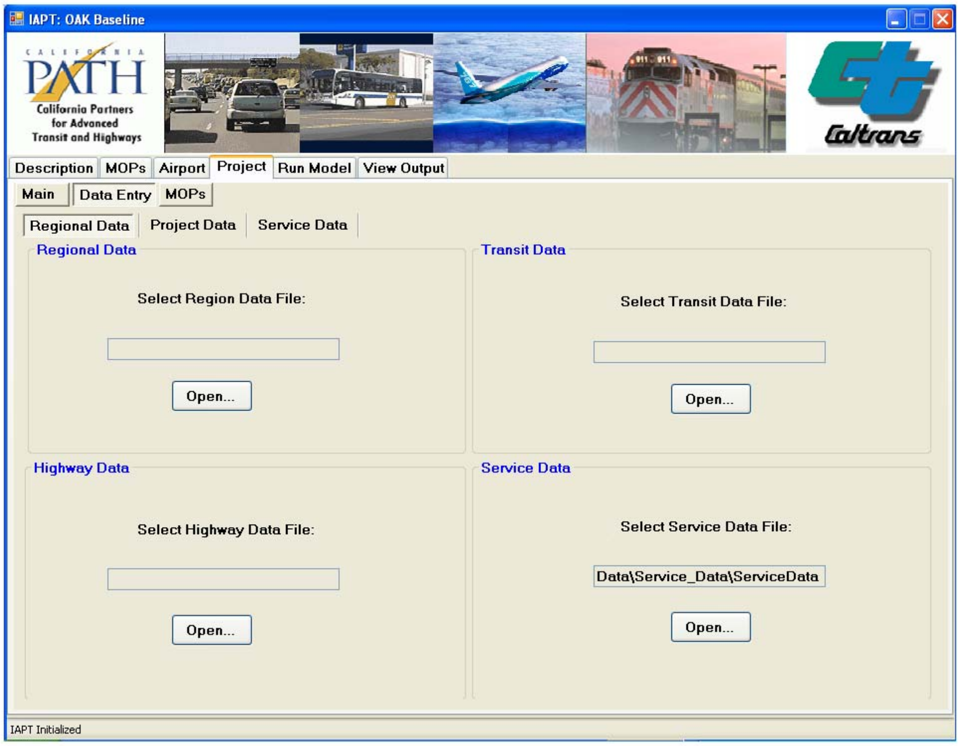
With the project selected, users can switch to the ***Data Entry*** screen, which include three second level sub-tabs: Regional Data, Project Data and Service Data. The ***Data Entry*** sub-tabs provide the user with access to a sequence of screens for data enter. The GUI uses a consistent approach to data entry for the wide range of data that are needed to support the analysis. 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 ***Service Data*** sub-tab allows the user to access service parameters related to a mode including service parameters such as fare, capital cost and operational cost, and to modify for different alternatives and scenario runs and to update them.

(1) Regional Data

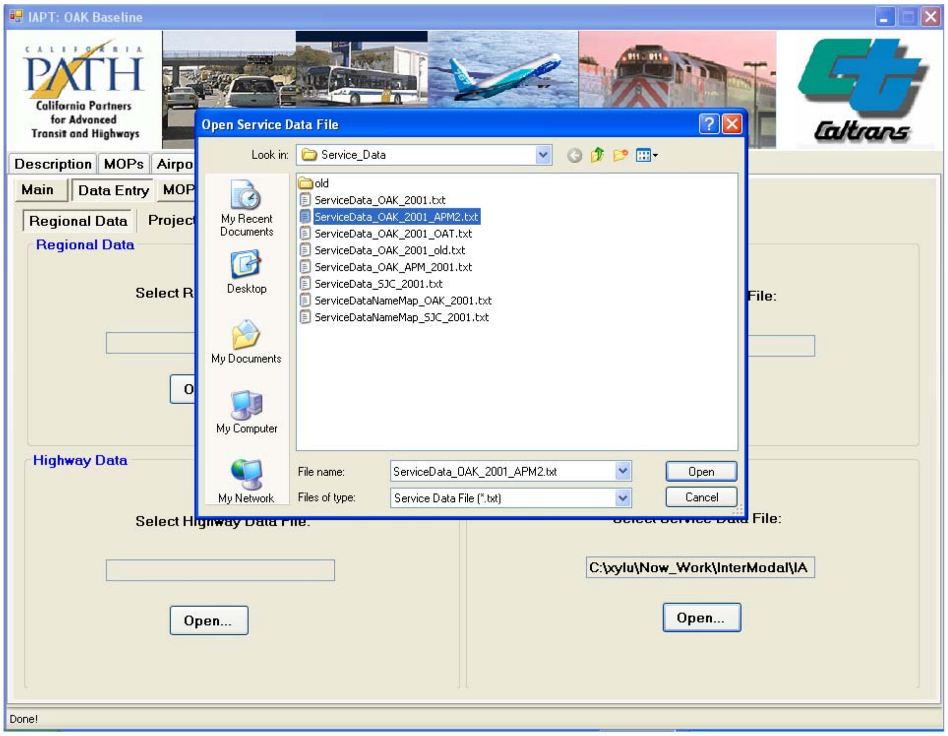
Clicking the Regional Data sub-tab will show four types of data entries: Region Data, Transit Data, Highway Traffic Data and Service Data. They will allow users to select a data file for the project store in a directory. Usually, this is only necessary to be conducted once for a new baseline project since the data have system wide scope. After being selected and saved once for the new baseline project, all those data are linked to it, and are to be inherited by its child projects. This is also true for relevant Highway Data and Transit Data.

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. The Service Data File button (different from and in lower level than the Service Data sub-tab) allows the user to enter service data related to a specific project.



Select Service Data File: Data\Service_Data\ServiceData

Figure 4-11: Data Entry Screen – Regional Data



File name: ServiceData_OAK_2001_APM2.txt

Files of type: Service Data File (*.txt)

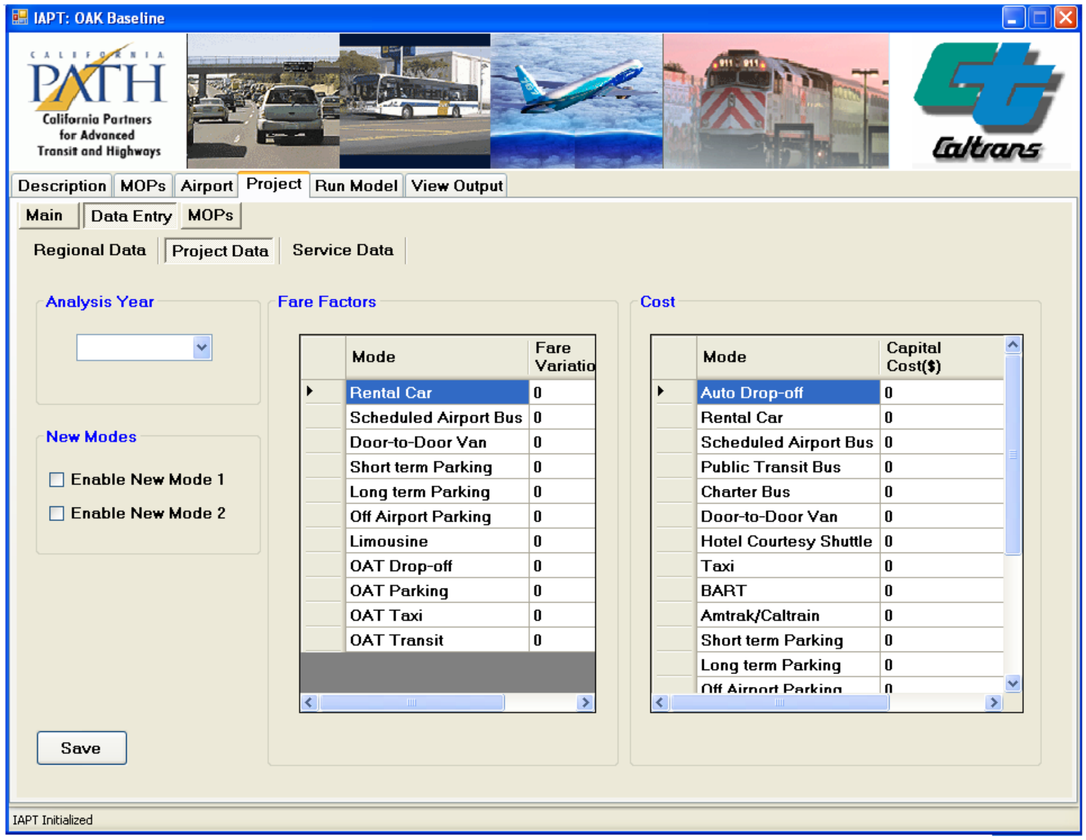
C:\xylu\Now_Work\InterModal\IA

Figure 4-12: Data Entry – Clicking Any "Open" Button Allows User to Input the File from the Windows File Server

(2) Project Data:

Selecting the ***Project Data*** sub-tab allows the user to define the available ground access modes for a selected project and enter or edit the modal service and cost data.

In this sub-screen, users can select the analysis year for the project, and vary the fare level, as a percentage from the parent project, and cost information for each mode. Users can also enable either or both of the new modes. If a new mode is enabled, the analysis will take it into account; otherwise, the new mode's data is ignored.



☐ Enable New Mode 1
☐ Enable New Mode 2

Mode	Fare Variatio
Rental Car	0
Scheduled Airport Bus	0
Door-to-Door Van	0
Short term Parking	0
Long term Parking	0
Off Airport Parking	0
Limousine	0
OAT Drop-off	0
OAT Parking	0
OAT Taxi	0
OAT Transit	0

Mode	Capital Cost($)
Auto Drop-off	0
Rental Car	0
Scheduled Airport Bus	0
Public Transit Bus	0
Charter Bus	0
Door-to-Door Van	0
Hotel Courtesy Shuttle	0
Taxi	0
BART	0
Amtrak/Caltrain	0
Short term Parking	0
Long term Parking	0
Off Airport Parking	0

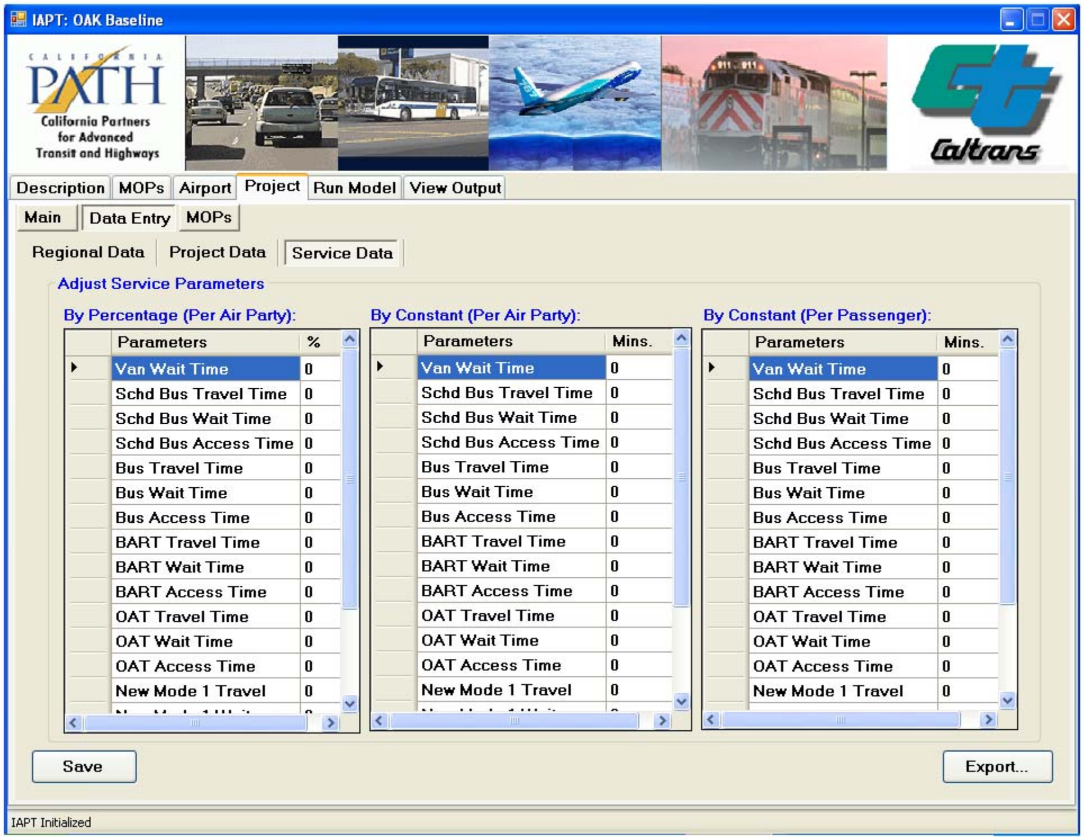
Figure 4-13: Data Entry Screen – Modal Fare and Cost Data

(3) Service Data:

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. This way defining the utility functions 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. Select Service Data button allows the user to change the fares in more detail:

- Change in percent by air party
- Change in constant amount per air party
- Change in constant amount per air passenger

Such flexibility allows the user to evaluate the effect of very detailed fare changes by transportation providers on the mode choice (Figure 4-14). Note that the percentage adjustments will be applied to the service data first, followed by the constants.



Adjust Service Parameters

By Percentage (Per Air Party):

Parameters	%
Van Wait Time	0
Schd Bus Travel Time	0
Schd Bus Wait Time	0
Schd Bus Access Time	0
Bus Travel Time	0
Bus Wait Time	0
Bus Access Time	0
BART Travel Time	0
BART Wait Time	0
BART Access Time	0
OAT Travel Time	0
OAT Wait Time	0
OAT Access Time	0
New Mode 1 Travel	0

By Constant (Per Air Party):

Parameters	Mins.
Van Wait Time	0
Schd Bus Travel Time	0
Schd Bus Wait Time	0
Schd Bus Access Time	0
Bus Travel Time	0
Bus Wait Time	0
Bus Access Time	0
BART Travel Time	0
BART Wait Time	0
BART Access Time	0
OAT Travel Time	0
OAT Wait Time	0
OAT Access Time	0
New Mode 1 Travel	0

By Constant (Per Passenger):

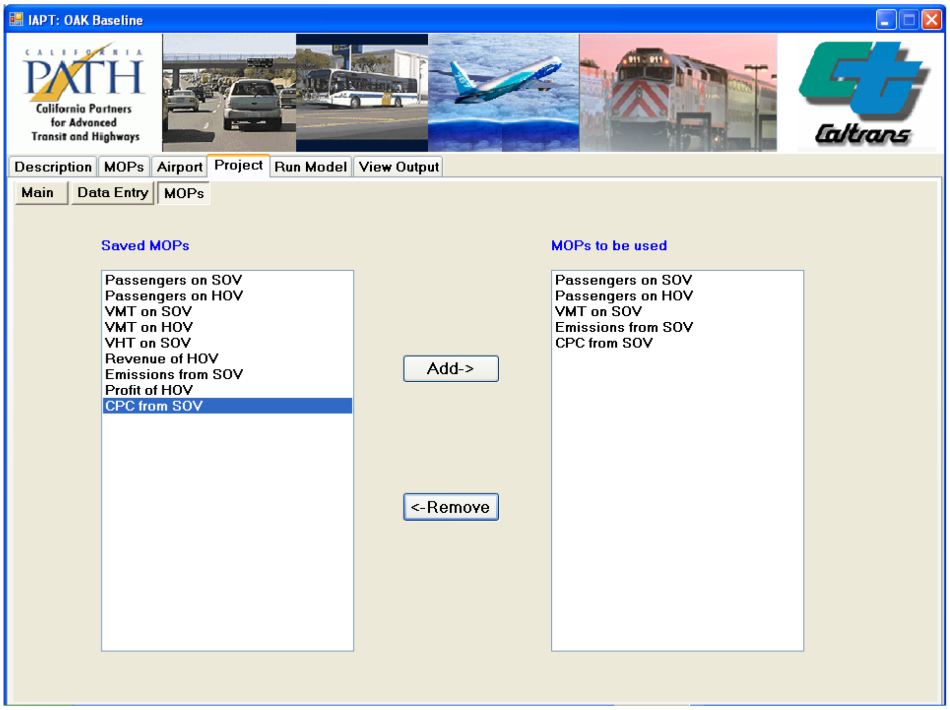
Parameters	Mins.
Van Wait Time	0
Schd Bus Travel Time	0
Schd Bus Wait Time	0
Schd Bus Access Time	0
Bus Travel Time	0
Bus Wait Time	0
Bus Access Time	0
BART Travel Time	0
BART Wait Time	0
BART Access Time	0
OAT Travel Time	0
OAT Wait Time	0
OAT Access Time	0
New Mode 1 Travel	0

Figure 4-14: Data Entry Screen – Transportation Provider Service Data

4.4.6 Selecting Measures of Performance

With the project selected and data entered, users can switch to the “MOPs” screen (Figure 4-15), where users can select MOPs that are applicable to the project from the list of available MOPs. The selected MOP need to be added for calculation in program run by press the

“Add button” which will make it appear on the right sub-window. Those MOPs listed in the right sub-window will be shown in the output screens and can be saved to files. In the example screen, five MOP parameters are selected. The user can organize the performance list in any order of preference for convenience of viewing and output.



Saved MOPs

- Passengers on SOV
- Passengers on HOV
- VMT on SOV
- VMT on HOV
- VHT on SOV
- Revenue of HOV
- Emissions from SOV
- Profit of HOV
- CPC from SOV

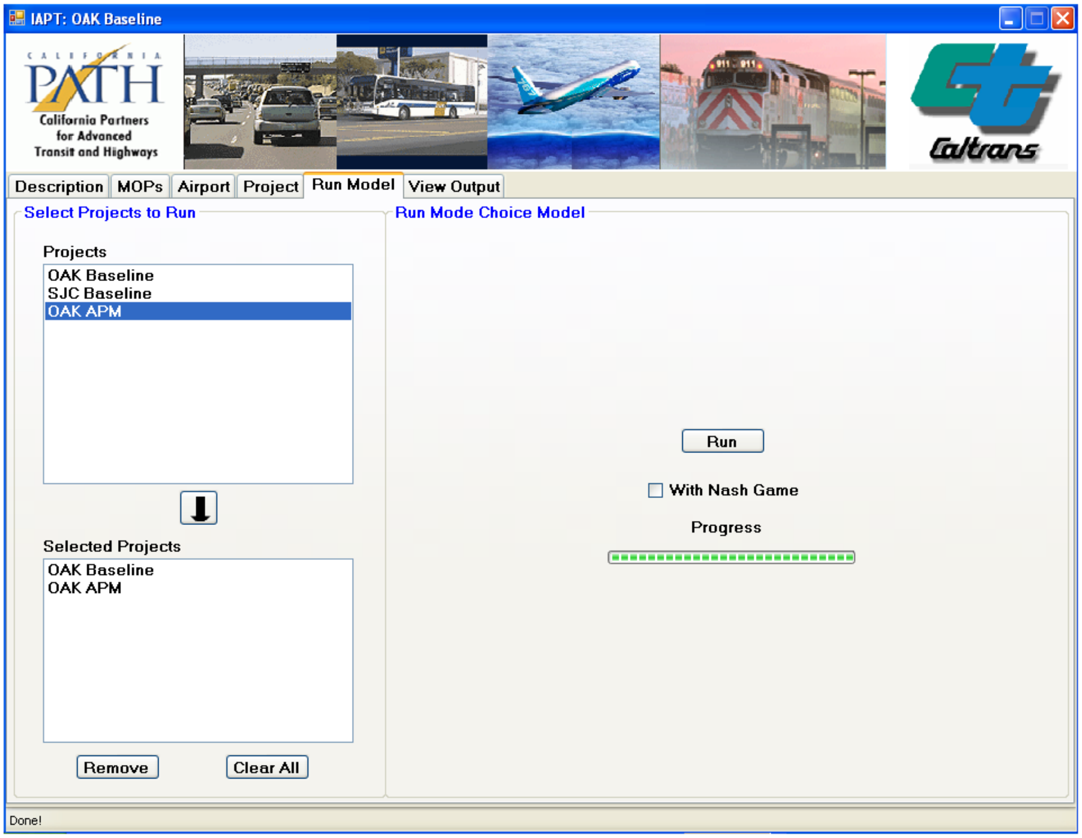
MOPs to be used

- Passengers on SOV
- Passengers on HOV
- VMT on SOV
- Emissions from SOV
- CPC from SOV

Figure 4-15: Selection of MOP List for Viewing and Output

4.4.7 Perform Analysis

Once the project is defined, data entry is completed and the MOP list is selected, the analysis is performed from the ***Run Model*** navigation button. Figure 4-16 shows the layout of the screen. Before running the project, it is necessary to select the project(s) to be run. The previously defined and selected project list in the Main Project tab appears in the left upper “Project” screen. Select whatever project(s) to be run in a batch mode. It allows the use to run any combined list of projects for comparison. It also allows the user to select whether the Nash Game approach should be applied to model the transportation provider competitive behavior. After all the selection, simply press “Run” button to execute the analysis process. The progress bar will be filled up with green if the process is finished.



Projects: OAK Baseline, SJC Baseline, OAK APM

Selected Projects: OAK Baseline, OAK APM

☐ With Nash Game

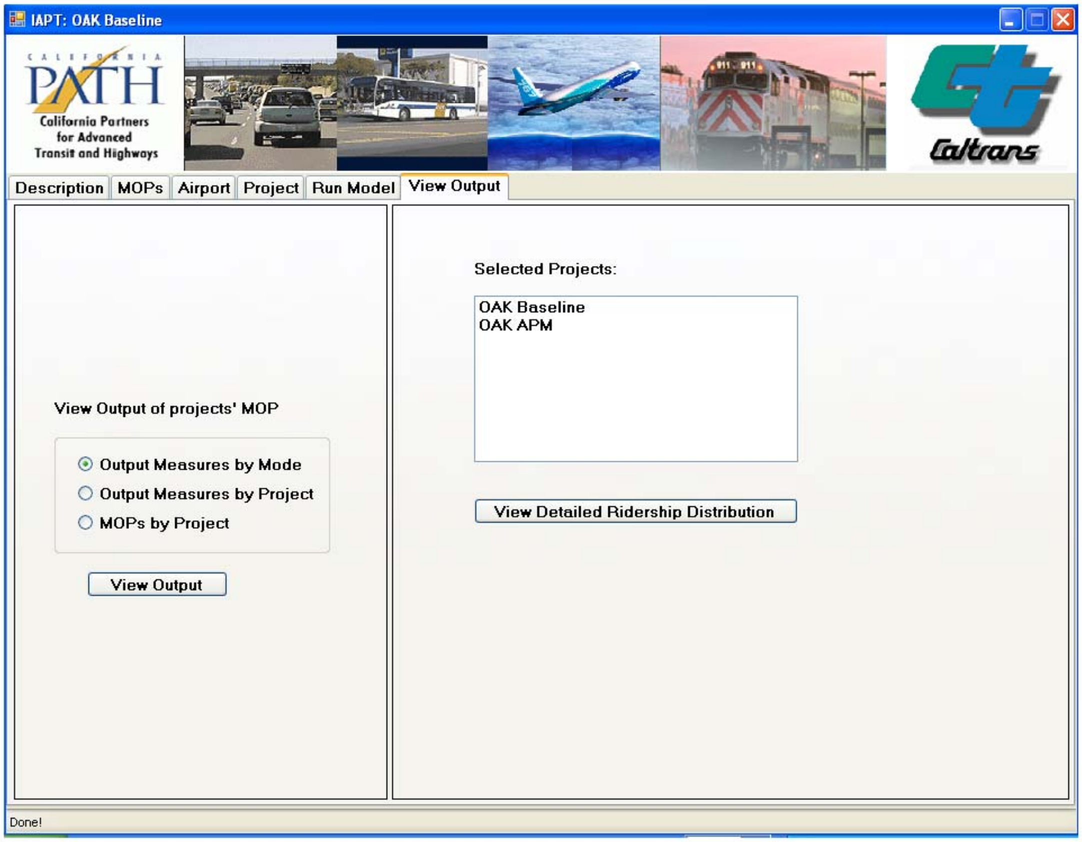
Figure 4-16: Representative Model Run Definition Screen

4.4.8 Display or Export Analysis Results

Selecting the ***View Output*** navigation button allows the user to select an airport and displays the results of all the selected projects analysis runs. The analysis runs are grouped by project and listed in date order, showing the run date/time and the analysis year for each run. The user can select one or more analysis years for a given project and one or more MOPs for that project (Figure 4-17). The results can be viewed in different levels of details:

- Output Measures by Mode
- Output Measures by Project
- MOP’s by Project

One can also view the detailed ridership distribution between modes, which is the most detailed output information to be used for system development.



View Output of projects' MOP

● Output Measures by Mode
○ Output Measures by Project
○ MOPs by Project

Selected Projects:

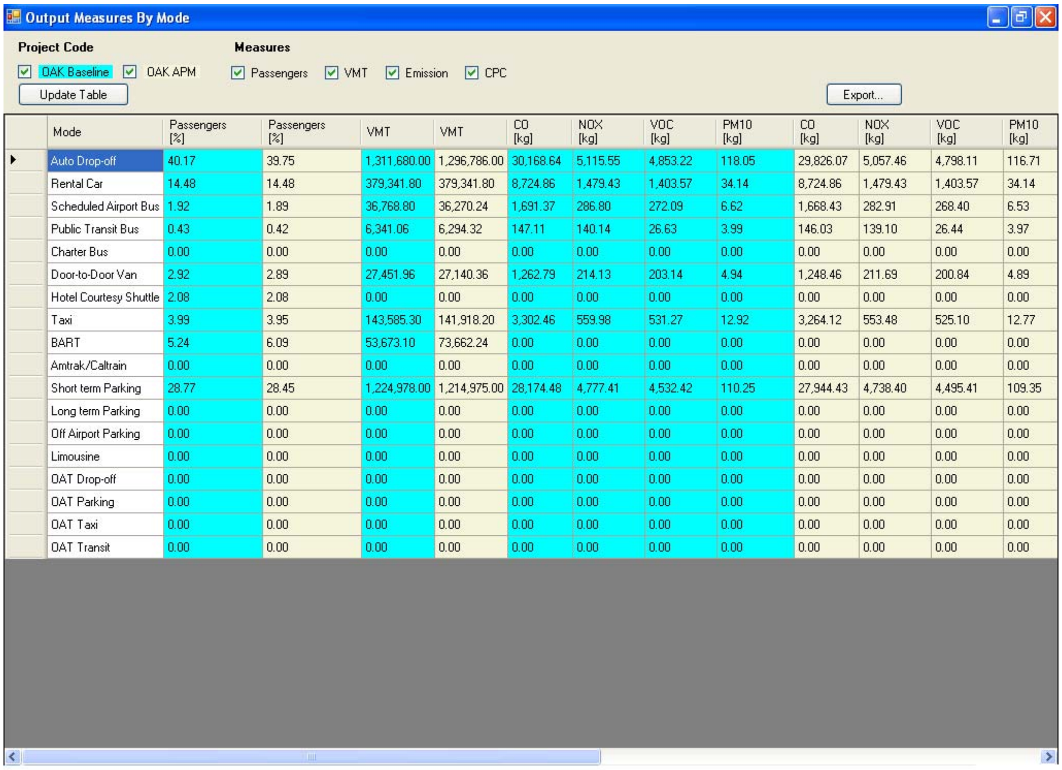
OAK Baseline
OAK APM

Figure 4-17: Selection of Different Output for Viewing

The different displays of output measures or MOPs are described below. The figures illustrate selected performance output measures for two representative projects: termed the OAK Baseline and OAK APM (Automated People Mover).

Output Measures by Mode:

The output will display all applicable output measures (including performance measures and some intermediate parameters) for all the relevant modes of the selected projects. Two projects are displayed in Figures 4-18 and 4-19: OAK Baseline (in blue) and OAL APM (in white). All the modes are listed as rows and MOP parameters are listed as columns. Color differentiates the two projects. In this case, only VHT and VMT are calculated for comparison.

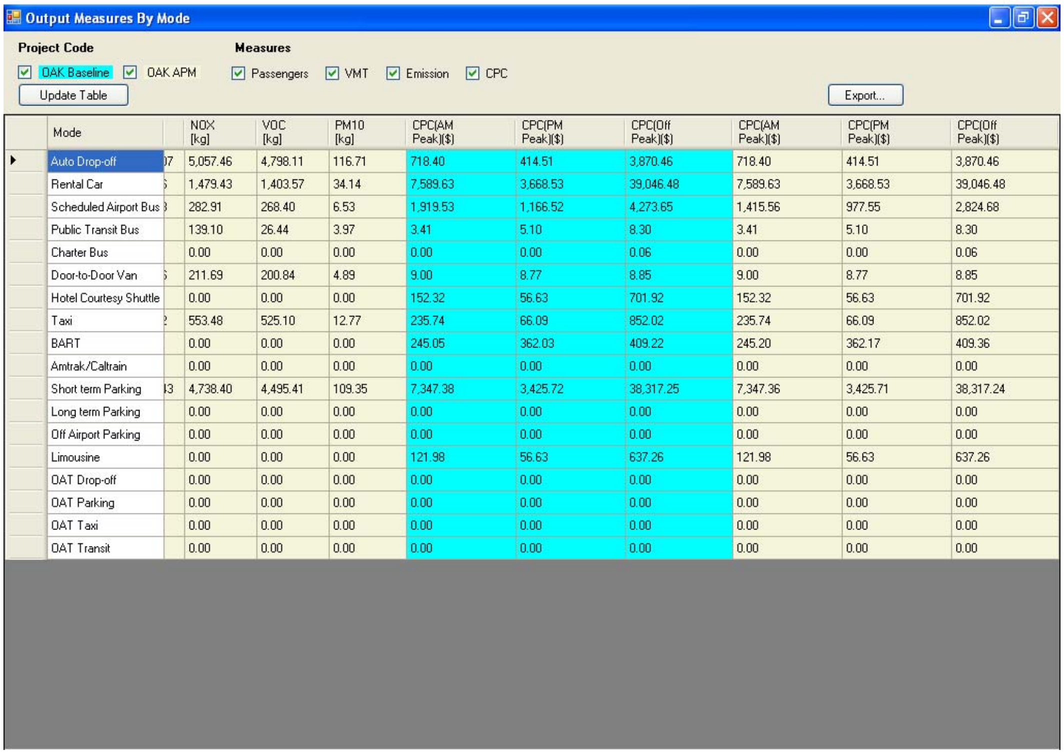


Project Code
☑ OAK Baseline ☑ OAK APM

Measures
☑ Passengers ☑ VMT ☑ Emission ☑ CPC

Mode	Passengers [%]	Passengers [%]	VMT	VMT	CO [kg]	NOX [kg]	VOC [kg]	PM10 [kg]	CO [kg]	NOX [kg]	VOC [kg]	PM10 [kg]
Auto Drop-off	40.17	39.75	1,311,680.00	1,296,786.00	30,168.64	5,115.55	4,853.22	118.05	29,826.07	5,057.46	4,798.11	116.71
Rental Car	14.48	14.48	379,341.80	379,341.80	8,724.86	1,479.43	1,403.57	34.14	8,724.86	1,479.43	1,403.57	34.14
Scheduled Airport Bus	1.92	1.89	36,768.80	36,270.24	1,691.37	286.80	272.09	6.62	1,668.43	282.91	268.40	6.53
Public Transit Bus	0.43	0.42	6,341.06	6,294.32	147.11	140.14	26.63	3.99	146.03	139.10	26.44	3.97
Charter Bus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Door-to-Door Van	2.92	2.89	27,451.96	27,140.36	1,262.79	214.13	203.14	4.94	1,248.46	211.69	200.84	4.89
Hotel Courtesy Shuttle	2.08	2.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Taxi	3.99	3.95	143,585.30	141,918.20	3,302.46	559.98	531.27	12.92	3,264.12	553.48	525.10	12.77
BART	5.24	6.09	53,673.10	73,662.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amtrak/Caltrain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Short term Parking	28.77	28.45	1,224,978.00	1,214,975.00	28,174.48	4,777.41	4,532.42	110.25	27,944.43	4,738.40	4,495.41	109.35
Long term Parking	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Off Airport Parking	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limousine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OAT Drop-off	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OAT Parking	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OAT Taxi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OAT Transit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 4-18: Viewing Output Measures by Mode



Project Code
☑ OAK Baseline ☑ OAK APM

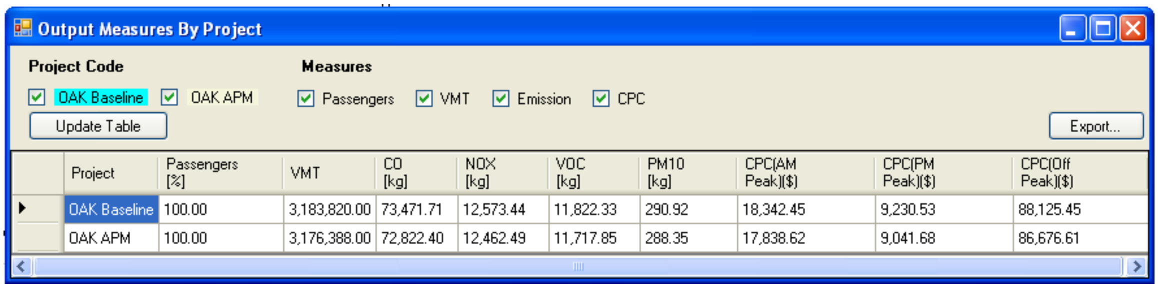
Measures
☑ Passengers ☑ VMT ☑ Emission ☑ CPC

Mode	NOX [kg]	VOC [kg]	PM10 [kg]	CPC(AM Peak)($)	CPC(PM Peak)($)	CPC(Off Peak)($)	CPC(AM Peak)($)	CPC(PM Peak)($)	CPC(Off Peak)($)
Auto Drop-off	5,057.46	4,798.11	116.71	718.40	414.51	3,870.46	718.40	414.51	3,870.46
Rental Car	1,479.43	1,403.57	34.14	7,589.63	3,668.53	39,046.48	7,589.63	3,668.53	39,046.48
Scheduled Airport Bus	282.91	268.40	6.53	1,919.53	1,166.52	4,273.65	1,415.56	977.55	2,824.68
Public Transit Bus	139.10	26.44	3.97	3.41	5.10	8.30	3.41	5.10	8.30
Charter Bus	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.06
Door-to-Door Van	211.69	200.84	4.89	9.00	8.77	8.85	9.00	8.77	8.85
Hotel Courtesy Shuttle	0.00	0.00	0.00	152.32	56.63	701.92	152.32	56.63	701.92
Taxi	553.48	525.10	12.77	235.74	66.09	852.02	235.74	66.09	852.02
BART	0.00	0.00	0.00	245.05	362.03	409.22	245.20	362.17	409.36
Amtrak/Caltrain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Short term Parking	4,738.40	4,495.41	109.35	7,347.38	3,425.72	38,317.25	7,347.36	3,425.71	38,317.24
Long term Parking	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Off Airport Parking	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limousine	0.00	0.00	0.00	121.98	56.63	637.26	121.98	56.63	637.26
OAT Drop-off	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OAT Parking	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OAT Taxi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OAT Transit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 4-19: Viewing Output Measures by Mode (cont.) – Right Side of Window

Output Measures by Project

Some aggregated performance parameters and intermediate parameters can be viewed and saved by mode (Figure 4-20). The aggregation is conducted over relevant modes.

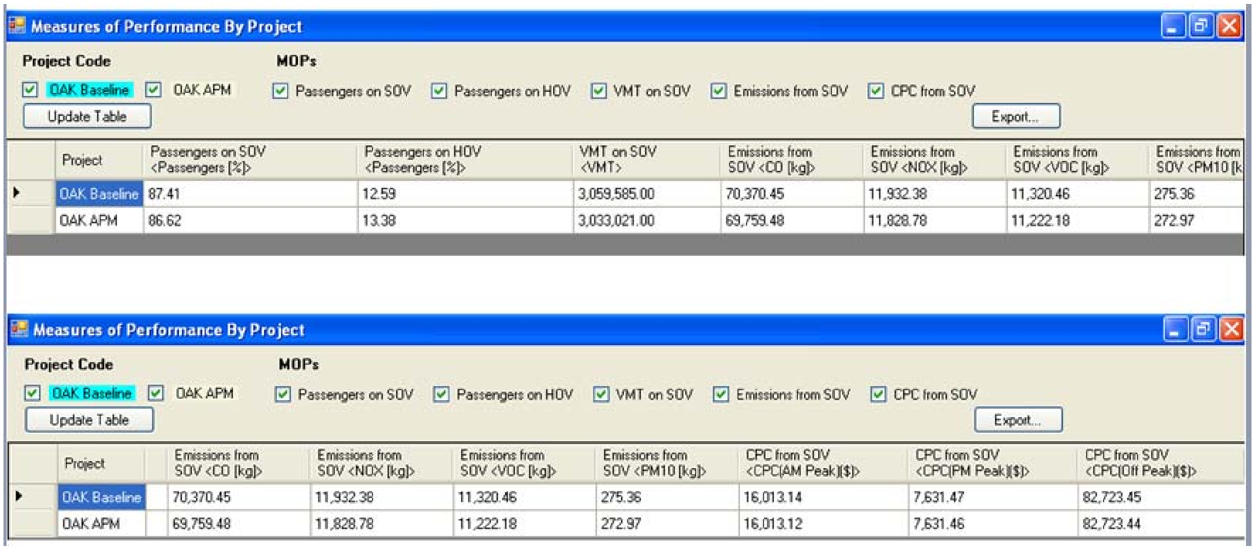


Project	Passengers [%]	VMT	CO [kg]	NOX [kg]	VOC [kg]	PM10 [kg]	CPC(AM Peak)($)	CPC(PM Peak)($)	CPC(Off Peak)($)
OAK Baseline	100.00	3,183,820.00	73,471.71	12,573.44	11,822.33	290.92	18,342.45	9,230.53	88,125.45
OAK APM	100.00	3,176,388.00	72,822.40	12,462.49	11,717.85	288.35	17,838.62	9,041.68	86,676.61

Figure 4-20: Viewing Output by Project

MOPs by Project:

The measure of performance can also be displayed with further aggregation by project but in a different way (Figure 4-21). This is useful for higher-level comparison of two possible alternative projects at the same level.



Project	Passengers on SOV <Passengers [%]>	Passengers on HOV <Passengers [%]>	VMT on SOV <VMT>	Emissions from SOV <CO [kg]>	Emissions from SOV <NOX [kg]>	Emissions from SOV <VOC [kg]>	Emissions from SOV <PM10 [k
OAK Baseline	87.41	12.59	3,059,585.00	70,370.45	11,932.38	11,320.46	275.36
OAK APM	86.62	13.38	3,033,021.00	69,759.48	11,828.78	11,222.18	272.97

Project	Emissions from SOV <CO [kg]>	Emissions from SOV <NOX [kg]>	Emissions from SOV <VOC [kg]>	Emissions from SOV <PM10 [kg]>	CPC from SOV <CPC(AM Peak)[$]>	CPC from SOV <CPC(PM Peak)[$]>	CPC from SOV <CPC(Off Peak)[$]>
OAK Baseline	70,370.45	11,932.38	11,320.46	275.36	16,013.14	7,631.47	82,723.45
OAK APM	69,759.48	11,828.78	11,222.18	272.97	16,013.12	7,631.46	82,723.44

Figure 4-21: Viewing MOP by Project: Lower Panel is a Continuation of the Upper Panel

Export Data to outside tools (e.g. Microsoft Excel):

In all three of the output screens, users can click “Export” to export the current output as a comma-delimited CSV (comma-separated values) file, which can be opened by outside applications such as Microsoft Excel.

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.

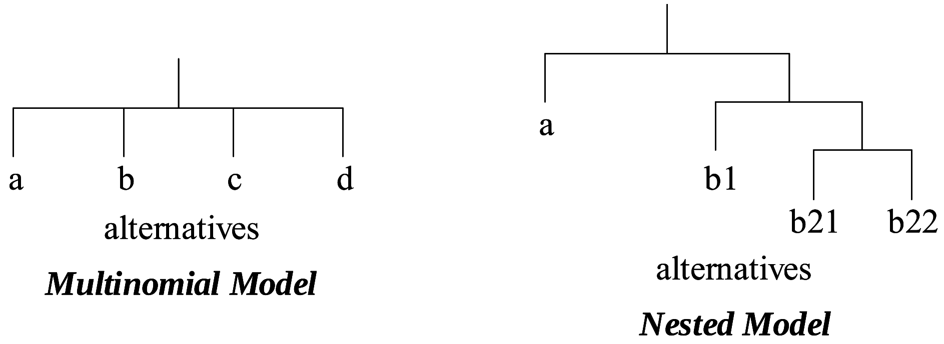


Figure 5-1: Multinomial and Nested Choice Models

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:

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

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:

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

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:

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

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

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, as reviewed in a recent Airport Cooperative Research Program (ACRP) synthesis study (Gosling, 2008). This section describes 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 these two literature reviews, a number of other airport ground access mode choice models have been subsequently identified as part of the recent ACRP synthesis study (Gosling, 2008). 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, which provide a representative indication of the current state of practice.

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 Massachusetts Bay Transportation 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 A.

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 A.

SERAS Model

As part of the South East and East of England Regional Air Service (SERAS) study undertaken for the United Kingdom (U.K.) 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 A.

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 A.

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.

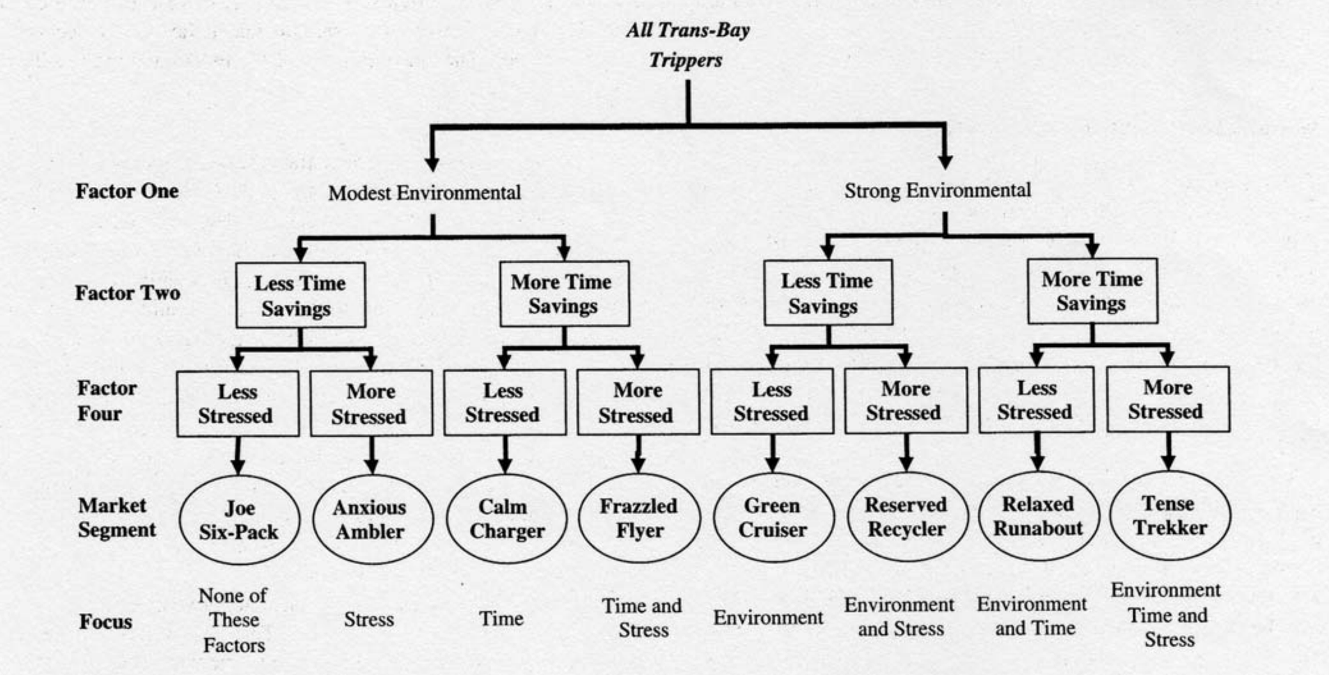
One approach that has been applied to a number of transportation mode choice problems is based on market segmentation by traveler attitude, rather than more objective criteria such as trip purpose or residence location. Proussaloglou and Koppelman (1989) applied this approach to the design of rail services 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 the 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:

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

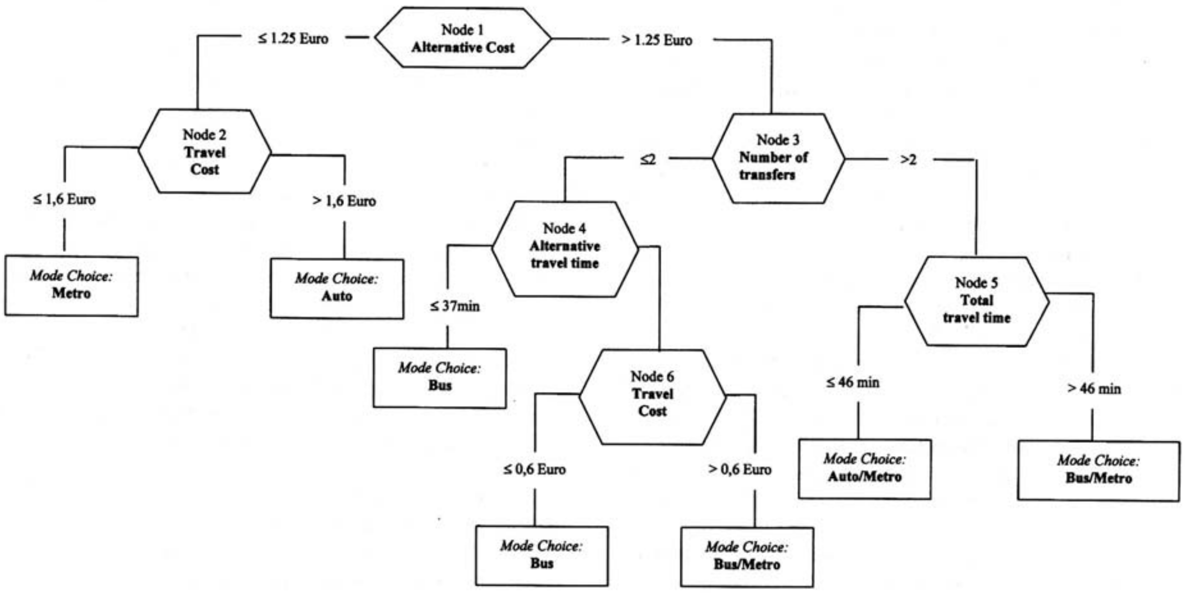
where $h(v)$ = heterogenity of subset v (Gini Index of Diversity)

$p(j|v)$ = 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.

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.



Source: Karlaftis, 2004

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

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 (Statistical Package for the Social Sciences) file. It included the respondent trip origin locations, geocoded to latitude and longitude. This allowed each location to be assigned to the appropriate MTC transportation 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 transportation 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.

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

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 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 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 age 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.

In the course of model development, it was discovered that some of the geocoded locations of the trip origins in the air passenger survey results were incorrect. These errors placed the trip origin in the wrong transportation analysis zone (TAZ) and thus assigned the wrong ground access travel times and costs to that response. It was not possible to repeat the geocoding of the air passenger survey data within the resource constraints of the current project, but an attempt was made to adjust the data to minimize the impacts of any geocoding errors on the transportation service data assigned to each response. The trip origin TAZ for each survey response was compared to the zip code given for the trip origin address, or the trip origin city where a zip code was not given. If the trip origin TAZ did not lie within the zip code (or city), it was changed to the TAZ within that zip code (or city) with the highest population. Where a TAZ was split by a zip code boundary, the TAZ population was divided between the different segments within each zip code on the basis of the area of the segments.

5.4 Model Development and Calibration

Once the model estimation dataset was finalized, the development of the mode choice model was undertaken in an iterative process, in which the model formulation was revised in the light of the estimation results. This exploratory development cycle examined changes to the model specification as well as the inclusion of additional explanatory variables. As with any model development activity, the objective was 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

It was envisaged that the ultimate formulation of the planned model would use a nested logit structure, with modes with similar characteristics grouped together, as illustrated in Figure 5-4. 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 included in the model, but is a higher-level choice based on trip purpose, trip origin type and trip 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: Planned 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.

5.4.4 Initial Model Estimation

The initial implementation of the IAPT is based on a multinomial logit mode choice model. Extending this to a nested logit model is not in principle difficult, but proved beyond the resources of the current phase of the project.

Therefore it was decided to initially estimate a multinominal logit model for Oakland International Airport (OAK) for use in demonstrating the functionality of the IAPT. Separate estimated coefficients and somewhat different functions specifications were used for each of the following market segments:

- Resident Business (RB)
- Resident Personal (RP)
- Visitor Business (VB)
- Visitor Personal (VP).

<u>Modes Included in the Model</u>

The following modes are included in the model:

- Drop-off by private vehicle (Drop-off)
- Private vehicle parked at the airport for the trip (Park)
- Bay Area Rapid Transit (BART)
- Scheduled airport bus (Airport bus)
- Taxi
- Limousine
- Shared-ride van

There was no use of public transit bus for the trip to the airport in the data used to estimate the model, so this mode is not included. Air parties using rental car or hotel courtesy shuttle to access the airport were assumed to either require the rental car for other purposes or be staying at a hotel that provided courtesy shuttle. In either case, these travelers were assumed not to face a mode choice decision and were not included in the model. In applying the mode choice model in the IAPT, those air parties in the data using rental car or hotel courtesy shuttle can be assumed to continue to do so, irrespective of changes in service levels of the other modes.

Scheduled airport bus service to OAK at the time of the 2001 MTC survey was only available from the North Bay (Marin, Napa, Solano and Sonoma Counties). There was no use of these services by air parties from the rest of the region and it was assumed that this mode was not considered by those travelers, and was excluded from their choice set. Similarly, there was no shared-ride van service to OAK from Marin, Napa and Sonoma Counties, and this mode was excluded from the choice set of air parties from those counties. Shared-ride van service was available from part of Solano County and this was included in the model.

Although all air parties from throughout the region could in principle use BART to access OAK, there was no use of BART in the 2001 MTC survey data from the North Bay counties. This is not surprising, since air travelers from the North Bay would have a lengthy access trip to reach the nearest BART station that would include crossing one of the Bay toll bridges. Transit access to the nearest BART station from most of the North Bay is very limited, so anyone considering using BART would most likely need to be dropped off or take a taxi. Initially, this alternative was included in the model for North Bay air parties, but in the absence of any use of BART by North Bay air parties, it was assumed that this option is not considered by those travelers, and was excluded from their choice set.

The Park alternative is only relevant for resident trips, and was excluded from the choice set for visitor trips. Airport access trips by visitors occur at the end of their visit to the region, so it would make no sense to leave a car parked at the airport while they are visiting the area, even if they had access to a private vehicle during their visit, which most do not. Although visitors on business trips starting their airport access trip from the North Bay counties could in principle use scheduled airport bus, in practice there was no use of this mode by air travelers in this market segment in the 2001 MTC survey data, so it was not possible to estimate coefficients for this mode for VB trips and it was excluded from the choice set for these air parties. However, it would be possible to include this mode in the model implementation in the IAPT by assuming a value for the alternative-specific constant as discussed further below.

Specification of the Model Utility Functions

The basic form of the utility function for each mode consisted of an alternative-specific constant (ASC) and travel time and cost variables. However, decisions are required on whether costs and times should be defined on a per-person or per-party basis, how to account for the effect of differences in household income on perceived value of travel time, how to account for the operating cost of private vehicles, whether to account for the time of the driver dropping an air party off at the airport or a BART station or scheduled airport bus stop, and how much weight to assign to waiting time compared to travel time. A large number of model estimation runs were performed in order to explore the effect of alternative specifications. It was found that allowing the model estimation to attempt to determine all these factors generally resulted in statistically insignificant values of key coefficients or implausible implied values given by the estimated coefficients. These estimation problems appear to arise from the lack of variation in the data values for many of the service attributes. For example, all the highway-based modes have essentially the same travel time to the airport.

The exploratory estimation runs suggested that the effect of household income would be best accounted for by dividing costs by the following function of household income:

$$f(\mathrm{Inc}) = 0.5 * (1 + (\mathrm{Inc}/90))$$

where *Inc* is the annual household income of the respondent in thousands of dollars for the year preceding the MTC 2001 survey. All costs in the model are expressed in 2001 dollars. It can be seen that this function has a value of unity for a household income of $90,000 (the median household income reported in the survey for resident personal trips). Thus the estimated coefficients give the implied value of travel time in dollars per hour for air parties with a household income of $90,000. The implied value of time for other travelers can be obtained by multiplying this value of time by the above function. Thus air travelers with a household income of $15,000 per year will have an implied value of time of 58% of those with a household income of $90,000 per year, while air travelers with a household income of $270,000 per year would have an implied value of time twice that of those with a household income of $90,000 per year. A range of functional forms were explored as part of model estimation and the above function appears to give the best fit to the data.

The general form of the utility functions is given by:

$$U(i) = a0*\mathrm{PartySize} + a1*\mathrm{TravTime} + a2*\mathrm{Cost} + a3*\mathrm{Dum1}*\mathrm{PartySize} + a4*\mathrm{Dum2}$$

where *U(i)* is the utility of mode *i*, *PartySize* is the number of air travelers in air party, *TravTime* is the total travel time of all the air party members, *Cost* is the total cost paid by the air party, including any private vehicle operating costs attributed to the access trip, and *Dum1* and *Dum2* are dummy variables (discussed below).

The air party travel time includes the access time to scheduled modes and any waiting time (weighted as noted in Table 5-1). Where some fraction of the driver time for drop-off trips is included in the utility function (as noted in Table 5-1), this is added to the air party travel time. Where a separate coefficient is estimated for the driver time for drop-off trips, this can be included as separate term in the utility function or the driver time, weighted by the ratio of the estimated coefficient of driver time to air traveler time, can be added to the air party travel time.

The driver time for drop-off trips includes travel in both directions (*i.e.* twice the one-way travel time). Air parties are assumed to access scheduled modes (BART and scheduled airport bus) by being dropped off by private vehicle. Thus these access trips incur the estimated private vehicle operating costs and (where included in the utility function) some fraction of the driver time.

Dummy variables are defined for trips that start at a non-home origin (business, hotel, etc.) and (for air travelers on resident personal trips dropped off at the airport) two-person air parties. Home origins include both the air traveler's own home and that of someone else. The trip origin dummy variable is multiplied by the air party size (*i.e.* it implies a constant additional disutility on a per-person basis). This dummy variable reflects the greater availability of someone who can drop off an air party at the airport or a station or bus stop, compared to other types of trip origin. The air party size dummy variable reflects the lower use of being dropped off at the airport by two-person resident air parties on personal trips compared to air parties with one or three or more travelers observed in the survey data. This may be due to the fact that in two-person households, if both household members are taking an air trip together there may be nobody else who can drive them to the airport.

The transportation service data assembled for the model estimation only included the access time to BART stations or scheduled airport bus stops, not the distance. For the purpose of estimating the perceived operating costs of using a private vehicle to access these stations or bus stops, the access distance was estimated for these trips by assuming that the first 12 minutes of the access trip was made on local streets at an average speed of 20 mph, while the remainder of the access trip (if any) was made on freeways at 60mph. The estimated perceived operating costs of private vehicles used to drop air parties off at the airport or stations or bus stops were based on the round-trip distance, while that for private vehicles parked at the airport for the trip duration only counted the one-way trip.

Estimated Coefficients

The estimated model coefficients are given in Table 5-1, together with the t-statistics (in parentheses) and the implied values of time for air travelers with an annual household income of $90,000. Table 5-1 also shows the assumed values of waiting time and driver time for drop-off trips by private vehicle relative to air passenger time, as well as the estimated private vehicle operating cost per mile.

Table 5-1: Estimated Mode Choice Model Coefficients

	Res Bus		Res Pers		Vis Bus		Vis Pers	
Continuous variables		*t-stat*		*t-stat*		*t-stat*		*t-stat*
Travel time (min.)	-0.0322	*(3.67)*	-0.0085	*(1.61)*	-0.0194	*(1.59)*	-0.0141	*(2.28)*
Travel cost / f(Inc) ($)	-0.0511	*(7.14)*	-0.0323	*(8.20)*	-0.0421	*(4.00)*	-0.0383	*(2.82)*
Driver time (drop-off) (min)	*assumed*		-0.0051	*(1.86)*	*assumed*		*assumed*	
Alternative-specific const.								
Park	+0.172	*(1.28)*	+0.149	*(1.87)*	n/a		n/a	
BART	-2.757	*(4.76)*	-0.998	*(6.18)*	-1.755	*(2.45)*	-2.100	*(4.03)*
Scheduled airport bus	+3.927	*(2.58)*	+0.978	*(1.24)*	*excluded*		0.0	*fixed*
Taxi	-2.610	*(3.61)*	-1.705	*(5.19)*	-1.280	*(1.82)*	-1.659	*(2.62)*
Limousine	0.0	*fixed*	-0.597	*(2.57)*	-0.921	*(1.25)*	-1.317	*(1.70)*
Shared-ride van	-3.355	*(3.09)*	-0.698	*(3.11)*	-1.633	*(1.90)*	-1.294	*(2.63)*
Dummy variables								
Non-home trip origin	-0.662	*(1.81)*	-0.659	*(2.51)*	-1.421	*(2.14)*	-2.039	*(4.20)*
Two-person party (drop-off)	n/a		-0.421	*(1.96)*	n/a		n/a	
Private vehicle operating cost	56 ¢/mi	*(2.00)*	26 ¢/mi	*(1.84)*	85 ¢/mi	*(2.67)*	47 ¢/mi	*(1.63)*
Travel time assumptions								
Waiting time	2x travel time		2x travel time		2x travel time		2x travel time	
Driver time for drop-off trips	0.5x air pax		*see above*		none		none	
Implied value of time ($/hr)	37.8		15.7		27.6		22.0	

Notes: 1. Costs expressed in 2001 dollars.
2. All costs and times computed on an air party basis. Travel times multiplied by air party size.
3. Implied values of time for air travelers with an annual household income of $90,000 in 2000.

4. Alternative specific constants and non-home trip origin dummy variable multiplied by air party size.

n/a Not applicable

The estimated model coefficients appear to be generally reasonable. The implied values of travel time are plausible and have a reasonable relationship to each other, with the implied values of travel time for personal trips lower than for business trips. The estimated values of the perceived costs of operating private vehicles appear high. However, it should be noted that these assume that access to BART or scheduled airport bus stops is by private vehicle. To the extent that many of these trips in fact use other modes, including walking, local bus, or taxi, this would increase the disutility (time or cost), leading to a higher value for the estimated coefficient. It should be noted that perceived cost of operating a private vehicle is higher for visitor trips than resident trips. Of course, the visitors do not own the vehicles being used to drop them off, and in many cases do not have access to anyone who can drop them off. Therefore this higher perceived cost may simply reflect a greater use of other, more expensive or time consuming, modes.

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.

Fortunately, the Metropolitan Transportation Commission undertook a comprehensive air passenger survey at both OAK and SFO between later August and early October 2006 (JD Franz Research, 2007). In order to better understand the extent to which the ground access mode use changed over time, it would be important to supplement the air passenger survey data with a careful analysis of the available time series data on airport access mode use from airport and transportation agency statistics.

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.

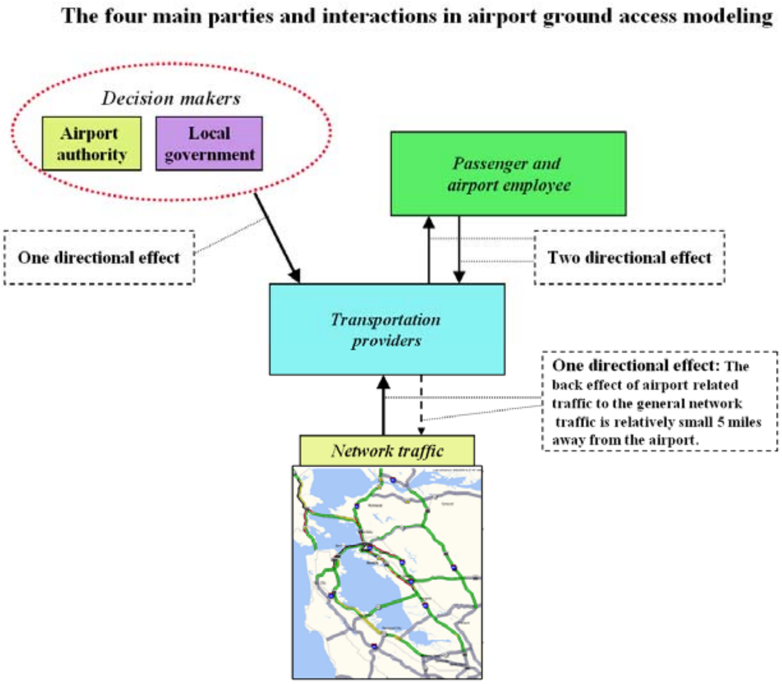
In general, the transportation providers will respond to changes in their own traffic level as well as the service characteristics (fares, frequencies, etc.) of their competitors. While changes in the service offered by their competitors, if unmatched by changes of their own service characteristics, 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.


The four main parties and interactions in airport ground access modeling

One directional effect: The back effect of airport related traffic to the general network traffic is relatively small 5 miles away from the airport.

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 Standard 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, the Transit Cooperative Research Program (TCRP) sponsored a study of the elasticity of fare for multiple modes/providers (TCRP, 1997). 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 the Los Angeles region, one in Washington D.C., and one in Ontario, Canada, 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 the U.K. caused such full competition between bus service providers as studied by 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 origin-destination (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 to 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 comprise two broad types:

(1) Public transportation providers: Rail transit systems, such as BART, other rail systems, or transit bus. Rail systems may be connected to the airport by shuttle bus or APM link. Airport authorities can (and typically do) determine the details of the connecting service provided, including operating frequencies 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. Strategy (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 both public and private providers such as transit 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 or other train
- Transit bus and BART
- Rental car and rental car shuttle
- Shuttle van
- Taxi
- Direct transit 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.

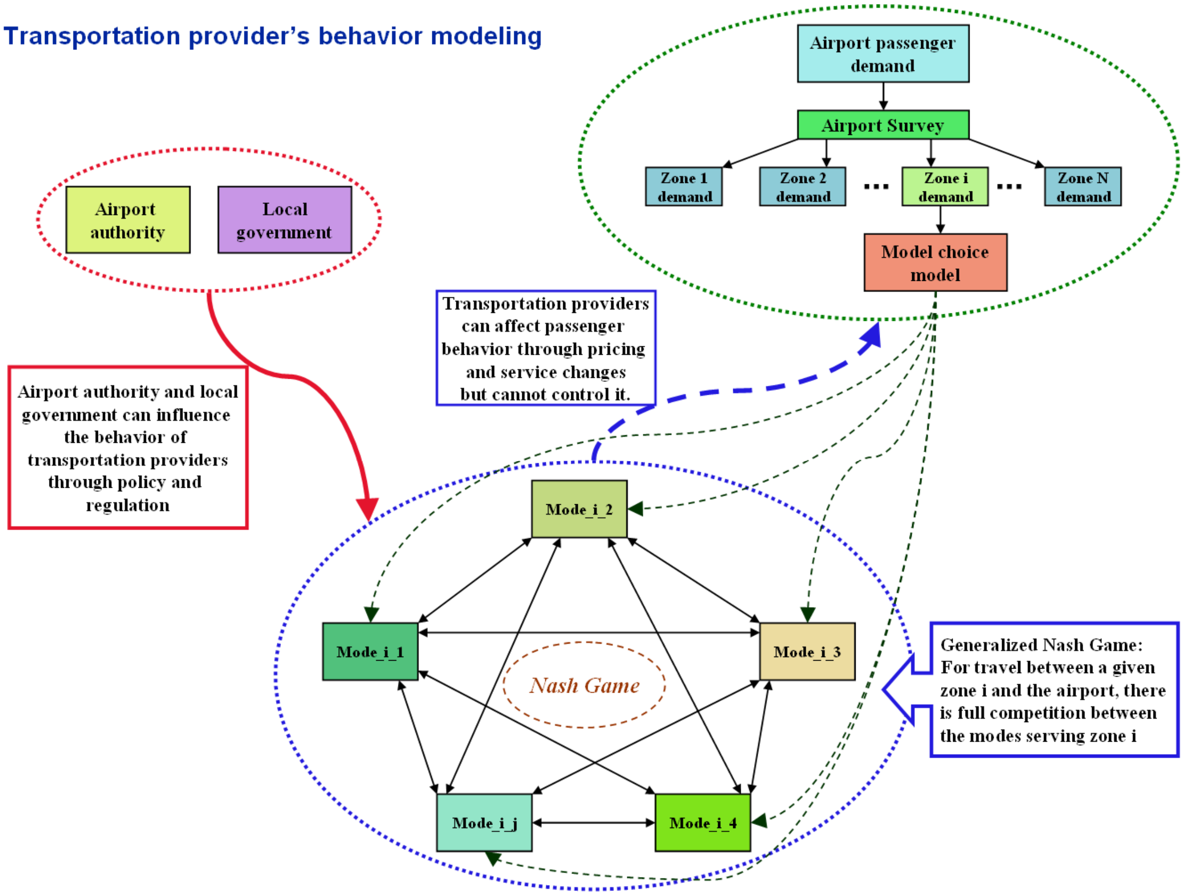


Figure 6-2: Transportation Provider Modeling

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 know 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

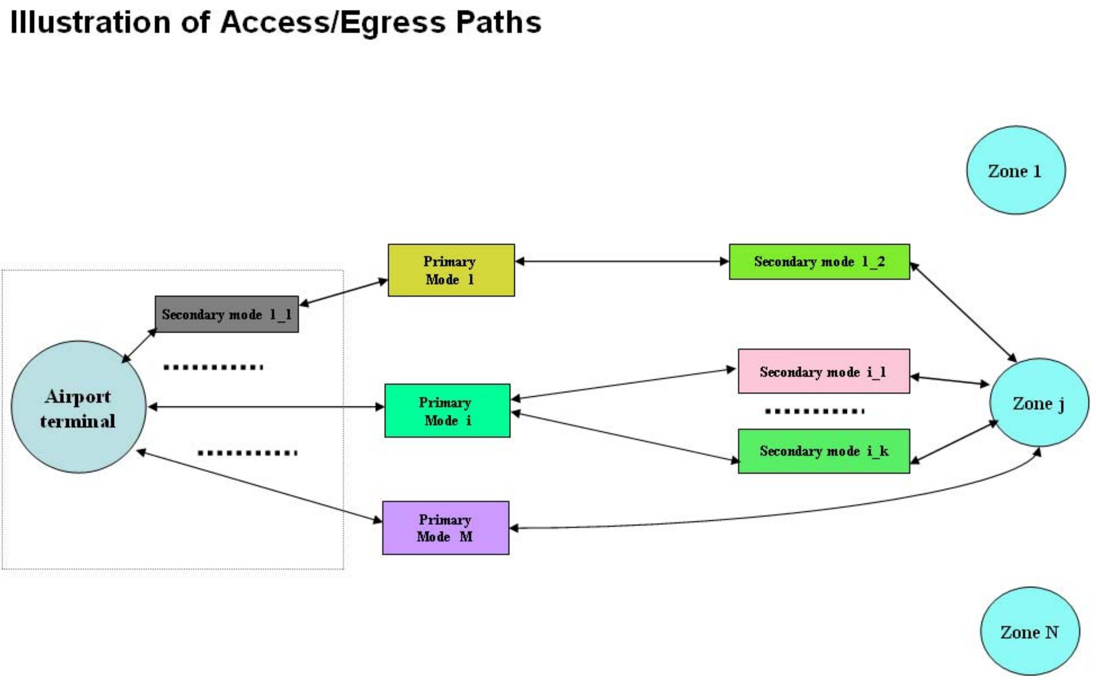


Figure 6-3: Path Choice is Equivalent to Primary (Representative) and Secondary Mode Choice

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 those areas can be 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;

6.5 Transportation Provider Costs

Transportation provider behavior is governed by their economical view for operation. Ideally, a provider is to maximize the benefit whenever possible. If we model the provider competition behavior in the Generalized Nash Game approach by maximizing the profit, it is necessary to have a correct estimation/calculation of the cost of each mode, which includes all the fixed and variable (operational) costs. However, due to competition variation between providers, and passenger demand market variation, what a provider can often achieve is the maximization of the revenue. Revenue maximization only needs to consider the income from the fare charge to customers. We initially planned for both profit maximization and revenue maximization in the data collection phase. However, due to data availability, only revenue maximization has been currently implemented.

For these modes we need to define short-run cost functions in order to model provider behaviors when demand shifts due to air ridership increase or addition of new modes in the market.

The other modes (auto drop, taxi, public transit, and hotel shuttle) are assumed to not vary their prices or service pattern in response to changes in ridership or patronage.

The cost coefficient estimation of the modes have been conducted through the following procedures: (a) data collection: most important providers in those modes have been contacted or their websites have been visited for data. Other data sources include the revenue source from the airport; and (b) the estimation method is basically averaging the corresponding value over time and over available transportation providers in a mode since we consider the average cost of a mode. Some assumptions have been made in the estimation with respect to each mode.

6.5.1 Rental Car

The fare strategy of rental car is very complicated due to its variable service plans, which not just affect their revenue, but also the variable cost. It is impossible to catch those variations accurately. The cost factors considered here are related normal services provided. The following assumptions have been made for the derivation of cost function for rental cars: (1) major rental car companies have similar profit margin because the market is nearly perfectly competitive and they all use variable plans for their customers; (2) fixed cost is negligible; and (3) rental car companies operate 365 days/year.

Factors in Variable Cost Estimation

- Vehicle ownership: vehicles are deployed to each location based on demand.
- Labor: staffing can be adjusted according to demand with possibly minimum staffing at each location.
- Vehicle maintenance: vehicle maintenance and cleaning are usually contracted out
- Facility and shuttle service: Usually, the airport own the land which are usually leased to rental car companies based on revenue or through-transaction charge
    - SFO – higher of 10% of gross revenues or minimum guaranteed rent (ACSF, 2005)

  - OAK – fixed Customer Facility Charge per rental car transaction (OAKMP, 2005)

Cost Function Derivation

The method used for cost function derivation includes the following procedures:

- Data Collection: several rental car companies have been contacted and their website have been visited to collect the following information:
  - Average annual mileage on rental cars
  - Average daily and weekly rental rates
  - Profit margin (net income/revenue)
- Coefficient Estimation:
  - Average operating cost per vehicle per unit of time: based on rental rates and profit margin.
  - Average operating cost per mile: based on rental rates, profit margin, and average annual mileage.
  - Average operating cost per vehicle rental: based on the average rental duration (trip duration) for air passengers.

6.5.2 Scheduled Airport Bus

The following assumptions have been made for scheduled airport bus: (a) buses operate at low average load factor therefore operating cost is largely fixed and independent of the number of passenger; (b) bus schedule and frequency is fixed in the short run; (c) Vehicle size in fleet are uniform (although this may not be true in some cases where company deploys smaller vehicle during off peak seasons to minimize cost); and (d) marginal cost is negligible.

Fixed Costs Include

- Vehicle operation: frequency, route, and hours are fixed from day to day
- Labor: operation hours and vehicles are fixed from day to day
- Administration

Cost Function Derivation

- Data Collection
  - Annual passenger miles served

  - Annual vehicle miles operated
  - Annual vehicle hours operated
  - Annual operating cost
- Coefficient Estimation
  - Average operating cost per vehicle per unit of time: based on annual vehicle hours operated and annual operating cost
  - Average operating cost per mile: based on annual vehicle miles operated and annual operating cost
  - Average operating cost per trip: based on operating cost per mile and average trip distance and operating cost per hour and average trip duration

6.5.3 On-Airport Parking Lot Operator

The following assumptions have been made for the on-airport parking: (a) variable costs are negligible; and (b) Since operating cost information can only be obtained for OIA, we assume all three Bay Area airports adopt similar cost/benefit ratio in ground access and parking operation; and (c) Except at SFO where ground access is provided by AirTrain (automated people mover) and cost does not vary much with increasing demand.

Fixed Costs

- Facility operation/maintenance: parking facilities are fixed in capacity therefore operation cost does not vary with level of patronage
- Staffing: fixed except during peak seasons when more cahier windows need to be opened
- Parking lot shuttle: mostly fixed when frequency is fixed during normal traffic

Variable Costs

- Parking lot shuttle: frequency may increase with increasing traffic during peak season or in the long run

Cost Function Derivation

- Data Collection
  - Annual operating revenue from parking and ground access
  - Annual operating expenses from parking and ground access
  - Parking facility capacity

- Coefficient Estimation
  - Operation cost per 1000 parking stall: based on parking facility capacity and operating expenses

6.5.4 Limousine

The following assumptions have been made for the limousine: (a) fixed cost is negligible; (b) since we were unable to obtain operation costs for limousine companies, we assume the profit margin is similar to that of rental car companies. Furthermore, we assume profit margin is similar across the market due to its competitive nature; and (c) there is an average waiting/loading time of 30 minutes on top of actual in-vehicle travel time.

Fixed Costs

- Administration: making reservations and scheduling dispatch
- Vehicle ownership

Variable Costs

- Vehicle maintenance: normally based on mileage (demand).
- Drivers: since drivers do not work full time, it is easy to adjust deployment based on demand.
- Fuel: based on mileage (demand).

Cost Function Derivation

- Data Collection
  - Average hourly rate based on vehicle size/capacity
  - Average distance and ride time for airport trips on limousine for OAK, SJC, and SFO (based on AIRPAX Survey 2001).
  - Average party size for limousine patrons traveling to or from the airport (based on AIRPAX Survey 2001).
- Coefficient Estimation
  - Average hourly operating cost:
    - Use hourly rates based on vehicle size for different companies to extrapolate linear relationship between cost and vehicle capacity (See figure 6-4).

    - Use average y-intercept as fixed cost/vehicle/hour
    - Use average slope as cost/additional capacity/hour
  - Fixed cost per trip: based on average trip duration and fixed cost/vehicle/hour
  - Variable cost per trip: based on average trip duration, average party size, and variable cost/additional capacity/hour. Note that minimum vehicle capacity is 4, therefore we apply this minimum to travel parties smaller than 4.
  - Total operation cost per trip: this is the variable cost per trip to the limousine company
  - Operation cost per vehicle mile: based on operation cost per trip and average travel distance for limousine air parties.
  - Operation cost per vehicle hour: based on operation cost per trip and average travel time for limousine air parties.

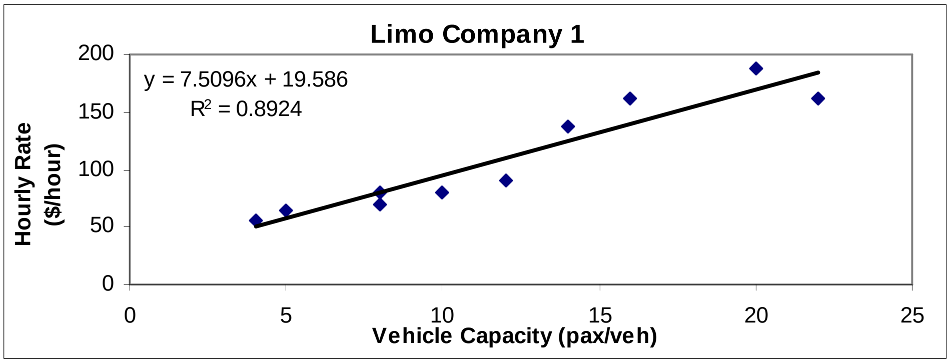


Figure 6-4: Sample Extrapolation of Hourly Rate

6.6 Model Implementation Issues and Current Status

The mathematical models for Generalized Nash Game with revenue maximization has been implemented in the analysis functionality of the IAPT. As indicated in Appendix B, three approaches have been tried.

6.6.1 First Implementation: Air Party Based Total Revenue Maximization

This consideration is due to the availability of airport survey data. Due to limited air party data available, air passenger mode choice model was initial estimated base air parties. i.e. the mode choice generates the probability function for the a specific air party to a choose a given mode. Since some TAZ does not have air party data available although it is likely that residents in that TAZ will use the project related airport, it is difficult for us determine how the ridership would distribute at that zone without enough data. For the approach, it is assumed that:

- The competition between mode is only reflected in the total revenue instead of for the available modes to compete at each TAZ;
- Only a fixed percentage of fare change is allowed for each mode.

6.6.2 Second Implementation: Competing at Each Zone

The following analysis uses zonal passenger flow corresponding to each air party as the decision variable. Such choice makes the objective function globally concave. Thus, revenue optimization or profit optimization do not much difference. Previous approach uses a uniform price change parameter for all the zones (air parties). i.e. they change the fare by percentile irrespective pf the distance of the zone (air party). Although it simplifies the dimension of the problem, the objective function is only conditionally concave. To avoid this problem, we use a second approach: each mode maximize its revenue (profit) at each zone (air party) by changing the fare.

6.6.3 Third Implementation: Competing at Each Super-Zone

To avoid the difficulty in the previous implementation, and also the shortage of air party data, the 1454 TAZs in the Bay Area have been aggregated into super-zones according their geographical locations. The principle for such aggregation is that each super-zone should have at least one air party to choose the available mode so that the probability for the air party to choose a mode can be determined. With this implementation, a *data aggregation* and *a data dissemination* process must be involved for each recursive step n the Generalized Nash Game optimization procedure as shown in Figure 6-5. This is because (a) the mode choice model is calibrated based air party data; (b) the practical calculation of the probability is also based the air party survey data in the analysis process.

Fare changes are made flexible in the implementation: the fare for each mode changing by a percent value or by a fixed amount. Implementation of this approach shows that most modes in the competition are convergent to a reasonable value except for the two airport parking modes. The reason for this will need to be investigated further. The causes could be any of the following: a code error in the implementation, optimization software problem (although we have tried the software with known simple optimization problem as preliminary tests), sensitivity of the mode choice model, or the way the super-zones are aggregated may not be reasonable. In any case, to investigate those causes would require considerable resources which are not available for this project. However, those problems can be overcome in the future phase of the project.

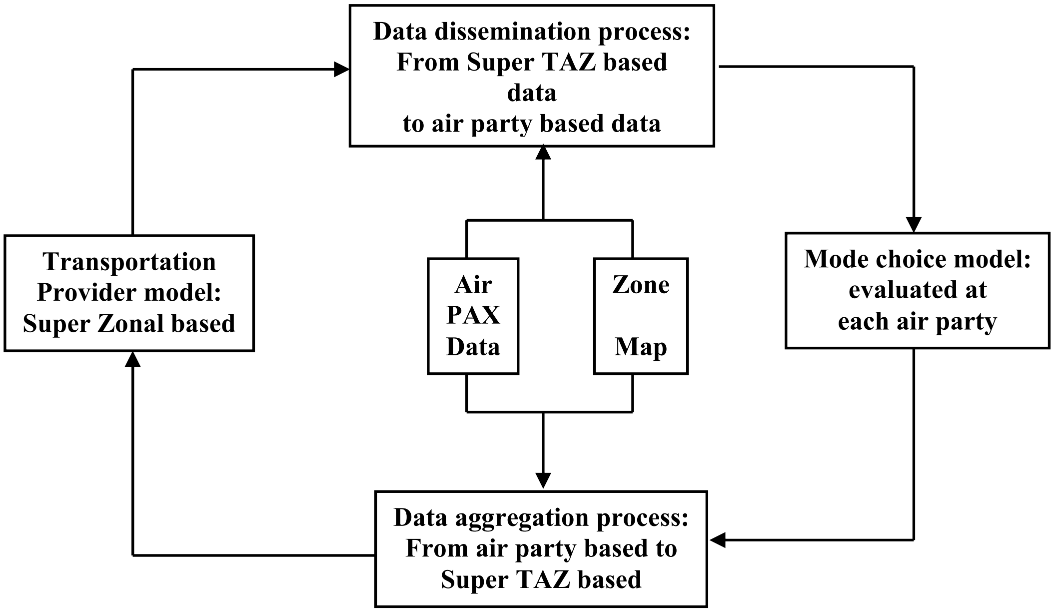


Figure 6-5: Data Aggregation and Dissemination at Each Recursive Step in the Generalized Nash Game Optimization Process

The implementation results show that the Generalized Nash Game approach does converge not properly for some modes, which may be due to many factors: (a) the quality of the Air PAX data; (b) the incompatibility with the mode choice model; (c) needs for further calibration of mode choice model; (d) the non-professional optimization software; and (e) the combination of some or all factors above. This will need further investigation in future project.

Chapter 7. Intermodal Airport Ground Access Systems Performance Measurement

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, (ii) detecting segments of the airport access/egress system where the level of connectivity needs improving, (iii) performance parameter definition. However, the mathematical formula of the performance parameters for calculation has been listed in Appendix C 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*. It is noted that most of those attributes have been used as parameters in utility function of the mode choice model discussed in Chapter 5. Thus their effects on the passenger mode choice are reflected in the probability for given passenger to choose a specific mode.

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. Although this project does not propose to address those issues, there is need for research to better understand the influence of these qualitative factors on the perceived utility of different services and modes in future research.

Airport capacity may be another important weakness point indirectly affecting passenger mode choice, although it is one of the main factors affecting air passenger airport choice which is not considered in this project. 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.

7.4 Measuring Intermodal Airport Ground Access Connectivity

The main goal of this project is to provide tools for improving airport connectivity elements and activities; this is one of the most vital tasks in airport planning and operation. Improvement in airport accessibility usually involves large investment, but hardly one can tell by how much this improvement results. Ostensibly the lack of a well-defined (airport) connectivity measure precludes from weighing and quantifying the result of such improvement. This working paper provides an overview, definitions, and formulae of measures of performance of airport access and egress connectivity elements and activities.

7.4.1 Attributes

Following, as a background material, is a list of attributes to affect the quality-of-connectivity measures (Ceder, 2005).

- Average and variance of walking time (to a service point)
- Average and variance of waiting time (for scheduled/non-scheduled services)
- Average and variance of travel time (on a given mode and path)
- Average and variance of scheduled headway.

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

- Smoothness (ease)-of-transfer (for a given discrete scale)
- Availability of easy-to-observe and easy-to-use information channels (for a given discrete scale, as a measure of uncertainty)
- Overall inter-modal connectivity satisfaction (for a given discrete scale).

These hard-to-quantify attributes will be termed *qualitative attributes.* A note worth pertaining is that the value of all these attributes may be perceived differently by different passengers or by same passenger in different situations. These different perceptions are captured in the average weighing of each attribute. The weight of each attribute is survey-based and/or based on the results of mode (path)-choice model; in this project an the Intermodal Airport Ground Access Planning Tool (IAPT) was developed and contained an advanced mode-choice model.

7.4.2 Common Measures of Performance

Known measures of performance (MOPs) in the transit industry are shown in Table 7-1. These MOPs appear in METRO (1984), TCRP Report 10 (TCRP, 1995), and TCRP Synthesis 56 (TCRP, 2004). The two most critical MOPs are: (i) passengers/vehicle-hour, and (ii) subsidy/passenger. Following are two lists of alternative benefit-and-cost measures (commonly in use worldwide) accompanied with their pros and cons.

Table 7-1: Known Transit MOPs in the US – Especially for Buses

Measure	% of US agencies using measure	Minimum standard (median)
Passengers/veh-hr	78%	11-35 pass/veh-hr
Cost/passenger	63%	3 times (system average)
Passengers/veh-mile	58%	1-3 pass/veh-mile
Passengers/trip	53%	–

__Alternative Benefit Measures__

Revenue

Pros: - relevance to financial concern
- related to willingness to pay

Cons: - discounts value of reduced fare trips
- favors higher income users

Passengers

Pros: - reflects number of people who benefit
- values each passenger equally

Cons: - doesn’t reflect trip length

Passenger miles

Pros: - weights longer trips more
- most reflective of some benefits

Cons: - hardest to measure

__Alternative Cost Measures__

Net Cost

Pros: - usually most directly constrained

Cons: - hardest to estimate

Cost

Pros: - may be directly constrained

Cons: - hard to estimate

Vehicle miles

Pros: - easy to measure

Cons: - directly reflects only about 30% of costs
- penalizes fast services

Vehicle hours

Pros: - easy to measure
- relates to more than 50% of costs

Cons: - doesn't reflect cost differences between peak and off-peak service

An assessment of ridership productivity and financial performance of any transit agency largely relies on five variables, determined on a route basis: (a) Vehicle-hours, (b) Vehicle-mile,

(c) Passenger measures, (d) Revenue, and (e) Operating cost. These five variables form the base for seven economic and operational MOPs that are in use in the U.S. (METRO, 1984; TCRP, 1995; and TCRP, 2004): (i) Passengers per vehicle-hour, (ii) Passengers per vehicle-mile, (iii) Passengers per trip, (iv) Cost per passenger, (v) Cost-recovery ratio, (vi) Subsidy per passenger, and (vii) Relative performance.

The main MOPs currently utilized can be divided into two categories: (i) passenger-based and (ii) cost-based; the first relates to ridership productivity criteria, and the second to financial criteria. These MOPs are inserted into Table 7-2 by category, number, MOP name, typical criteria range, and remarks. MOP 1 in Table 7-2, pass/veh-hour, is the most widely used productivity criterion, mainly because of the fact that the operating budget is paid out on an hourly basis. It is based, to the greatest extent possible, on unlinked passenger trips (i.e., each boarding adds one to the amount of passengers) and service (revenue) hours. MOP 2, pass/veh-mile, reflects the number of riders boarding a vehicle along a unit of distance rather than a unit of time; it, too, is based on unlinked passenger trips and on service miles. MOP 3, pass./trip, is the number of boarding passengers per single (one-way) trip; its advantage lies is in its simplicity. MOP 4, cost/pass, is a financial criterion attempting to ascertain the productivity of a route. MOP 5, cost-recovery ratio, is the ratio between direct operating costs (wages, benefits, and maintenance costs) and the share recovered by the fares paid by the riders. MOP 6, subsidy/pass, is usually the difference between cost/pass and revenue/pass. The revenue/pass. criterion reflects different fares and is used as a measure for one of the comparisons of routes. The last MOP in Table 7-2 is the relative performance of a route compared to other routes usually having the same characteristics, such as its percentile rank in either an overall ranking of system routes or in a group of routes associated with same type of service. The exact measure of this ranking varies across transit systems. Table 7-2 shows typical criteria ranges for each MOP that can be used informally or in a more formal manner. The remarks provide extra information on each MOP that will enhance implementation simplicity.

Table 7.2 List of MOPs Accompanied by their Typical Criteria Range and Data Required

Category	#	MOP Item	Typical Criteria Ranges	Data Required
Passenger - based	1	Pass. per ** Veh - hour (PVH)	Min of 8-40 PVH; Min 50-100% systemwide PVH average	Average pass. counts and scheduled veh-hours adjusted by real records
	2	Pass. per ** Veh - km (PVK)	Min of 0.6-1.5 PVK; Min of 60-80% systemwide PVK average	Average pass. counts and scheduled veh-km adjusted by real records
	3	Pass. per Trip	Min of 5-15 riders per trip; Min of 15 pass. as average load for all routes	Average pass. counts obtained from ride-check
Cost-based	4	Cost per Pass.	Max of 1.4 of system average	Average pass. counts and operational cost from financial and accounting records
	5	Cost Recovery Ratio **	Min of 0.15 – 0/30 ratio; Min of 1.0 ratio for express-type services	Revenue counts and operating costs per route
	6	Subsidy per Pass. **	Based on revenue per pass. with Min of 25-33% of system average	Average pass. and revenue counts along with operational costs
	7	Relative Performance	Min of 10-20% across all routes of a composite productivity score	Average pass. and revenue counts, and operational costs

** MOP commonly in use

7.4.3 Evaluation Methods

The evaluation methods that take place in transportation systems usually use one (or combination of) the following three approaches: (1) measures of performance (MOPs), (2) optimization techniques, and (3) fuzzy-set techniques. This chapter covers the first approach while suggesting that the other two can be included in an extension to this project.

The optimization techniques that may fit this project are based on multi-objective programming that can be classified into two differing alternative characteristic types: discrete problems and continuous problems. Discrete-type problems are based on a number of alternatives from which one is preferred. Continuous problems require a model entailing decision variables, constraints, and objective functions for creating suggested alternatives. Such variables may have any value from a given successive value structure (Cohon, 1978; Coello Coello, et al. 2002). The solution techniques of multi-objective programming are based on the fact that the dimension of the space of the objective functions in most practical problems is much smaller than that of the decision variables; hence, it is easier to perform the space of the objective functions while referring only occasionally to that of the decision variables. The choice of multi-objective technique requires two stages: creating efficient solutions and choosing the compromise solutions. The problem, when analyzed is, of a non-linear nature (concave) and contains integer variables, including the complex form of NP-complete. Such characteristics prevent the use of mathematical programming techniques usually inherent in small dimensional problems.

The fuzzy-set techniques are aiming at handling qualitative attributes and variables. A review of these techniques can be found in Avineri et al. (2000).

7.5 Performance Measurement Definitions and Implementaion in the IAPT

Three components of the evaluation process in the project are schematically presented in Figure 7-1 in which their interaction with the Intermodal Airport Ground Access Planning Tool (IAPT) is clearly ilustrated. The three components covers the work presented by Ceder (2005) and in this working paper.

7.5.1 Measure of Performance Analysis

The measures of performance (MOPs) will be divided to two groups: (1) measures of system performance (MOSP) and (2) measures of connectivityperformance (MOCP), as shown in Figure 7-1. All MOPs will be defined in terms of the output measures to be generated by the IAPT.

The MOSP are related to each of the system components; that is, transportation providers, and other public and private agencies and firms such as airport parking. The MOCP are related to the connection elements between and within systems. Both groups of measures will be attribute-based to be derived from the IAPT output measures.

Figure 7-1 shows that the MOPs can be computed for three levels of aggregate details. The first is a *path* level, defined as either an access path from a transportation analysis zone (TAZ) to a given airport terminal, or as an egress path in opposite direction. The second aggregation level refers to a given terminal in which all relevant paths (to or from, by time of day) are considered. The third is the airport level in which all terminals in the airport are considered for the category requested (access or egress, and by time of day).

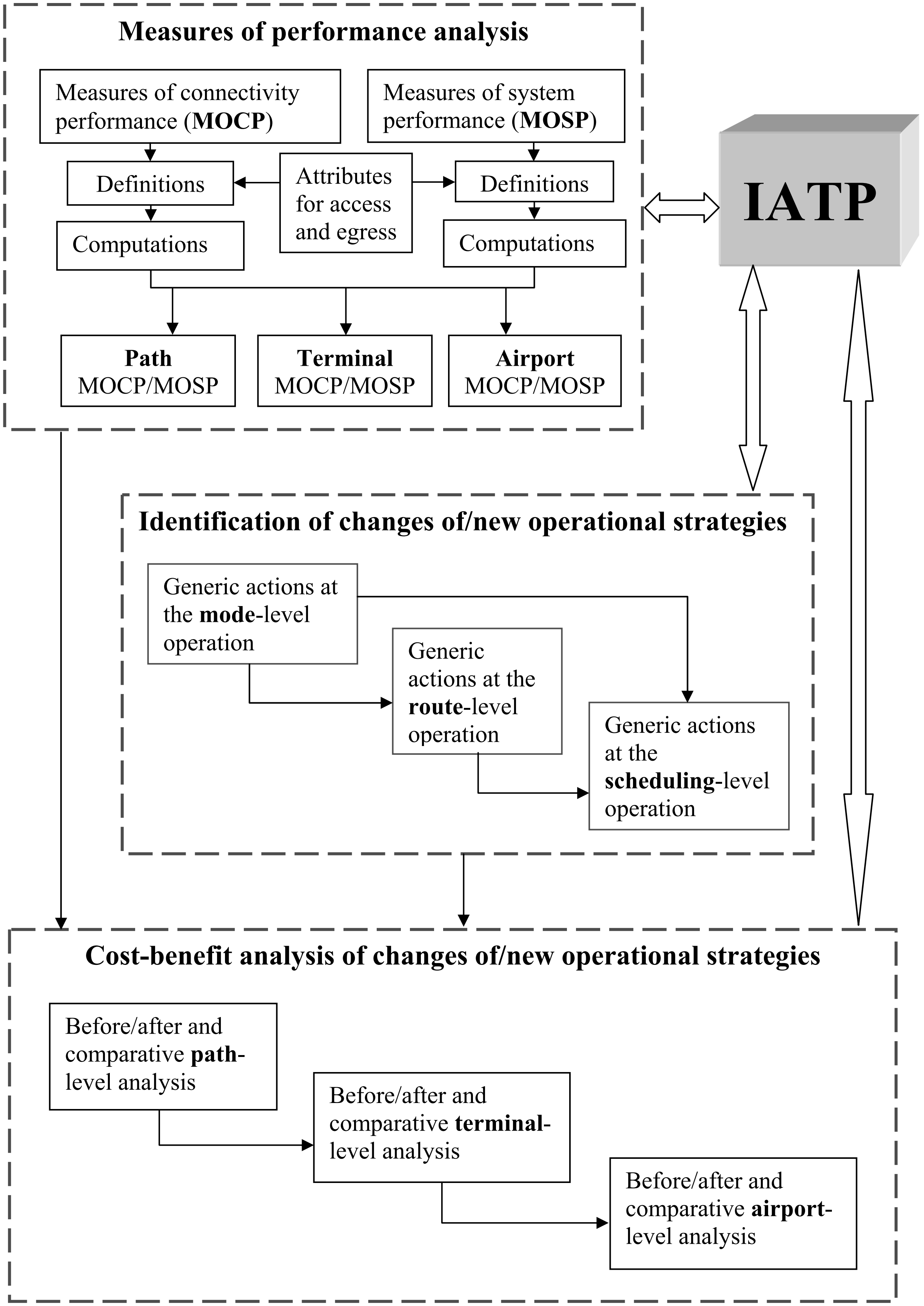


Figure 7-1: Overview of Three Interrelated Study Components

The following example illustrates the calculation of an MOCP. Assuming that from TAZ_i to terminal *q* there is a path comprising the following intermodal chain: bus-transfer to BART-walking to *q*, and the MOCP is waiting+walking times per passenger in the AM peak (at the access path-level). The relevant MOCP inputs will be the IAPT output measure of the total number of passengers on this access-path in the AM peak, the frequencies of the bus service and BART associated with the path (from which the the waiting-time components will be derived), and the distance between the BART station (in the path) and terminal *q*. Average walking speed can be extracted from the literature (e.g. from TCRP Report 100 (TCRP, 2003), in Part 7 on Terminal Capacity).

7.5.2 Evaluation Framework

The evaluation of the goodness of the intermodal airport ground service connectivity is conceptually based on three criteria: cost-efficiency, cost-effectiveness, and service-effectiveness. These three criteria are illustrated in Figure 7-2 on an input-output-consumption triangular. The MOSP and MOCP defined and formulated are used for these three criteria.

Practically speaking, the most significant measure of connectivity is the connectivity-production cost (CPC). This measure can be used for the appraisal of improvement and new projects related to intermodal airport ground access/egress activities. This CPC measure should be accompanied with four more productivity-based and environmental-based MOSP:

- Passenger/vehicle-hour (PVH)
- Passenger/ vehicle-mile (PVM)
- Revenue/passenger (RP)
- Emissions (E)

This is to say that in the comparison between before and after scenarios, or between existing system to a new or improved system, attention should be given to the following:

(1) the lower is the CPC, the better is its connectivity measures
(2) the higher is the PVH and PVM, the better is the productivity of the system proffered
(3) the lower is the value of E, the less pollutants are produced.

The following section provides a detailed example on how to use this practical approach.

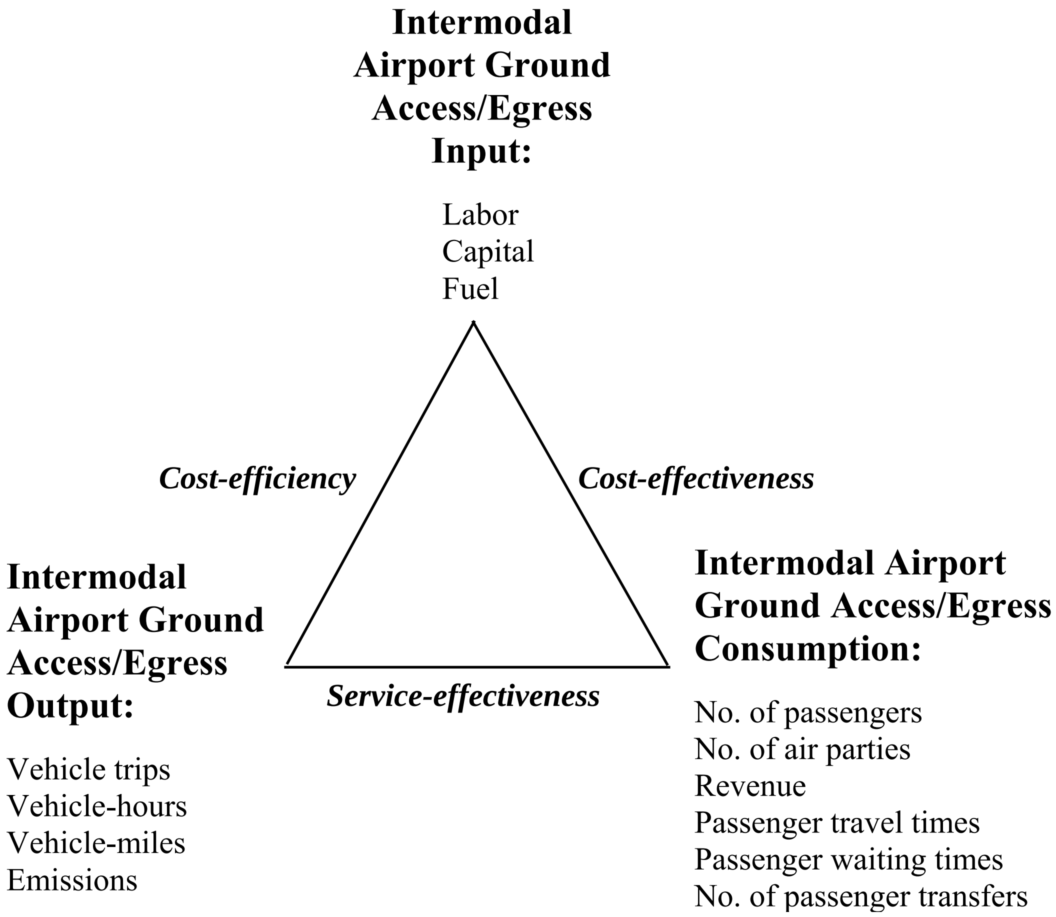


Figure 7.2: Measures and Relationships Among Service Input, Service Output and Service Consumption

The remaining MOSP and MOCP can be looked at through the perspectives of the three criteria shown in Figure 7-2 along with “better” or “worse” indications. Lastly, and following Section 7.4.3 above, it is recommended to extend this study and to include one or two of the techniques that attempt to further analyze the MOSP and MOCP using optimization and fuzzy-set modeling.

7.6 Example of MOP Calculation

Assuming that a new project is being considered of connecting a given airport terminal to its nearest BART station by a people-mover automated system. Two existing access modes are given: (a) BART and then by a shuttle bus to the terminal, and (b) drop-off by private cars. Let

P_1 people use the BART option and P_2 the drop-off option. If the people-mover automated system will become available then the two access modes will be: (c) BART and then by people-mover to the terminal, and (d) drop-off by private cars. The mode-choice model outcome is that P_3 people, $P_3>P_1$, will use option (c) and P_4 people, $P_4<P_2$, option (d); it is also assumed, for the sake of clarity, that $P_1+P_2 = P_3+P_4$, and that all P_i , i =1,2,3,4 are initiating at the same origin zone and aiming at the same terminal in a given time period. The question arises as to weather or not is justified, from the intermodal connectivity perspective, to construct the automated system.

The answer to the question can be aided by comparing the connectivity-production cost measure CPC_{before} of options (a) and (b) to CPC_{after} of options (c) and (d). The P_1 path is *wait*-BART-*wait*-shuttle; the P_3 path is *wait*-BART-*wait*-people mover; and the P_2 and P_4 paths are direct without wait. The following given data are necessary for the CPC calculation.

(1) Average private car occupancy to the terminal =1.5 people
(2) Private car average riding time = 45 minutes (3/4 hr)
(3) BART headway = every 20 minutes (average wait = 10 minutes = 1/6 hr)
(4) BART average riding time = 30 minutes (1/2 hr)
(5) Average shuttle bus occupancy = 12 people
(6) Shuttle headway = 10 minutes (average wait = 5 minutes = 1/12 hr)
(7) Shuttle average riding time = 8 minutes (2/15 hr)
(8) Average people mover expected occupancy = 10 people
(9) People mover headway = 6 minutes (average wait = 3 minutes = 1/20 hr)
(10) People mover average riding time = 4 minutes (1/15 hr)
(11) One-hour waiting time cost per passenger = e_{37} = \$10
(12) Transfer penalty per passenger = e_{38} = \$2
(13) One-hour travel time cost per passenger = e_{39} = \$8
(14) Average combined veh-hr operating cost for BART $e_{40}^{R} = 0$ (N/A), for private car e_{40}^{1}=\$15, for shuttle bus e_{40}^{3}=\$20, and for people mover e_{40}^{pm} = \$150
(15) Drop cost = e_3 = \$3.

The BART operating cost e_{40}^{R} is zero as the train traverses the airport area even if no passenger considered for the airport terminal is using it. The shuttle and people mover hourly operating cost includes crew, fuel, and maintenance costs.

7.6.1 Calculation of CPC_{before}

For the P_1 demand:

- Wait for BART cost ($): $P_1 \cdot (1/6) \cdot 10 = 5/3\ P_1$
- Ride on BART cost ($): $P_1 \cdot (1/2) \cdot 8 = 4\ P_1$
- Wait for shuttle cost ($): $P_1 \cdot (1/12) \cdot 10 = 5/6\ P_1$
- Ride on shuttle cost ($): $P_1 \cdot (2/15) \cdot 8 = 16/15\ P_1$
- Shuttle veh-hr operating cost ($): $(1/12)\ P_1 \cdot (2/15) \cdot 20 = 2/9\ P_1$

For the P_2 demand:

- Ride in car cost ($): $P_2 \cdot (3/4) \cdot 8 = 6\ P_2$
- Drop cost ($): $(1/1.5)\ P_2 \cdot 3 = 2\ P_2$
- Car veh-hr operating cost ($):$(1/1.5)\ P_2 \cdot 15 = 10\ P_2$

Thus, $CPC_{before}(\$) = 7.788\ P_1 + 18\ P_2$

7.6.2 Calculation of CPC_{after}

For the P_3 demand:

- Wait for BART cost ($): $5/3\ P_3$
- Ride on BART cost ($): $4\ P_3$
- Wait for people mover cost ($): $P_3 \cdot (1/20) \cdot 10 = 1/2\ P_3$
- Ride on people mover cost ($): $P_3 \cdot (1/15) \cdot 8 = 8/15\ P_3$
- People mover veh-hr operating cost ($): $(1/10)\ P_3 \cdot (1/15) \cdot 150 = P_3$

For the P_4 demand:

- Ride on car cost ($): $6\ P_4$
- Drop cost ($): $2\ P_4$
- Car veh-hr operating cost ($): $10\ P_4$

Thus, $CPC_{after}(\$) = 7.7\ P_3 + 18\ P_4$.

For instance, $P_1 + P_2 = P_3 + P_4 = 1000$ people, where $P_1 = 200$, $P_2 = 800$, $P_3 = 300$, and $P_4 = 700$ people. Then, $CPC_{before} = 1558 + 14400 = \$15958$ and $CPC_{after} = 2310 + 12600 = \$14910$, meaning that the people mover project is worth consideration.

If P_1 and P_2 are unchanged, but $P_3 = 400$, and $P_4 = 600$ people; then, CPC_{before} is unchanged and $CPC_{after} = 3080 + 10800 = \$13880$, meaning that the less people use the private car drop-off option and switch to BART, the less is the connectivity-production cost. In addition when applying the people mover system the productivity measures of passengers/veh-mile, passengers/veh-hr and revenue/passenger will go up and the emission will go down; this is an additional support for constructing the new project.

Chapter 8. Guidelines for Project Evaluation Using the IAPT

These guidelines provide information on the use of the Intermodal Airport Ground Access Planning Tool (IAPT) to perform project evaluation for planning improved intermodal connectivity at airports. In particular, the guidelines outline the core concepts in evaluating potential projects through the quantitative analysis approach implemented in the IAPT.

The objective of performing quantitative analysis on proposed improvements to intermodal connectivity at an airport is to provide a basis for estimating the likely usage of the proposed facilities or services, the resulting cost-effectiveness of the proposed project, the economic impacts on the other transportation providers at the airport, and the environmental impacts in the rest of the transportation. The estimated measures of system performance that are output by the IAPT can be used by planners to evaluate the feasibility of the proposed project and the potential overall impact of the project on the airport ground access system and larger transportation system.

The MOPs (Measures of Performance) used in this chapter are described in Chapter 7.

8.1 Project Definition

The IAPT is designed to analyze a set of defined project alternatives at a given airport, where each project alternative represents a specified combination of ground access modes and associated service levels. Projects are defined in a hierarchical structure for a specific airport. At the top-level of the hierarchy is the baseline project that serves as a framework for project alternatives. The user could define the baseline project to represent the current airport ground access system or any user desired configuration. The project alternatives built under the baseline project will inherit its characteristics before the user make the alterations to the alternatives. The baseline project will serve as a comparative framework after project alternatives are evaluated. Prior to evaluation of a potential improvement, the planner or decision makers needs to undertake the following actions

8.1.1 Identify the Extent of the Ground Access System to Be Evaluated

The relevant elements to be considered in the analysis may include various decision makers (*e.g.* different levels of government), system users (air passengers, air cargo shippers, and airport employees), ground transportation providers and operators, and the relevant surface transportation network.

8.1.2 Identify and Prioritize the Main Goals for the Proposed Project

These goals should not only represent the anticipated advantages of developing the proposed project but also consider the collective interests of all the relevant stakeholders in the airport ground transportation system mentioned above. The priorities that are assigned to each goal should aim to maintain or improve airport ground accessibility and maximize overall social and economic benefits. These goals should include but not be limited to balancing demand and capacity, minimizing passenger travel time and user costs, minimizing total travel time and vehicle-miles of travel on the overall system, minimizing air pollution, highway traffic congestion, and system costs, and maintaining financial viability of transportation providers. Although it is often difficult to obtain general consensus among the various stakeholders, there should be adequate interagency coordination among the decision makers and operators to ensure the goals selected represent general interests.

8.1.3 Identify the Set of Attributes that Defines the Proposed Project Alternative

The attributes could refer to the changes in an existing service such as fare or frequency adjustments. If a new transportation mode is proposed, the planner will need to define the relevant service characteristics. For example, in evaluating the effect on the ground transportation system performance of implementing an automated people-mover link between an airport and a nearby rail station, the user will need to provide information on system capacity, trip times, service frequency, and fare.

8.2 Project Evaluation

Once user-defined MOPs have been generated for a baseline project and project alternatives, the following evaluation steps can be followed.

8.2.1 Alignment of Project Performance with Project Goals

The planner should evaluate whether the performance of each project alternatives is aligned with the main goals identified for the proposed improvements by either the airport or relevant planning agencies. For example, if the airport proposed a new automated people-mover with the goal of generating greater transit ridership than the current shuttle system, the extent to which this has been achieved will be evident from the ridership performance measures for the various project alternatives. The ridership estimates will also help assess whether the project is economically feasible and which alternatives qualify for further consideration.

8.2.2 Feasibility Check

The proposed alternative should be feasible physically (*e.g.* the ridership generated for a mode cannot be greater than the capacity) and financially (*e.g.* a system with a high operating frequency may incur unacceptably high operating costs). The planner should also check the feasibility of the project alternatives from the short term perspective, in which competing transportation providers are likely to change their service characteristics to adapt to the change in the system; and the long term perspective by projecting ridership and modal split for future air passenger demand. The proposed service attributes should promote overall network efficiency and generate either direct or indirect social and economical benefits through minimizing travel time, passenger waiting and transfer time, and vehicle emissions, or by improving system cost-effectiveness.

8.2.3 Review of Goal Priorities

Since more than one project alternative may satisfied the pre-set goals, the planner should compare the resulting measurement values with the list of priorities set for each of the project goals. Increased cost-effectiveness and revenue generation, for instance, may stand higher on the priority list than reducing vehicle emissions.

8.2.4 Identification and Resolution of System Performance Issue

When the resulting performance measurements do not show the proposed projects meeting the expected or desirable results, the values of the analysis output measures should be studied and compared between projects and across modes to help identify the causes of the deficiency in the proposed system. If the issue appears to be a localized problem affecting a single aspect of the system, such as providing direct service to too many different locations, the planner could make adjustments accordingly and redo the evaluation. This process calls for some interpretation of the model output on the user's part and may require a certain degree of trial-and-error. If a project alternative cannot generate improvements in the system performance no matter how the operating parameters are altered, this is likely to indicate an inherent shortcoming in the project alternative. In this event, the planner should go back to project definition stage and reformulate the proposed improvement.

8.3 Institutional Considerations

While the development of the IAPT provides an analytical approach to address airport ground access problems from a technical and quantitative perspective, it is worth noting that a significant part of the impediments to improved airport ground access arises from institutional considerations.

8.3.1 Potential Institutional Issues in Airport Ground Access

Awareness and understanding of the issues for all stakeholders is an integral step in addressing airport ground access needs. The recent *Ground Access to Airport Study* performed for the California Department if Transportation (Landrum & Brown Team, 2001a, 2001b) explored these issues in some detail. The central issues identified in the study can be summarized as follows:

(1) Failure to Recognize the Need for Improvement in Airport Ground Access

While much of the federal resources devoted to airport planning focuses on improving efficiency and alleviating congestion on the airside, not nearly enough attention and funding is given to the landside operations, resulting in an inadequate level of accessibility. This phenomenon occurs due to a common misconception that airport ground access is a localized airport issue but in fact the system serves users and cargo from different places and is an important traffic generator that can produce considerable impact on the regional transportation infrastructure and network. Airport ground access plays a key role in supporting aviation activity that induces significant economic benefits on the regional and state level and plays a major role in national competitiveness. Failure to ensure that decision-makers at appropriate levels of authority are aware of the importance of airport ground access needs can limit the likelihood of ground access projects being considered for funding or implementation.

(2) Lack of Comprehensive Interagency Communications and Coordination

Ground access planning usually involves a number of agencies spanning multiple jurisdictions from local airport operators to government at the regional, state, and even federal level. The specific responsibilities of each agency and the roles each plays in ground access planning rely heavily on the individual institutional responsibilities defined in the relative legislative authority. Very often the necessary actions that can be taken by each agency are not mutually exclusive or collectively exhaustive. At the same time, airport ground access issues often get overlooked because these agencies tend to act independently of each other on intermodal issues and the current system lacks appropriate protocols for efficient communication and coordination. This results in an unbalanced distribution of resources where one problem area might be receiving duplicate attention while another is being overlooked completely. Since responsibility for airport ground access planning involves both airport authorities and a wide range of transportation planning and operating agencies, successful ground access planning demands careful attention to interagency relationships and requires a considerable degree of coordination between these agencies.

(3) Lack of Consensus in Setting Overall Objectives

Implementation of airport ground access improvement projects affects a multitude of public and private stakeholders, including transit and highway agencies, environmental agencies, air passengers, local residents, airport employees, and various ground transportation service providers. Among these interest groups, many share similar objectives for improving airport ground access while some have goals in direct conflict with one another. For example, intermodal connectivity and airport accessibility can be enhanced from several approaches including reducing waiting and travel times, increasing convenience, and lowering costs. Unfortunately these measures frequently involve difficult trade-offs. Travel time or convenience can be improved but at a cost that may have to be borne by the system users or even at the expenses of the general travelers in the transportation network. Thus considerations of efficiency and service quality must attempt to address the entire spectrum of transportation needs to avoid actions that have unintentional adverse impacts on other parts of the transportation system.

8.3.2 Handling Institutional Issues at the Regional and Inter-Regional Levels

In devising airport ground access improvement plans, practitioners should approach the problems from both technical and institutional perspectives. By looking in depth at the key institutional issues mentioned above, practitioners should outline a course of action tailored to the specific institutional environment for an individual airport and designed to address each of the key issues. The following recommended strategies can be adopted and altered to suit the particular needs and functional characteristics of individual airports.

(1) Airports Should Be Actively Involved in Regional and State Transportation Planning

Since there is a lack of understanding and recognition of the needs to improve airport ground access outside of local jurisdictions, the responsibility of making these needs heard at the upper level falls on the airport authorities. By becoming an active participant in the regional and state transportation planning and policy-making process, the airport can assure that its needs are being integrated into the regional and statewide objectives. This involvement will not only increase awareness of the airport's role in improving statewide competitiveness and contributing to the economic system, but enable airports to also enhance their access to funding from non-aviation sources. To do so, the airports need to familiarize themselves with the planning process and funding programs, while the state and regional agencies should encourage the attendance of airport representatives at planning sessions and meetings.

(2) Airport Authorities Need to Proactively Address Intermodal Access Issues

Airport authorities need to increase the attention given to improving intermodal connectivity within their overall ground access planning activities. In particular, this planning needs to consider the following issues:

- Matching of airport demand to the capacity of ground access system
- Addressing right of way issues involved in improving airport access links
- Considering the role of surrounding land uses in the demand on the ground transportation system serving the airport.

(3) Better Coordination Methods Should be Implemented Among Planning Agencies to Address Airport Ground Access Issues

Since many institutional issues originate from the lack of interagency interactions and coordination, airport ground access planning needs to be integrated into the existing comprehensive multi-modal planning process in order to ensure that the appropriate coordination occurs within the existing framework for intermodal planning. This will help ensure that airport ground access issues receive appropriate consideration as part of the overall transportation planning framework and allow the airport ground access planning process to take advantage of existing procedures for interagency coordination.

(4) Integrating Airport Ground Access Planning into Local and Regional Transportation System Planning

Planning for airport ground access needs to be integrated into the relevant existing transportation plans prepared by local and regional agencies. These include the Regional Transportation Plan (RTP), transportation elements of the general and specific plans prepared by jurisdictions adjacent to the airport, and strategic and development plans of public transportation agencies serving the airport. This integration will help ensure that airport ground access considerations will be considered by those agencies when preparing and updating their plans. In order to provide a forum in which these integration issues can be addressed, it may be desirable for airport authorities and regional transportation planning agencies to jointly sponsor an airport ground transportation planning working group that would meet periodically to review issues of common interest and coordinate the inclusion of airport ground access considerations in other plans. Airport authorities are increasingly recognizing the need for similar formal coordination efforts in the area of airport noise management and compatible land use planning. It would be a fairly logical extension of these activities to establish a parallel effort to address airport ground access issues.

8.3.3 Handling Institutional Issues at the Project Level

At the level of individual projects, institutional issues can often arise between the airport authority and the surrounding jurisdictions and the wide range of public and private transportation providers serving the airport.

(1) Institutional Issues Regarding the Relationship between Airports and Local Government

Since airport ground access projects often involve facilities that are off the airport property and current federal regulations restrict the ability of airport authorities to spend airport funds off airport property, coordination with surrounding jurisdictions is needed to address a range of issues, including:

- Land use planning and project approval
- Capital investment in off-airport facilities
- Operational and maintenance responsibilities for off-airport facilities.

(2) *Institutional Issues Regarding the Relationship between Airports and Transportation Providers*

The majority of airport ground transportation services are provided by private sector firms on a for-profit basis. For many modes, multiple firms are in competition with each other. Thus airport ground transportation planning needs to consider both the relationship between the airport authority and these providers as well as the relationships between different providers. Relevant issues include:

- Access fees for use of airport facilities and the right to pick up passengers
- Operational coordination between providers
- Contractual arrangements between ground transportation providers and the airport.

(3) *Regional Transportation Planning Agencies and Airports should Jointly Establish and Maintain an Integrated Database for Ground Access Planning*

For planners, acquiring the necessary data to perform airport ground access system analysis is an integral component in developing innovative solutions to airport intermodal connectivity issues. Due to the wide range of factors affecting intermodal connectivity, it is often very difficult to obtain the necessary information for project evaluation. If a comprehensive database can be implemented that gives planners easy access to pertinent airport ground access information, this should encourage innovative solutions and improve efficiency in planning for airport ground access. Such a database could incorporate the following information:

(a) Airport data

- Airport master plans and ground access planning studies
- Air passenger and cargo traffic statistics
- Air passenger survey data
- Airport employee access/egress travel patterns
- Airline flight schedule and fare data

- Ground transportation modes and service characteristics
    - Service area
    - Routes and system connectivity
    - Schedules
    - Fares
    - Ridership and vehicle trip statistics
    - Operating cost information
- Airport roadway and terminal curb activity information, including time-based classified vehicle counts
- Airport parking information, including rates and use statistics

(b) Regional Data

- Regional transit network information: connectivity information, etc.
- Regional highway network information: travel distances and travel times
- Regional population density and household income information.

While much of the foregoing data already exists in a variety of airport authority or regional transportation planning agency databases, assembling the information in a consolidated database will not only simply its use for airport ground transportation planning but also allow any missing data to be identified and assembled.

Chapter 9. Potential Bay Area Case Study Analysis

This chapter presents a potential feasibility analysis of five case study projects using the IAPT. Scenarios of the case study analysis are discussed in some detail. However, due to the large amount of work involved in the development of the mode choice model and the prototype IAPT, and funding constraints, detailed analysis was deferred to a future phase of the research. The five potential Bay Area case studies were described in Chapter 3 comprise:

- The Oakland Airport Connector automated people-mover between the Coliseum BART and Amtrak stations and Oakland International Airport;
- A planned automated people mover at San José International Airport connecting the airport to nearby stations of the Santa Clara Valley Transportation Authority light rail system and the Caltrain commuter rail line serving communities between Santa Clara County and San Francisco;
- A proposed ferry service linking a terminal serving San Francisco International Airport with downtown San Francisco and the East Bay;
- An off-airport terminal located in the South Peninsula serving Oakland International Airport and potentially San Francisco International and San José International Airports;
- An off-airport terminal located to the south of downtown San José providing service between Santa Clara County and both Oakland International Airport and San Francisco International Airport.

Each of these case studies can be analyzed using the Intermodal Airport Ground Access Planning Tool (IAPT) for a range of different analysis scenarios. These alternative service scenarios were selected in order to explore the impact of varying the service characteristics of the proposed intermodal projects on the ridership and operating economics. Each project should first be evaluated based on the proposed service characteristics assumed in prior studies or adopted for similar services elsewhere in the region. A sensitivity analysis can then be performed by evaluating each project for a range of service levels (*e.g.* higher or lower fares and frequencies).

The current version of IAPT has the capability to define three types of new project:

- Adjustment to the service levels and fares for an existing service
- Introduction of a new service for an existing mode
- Implementation of a new mode not currently available in the system.

The first two case study projects involve the implementation of a new mode as a replacement for an existing service. The Oakland Airport Connector (OAC) and the San José International Airport (SJC) APM will replace existing shuttle bus services that provide connections between the airports and the regional rail transit system. The third case study project, the proposed South San Francisco ferry terminal, involves the implementation of a new service that makes use of a new mode that is not currently used to provide airport ground access service. The South Peninsula and Santa Clara County off-airport terminals are new services, but utilizing a mode that is currently serving other parts of the region.

Thus the choice of case study projects not only represents a broad range of potential ways to enhance intermodal connectivity at the Bay Area airports, but also serves to demonstrate the capabilities of the IAPT to analyze different types of projects.

9.1 Definition of the Analysis Scenarios

In the case of the OAC and SJC APM projects, the proposed people movers will provide reduced travel time and waiting time compared to the existing shuttle bus service, but the baseline assumption is that there will be no change in the fare currently charged in the case of the OAC, while the SJC people mover link will continue to provide a free connection to the VTA light rail and Caltrain stations as presently offered by the Airport Flyer bus. The alternative service scenarios for the sensitivity analysis should vary the travel time, waiting time, and fare assumptions. These scenarios include eliminating the fare in the case of the OAC and charging a fare in the case of the SJC people mover link.

In the case of the SJC people mover link there is also a small reduction in the time required to walk to and from the people mover compared to the existing shuttle bus. This is not varied in the analysis scenarios. Similarly, the travel time involved in using the proposed ferry service to San Francisco International Airport (SFO) includes riding a shuttle bus connection between the Oyster Point ferry terminal and the airport terminals. This will be assumed to take

10 minutes, including the time to board passengers at the ferry terminal, and will not be varied in the analysis scenarios. It will also be assumed that the shuttle bus waits for the ferry and departs as soon as the last passenger has disembarked from the ferry. In reality, the access and egress times for the proposed intermodal connecting services will also depend on the passenger terminal used by each traveler.

In the case of SFO the travel time will also differ between arriving and departing passengers due to directionality of the terminal roadway circulation, with those being dropped off first on the access trip to the airport also being picked up first (and hence having a longer travel time) on the egress trip. These differences will therefore tend to cancel out, although passengers may view access travel time differently from egress travel time, due to the importance of not missing a flight. In the case of the SJC people-mover, the effect of the direction of circulation on the terminal roadway system affect the travel time on the existing shuttle bus in the same way as for SFO, but due to the planned configuration of the automated people mover, travelers between the VTA light rail station and Terminal A will have a longer ride on the people mover in both directions than travelers between the light rail station and the new Terminal B. However, the reverse is true in the case of travelers using Caltrain. While this difference could be explicitly included in the analysis, it is small enough that it can be effectively ignored.

The off-airport terminal case study analysis scenarios also include the daily parking rate at the off-airport terminal. Since this is likely to have a variable effect on the attractiveness of the service, depending on the traveler’s trip duration, the service scenarios include different parking rates.

In order to limit the number of service scenarios to be analyzed, a baseline scenario and six alternative scenarios were defined for each case study, as shown in Table 9-1. While these do not cover all possible combinations of the alternative assumptions for waiting time, travel time, and cost variables, they have been chosen to give an indication of the trade-offs involved between these operational parameters.

Table 9-1: Input Parameters for Case Study Baseline and Sensitivity Analysis

1. Oakland Airport Connector

	Service Level		*IAPT Input Value*[1]	*Input Values for Sensitivity Analysis*[1]					
	AirBART	OAC		1	2	3	4	5	6
Service Data									
Wait Time (min)	5	1.75	-3.25	-2.5	-2.5	-3.25	-3.25	-3.25	-3.25
Travel Time (min)	15	6.4	-8.6	-8.6	-8.6	-8.6	-8.6	-5	-10
Fare ($)	3	3	0	0	-3	-3	2	0	0

2. Automated People Mover Link at SJC to VTA Light Rail Transit Service

	Service Level		*IAPT Input Value*[1]	*Input Values for Sensitivity Analysis*[1]					
	Airport Flyer	APM		1	2	3	4	5	6
Service Data[1]									
Wait Time (min)	5	2.5	-2.5	0	-3.75	-2.5	-2.5	-2.5	-2.5
Access Time (min)	4	3.6	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Travel Time (min)	9	1.8	-7.2	-7.2	-7.2	-4	-4	-7.2	-7.2
Fare ($)	0	0	0	0	0	0	2	2	5

3. Ferry Service to SFO

	Service Level	*Input Values for Sensitivity Analysis*[2]					
	Ferry	1	2	3	4	5	6
Service Data							
Wait Time (min)	30	10	15	10	15	30	10
Access Time (min)	10	10	10	10	10	10	10
Travel Time (min)	30	30	30	20	20	30	20
Fare ($)	5	5	5	5	5	10	10

4. & 5. South Peninsula and Santa Clara Off-Airport Terminals

	Service Level	*Input Values for Sensitivity Analysis*[2]					
	Off-Airport Terminal	1	2	3	4	5	6
Service Data[1]							
Wait Time (min)	15	10	30	10	10	15	15
Travel Time (min)	60	60	60	45	45	60	60
Fare ($)	18	18	18	12	18	12	6
Parking ($/day)	4	4	4	4	10	4	2

Note: 1. Input values for the Oakland Airport Connector and SJC automated people mover represent changes relative to the current shuttle bus service level.

2. Input values for the SFO ferry service and South Peninsula and Santa Clara off-airport terminals represent the assumed service level for that scenario.

In the case of the OAC, headways are assumed to vary between 2 and 3.5minutes. In the case of the SJC people mover, headways are assumed to vary between 2.5 minutes and 5 minutes. In some analysis scenarios, travel times in the people mover should also be varied. Although operating speeds are generally constant for a given technology and system configuration, choice of technology, route alignment, or inclusion of intermediate stations could affect the travel time. Service headways for the ferry case study and off-airport terminals are assumed to vary between 20 minutes and an hour. Travel times are also assumed to vary in some scenarios, reflecting a choice of technology in the case of the ferry system or differences in terminal location in the case of the of-airport terminals.

9.2 Representation of the Case Studies Using the IAPT

Analysis of the case study scenarios using the IAPT requires an initial set of input data describing the existing conditions to be defined. This is based on the 2001 MTC air passenger survey data with corresponding 2001 service levels for each of the existing ground access modes. In the case of the OAC and SJC people mover links, analyzing each of the service scenarios simply involves changing the service characteristics for the respective rail transit modes (BART, VTA light rail, or Caltrain) to reflect the difference between the people mover service scenario and the current shuttle bus service. In the case of the ferry service or off-airport terminal scenarios, a new mode must be defined with the appropriate service characteristics. This is somewhat more complicated, since the transportation service levels for the proposed service from each transportation analysis zone (TAZ) must include the access time to reach the appropriate ferry terminal or off-airport terminal.

9.2.1 Access to Ferry Terminals

The ferry service case study assumes that ferry service would be provided to a terminal at Oyster Point from both the downtown San Francisco ferry terminal and a ferry terminal at Harbor Bay Isle. Airport travelers using the ferry would need to first access either the San Francisco or Harbor Bay Isle terminal. There is currently very limited parking at the downtown San Francisco ferry terminal and parking in the vicinity of the terminal is fairly expensive. Therefore it is assumed that airport travelers using the ferry from San Francisco would use public transportation to reach the terminal. It is unlikely that many people would be dropped off at the terminal by private vehicle, since the majority of airport travelers attracted to the service are likely to come from the immediate downtown or nearby North Beach area of San Francisco. Travelers from other areas of San Francisco are likely to find BART a much more convenient way to reach the airport.

Some airport travelers from Marin, Napa and Solano counties may find it convenient to use other ferry services to the San Francisco ferry terminal from Sausalito, Larkspur or Vallejo and transfer to the Oyster Point service at the terminal, although it should be noted that the Marin Airporter Larkspur Landing terminal is located across the street from the Larkspur ferry terminal. There is no charge for parking at the Vallejo ferry terminal and overnight parking is allowed for up to 48 hours. Parking at the Larkspur ferry terminal is limited to 24 hours, although there is long-term parking at the Marin Airport terminal across the street for $4 per day. There is no dedicated ferry parking at the Sausalito ferry pier, although there are nearby municipal lots that have a 72-hour parking limit.

For the purposes of the case studies, it will be assumed that Bay Area residents using the ferry system from Marin, Napa or Solano counties or the East Bay would park at or near the terminal for trips of two days or less. Residents on longer trips or visitors starting their access trip from a home of family or friends or from a business will be assumed to be dropped off by private vehicle. Visitors starting their access trip from a hotel not using rental car will be assumed to use taxi to access the ferry terminal. Visitors using rental car will be assumed to need to return the car to the airport and thus will not consider this airport access option.

It will also be assumed that only those airport travelers from San Francisco or the East Bay with trip origins within a reasonably close proximity to the ferry terminals will consider this option. This comprises MTC Superdistrict 1 in San Francisco (downtown and North Beach), and transportation analysis zones in the City of Alameda and the City of Oakland south of 23rd Avenue.

9.2.2 Access Travel Time to Off-Airport Terminals

It will be assumed that residents of the Bay Area using the off-airport terminals on trips of six days or less will park at the terminal. Residents on longer trips or visitors starting their access trip from a home of family or friends or from a business will be assumed to be dropped off by private vehicle. Visitors starting their access trip from a hotel not using rental car will be assumed to use taxi to access the terminal. Visitors using rental car will be assumed to need to return the car to the airport and thus will not consider this airport access option.

9.2.3 Alternative-Specific Constants for Automated People Mover Case Studies

The ridership analysis of the proposed SJC automated people mover (APM) undertaken by Dowling Associates (2002) included a stated preference survey that was used to assess the increased attractiveness of the people mover compared to the existing shuttle bus. This resulted in generally slightly higher alternative-specific constants (ASCs) for transit routes involving the APM than for those not using the APM, as discussed in Chapter 3. However the SJC mode choice model also included separate coefficients for rail transit time and bus transit time that were adopted from an earlier model, and so it is unclear how the difference in the ASCs would change if different values were to be estimated for the travel time coefficients, or indeed if the same coefficient were to be used for rail transit and bus transit travel times. The differences in the values of the ASCs are fairly small, having an implied value between about 30 and 80 cents in 1985 dollars, depending on the market segment, or between about 50 cents and $1.40 in 2001 dollars. It seems reasonable that airport travelers would perceive an APM as offering a higher level of comfort and convenience than a shuttle bus, although it is less clear whether it would be valid to apply the ASC values developed for the SJC ridership analysis to another model. In the absence of more detailed information supporting the use of a different value, it will be assumed that the ASC for an APM link to a regional rail system will have a higher utility than that for a shuttle bus service by an amount equivalent to $1 in 2001 prices.

9.24 Alternative-Specific Constants for Ferry Service and Off-Airport Terminals

In addition to the travel times and costs, the mode choice model utility function for the proposed ferry service requires an alternative-specific constant. This cannot be estimated for the Bay Area, since there is currently no ferry service to any Bay Area airports. However, the mode choice model estimated for Boston Logan airport that is described in Chapter 5 included a water shuttle ferry between downtown Boston and the airport. An alternative-specific constant for the proposed Bay Area ferry service will be assumed based on applying the ratio of the alternative-specific constants for the water shuttle and the Boston rail transit system to the estimated alternative-specific constant for BART.

The alternative-specific constants for the South Peninsula and Santa Clara off-airport terminals will be assumed to be the same as the estimated alternative-specific constant for the Marin Airporter off-airport terminal.

9.2.5 Growth in Air Travel

Although it is envisaged that the IAPT analysis will be based on air party characteristics and transportation service patterns for 2001, the analysis will be performed for expected levels of air traffic in 2010, the earliest year in which any of the proposed case study projects could realistically be implemented. The growth in air passenger traffic at the three airports from 2001 to 2010 will estimated based on the Federal Aviation Administration Terminal Area Forecasts (FAA, 2007).

9.2.6 Capital and Operating Costs

The IAPT provides the capability for users to enter capital and operating cost data for proposed projects in order to analyze the economic feasibility of the project. Preliminary estimates of capital and operating costs for the case study projects are given in Chapter 3. No capital or operating costs for the ferry service itself will be allocated to airport travelers, since it is assumed that the service will operate whether or not airport travelers use it. However, the operating costs for the shuttle bus connection between the ferry terminals and the airports will be included in the analysis.

Chapter 10. Policy Recommendations

Although airport access and egress travel represents a fairly small proportion of total regional travel, major commercial airports generate a large number of vehicle trips on the regional highway system and are often one of the largest single trip generators in the region. In addition, the level of airport-generated vehicle traffic on surrounding streets and highways are often of significant concern to surrounding communities. Continued growth in air travel is likely to result in even greater levels of highway traffic and resulting congestion in the future if nothing is done to expand the capacity of the surface transportation system serving the airports. In many situations, particularly where airport access highways also serve significant amounts of regional traffic, opportunities to increase the capacity of the highway system are limited.

Additional constraints may also exist in areas that are not in attainment of regional air quality standards, and expansion of airport capacity may require the implementation of mitigation measures designed to reduce vehicle travel generated by the airport. Recent legislation in California addressing greenhouse gas emissions may also create new constraints in the future as regulations are developed to implement the goals of reducing carbon emissions. Airports may face a particular challenge because options to reduce emissions from aircraft are limited and largely outside the control of the airport operators.

For all these reasons, there is an increasing interest in strategies to improve the connectivity between airports and other elements of the regional public transportation system, particularly rail systems. At the same time, it must be recognized that many potential projects are not only costly to implement, but may be of limited effectiveness in reducing the amount of vehicle travel generated by the airport served by the project. It is therefore important to carefully evaluate potential opportunities in order to understand the extent to which they may contribute to meeting the dual policy goals of reducing vehicle travel and emissions.

At both Los Angeles International and San Francisco International Airports, a significant fraction of runway capacity is utilized by regional airline flights that provide access to the national and international airline network for air travelers from smaller communities throughout the state and beyond. As runway capacity becomes increasingly constrained at the major airports, it will become desirable to seek creative ways to reduce the number of regional airline flights to free up capacity for use by larger aircraft. One such strategy is to make greater use of the surface transportation system for travel between smaller communities in the state and the largest commercial service airports. Improved intermodal connectivity at the congested airports can leverage past and future investments in improved intercity rail service.

This chapter examines some of the policy implications of the findings of the current study and presents recommendations for actions that the California Department of Transportation (Caltrans) should take to encourage greater intermodal connectivity at the larger commercial service airports in the state.

10.1 Potential Opportunities for Improved Intermodal Connectivity

This report has identified a number of potential opportunities to improve intermodal connectivity at various California airports and has developed a more detailed case study analysis of several potential projects in the Bay Area that can be undertaken as part of future work.

Some of the potential opportunities identified in this report are currently being studied by the relevant agencies. Caltrans should monitor the results of those studies as they become available and assess whether the approaches examined may be applicable at other airports in the state. It would also be worthwhile to perform a more detailed assessment of those potential opportunities discussed in this report but not yet studied by other agencies or included in the analysis of the Bay Area case studies described in Chapter 9.

Recommendation: Caltrans should continue to study potential opportunities to improve airport intermodal connectivity in California, both by monitoring on-going studies by other organizations and sponsoring or performing additional studies itself. The IAPT provides a flexible means to analyze a wide range of projects in different regions on a consistent basis. Caltrans should consider assembling the necessary regional datasets to be able to apply the IAPT in each major metropolitan region in the state. Once such datasets are available for other regions, the IAPT can be used to perform more detailed analysis of the potential opportunities for improved intermodal connectivity at airports in those regions discussed in Chapter 3.

10.2 Institutional Aspects

The nature of airport intermodal access projects necessarily involves a large number of different agencies and other organizations, which can lead to a very complex institutional environment in the context of any given project. As the agency responsible for statewide transportation, Caltrans is in a unique position and indeed has a unique responsibility to exercise leadership in improving intermodal connectivity between the airports in the state and the rest of the surface transportation system and to facilitate these institutional relationships. However, this has to be done through effective cooperation with regional and local agencies, so that these agencies not only appreciate the importance of improved intermodal connectivity to the ability of the airports in their region to meet the regional air transportation demands but also take ownership of the resulting planning and project implementation process. In many cases the regional and local agencies are already aware of the need for improved airport access and may even be pursuing potential projects, and only require Caltrans to help facilitate the process. In other cases, it may be necessary for Caltrans to create a suitable institutional framework within which to work with the regional and local agencies to define the opportunities and agree on which ones to pursue.

At the same time, it should be recognized that the local situation varies from region to region and not every commercial service airport in the state either needs or can justify the type of intermodal access projects addressed in this report. Caltrans should begin by focusing on the largest airports in the state both in order to gain experience in facilitating the development of appropriate projects as well as to ensure that resources are directed where they are likely to be of greatest benefit. At the same time, discussions can be held with appropriate agencies in other regions to identify opportunities for future consideration.

Recommendation: Caltrans should coordinate with appropriate staff in the metropolitan planning organizations and relevant airport authorities to convene regional Airport Intermodal Access Task Forces in selected regions to pursue opportunities to improve airport intermodal connectivity. These task forces should involve a broad range of stakeholder agencies, including regional transit agencies, local jurisdictions, and air quality management districts. Each task force will review existing plans for improved intermodal connectivity at airports in the region, identify and evaluate opportunities for additional projects, identify barriers to implementation of planned or potential projects, and develop an action plan to pursue promising projects.

The work of the multi-agency Airport Transit/Roadway Committee in San Diego to develop an Airport Transit Plan for San Diego International Airport provides a good model for such task forces.

10.3 Project Funding

Projects designed to improve intermodal connectivity at airports typically involve several different agencies and jurisdictions, and thus it is often not clear how they can be funded. Individual agencies may recognize the value of the project, but have higher priorities for their own funds. Since the projects are primarily designed to serve airport users, other agencies often feel that they should be funded, at least in part, from airport sources. However, airports are typically limited in their ability to spend money on projects off airport property and Federal funding for airport development is quite restricted in its use for airport access projects.

At the same time, Caltrans has access to significant sources of funds to support development of the state highway system and has increasingly been providing financial support to develop intercity rail service in the state. In several regions in the state the regional transit agencies have been pursuing Federal transit capital grants to extend local rail transit systems to airports or construct improved links between existing stations and a nearby airport. Finally, the Federal Aviation Administration has begun to recognize the importance of improving public transportation access to airports as a necessary element of meeting future airport capacity needs, and in some situations has begun to allow the use of airport development grant funds for airport access projects.

There are a number of steps that Caltrans can take to facilitate the funding of projects to improve intermodal connectivity at airports. These include:

- Identifying existing sources of funding within Caltrans and ensuring that projects to improve intermodal connectivity get appropriate consideration when these funds are programmed;
- Providing guidance material to regional and local agencies on sources of funding for airport intermodal connectivity projects, together with any associated restrictions and application procedures;
- Coordinating with the Regional Transportation Planning Agencies and major airport authorities in the state to ensure that airport intermodal connectivity projects are incorporated in the airport master plans and capital improvement plans, as well as in the regional Transportation Improvement Programs.

In addition to documenting the availability of existing funding sources to support airport intermodal connectivity projects, Caltrans should explore new sources of funding to support improved airport intermodal connectivity. This could include changes in funding program regulations or authorizing legislation to allow airport authorities to play a larger role in funding improved links between airports and the regional surface transportation system.

Recommendation: Caltrans should assemble information on available funding sources to support airport intermodal connectivity projects, together with any restrictions on their use and application procedures. Caltrans Division of Aeronautics should work with other Caltrans divisions to identify eligible funds within existing state transportation programs and work with the California Transportation Commission to define a specific program to support projects to improve airport intermodal connectivity.

10.4 Technical Support

Analysis of potential projects to improve airport intermodal connectivity, as with many aspects of airport ground transportation planning, is a rather specialized topic and one that is generally outside the typical experience of transportation modelers in metropolitan planning organizations as well as most airport planning staff. Standard urban travel demand models are generally unsuitable for modeling airport user travel decisions, due to both the unique characteristics of air passenger travel, such as multi-day trips and multi-person travel parties, and the much larger number of transportation modes and services that are typically available to serve airport trips.

Caltrans can facilitate the efforts of airports and regional transportation planning agencies to analyze the potential ridership and economic feasibility of proposed projects to improve airport intermodal connectivity by providing technical support. This could include guidance documents as well as making the IAPT available for use by other organizations and providing technical support and training in its use.

Finally, the current research has identified a number of issues that are not as well understood as they should be in order to adequately assess the likely use of proposed projects to improve intermodal connectivity. These include how to model airport employee access mode choice, factors that influence the decision by visitors to a region to rent a car, how to account for household income in air passenger mode choice, and the role of information on the availability of different transportation services in airport traveler mode choice decisions. Given the large capital and operating costs involved in many of the proposed projects to improve airport intermodal connectivity, it would be prudent to continue to research these issues so that the reliability of techniques to analyze the likely use of proposed projects can be improved.

Recommendation: Caltrans should develop an *Airport Intermodal Access Planning Handbook* modeled after the *California Airport Land Use Planning Handbook* that will provide guidance to Caltrans District Offices, airport authorities, regional transportation planning agencies, regional transit agencies, and local jurisdictions on the full range of planning considerations involved in airport intermodal access projects, including relevant funding sources and procedures.

Recommendation: Caltrans should support to improve/refine the Intermodal Airport Ground Access Planning Tool and make it available for use by other organizations, including user documentation and technical support and training. This may require some enhancements to the tool to allow it to be easily adapted for use in other regions than the Bay Area.

Recommendation: Caltrans should continue to study technical issues involved in analyzing the feasibility and effectiveness of potential projects to improve airport intermodal connectivity, including development of models of airport employee access mode choice behavior, improved models of air passenger access mode choice, and appropriate ways to address the availability of ground transportation information in analyzing airport traveler mode choice.

Chapter 11. Concluding Remarks and Recommendations for Future Development

This study 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 has pursued the detailed implementation of this analytical capability and demonstrated the functionality of the prototype Intermodal Airport Ground Access Planning Tool (IAPT). Based on the research undertaken in the course of the project, a number of recommendations have been developed to help Caltrans formulate appropriate policies and programs to improve the intermodal connections at the state's airports.

11.1 Potential Follow-on Research

The research undertaken has identified a number of additional research topics that would be useful to explore in future follow-on research projects.

The first three of the following seven topics describe potential enhancements to the version of the IAPT that has been developed under the current project. The fourth 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.

11.1.1 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.

11.1.2 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.

11.1.3 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 2001/2002 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 transportation analysis zones for transportation modeling. Thus on average there were less than four responses from each analysis zone. However, given the uneven distribution of air party trip origins in the region, the inherent variation of statistical sampling, and missing trip origin information in the survey responses (about 15 percent of the responses gave insufficient information to identify their origin zone), many analysis zones had even fewer responses while 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.

11.1.4 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.

11.1.5 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.

11.1.6 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.

11.1.7 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.

11.2 Future Development of the IAPT

Although the framework for IAPT is scalable to accommodate additional functionality, the current version of the IAPT is just a prototype. Due to limited funding and time constraints, further development of IAPT would need to be undertaken in the next phase of the research. Such development should be in two directions: (a) enhance and complete the functionalities of current version and to conduct case study analysis using the tool for validation and improvement; and (b) extend the functionalities to accommodate other applications which may include, but not exclusively, the following aspects:

(i) Improve the mode choice model for OAK and calibrate mode choice models for SFO and SJC; refine and validate the tool and demonstrate its use by analyzing the five Bay Area case study projects identified in the current phase of the research.

(ii) Complete the transportation provider behavior model implementation: Although the transportation provider model in a Generalized Nash Game approach has been implemented with the standard Frank Wolfe method for nonlinear programming, some modes did not converge to a solution during tests of the numerical iteration. This may be due to several reasons discussed in Appendix B, which need further investigation.

(iii) Calculate profit instead of just revenue for privately operated HOV modes. Although it is not much more complicated to calculate profit for HOV modes compared to the calculation of only revenue, data preparation for such calculation is much more involved, which include the information on fixed and variable costs, and direct and indirect cost.

(iv) Include a help menu for each tab and sub-tab: It will be more convenient to the user if a cascaded version of help menu is built for each tab and sub-tab including airport definition, project definition, data entry and modification, storage, and display of analysis results.

(v) Automate data use and transformation: In the current version, the data entered have some overlap. For example, service data, air passenger data, and transit data have some elements in common. Future development can avoid this by systematically building a database for automatically storing, linking and retrieving data. This means that a list of fundamental datasets will need to be identified that avoids duplicated fields. All the other data used for the IAPT can then be deduced from the primary datasets such as transportation service data for each analysis zone. This approach can help avoid problems data inconsistency provide improvements in the efficiency of computation, updating and storage.

(vi) Develop support procedures for air passenger mode choice model estimation and automatic generation of air party transportation service data: The air passenger mode choice model was manually estimated outside the IAPT using other model estimation software based on the air passenger and transportation service data. This procedure could be incorporated as a function within the IAPT, either by calling external model estimation software using data in the IAPT database, or incorporating model estimation software inside the IAPT itself.

(vii) Link the IAPT to highway network traffic information such as PeMS (Performance Measurement System) (Choe et al, 2002) to obtain updated historical data regarding travel times for use in future IAPT development.

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Appendix A: Details of Recent Air Passenger Model Choice Models

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

A-1 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.[2] 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 Massachusetts Bay Transportation 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 model variations, separate travel cost coefficients were estimated for low-income and high-

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[2] 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.

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 A-1 to A-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 A-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 A-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 A-1 to A-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 A-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 A-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 A-2 Boston Logan Resident Non-Business Model Coefficients

Mode	Const	Tree Coeff	Travel Time Coefficients				Travel Cost Coefficients			Dummy Variable Coefficients			
			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 A-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 A-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 A-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.

A-2 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.

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[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 A-6 to A-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 A-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 A-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 A-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 A-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 A-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 A-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 A-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.

A-3 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.

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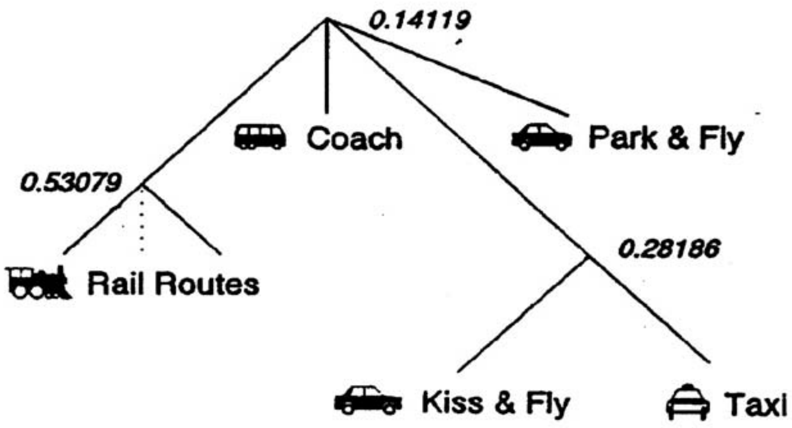
[4] Halcrow Group Ltd., SERAS Surface Access Modelling, Prepared for the Department of Transport, Local Government and the Regions, South East and East of England Regional Air Services Study, London, England, July 2002.

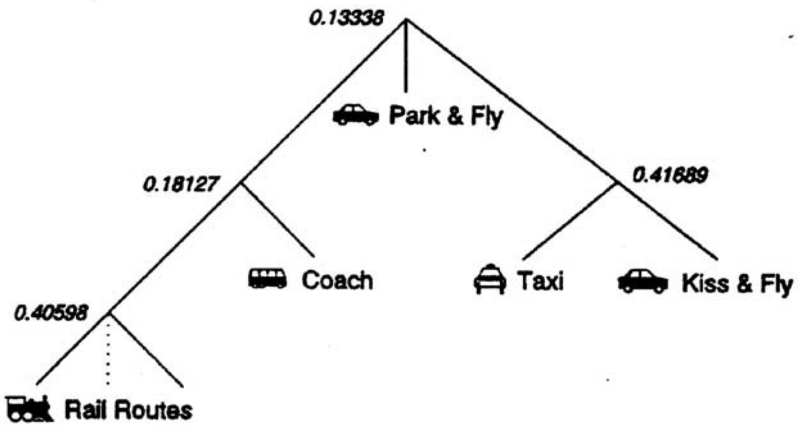
Although the term British Rail is used in the model documentation, these services are now provided by private companies (e.g. Great Western Trains) and British Rail as such no longer exists. The Park & Fly mode was assumed to only be available to U.K. passengers and was substituted by the Hire Car mode 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 A-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.

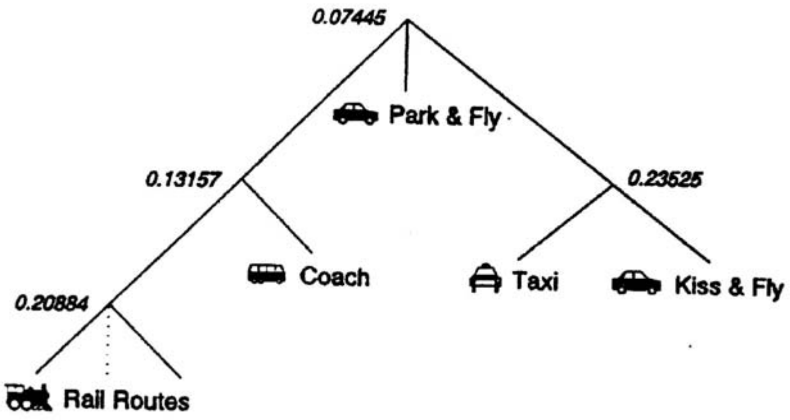
Segment 1 – UK Business Domestic Mode Choice Structure



Segment 2 – UK Business International Mode Choice Structure



Segment 3 – UK Leisure Domestic Mode Choice Structure



Segment 4 – UK Leisure International Mode Choice Structure

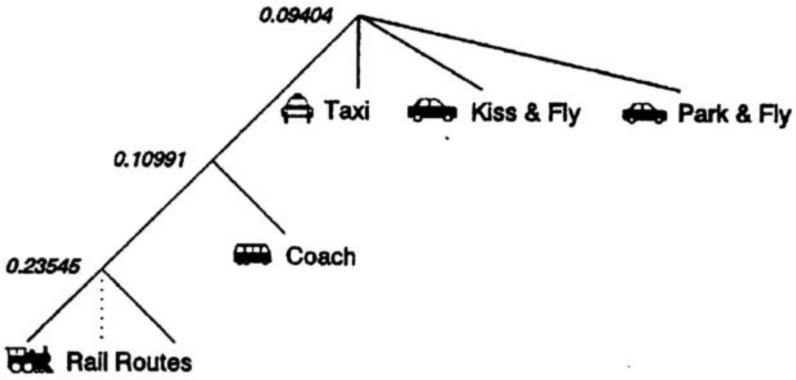
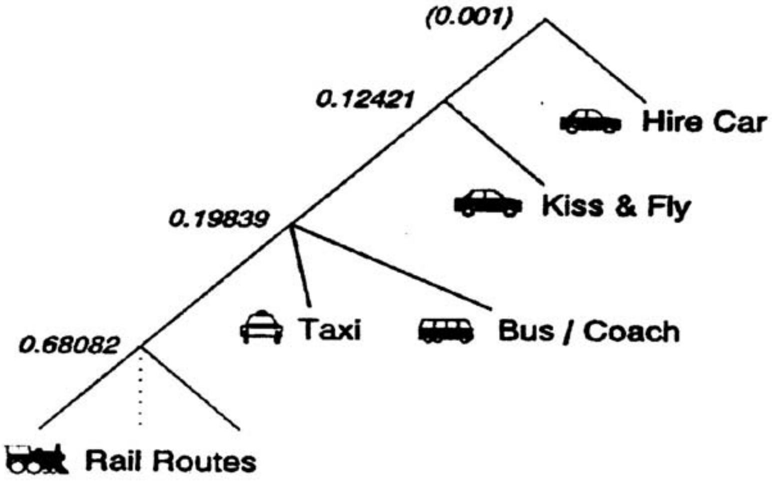
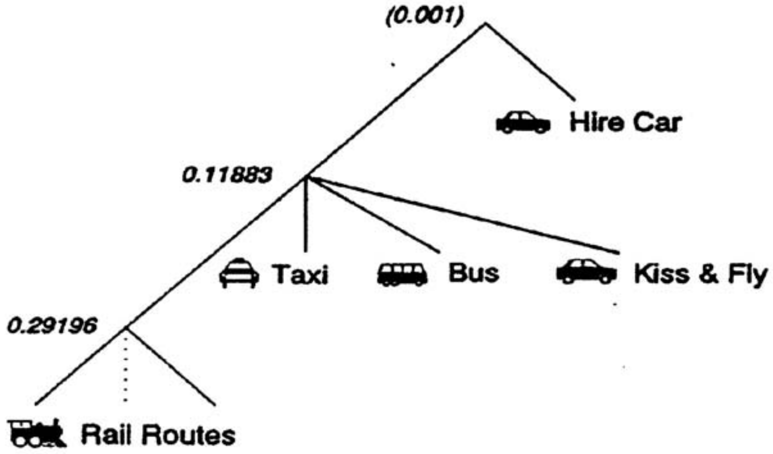


Figure A-1: SERAS Mode Choice Model Nesting Structure

Segment 5 – Non UK Business Mode Choice Structure



Segment 6 – Non UK Leisure Mode Choice Structure



Rail Routes Mode Choice Structure

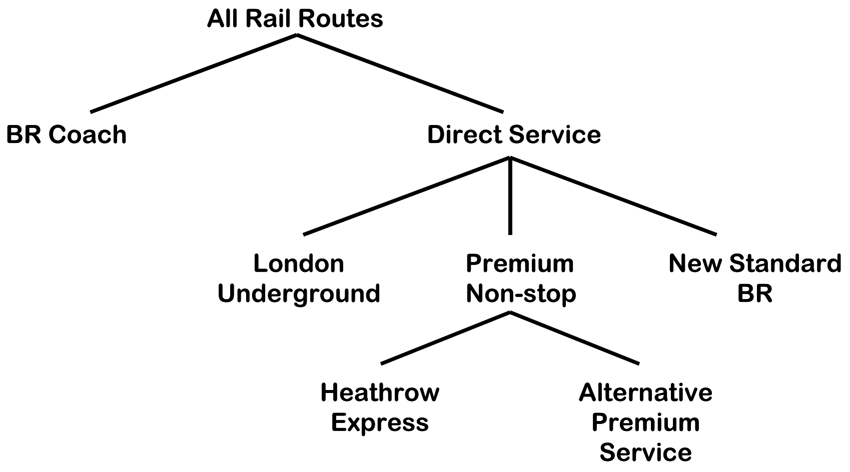


Figure A-1 (cont.): SERAS Mode Choice Model Nesting Structure

The utility functions for each mode are as follows:

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

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

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

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

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

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 A-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 A-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.

A-4 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 A-12. No goodness-of-fit statistics were provided in the report.

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[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 A-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 A-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 A-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 B: Implementation of Nash Game Modeling of Transportation Providers

This appendix describes in detail how to implement the Nash Game approach for modeling the competitive behavior of transportation providers for airport ground access/egress.

B-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 Intermodal Airport Ground Access Planning Tool (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.

B-2 Ridership from Mode Choice Model

Multinomial logit model

The *utility function* for passenger mode choice of mode i for given *OD* or *Air Party* w is

$$U_w^{(i)} = a^{(i)} T_w^{(i)} + b^{(i)} h_w^{(i)} + c^{(i)} p_w^{(i)} + \xi^{(i)} \tag{B.1}$$

where the following notations are used:

i	the mode index
M_w	the set of primary modes available for OD or Air Parties (depending on context) w, known; $i \in M_w$
W	the set of OD pairs or Air Parties (depending on context) for a give airport, known
$w \in W$	is an OD pair or Air Parties (depending on context), known
$W_w^{(i)}$	the set of all 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
$U_w^{(i)}$	the utility function of primary mode i for given w
$a^{(i)} < 0$	coefficient of travel time of primary mode i in passenger mode choice utility function, known constant or obtained from mode choice modeling, uniform for all air parties
$b^{(i)} < 0$	coefficient of operation headway for primary mode i in passenger mode choice utility function, obtained from mode choice modeling, uniform for all air parties
$c^{(i)} < 0$	coefficient of operation fare for primary mode i in passenger mode choice utility function, obtained from mode choice modeling, uniform for all air parties
$\xi^{(i)} \leq 0$	comfort factor for primary mode i in passenger mode choice utility function, obtained from mode choice modeling, uniform for all air parties
p_w	the price matrix of all modes for given w
$p_w^{(i,0)} > 0$	baseline fares of mode i for w
$x^{(i)} \geq 0$	fare changing rate of mode i uniformly across all the w's
$h_w^{(i)}$	headway for primary mode i with respect to w, decision parameter of transportation providers; Supposed to be constant and known.
$T_w^{(i)}$	travel time for primary mode i for given w, known from traffic model

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. The probability of a passenger choosing mode i among the M modes for a given w is

$$P_w^{(i)} = \frac{e^{U_w^{(i)}}}{\sum_{k \in M} \left(e^{U_w^{(k)}} \right)} \tag{B.2}$$

where $P_w^{(i)}$ is the probability that a passenger will choose mode i in a multinomial logit model for a given OD w.

Nested logit model

Suppose the m alternative modes are divided into disjoint nests $N_1, ..., N_s$. The probability of a mode chosen by a passenger being in nest m in a nested logit model is

$$P_w^{(i|m)} = \frac{\left(e^{U_w^{(i)}} \right)}{\sum_{k \in m} \left(e^{U_w^{(k)}} \right)}$$

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

where the following notations are assumed:

N_m	the set of modes in nest m
$P_w^{(m)}$	The marginal probability that a passenger will choose a mode in nest m in a nested logit model for a given w (*i.e.* the probability that the chosen mode will be in nest *m*)
$P^{(i\|m)}_{\ w}$	The conditional probability for a passenger to choose mode i given that the passenger has chosen nest m
μ_m	Nest related constant unknown parameter to be obtained from mode choice modeling

By Bayesian formula, we have the probability with the nested logit model,

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

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.

B-3 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 AIR PARTY demand D_w; and (b) they are competing over all air parties with their service area. Thus there may be two revenue functions:

(1) Revenue function for mode i for given AIR PARTY w directly from the hourly demand

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

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

(2) 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.

Total revenue function for mode i

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

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

$$\begin{aligned} u^{(i)} &= u^{(i)}\left(P, x\right) \\ &= \sum_{w \in W} p_w^{(i,0)}(1 + x^{(i)}) D_w P_w^{(i)} = \sum_{w \in W} p_w^{(i,0)} D_w P_w^{(i)} + x^{(i)} \sum_{w \in W} p_w^{(i,0)} D_w P_w^{(i)} \end{aligned} \qquad \text{(B.7)}$$

where $x = [x^{(1)}, ..., x^{(M)}]^T$ is the decision parameter.

Now the expression for $P_w^{(i)}$ can be written as:

$$P_w^{(i)} = \frac{\left(e^{U(i)}\right)}{\sum_{k \in M}\left(e^{U(k)}\right)} = \frac{\left(e^{\left(a^{(i)}T_w^{(i)} + b^{(i)}h_w^{(i)} + c^{(i)}p_w^{(i)} + \xi^{(i)}\right)}\right)}{\sum_{k \in M}\left(e^{\left(a^{(k)}T_w^{(k)} + b^{(k)}h_w^{(k)} + c^{(k)}p_w^{(k)} + \xi^{(k)}\right)}\right)} \qquad \text{(B.8)}$$

This still cannot avoid the zone-by-zone coordinate transformation. The problem is that the coefficients of $x^{(i)}$ would depend on both the model coefficient and the base-line price unless we assume tat each zone (corresponding to air party) increase the price by the same amount.

B-4 Nash Game Formulation for Complete Competition of Transportation Providers

Find x^* subject to the constraints on the fare variation and service headway variation such that

$$\begin{aligned} & u^{(i)}(x^{(i)}, x^{(M_w \backslash i)*}) \\ & \leq u^{(i)}\left(x^{(i)*}, x^{(M_w \backslash i)*}\right) \end{aligned} \qquad \text{(B.9)}$$

holds for all $j \in M_w$. $M_w \backslash j$ means to exclude j from the set M_w.

Remarks:

(i) In practical implementation, operation frequency needs to be applied properly. For example, the following service providers are demand based. Thus the objective function only have one possible variable which is the price:

- On-airport/off-airport parking

- Rental car
- Share-ride van

(ii) Taxi and Limo even cannot change their price arbitrarily. Instead, their price is fixed.

B-5 Constraints

How to determine those constraints? They are determined by the following economy of each transportation provider:

For all the air parties considered together:

$$\begin{aligned}
&\sum_{w\in W}\left(u_w^{(i)} - Cop_w^{(i)} - Ccap_w^{(i)}\right) \ge 0 \\
&i.e.: \sum_{w\in W} u_w^{(i)} - \left(Cop^{(i)} + Ccap^{(i)}\right) \ge 0 \qquad \text{(B.10)} \\
&0 \le x^{(i)} \le 0.5
\end{aligned}$$

which should hold for any mode i. The last constrains simply say that the price change would not go over 50%.

(iii) Due to the nonlinearity of mode choice model, the objective functions are nonlinear.

(iv) Calculation of $Cop_w^{(i)}$ for $i = 1,...,m$: See Appendix F for that mode – sum overall all the air party. N.B. There is NO variable $x^{(i)}$ here.

(iv) Calculation of $Ccap_w^{(i)}$ for $i = 1,...,m$: Total cost for that mode.

Both capital cost and operation cost are constants.

B-6 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 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

B-7 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.

B-8 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

$$\begin{aligned} &\min_X f(X) \\ &AX \le b \end{aligned} \tag{B.11}$$

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

$$\begin{aligned}&\min_{Y} \nabla f(X_k)^T Y \\ &AY \le b\end{aligned} \tag{B.12}$$

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

$$\begin{aligned}&\min_{\lambda} f[\lambda X_k + (1-\lambda)Y_k] \\ &0 \le \lambda \le 1\end{aligned} \tag{B.13}$$

Step 2.3 Let

$$X_{k+1} = \lambda_k X_k + (1-\lambda_k)Y_k \tag{B.14}$$

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. Some linearization is necessary to achieve this;

(2). The gradient $\nabla f(X_k)$ (the partial derivative of the object function with respect to all the decision variables) in (B.12) 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). (B.14) is a single variable nonlinear constrained optimization problem with respect to $\lambda : 0 \le \lambda \le 1$.

B-9 Simplification in Preliminary Implementation

(1) Each AIR PARTY here is understood as corresponding to an air party since the implementation is air party based;

(2) Consider operation frequency as constant. i.e. the decision parameter for each mode is the fare only. The problem is defined in (B.17) with objective function defined (B.19) which corresponds to different ways for changing the price.

(3) Consider the revenue of a mode for all the air parties or all the air parties concerned. In this way, there are only 18 objective functions and 18 decision variables. Here $x^{(i)}(k) \in \Omega^{(k)}(x^{-(i)}(k))$ is the feasible set of the decision variables which are determined by the constraints in (B.16). $x^{-(i)}(k)$ means, at step k, consider all the modes other than $x^{(i)}(k)$ as constant. In this way, it is able to determine the feasible set for the decision parameters from the constraints.

(4) We do not know the zonal demand which is a disadvantage. To calculate based on air party, we need to distribute the total demand at a airport to obtain the demand attribute to each air party. i.e. the D_w in (B.18) and (B.19):

$$D_w = \frac{sz^{(j)}}{\sum_{j \in over-all-air-parties} sz^{(j)}} D_{total} \qquad \text{(B.15)}$$

where D_{total} is total annual passenger demand of the airport and D_w is the demand corresponding to zone (air party) w.

B-10 Optimization Routines in C

For optimization of one variable, the Golden Section search method could be used (Numerical Recipes in C, 10.1) which is for constrained one variable nonlinear optimization.

The simplex method is also available in NR.

B-11 Practical Implementation

In the following discussion, $w \in W$ means that it runs through all the air parties.

(1) Implementation the derivatives of the revenue function independently as a function ***gen_der()*** with generic coefficients which will be read-in and fill up from data file

(2) Implementation a function ***rev_der()*** which calls ***gen_der()*** for four times respectively corresponding to

- Resident business
- Resident personal
- Visitor business

- Visitor personal

and fill in corresponding mode choice coefficient data;

(3) The modes which do not change prices are considered as constant in the optimization process. There are only 11 modes participating in the optimization process at this stage, as indicated in the following table.

Table B-1

Mode ID	Revised Mode Name	Definition/comment	Traffic Units	Price Change?	Freq Change?	Op Cost 1: per_veh_per_mile
1	Auto Drop-off	Private vehicle		N (No)	N	
2	Rental Car	Modeled separately for visitors	air parties	Y (Yes)	N	
3	Scheduled Airport Bus		air pax	Y	N	
4	Public Transit Bus			N	N	
5	Charter Bus	Modeled separately		N	N	
6	Door-to-Door Van		air pax	Y	N	
7	Hotel Courtesy Shuttle	Modeled separately (visitors only)		N	N	
8	Taxi			N	N	
9	BART	VTA Light Rail at SJC		N	N	
10	Amtrak/Caltrain			N	N	
11	Short term Parking		air parties	Y	N	N. A. (Not Applicable)
12	Long term Parking		air parties	Y	N	N. A. (Not Applicable)
13	Off Airport Parking		air parties	Y	N	N. A. (Not Applicable)
14	Limousine		air parties	Y	N	
15	OAT Drop-off	Off Airport Terminal - drop-off access		Y (see note 1)	N	
16	OAT Parking	Off Airport Terminal - park at terminal		Y (see note 2)	N	N. A. (Not Applicable)
17	OAT Taxi	Off Airport Terminal - taxi access		Y (see note 3)	N	
18	OAT Transit	Off Airport Terminal - transit access		Y (see note 3)	N	
19	*New Mode 1*	e.g. APM link to BART/Light Rail		N	N	
20	*New Mode 2*	e.g. Shuttle bus to Ferry terminal		N	N	

(4) Implement Frank-Wolfe Method for each revenue function

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

$$\min_{x^{(i)}} \left(-u^{(i)}\right)$$

$$s.b.:$$

$$x^{(i)} \sum_{w \in W} p_w^{(i,0)} D_w P_w^{(i)}(x) + \sum_{w \in W} p_w^{(i,0)} D_w P_w^{(i)}(x) - \left(Cop^{(i)} + Ccap^{(i)}\right) \geq 0 \qquad \text{(B.16)}$$

$$0 \leq x^{(i)} \leq 0.5$$

where $Cop^{(i)}$ and $Ccap^{(i)}$ are total operational cost and capital cost for mode i respectively. Note that in the constraints, the third term is the operational cost and the capital cost which need to be calculated for each mode over all the air parties.

(5) About Constraints: Since the changing rate $x^{(i)}$ also appears in the probability calculation:

$$P_w^{(i)} = P_w^{(i)}(x), w \in W$$

the constraints in (B.25) are thus nonlinear. However, Frank-Wolfe method requires linear constraints. To overcome this difficulty, at each iteration step *k*, a pseudo-linearization approach is taken by assuming the value of $x = x(k-1)$ as step *(k-1)* as follows:

$$P_w^{(i)} = P_w^{(i)}\left(x(k-1)\right), w \in W$$

Thus the constraints in (B.25) become:

$$\begin{aligned}
&-x^{(i)}(k)\sum_{w\in W} p_w^{(i,0)} D_w P_w^{(i)}\left(x(k-1)\right) \le \sum_{w\in W} p_w^{(i,0)} D_w P_w^{(i)}\left(x(k-1)\right) - \left(Cop^{(i)} + Ccap^{(i)}\right)\\
&x^{(i)}(k) \le 0.5 \qquad\qquad (B.17)\\
&-x^{(i)}(k) \le 0
\end{aligned}$$

which is linear in $x^{(i)}(k)$ at iteration step *k*.

If we only consider price as the decision variable, the last term is a constant for each mode at step *k*. So the constraints are linear in price changing rate $x^{(i)}$. The problem is thus a nonlinear optimization with linear constraints. It is noted as

$$AX \le b$$

with $X(k) = [x_1(k), \ldots, x_M(k)]^T$, *A* (a matrix) and *b* (a vector) are obtained from the constraints above as:

$$A = \begin{bmatrix} A_1 \\ I \\ -I \end{bmatrix}$$

$$A_1 = diag\left[-\sum_{w\in W} p_w^{(1,0)} D_w P_w^{(1)}\left(x(k-1)\right), \ldots, -\sum_{w\in W} p_w^{(M,0)} D_w P_w^{(M)}\left(x(k-1)\right)\right]$$

$$I = diag[1, 1, \ldots, 1]$$

$$b = \left[\sum_{w\in W} p_w^{(1,0)} D_w P_w^{(1)}\left(x(k-1)\right) - \left(Cop^{(1)} + Ccap^{(1)}\right), \ldots, \sum_{w\in W} p_w^{(M,0)} D_w P_w^{(M)}\left(x(k-1)\right) - \left(Cop^{(M)} + Ccap^{(M)}\right), 0.5, \ldots, 0.5, 0, \ldots, 0\right]^T$$

Computer Algorithm:

Step 0: Set *k*=0 corresponding to the initial condition;

Step 1: Set *k*=1;

Step 2: For *i=1:M* (Step 2 is to run over for all the modes- the inner loop)

(2-a) Calculate the gradient $\left.\frac{\partial u^{(i)}(k)}{\partial x^{(j)}}\right|_{x=x(k-1)}$ and evaluate it at the price of step *(k-1)*;

(Note that $x^{(i)}(0)=0, i=1,\ldots,M$ initial price at *k=0*)

(2-b) Solve the following linear constrained optimization problem using Simplex method:

$$\begin{aligned}&\min_{Y}\left(-\nabla u^{(i)}\left(x(k-1)\right)^{T} Y(k)\right)\\&AY(k)\le b\end{aligned} \tag{B.18}$$

where $Y(k)=[y_1(k),\ldots,y_M(k)]^T$ is a dummy variable vector. Then apply Simplex method; the objective function $J^{(i)}=-\nabla u^{(i)}\left(x(k-1)\right)^{T} Y(k)$ is a scalar for any fixed *i*.

The gradient $\nabla u^{(i)}(x)$ can be calculated as follows:

$$\begin{aligned}&\frac{\partial u^{(i)}}{\partial x^{(i)}}=\sum_{w\in W} p_w^{(i,0)} D_w \frac{\partial P_w^{(i)}}{\partial x^{(i)}}+\sum_{w\in W} p_w^{(i,0)} D_w P_w^{(i)}+x^{(i)}\sum_{w\in W} p_w^{(i,0)} D_w \frac{\partial P_w^{(i)}}{\partial x^{(i)}},(j=i)\\&\frac{\partial u^{(i)}}{\partial x^{(j)}}=\sum_{w\in W} p_w^{(i,0)} D_w \frac{\partial P_w^{(i)}}{\partial x^{(j)}}+x^{(i)}\sum_{w\in W} p_w^{(i,0)} D_w \frac{\partial P_w^{(i)}}{\partial x^{(j)}},(j\ne i)\end{aligned} \tag{B.19}$$

Modify the gradient $\nabla u^{(i)}(x)$ as follows:

$$\begin{aligned}&\frac{\partial u^{(i)}}{\partial x^{(i)}}=\sum_{w\in W} p_w^{(i,0)} D_w \frac{\partial P_w^{(i)}}{\partial x^{(i)}}+\sum_{w\in W} p_w^{(i,0)} D_w P_w^{(i)}+x^{(i)}\sum_{w\in W} p_w^{(i,0)} D_w \frac{\partial P_w^{(i)}}{\partial x^{(i)}},(j=i)\\&\frac{\partial u^{(i)}}{\partial x^{(j)}}=0,(j\ne i)\end{aligned} \tag{B.20}$$

This has been tried and produced no significant changes (02/26/07).

(2-c) Find $\lambda_k^{(i)}$ by solving the following one variable nonlinear optimization problem with one variable for each *i*

$$\begin{aligned}&\min_{\lambda}\left(-u^{(i)}[\lambda^{(i)}x(k-1)+(1-\lambda^{(i)})Y(k)]\right)\\&0\le\lambda^{(i)}\le 1\end{aligned} \tag{B.21}$$

Here both $x(k-1)$ and $Y(k)$ are fixed vectors, but the objective function to be minimized $-u^{(i)}[\lambda^{(i)}x(k-1)+(1-\lambda^{(i)})Y(k)]$ is a scalar. It just says that the objective function should be evaluated at the point $\lambda^{(i)}x(k-1)+(1-\lambda^{(i)})Y(k)$ which is a point in M-dimensional space. The dependent variable $\lambda^{(i)}$ is a scalar. Thus it is a ONE variable nonlinear optimization problem. Suppose the optimal point is $\lambda_k^{(i)}$.

(2-d) Set

$$\begin{aligned} &x^{(i)}(k)=\lambda_k^{(i)}x^{(i)}(k-1)+(1-\lambda_k^{(i)})Y^{(i)}(k) \\ &i=1,\ldots,M \end{aligned} \qquad \text{(B. 22)}$$

Then $\left[x^{(1)}(k),\ldots,x^{(M)}(k)\right]^T$ is the starting point for the next BIG STEP (Step 2).

(**Inner *i*-loop end**)

Step 3: Check if $\|x(k)-x(k-1)\|\le\varepsilon$

```
If Yes:
    Stop;
Else:
    Set  k=k+1;
    Go to Step 1.
```

End

B-12 Second Implementation (02/16/07)

The following analysis uses zonal passenger flow corresponding to each air party as the decision variable. Such choice makes the objective function globally concave. Thus, revenue optimization or profit optimization does not make much difference.

The previous approach uses a uniform price change parameter for all the zones (air parties). i.e. they change the fare by percentile irrespective of the distance of the zone (air party). Although it simplifies the dimension of the problem, the objective function is only conditionally concave. To avoid this problem, we use a second approach: each mode maximizes its revenue (profit) at each zone (air party) by changing the fare. Now the fare for each mode would become a vector: $x^{(i)} = \left[x_w^{(i)} \right]_{w \in W}$. At each zone (air party):

$$x_w = [x_w^{(1)}, ..., x_w^{(M_w)}].$$

The corresponding objective function would become

$$\begin{aligned} & u_w^{(i)} = p_w^{(i,0)} D_w P_w^{(i)}(x_w) + x_w^{(i)} p_w^{(i,0)} D_w P_w^{(i)}(x_w) \\ & \min_{x_w^{(i)}} \left(-u_w{}^{(i)} \right) \end{aligned} \qquad \text{(B.23)}$$

Constraints: For revenue optimization, each mode is to maximize the revenue for each zone (air party). No obvious constraints on percentile x_w.

Since the objective function is not globally concave directly with respect to price and its changing rate, a transformation from price changing rate to probability or line flow are used. There are two alternative ways to choose decision parameters: the probability or the passenger demand at each mode. Using probability or passenger line flow as decision variables are equivalent mathematically because they only differ by the total demand. Since the probability for some mode might be very small in computation, it is to use the passenger demand at each zone (air party) as the decision variable. From (B.24):

$$D_w = \frac{sz^{(j)}}{\sum_{j \in over-all-air-parties} sz^{(j)}} D_{total} \qquad \text{(B. 24)}$$

where D_{total} is total annual passenger demand of the airport and D_w is the demand corresponding to zone (air party) w. The passenger flow for each mode i is $D_w^{(i)}$. There exists a relationship:

$$D_w = \sum_{i=1}^{M_w} D_w^{(i)}$$

which should be the constraints for optimization at each zone (the OD corresponding to the air party).

For given an OD, the relationship between probability and fares are in the mode choice model:

$$D_w^{(i)} = D_w P_w^{(i)} = \frac{\left(e^{U(i)}\right)}{\sum_{k \in M} \left(e^{U(k)}\right)} D_w \qquad \text{(B.25)}$$

where the utility function is:

$$U_w^{(i)} = a^{(i)} T_w^{(i)} + b^{(i)} h_w^{(i)} + d^{(i)} p_w^{(i)} + \xi^{(i)}$$

If we treat

$$p_w{}^{(i)} = p_w^{(i,0)}(1 + x_w^{(i)}) \qquad \text{(B.26)}$$

where $x^{(i)}$ is the fare change rate (percentage) for mode *i* uniformly for all the ODs,

$$U_w{}^{(i)} = a^{(i)} T_w{}^{(i)} + b^{(i)} h_w{}^{(i)} + c^{(i)} p_w^{(i,0)}(1 + x_w^{(i)}) + \xi^{(i)} \qquad \text{(B.27)}$$

In the case of two modes: *i=1,2*

$$\frac{D_w^{(1)}}{D_w^{(2)}} = \frac{e^{U(1)}}{e^{U(2)}} \qquad \text{(B.28)}$$

$$\ln\left(D_w^{(1)}\right) - \ln\left(D_w^{(2)}\right) = U(1) - U(2)$$

$$\Rightarrow x_w^{(1)} = \frac{1}{-c_w{}^{(1)} p_w^{(1,0)}} \left[\left(\ln\left(D_w^{(2)}\right) - \ln\left(D_w^{(1)}\right) \right) - U(2) + (a^{(1)} T_w{}^{(1)} + b^{(1)} h_w{}^{(1)} + c^{(1)} p_w^{(1,0)} + \xi^{(1)}) \right]$$

Similarly, we have

$$x_w^{(2)} = \frac{1}{-c_w{}^{(2)} p_w^{(2,0)}} \left[\left(\ln\left(D_w^{(1)}\right) - \ln\left(D_w^{(2)}\right) \right) - U(1) + (a^{(2)} T_w{}^{(2)} + b^{(2)} h_w{}^{(2)} + c^{(2)} p_w^{(2,0)} + \xi^{(2)}) \right]$$

As an example, in the case of $M_w = 2$, i.e. there is only 2 modes at zone w or corresponding to air party w, replacing them into (B.25) to obtain:

$$
\begin{aligned}
&u_w^{(1)} = p_w^{(1,0)} D_w^{(1)} + \\
&\frac{1}{-c_w{}^{(1)}} D_w^{(1)} \cdot \left[\left(\ln\left(D_w^{(2)}\right) - \ln\left(D_w^{(1)}\right) \right) - U(2) + (a^{(1)} T_w{}^{(1)} + b^{(1)} h_w{}^{(1)} + c^{(1)} p_w^{(1,0)} + \xi^{(1)}) \right] \\
&u_w^{(2)} = p_w^{(2,0)} D_w^{(2)} + \\
&\frac{1}{-c_w{}^{(2)}} D_w^{(2)} \left[\left(\ln\left(D_w^{(1)}\right) - \ln\left(D_w^{(2)}\right) \right) - U(1) + (a^{(2)} T_w{}^{(2)} + b^{(2)} h_w{}^{(2)} + c^{(2)} p_w^{(2,0)} + \xi^{(2)}) \right] \\
&\min_{D_w^{(i)}} \left(-u_w{}^{(i)} \right), i = 1, 2
\end{aligned}
$$

Now considering the decision variables of other modes, which are assumed known constants, we have

$$
\begin{aligned}
&\frac{\partial u_w^{(1)}}{\partial D_w^{(1)}} = p_w^{(1,0)} + \frac{1}{c_w{}^{(1)}} \cdot \left[\left(\ln\left(D_w^{(2)}\right) - \ln\left(D_w^{(1)}\right) \right) - U(2) + (a^{(1)} T_w{}^{(1)} + b^{(1)} h_w{}^{(1)} + c^{(1)} p_w^{(1,0)} + \xi^{(1)}) \right] \\
&+ \frac{1}{c_w{}^{(1)}} \\
&\frac{\partial^2 u_w^{(1)}}{\partial \left(D_w^{(1)}\right)^2} = \frac{-1}{c_w{}^{(1)} \cdot D_w^{(1)}} < 0
\end{aligned}
$$

which means that $u_w^{(1)}$ is strictly concave with respect to $D_w^{(1)}$. This is the advantage using passenger flow for each mode as the decision variable.

In general, the coordinate transformations are calculated as follows:

$$
\begin{aligned}
&x_w^{(1)} = \frac{1}{-c_w{}^{(1)} p_w^{(1,0)}} \cdot \left[\left(\ln\left(D_w^{(2)}\right) - \ln\left(D_w^{(1)}\right) \right) - U(2) + (a^{(1)} T_w{}^{(1)} + b^{(1)} h_w{}^{(1)} + c^{(1)} p_w^{(1,0)} + \xi^{(1)}) \right] \\
&\text{...........} \\
&x_w^{(i)} = \frac{1}{-c_w{}^{(i)} p_w^{(i,0)}} \cdot \left[\left(\ln\left(D_w^{(i+1)}\right) - \ln\left(D_w^{(i)}\right) \right) - U(i+1) + (a^{(i)} T_w{}^{(i)} + b^{(i)} h_w{}^{(i)} + c^{(i)} p_w^{(i,0)} + \xi^{(i)}) \right] \\
&\text{...........} \\
&x_w^{(M_w)} = \frac{1}{-c_w{}^{(M_w)} p_w^{(M_w,0)}} \cdot \left[\left(\ln\left(D_w^{(1)}\right) - \ln\left(D_w^{(M_w)}\right) \right) - U(1) + (a^{(M_w)} T_w{}^{(M_w)} + b^{(M_w)} h_w{}^{(M_w)} + c^{(M_w)} p_w^{(M_w,0)} + \xi^{(M_w)}) \right]
\end{aligned}
\tag{B.29}
$$

$$u_w^{(1)} = p_w^{(1,0)} D_w^{(1)} +$$

$$\frac{1}{-c_w^{(1)}} D_w^{(1)} \cdot \left[\left(\ln\left(D_w^{(2)}\right) - \ln\left(D_w^{(1)}\right) \right) - U(2) + (a^{(1)} T_w^{(1)} + b^{(1)} h_w^{(1)} + c^{(1)} p_w^{(1,0)} + \xi^{(1)}) \right]$$

....

$$u_w^{(i)} = p_w^{(i,0)} D_w^{(i)} +$$

$$\frac{1}{-c_w^{(i)}} D_w^{(i)} \left[\left(\ln\left(D_w^{(i+1)}\right) - \ln\left(D_w^{(i)}\right) \right) - U(i+1) + (a^{(i)} T_w^{(i)} + b^{(i)} h_w^{(i)} + c^{(i)} p_w^{(i,0)} + \xi^{(i)}) \right]$$

....

$$u_w^{(M_w)} = p_w^{(M_w,0)} D_w^{(M_w)} +$$

$$\frac{1}{-c_w^{(M_w)}} D_w^{(M_w)} \left[\left(\ln\left(D_w^{(1)}\right) - \ln\left(D_w^{(M_w)}\right) \right) - U(1) + (a^{(M_w)} T_w^{(M_w)} + b^{(M_w)} h_w^{(M_w)} + c^{(M_w)} p_w^{(M_w,0)} + \xi^{(M_w)}) \right] \tag{B.30}$$

The optimization problem is formulated as:

$$\begin{aligned} &\min_{D_w^{(i)}} \left(-u_w^{(i)} \right), i = 1, 2 \\ &s.t.: \\ &D_w^{(i)} \geq 1 \\ &D_w = \sum_{i=1}^{M_w} D_w^{(i)} \end{aligned} \tag{B.31}$$

Here it is assumed that any mode would have at least 1 passenger for each of the four types in a given super-zone. This assumption would not affect much the end results, but it avoids the singularity in the coordinate transformation, i.e. to void demand to be zero, which is not allowed in (B.27) and onwards discussions. This assumption also affects a little on the partition of the total airport demand into zonal demands (06/20/07).

Another advantage of using the demand as decision variable is that the constraints are naturally linear although the objective function is nonlinear. This means that there no need for pseudo-linearization for the objective function – it can evaluate at the current step demand value.

Calculate Jacobean Matrix, which is diagonal:

$$\frac{\partial(u_w^{(1)},\ldots,u_w^{(M_w)})}{\partial(D_w^{(1)},\ldots,D_w^{(M_w)})} = diag\left[\frac{\partial u_w^{(1)}}{\partial D_w^{(1)}},\ldots,\frac{\partial u_w^{(M_w)}}{\partial D_w^{(M_w)}}\right]$$

$$\frac{\partial u_w^{(1)}}{\partial D_w^{(1)}} = p_w^{(1,0)} - \frac{1}{c_w{}^{(1)}}\cdot\left[\left(\ln\left(D_w^{(2)}\right)-\ln\left(D_w^{(1)}\right)\right) - U(2) + (a^{(1)}T_w{}^{(1)} + b^{(1)}h_w{}^{(1)} + c^{(1)}p_w^{(1,0)} + \xi^{(1)})\right]$$
$$+\frac{1}{c_w{}^{(1)}}$$

....

$$\frac{\partial u_w^{(i)}}{\partial D_w^{(i)}} = p_w^{(i,0)} - \frac{1}{c_w{}^{(i)}}\cdot\left[\left(\ln\left(D_w^{(i+1)}\right)-\ln\left(D_w^{(i)}\right)\right) - U(i+1) + (a^{(i)}T_w{}^{(i)} + b^{(i)}h_w{}^{(i)} + c^{(i)}p_w^{(i,0)} + \xi^{(i)})\right]$$
$$+\frac{1}{c_w{}^{(i)}}$$

....

$$\frac{\partial u_w^{(M_w)}}{\partial D_w^{(M_w)}} = p_w^{(M_w,0)} - \frac{1}{c_w{}^{(M_w)}}\cdot\left[\left(\ln\left(D_w^{(1)}\right)-\ln\left(D_w^{(M_w)}\right)\right) - U(1) + (a^{(M_w)}T_w{}^{(M_w)} + b^{(M_w)}h_w{}^{(M_w)} + c^{(M_w)}p_w^{(M_w,0)} + \xi^{(M_w)})\right]$$
$$+\frac{1}{c_w{}^{(M_w)}}$$

(B.32)

Difficulties and Remedies:

(1) Since the utility function (or mode choice model) coefficients appear in the coordinate transformation, it is impossible to separate the mode choice model and the transportation provider model. Numerical calculation will not work here.

(2) This must be zonal based. Air party based does not make any sense since the air party is from a definite mode;

(3) It is necessary to know the modes available for each zone;

(4) This is a nonlinear optimization problem but with linear constraints. To use the Frank Wolfe method, simplex method, pseudo-linearization is not necessary, current step value is used for the nonlinear part evaluation. (06/21/07). This is the whole point for using

To implement:

(1) Modify previous implementation:
    i. Still use the previous variable defined
    ii. But optimization w. r. t. each air party (at each zone)

(2) Calculate D_w based on (B.24) – the zonal demand or demand corresponding to air party w.

(3) To calculate objective function according to (B.30)

(4) Calculate the Jacobean Matrix of objective function w. r. t. the decision parameters while considering other decision parameters as constants;

(5) After optimization w. r. t. each air party (zone) – converging to equilibrium, transform back to price changing rate using (B.29)

(6) Select larger convergence criteria: e. g . 0.5 or 1.0

(7) Using the Nash Equilibrium passenger line flow to calculate other performance parameters including probability;

(8) After reaching convergence, the recommended price should be aggregated over the 4 types of passengers for in zone statistically using (B.29). This could be done based on the traffic of each type of passenger. Such aggregation is unnecessary at any intermediate step because the price parameter does not appear (06/20/07).

B-13 Third Implementation

The third implementation is actually a combination of the previous two implementations. This is necessary based on the consideration of mode choice modal calibration, which must work on air parties instead of transportation analysis zones (TAZs) or Super-TAZs. This means that the two models need to run with different dimensions: (a) whenever the mode choice model is evaluated for probability and the derivatives of the performance measures, it is evaluated over all the air party based data; (b) transportation provider need to run on super-zones (Super-TAZ based). This means that a data aggregation process and a dissemination process need to be built, which is based on a mapping between TAZ and Super-TAZ. This implementation is depicted in the following figure

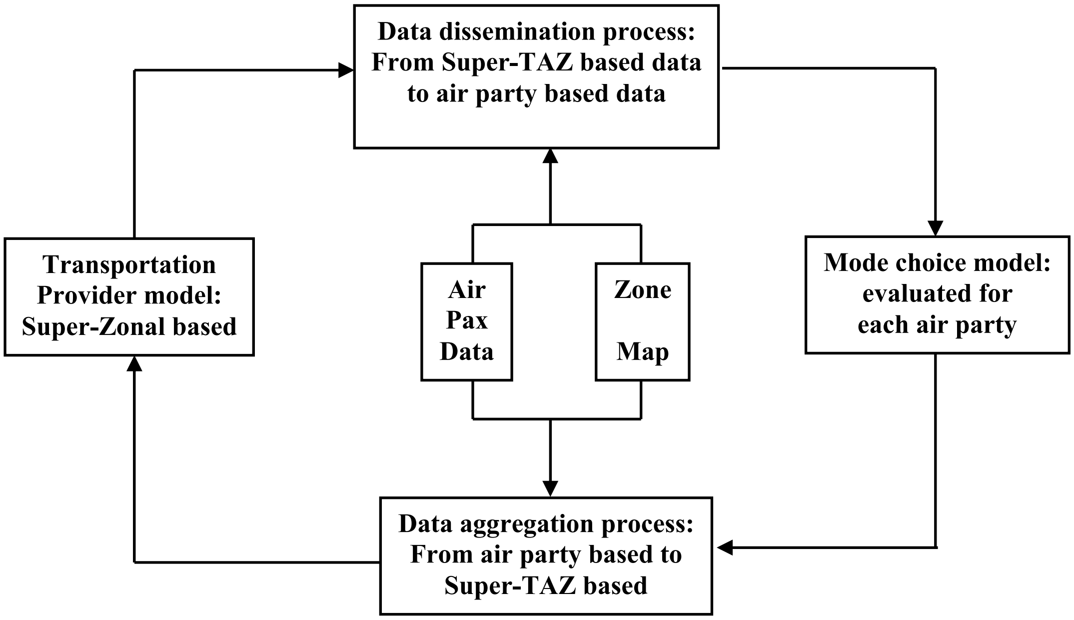


Figure B-1

This means that it is necessary to combine the previous two implementations into one. Those two parameter aggregation/dissemination processes can be implemented as:

(1) Aggregation:

Suppose $P_w^{(i)}$ has been calculated from the 1st implementation.

Let $Z = \{Z_1, ..., Z_\varsigma\}$ denote the index of super zones. We know in advance a given air party belongs to which super zone. Thus, given an air party index, $w \in Z_j$ can be determined from the zonal map.

If we treat

$$p_{Z_j}^{(i)} = p_{Z_j}^{(i,0)}(1 + x_{Z_j}^{(i)}) \tag{B.33}$$

where $x^{(i)}$ is the fare change rate (percentage) for mode i and air party v, the utility can be written as

$$U_v{}^{(i)} = a^{(i)} T_v{}^{(i)} + b^{(i)} h_{Z_j}{}^{(i)} + c^{(i)} p_{Z_j}^{(i,0)}(1 + x_{Z_j}^{(i)}) + \xi^{(i)}$$

The following aggregated parameters can be calculated:

(a) Zonal Probability and Demand:

$$P_{Z_j}^{(i)} = \frac{\sum_{v \in Z_j} P_v^{(i)}}{\sum_k \sum_{v \in Z_j} P_v^{(k)}}$$

$$D_{Z_j} = D_{total} \cdot \frac{\sum_i \sum_{v \in Z_j} P_v^{(i)}}{\sum_{k,v} P_v^{(k)}}$$

This is the number D_w used in the second implementation (B.25a), where w represents the zone.

(b) Average Air Party Size and Average Duration for Airport Parking:

Let s_w and $dur_w^{(i)}$ denote the air party size and parking duration for air party w. Then average party size $\overline{s}_{z_j}$ and average parking duration $\overline{dur}_{Z_j}^{(i)}$ in super zone Z_j can be calculated as:

$$\bar{s}_{Z_j}^{(i)} = \frac{\sum_{w \in Z_j} s_v^{(i)} \cdot P_v^{(i)}}{\sum_{v \in Z_j} P_v^{(i)}}$$

$$\overline{dur}_{Z_j}^{(i)} = \frac{\sum_{v \in Z_j} dur_v^{(i)} \cdot P_v^{(i)}}{\sum_{v \in Z_j} P_v^{(i)}}$$

(c) Average Price for Mode i in a Super Zone:

It is reasonable to assume that the price for mode i is $p_w^{(i)}$ for the given super zone. Such process for aggregate the TAZ laid out by MTC is for the implementation in Bay Area only. For other areas, one can directly use the zone in a supper zone level. In that case, the process of aggregating from TAZ to supper TAZ is not necessary.

(d) Objective Function Calculation:

The objective function in a Super TAZ Z_j for a **non-parking mode** can thus be calculated as follows:

$$u_{Z_j}^{(i)} = p_{Z_j}^{(i,0)} D_{Z_j} P_{Z_j}^{(i)} + x_{Z_j}^{(i)} p_{Z_j}^{(i,0)} D_{Z_j} P_{Z_j}^{(i)}$$

where $x_{Z_j}^{(i)}$ are decision parameter for mode i.

The objective function for a **parking mode** j related to a Super TAZ Z_j can be calculated as:

$$u_{Z_j}^{(j)} = \frac{\overline{dur}_{Z_j}^{(j)}}{\bar{s}_{Z_j}^{(j)}} p_{Z_j}^{(j,0)} D_{Z_j} P_{Z_j}^{(j)} + \frac{\overline{dur}_{Z_j}^{(j)}}{\bar{s}_{Z_j}^{(j)}} x_{Z_j}^{(j)} p_{Z_j}^{(j,0)} D_{Z_j} P_{Z_j}^{(j)}$$

where $x_w^{(i)}$ are decision parameters.

Those average values should be used in coordination transformation (B.29), revenue calculation in (B.30) and Jacobean Matrix (B.32).

It is noted that those average parameters are related to air party based probability, they should be updated at each step of iteration, which has not been implemented yet. Those averaged and updated value should be used for the revenue calculation for airport parking, which is yet to be done.

(2) Data Dissemination

Data dissemination is easier to implement: all the air parties in the same super zone use the same value for a given parameter. In the combined approach, **there is no need** to partition the zonal demand further into four parts:

$$D_w = D_{w,rb} + D_{w,rp} + D_{w,vb} + D_{w,vp}$$

where

$D_{w,rb}$ – demand of resident business
$D_{w,rp}$ – demand of resident personal
$D_{w,vb}$ – demand of visitor business
$D_{w,vp}$ – demand of visitor personal

This is because the mode choice model is evaluated just based on air party as in the first implementation.

Appendix C: Measures of Performance and Evaluation Analysis

C-1 Notations, Variables and Formulae for MOSP and MOCP

This appendix contains fourteen measures of performance; eleven of which are measures of system performance (MOSP), and three are measures of connectivity performance (MOCP). Table C-1 lists all the considered measures and their designated symbols.

Table C-1: List of MOSP and MOCP Considered and their Notations

MOSP Designated	notation	MOCP Designated	notation
Number of passengers	**P**	Passenger waiting times	**PWT**
Number of air parties	**A**	Passenger transfers	**PTR**
Revenue	**R**	Connectivity-production cost*	**CPC**
Vehicle trips	**V**		
Vehicle-miles of travel	**VMT**		
Passenger travel times	**PTT**		
Emissions	**E**		
Vehicle-hours of travel	**VHT**		
Passengers/veh-hr	**PVH**		
Passengers/veh-mile	**PVM**		
Revenue/passenger	**RP**		

* Passenger waiting-time, transfer and on-board travel time cost plus average combined veh-hr operating cost

Interpretation, formulation and notes of each measure appear in the Tables C-3 and C-4 below. However a few more notes pertaining emissions are as follows.

(1) The Table C-2 of emission data below is based on U.S. Environmental Protection Agency (EPA) models

(2) MOBILE5 vehicle emission modeling software and PART5 model (for estimating particulate emissions from highway vehicles) were used

(3) EPA, National Emission Inventories Air Pollutant Trend Web site: www.epa.gov/ttn/chief/trend

(4) A more update model by EPA is MOBILE6 that can be found in: www.epa.gov/otaq/m6.htm .

(5) The following Table C-2 (using MOBILE5 and PART5 software) provides data by vehicle type, per single vehicle and in parenthesis on a per passenger basis; the latter is based on occupancy of 35 passengers/bus and 150 passengers/train.

Table C-2: Average Emission of Pollutant per Vehicle-mile
(in parenthesis per passenger-mile) in gram/mile

	CO NO	**$_x$ VOC**		**PM$_{10}$**
Diesel bus	**23.2** (0.66)	**22.1** (0.63)	**4.2** (0.12)	**0.63** (0.02)
Automobile	**23.0** (19.17)	**3.9** (3.25)	**3.7** (3.08)	**0.09** (0.075)
Rail	**0.03** (0.0002)	**0.47** (0.003)	**0.02** (0.0001)	**0.009** (0.0001)

The selection of MOSP and MOCP for the project is based on the commonly used and known measures of performance (MOPs) (see explanation in Section C-1 above). The only new measure is the connectivity production cost (CPC); this measure attempts to capture the estimated cost involved with the linking/transferring points; thus, to represent the so-called connectivity-production cost.

Table C-3 provides all the notations used in this appendix with indication of the data elements extracted from the MTC air passenger survey from which data in taken for the Intermodal Airport Ground Access Planning Tool (IAPT). The attributes elements are designated with "e" and an index.

Table C-3. Air-Passenger and Service Data Notation

Type of data	**Data item** (* means not in data files)	**Designated notation**	**Interpretation**
Air passengers	**Party ID**	i	**Air party survey ID**
	TAZ	z_i	**MTC traffic analysis zone for air party i**
	Party size	p_{imt}	**Air party size for air party i, access/egress mode m and time of day t**
	Park duration	d_i	**Number of days car would be parked at airport if parked for duration of air trip for air party i**

(Table C-3 cont.)	**Trip type**	r	**Air party trip type** **1**=resident business, **2**=resident personal, **3**=visitor business, **4**=visitor personal
Air passengers (cont.)	**Origin type**	g	**Ground origin type** **1**=Own home, **2**=Someone else's home, **3**=Place of business, **4**=Hotel, motel, inn, etc., **5**=Restaurant, **6**=Convention center, **7**=School or college, **8**=Other type of place
	Time day	t	**Time of day code** **1**=AM peak (weekday 7 – 10 am), **2**=PM peak (weekday 4:30 – 7:30 pm), **3**=Off-peak (all other times)
	*Time of day length**	t'	**Length of time of day (minutes)**
	Inc 2000	I_i	**Household income in year 2000 for air party i ($000)**
	Mode used	m	**Ground access mode used** **1**=Drop off by private vehicle, **2**=Private vehicle parked for duration of air trip, **3**=Shuttle bus from train (BART, Caltrain, etc.), **4**=Public transit bus, **5**=Scheduled airport bus, **6**=Taxi, **7**=Hotel/motel courtesy shuttle, **8**=Pre-arranged limousine, **9**=Shared-ride door-to-door van, **10**=Charter bus, **11**=Other mode, **12**=Rental car, **R**=Rail (BART, Caltrain, etc.)
	*Party ID mode**	I_{mt}	**Set of party ID for access/egress mode m and time of day t**
	*Number of passengers**	P_{mt}	**Number of passengers by mode m and time of day t**
	*Number of air parties**	A_{mt}	**Number of air parties by mode m and time of day t**
	*Revenue**	R_{mt}	**Revenue by mode m and time of day t ($)**
	*Vehicle trips**	V_{mt}	**Vehicle trips by mode m and time of day t**
	*Vehicle-miles of travel**	VMT_{mt}	**Vehicle-miles of travel by mode m and time of day t (veh-mile)**

(Table C-3 cont.)	*Passenger travel times**	PTT_{mt}	**Passenger travel times by mode m and time of day t (hours)**
Air passengers (cont.)	*Emissions**	E_{mt}	**Vector of average four emission of pollutants by mode m and time of day t (kg)**
	*Vehicle-hours of travel**	VHT_{mt}	**Vehicle-hours of travel by mode m and time of day t (veh-hr)**
	*Passengers per veh-hr**	PVH_{mt}	**Ratio of passengers per vehicle-hour by mode m and time of day t (pax/veh-hr)**
	*Passengers per veh-mile**	PVM_{mt}	**Ratio of passengers per vehicle-mile by mode m and time of day t (pax/veh-mile)**
	*Revenue per passenger**	RP_{mt}	**Revenue per passenger by mode m and time of day t ($)**
	*Passenger waiting times**	PWT_{mt}	**Passenger waiting times by mode m and time of day t (hours)**
	*Passenger transfers**	PTR_{mt}	**Number of passenger transfers (between and within modes of travel) by mode m and time of day t**
	*Connectivity-production cost**	CPC_{mt}	**Cost of passenger waiting-time, transfer penalty and on-board travel time plus average combined operating cost of vehicle-hour by mode m and time of day t ($)**
Service Levels	**Party ID**	i	**Air party survey ID for air party i (same as above)**
	Drive Time	e_{1it}	**Highway travel time between the centroid of the trip origin z_i and the airport for air party i and time of day t (minutes)**
	Drive Distance	e_{2it}	**Highway distance between the centroid of the trip origin z_i and the airport for air party i and time of day t (miles)**
	Drop cost	e_{3it}	**Pickup/drop-off access/egress fees for airport roadways for air party i and time of day t ($)**
	Park cost	e_{4it}	**Total cost for access trip by auto parked at airport for duration of air trip, for air party i and time of day t ($)**

(Table C-3 cont.) **Service Levels (cont.)**	*Parking-shuttle wait**	e_{5t}	**Passenger waiting time for airport-parking shuttle bus (minutes)**
	*Parking-shuttle time**	e_6	**Airport-parking shuttle bus travel time (minutes)**
	*Parking-shuttle distance**	e_7	**Airport-parking shuttle bus travel distance (miles)**
	Taxi fare	e_{8it}	**Taxi fare for air party i and time of day t ($)**
	*Van time**	e_{9t}	**Van travel time for time of day t (minutes)**
	*Van distance**	e_{10t}	**Van travel distance for time of day t (miles)**
	Van wait	e_{11t}	**Passenger waiting time for door-to-door van for time of day t (minutes)**
	Van fare	e_{12it}	**Door-to-door van fare for air party i and time of day t ($)**
	Scheduled-bus time	e_{13t}	**Scheduled airport bus travel time for time of day t (minutes)**
	*Scheduled-bus distance**	e_{14t}	**Scheduled airport bus travel distance for time of day t (miles)**
	Scheduled-bus wait	e_{15t}	**Passenger waiting time for scheduled airport bus for time of day t (minutes)**
	Scheduled-bus access time	e_{16it}	**Driving time by private auto from trip origin z_i to scheduled airport bus, for air party i and time of day t (minutes)**
	*Scheduled-bus access distance**	e_{17it}	**Driving distance by private auto from trip origin z_i to scheduled airport bus, for air party i and time of day t (miles)**
	Scheduled-bus fare	e_{18it}	**Scheduled airport bus fare, for air party i and time of day t (($)**
	Bus time	e_{19it}	**Public transit bus travel time, for air party i and time of day t (minutes)**
	*Bus distance**	e_{20it}	**Public transit bus travel distance, for air party i and time of day t (miles)**
	Bus wait	e_{21t}	**Passenger waiting time for public transit bus for time of day t (minutes)**

(Table C-3 cont.)	**Bus walk**	e_{22it}	**Walking distance from trip origin z_i to access the nearest public transit bus, for air party i and time of day t (miles)**
	Bus fare	e_{23it}	**Public transit bus fare, for air party i and time of day t ($)**
	Rail time	e_{24it}	**Travel time on BART/Caltrain/VTA light rail, for air party i and time of day t (minutes)**
	*Rail distance**	e_{25it}	**Travel distance on BART/Caltrain/VTA light rail, for air party i and time of day t (miles)**
	Rail access time	e_{26it}	**Driving time by private auto from trip origin z_i to BART/Caltrain/VTA light rail, for air party i and time of day t (minutes)**
Service Levels (cont.)	*Rail access distance**	e_{27it}	**Driving distance by private auto from trip origin z_i to BART/Caltrain/VTA light rail, for air party i and time of day t (miles)**
	Rail wait	e_{28t}	**Passenger waiting time for BART/Caltrain/VTA light rail for time of day t (minutes)**
	Rail fare	e_{29it}	**BART/Caltrain/VTA light rail fare, for air party i and time of day t ($)**
	*Rail-shuttle wait**	e_{30t}	**Passenger waiting time for shuttle at the airport BART/Caltrain/VTA light rail stop, for time of day t (minutes)**
	*Rail-shuttle time**	e_{31}	**Rail-shuttle bus travel time (minutes)**
	*Rail-shuttle distance**	e_{32}	**Rail-shuttle bus travel distance (miles)**
	Rental cost	e_{33it}	**Assumed proportion of car rental cost attributable to ground access trip, for air party i and time of day t ($)**
	*Rental car-shuttle wait**	e_{34t}	**Passenger waiting time for shuttle at the airport return- rental-car point, for time of day t (minutes)**

(Table C-3 cont.)	*Rental car-shuttle time**	e_{35}	**Rental car-shuttle bus travel time (minutes)**
Service Levels (cont.)	*Rental car-shuttle distance**	e_{36}	**Rental car-shuttle bus travel distance (miles)**
	*Passenger waiting-time cost**	e_{37}	**Value of one hour waiting time ($)**
	*Transfer-penalty cost**	e_{38}	**Value of one transfer penalty ($)**
	*Passenger on-board travel time cost**	e_{39}	**Value of one hour on-board travel time ($)**
	*Vehicle-hour cost**	e_{40}^{m}	**Average combined operating cost of one vehicle-hour by mode m ($)**

*Data item which is not included in data files of the survey

Table C-4 provides all the access and egress transportation modes that were identified and considered in the MTC air passenger survey. In addition Table C-4 described the paths (Ceder, 2005) related to each mode. Table C-5 follows Table C-4 and provides all the formulae of MOSP and MOCP considered. In addition, under the first column of Table C-5, notes are inserted to explicate the assumption made and/or to provide further explanation of the measure described.

Table C-4: Access/Egress Modes and Paths

Code of mode (in MTC air passenger survey)	**Access/egress mode** (in MTC air passenger survey)	**Code of path**	**Access path description**	**Notes**
1	Drop off/pick-up by private vehicle	**k1**	**Auto-terminal**	No waiting
2	Private vehicle parked for duration of air trip	**k2**	**Auto-*wait*-parking shuttle-terminal**	
3	Shuttle bus from train (BART, Caltrain, etc)	**k3**	**Auto-*wait*-train-*wait*-shuttle-terminal**	
4	Public transit bus	**k4**	**Walk-*wait*-public bus-terminal**	
5	Scheduled airport bus	**k5**	**Auto-*wait*-airport bus-terminal**	
6	Taxi	**k6**	**Taxi-terminal**	No waiting
7	Hotel/motel courtesy shuttle	**k7**	**Courtesy shuttle-terminal**	No waiting
8	Pre-arranged limousine	**k8**	**Limousine-terminal**	No waiting
9	Shared-ride door-to-door van	**k9**	**Van-terminal**	No waiting, but not a straight ride
10	Charter bus	**k10**	**Charter bus-terminal**	No waiting, as it is a special ride
11	Other mode (bicycle, walking, etc)	**k11**	**N/A**	Lack of data
12	Rental car	**k12**	**Auto-*wait*-rental car shuttle-terminal**	

Table C-5: Formulae of Access/Egress Measures of System Performance (MOSP and MOCP)

Note: formulae use the aforementioned notations

Measures of access/egress	Path-based formulae	Terminal/airport-based formulae
Number of passengers	$P_{mt} = \sum_{i \in I_{mt}} p_{mit} \quad \forall \ m=1,2,\ldots,12; \quad t = 1,2,3$ *Result:* 36 measures by access/egress mode and time of day	$P_t = \sum_{m=1}^{12} P_{mt} \quad \forall \ t=1,2,3$ *Result:* 3 measures by time of day for the sum of all access/egress modes
Number of air-parties	$A_{mt} = \sum_{i \in I_{mt}} i \quad \forall \ m=1,2,\ldots,12; \quad t = 1,2,3$ *Result:* 36 measures by access/egress mode and time of day	$A_t = \sum_{m=1}^{12} A_{mt} \quad \forall \ t=1,2,3$ *Result:* 3 measures by time of day for the sum of all access/egress modes
Revenue *Notes:* **(1)** Charter bus fare per air party (see R_{10t}) is assumed the same as airport bus fare (e_{18it}) **(2)** Rental cost per air party (see R_{12t}) is assumed different although is currently the same in OAK and SJC files	***By access/egress mode:*** $R_{1t} = \sum_{i \in I_{1t}} e_{3it} \quad \forall \ t = 1,2,3$ $R_{2t} = \sum_{i \in I_{2t}} (e_{3it} + e_{4it}) \quad \forall \ t = 1,2,3$ $R_{3t} = \sum_{i \in I_{3t}} e_{29it} \quad \forall \ t = 1,2,3$ $R_{4t} = \sum_{i \in I_{4t}} e_{23it} \quad \forall \ t = 1,2,3$ $R_{5t} = \sum_{i \in I_{5t}} e_{18it} \quad \forall \ t = 1,2,3$ $R_{6t} = \sum_{i \in I_{6t}} e_{8it} \quad \forall \ t = 1,2,3$ $R_{7t} = 0 \quad \forall \ t = 1,2,3$ $R_{8t} = \sum_{i \in I_{8t}} e_{8it} \quad \forall \ t = 1,2,3$ $R_{9t} = \sum_{i \in I_{9t}} e_{12it} \quad \forall \ t = 1,2,3$	$R_t = \sum_{m=1}^{12} R_{mt} \quad \forall \ t=1,2,3$ *Result:* 3 measures by time of day for the sum of all access/egress modes

(Table C-5 cont.) **Revenue (cont.)**	$R_{10t} = \sum_{i \in I_{10t}} e_{18it} \quad \forall \quad t=1,2,3$ $R_{11t} = 0 \quad \forall \quad t=1,2,3$ $R_{12t} = \sum_{i \in I_{12t}} e_{33it} \quad \forall \quad t=1,2,3$ *Result:* 36 measures by access/egress mode and time of day	
Vehicle trips ***Notes:*** **(1)** The headway $2e_{5t}$ (2^{nd} mode) is 10 minutes (OAK and SJC) **(2)** The headway $2e_{30t}$ (3rd mode) is 15 minutes for OAK and 10, 15 minutes for SJC, for weekday and weekend, respectively ***Notes cont.* ⇒**	***By access/egress mode:*** $V_{1t} = A_{1t}, \quad t=1,2,3$ $V_{2t} = A_{2t} + \frac{t'}{2e_{5t}}, \quad t=1,2,3$ $V_{3t} = A_{3t} + \frac{t'}{2e_{28t}} + \frac{t'}{2e_{30t}}, t=1,2,3$ $V_{4t} = \frac{t'}{2e_{21t}}, \quad t=1,2,3$ $V_{5t} = A_{5t} + \frac{t'}{2e_{15t}}, \quad t=1,2,3$ $V_{6t} = A_{6t}, \quad t=1,2,3$ $V_{7t} = A_{7t}, \quad t=1,2,3$ $V_{8t} = A_{8t}, \quad t=1,2,3$ $V_{9t} = \frac{A_{9t}}{ap_{1t}}, \quad t=1,2,3$ $V_{10t} = \frac{A_{10t}}{ap_{2t}}, \quad t=1,2,3$ $V_{11t} = 0, \quad t=1,2,3$ $V_{12t} = A_{12t} + \frac{t'}{2e_{34t}}, \quad t=1,2,3$ *Result:* 36 measures by access/egress mode and time of day	$V_t = \sum_{m=1}^{12} V_{mt} \quad \forall \quad t=1,2,3$ *Result:* 3 measures by time of day for the sum of all access/egress modes ***Notes (cont.):*** **(3)** The headway $2e_{34t}$ (12th mode) is 10 minutes (OAK and SJC) **(4)** The parameter ap_{1t} is the average number of air parties on a single van during t (to consult van operators) **(5)** The parameter ap_{2t} is the average number of air parties on a single charter bus during t (to consult charter bus operators)
Vehicle-miles of travel	***By access/egress mode:*** $VMT_{1t} = \sum_{i \in I_{1t}} e_{2it}, \quad t=1,2,3$ $VMT_{2t} = \sum_{i \in I_{2t}} e_{2it} + \frac{t'}{2e_{5t}} \cdot e_7, \quad t=1,2,3$	$VMT_t = \sum_{m=1}^{12} VMT_{mt} \quad \forall \quad t=1,2,3$ *Result:* 3 measures by time of day for the sum of all access/egress modes

(Table C-5 cont.) **Vehicle-miles of travel (cont.)** *Notes:* **(1)** $e_{10t} \cong 1.1 \frac{\sum_{i\in I_{9t}} e_{2it}}{A_{9t}}$ That is, additional average of 10% distance for air parties using van, by time of day *Notes cont.* ⇒	$VMT_{3t} = \sum_{i\in I_{3t}} (e_{27it} + e_{25it}) + \frac{t'}{2e_{30t}} \cdot e_{32}, t = 1,2,3$ $VMT_{4t} = \sum_{i\in I_{4t}} e_{20it} \ , \ t = 1,2,3$ $VMT_{5t} = \sum_{i\in I_{5t}} e_{17it} + \frac{t'}{2e_{15t}} \cdot e_{14} \ , \ t = 1,2,3$ $VMT_{6t} = \sum_{i\in I_{6t}} e_{2it} \ , \ t = 1,2,3$ $VMT_{7t} = \sum_{i\in I_{7t}} e_{2it} \ , \ t = 1,2,3$ $VMT_{8t} = \sum_{i\in I_{8t}} e_{2it} \ , \ t = 1,2,3$ $VMT_{9t} = V_{9t} \cdot e_{10t} \ , \ t = 1,2,3$ $VMT_{10t} = V_{10t} \cdot e_{14t} \ , \ t = 1,2,3$ $VMT_{11t} = 0 \ , \ t = 1,2,3$ $VMT_{12t} = \sum_{i\in I_{12t}} e_{2it} + \frac{t'}{2e_{34t}} \cdot e_{36} \ , \ t = 1,2,3$ *Result:* 36 measures by access/egress mode and time of day	*Notes (cont.):* **(2)** Based on assumed speed of 20 mph: $e_7 = e_6 /3$ $e_{14} = e_{13} /3$ $e_{17i} = e_{16i} /3$ $e_{20} = e_{19} /3$ $e_{25} = e_{24} /3$ $e_{27i} = e_{26i} /3$ $e_{32} = e_{31} /3$ $e_{36} = e_{35} /3$ **(3)** Travel distance by charter bus (see VMT_{10t}) is assumed the same as for the airport bus
Passenger travel times *Notes:* **(1)** e_6=10 minutes (for OAK and SJC) **(2)** $0.047e_{22i}$= walking time to nearest public transit bus stop for air party i at time of day t *Notes cont.* ⇒	***By access/egress mode:*** $PTT_{1t} = \frac{1}{60} \sum_{i\in I_{1t}} (e_{1it} \cdot p_{1it}), \quad t = 1,2,3$ $PTT_{2t} = \frac{1}{60} \left[\sum_{i\in I_{2t}} (e_{1it} \cdot p_{2it}) + (e_{5t} + e_6) \cdot P_{2t} \right],$ $t = 1,2,3$ $PTT_{3t} = \frac{1}{60} \left\{ \sum_{i\in I_{3t}} [(e_{26it} + e_{24it}) \cdot p_{3it}] + \right.$ $\left. (e_{28t} + e_{30t} + e_{31}) \cdot P_{3t} \right\}, \quad t = 1,2,3$ $PTT_{4t} = \frac{1}{60} \left\{ \sum_{i\in I_{4t}} [(0.047e_{22it} + e_{19it}) \cdot p_{4it}] + \right.$ $\left. e_{21}t \cdot P_{4t} \right\}, \quad t = 1,2,3$	$PTT_t = \sum_{m=1}^{12} PTT_{mt} \quad \forall$ t=1,2,3 *Result:* 3 measures by time of day for the sum of all access/egress modes

(Table C-5 cont.) **Passenger travel times (cont.)** ***Notes (cont.):*** (assuming average walking speed of 250 ft/min=0.047 mile/min; from TCRP Report 100: Transit Capacity and Quality of Service Manual, 2nd Edition, TRB, 2003) ***Notes cont.*** ⇒	$PTT_{5t} = \frac{1}{60}\left[\sum_{i\in I_{5t}}(e_{16it}\cdot p_{5it}) + (e_{15t}+e_{13t})P_{5t}\right], \quad t=1,2,3$ $PTT_{6t} = \frac{1}{60}\sum_{i\in I_{6t}}(e_{1it}\cdot p_{6it}), \quad t=1,2,3$ $PTT_{7t} = \frac{1}{60}\sum_{i\in I_{7t}}(e_{1it}\cdot p_{7it}), \quad t=1,2,3$ $PTT_{8t} = \frac{1}{60}\sum_{i\in I_{8t}}(e_{1it}\cdot p_{8it}), \quad t=1,2,3$ $PTT_{9t} = \frac{1}{60}\cdot e_{9t}\cdot P_{9t} \quad t=1,2,3$ $PTT_{10t} = \frac{1}{60}\cdot e_{13t}\cdot P_{10t} \quad t=1,2,3$ $PTT_{11t} = \mathit{unknown}, \quad t=1,2,3$ $PTT_{12t} = \frac{1}{60}\left[\sum_{i\in I_{12t}}(e_{1it}p_{12it}) + (e_{34t}+e_{35})P_{12t}\right], \quad t=1,2,3$ *Result:* 36 measures by access/egress mode and time of day	***Notes (cont.):*** **(3)** $e_{9t} \cong 1.2\frac{\sum_{i\in I_{9t}} e_{2it}}{A_{9t}}$ That is, additional average of 20% travel time for air parties using van, by time of day **(4)** Travel time by charter bus (see PTT_{10t}) is assumed the same as for the airport bus; also passengers for Charter bus are assumed to have no wait **(5)** PTT_{11t} is assumed zero (unknown)
Emissions ***Notes:*** **(1)** E_{mt} is a vector of four emissions in kilograms ***Notes cont.*** ⇒	***General:*** $E_{mt} = \sum_{y=1}^{3} VMT_{mt}(y)\cdot\begin{pmatrix}CO_{my}\\ NO_{xmy}\\ VOC_{my}\\ PM_{10my}\end{pmatrix}, \ m=1,2,...12, \quad t=1,2,3$ where CO_{my}, NO_{xmy}, VOC_{my}, PM_{10my} (arranged in vector) are average emission of pollutant in grams per mile for access/egress mode m and vehicle type y; codes for y are 1=diesel bus, 2=automobile, 3=rail. ***By access/egress mode:*** $E_{1t} = \frac{VMT_{1t}}{1000}\cdot\begin{pmatrix}23.0\\ 3.9\\ 3.7\\ 0.09\end{pmatrix}, \quad t=1,2,3$	$E_t = \sum_{m=1}^{12} E_{mt} \ \forall\ t=1,2,3$ *Result:* 3 measures by time of day for the sum of all access/egress modes

(Table C-5 cont.) **Emissions (cont.)** ***Notes (cont.):*** **(2)** Taxi, limousine, shuttle bus and van are assumed to run on gasoline (not on diesel) **(3)** Information on vehicle emission appears in the beginning of this document	$E_{2t} = \frac{VMT_{2t}}{1000} \cdot \begin{pmatrix}23.0\\3.9\\3.7\\0.09\end{pmatrix}, \quad t = 1,2,3$ $E_{3t} = \left[\frac{\sum_{i\in I_{3t}} e_{27it}}{1000} + \frac{t'}{2e_{30t}} \cdot e_{32}\right] \cdot \begin{pmatrix}23.0\\3.9\\3.7\\0.09\end{pmatrix} +$ $\left[\frac{\sum_{i\in I_{3t}} e_{25it}}{1000}\right] \cdot \begin{pmatrix}0.03\\0.47\\0.02\\0.009\end{pmatrix}, \quad t = 1,2,3$ $E_{4t} = \frac{VMT_{4t}}{1000} \cdot \begin{pmatrix}23.2\\22.1\\4.2\\0.63\end{pmatrix}, \quad t = 1,2,3$ $E_{5t} = \left[\frac{\sum_{i\in I_{5t}} e_{17it}}{1000}\right] \cdot \begin{pmatrix}23.0\\3.9\\3.7\\0.09\end{pmatrix} + \frac{t' \cdot e_{14t}}{2000 \cdot e_{15t}} \cdot \begin{pmatrix}23.2\\22.1\\4.2\\0.63\end{pmatrix},$ $t = 1,2,3$ $E_{6t} = \frac{VMT_{6t}}{1000} \cdot \begin{pmatrix}23.0\\3.9\\3.7\\0.09\end{pmatrix}, \quad t = 1,2,3$ $E_{7t} = \frac{VMT_{7t}}{1000} \cdot \begin{pmatrix}23.0\\3.9\\3.7\\0.09\end{pmatrix}, \quad t = 1,2,3$ $E_{8t} = \frac{VMT_{8t}}{1000} \cdot \begin{pmatrix}23.0\\3.9\\3.7\\0.09\end{pmatrix}, \quad t = 1,2,3$ $E_{9t} = \frac{VMT_{9t}}{1000} \cdot \begin{pmatrix}23.0\\3.9\\3.7\\0.09\end{pmatrix}, \quad t = 1,2,3$	

(Table C-5 cont.) **Emissions (cont.)**	$E_{10t} = \frac{VMT_{10t}}{1000} \cdot \begin{pmatrix} 23.2 \\ 22.1 \\ 4.2 \\ 0.63 \end{pmatrix}, \quad t = 1,2,3$ $E_{11t} = 0, \quad t = 1,2,3$ $E_{12t} = \frac{VMT_{12t}}{1000} \cdot \begin{pmatrix} 23.0 \\ 3.9 \\ 3.7 \\ 0.09 \end{pmatrix}, \quad t = 1,2,3$ *Result:* 36 measures by access/egress mode and time of day	
Vehicle-hours of travel	***By access/egress mode:*** $VHT_{1t} = \frac{1}{60}\sum_{i\in I_{1t}} e_{1it}, \quad t = 1,2,3$ $VHT_{2t} = \frac{1}{60}\left(\sum_{i\in I_{2t}} e_{1it} + \frac{t'}{2e_{5t}} \cdot e_{6}\right), \quad t = 1,2,3$ $VHT_{3t} = \frac{1}{60}\left(\sum_{i\in I_{3t}} (e_{26it} + e_{24it}) + \frac{t'}{2e_{30t}} \cdot e_{31}\right),$ $t = 1,2,3$ $VHT_{4t} = \frac{1}{60}\sum_{i\in I_{4t}} e_{19it}, \quad t = 1,2,3$ $VHT_{5t} = \frac{1}{60}\left(\sum_{i\in I_{5t}} e_{16it} + \frac{t'}{2e_{15t}} \cdot e_{13}\right), \quad t = 1,2,3$ $VHT_{6t} = \frac{1}{60}\sum_{i\in I_{6t}} e_{1it}, \quad t = 1,2,3$ $VHT_{7t} = \frac{1}{60}\sum_{i\in I_{7t}} e_{1it}, \quad t = 1,2,3$ $VHT_{8t} = \frac{1}{60}\sum_{i\in I_{8t}} e_{1it}, \quad t = 1,2,3$ $VHT_{9t} = \frac{1}{60} V_{9t} \cdot e_{9t}, \quad t = 1,2,3$ $VHT_{10t} = \frac{1}{60} V_{10t} \cdot e_{13t}, \quad t = 1,2,3$ $VHT_{11t} = 0, \quad t = 1,2,3$	$VHT_{t} = \sum_{m=1}^{12} VHT_{mt} \quad \forall$ t=1,2,3 *Result:* 3 measures by time of day for the sum of all access/egress modes

(Table C-5 cont.) **Vehicle-hours of travel (cont.)**	$VHT_{12t} = \frac{1}{60}\left(\sum_{i\in I_{12t}} e_{1it} + \frac{t'}{2e_{34t}}\cdot e_{35}\right), \quad t=1,2,3$ *Result:* 36 measures by access/egress mode and time of day	
Passengers per vehicle-hour	$PVH_{mt} = \frac{P_{mt}}{VHT_{mt}} \quad \forall\, m=1,2,...,12, \quad t=1,2,3$ *Result:* 36 measures by access/egress mode and time of day	$PVH_t = \sum_{m=1}^{12} PVH_{mt} \quad \forall$ t=1,2,3 *Result:* 3 measures by time of day for the sum of all acc/egress modes
Passengers per vehicle-mile	$PVM_{mt} = \frac{P_{mt}}{VMT_{mt}} \quad \forall\, m=1,2,...,12, \quad t=1,2,3$ *Result:* 36 measures by access/egress mode and time of day	$PVM_t = \sum_{m=1}^{12} PVM_{mt} \quad \forall$ t=1,2,3 *Result:* 3 measures by time of day for the sum of all access/egress modes
Revenue per passenger	$RP_{mt} = \frac{R_{mt}}{P_{mt}} \quad \forall\, m=1,2,...,12, \quad t=1,2,3$ *Result:* 36 measures by access/egress mode and time of day	$RP_t = \sum_{m=1}^{12} RP_{mt} \quad \forall$ t=1,2,3 *Result:* 3 measures by time of day for the sum of all access/egress modes
Passenger waiting times	***By access/egress mode:*** $PWT_{1t} = 0, \quad t = 1,2,3$ $PWT_{2t} = \frac{1}{60}\cdot e_{5t}\cdot P_{2t}, \quad t=1,2,3$ $PWT_{3t} = \frac{1}{60}\cdot\left(e_{28t} + e_{30t}\right)\cdot P_{3t}, \quad t=1,2,3$ $PWT_{4t} = \frac{1}{60}\cdot e_{21t}\cdot P_{4t}, \quad t=1,2,3$ $PWT_{5t} = \frac{1}{60}\cdot e_{15t}\cdot P_{5t}, \quad t=1,2,3$ $PWT_{6t} = 0, \quad t = 1,2,3$ $PWT_{7t} = 0, \quad t = 1,2,3$	$PWT_t = \sum_{m=1}^{12} PWT_{mt} \quad \forall$ t=1,2,3 *Result:* 3 measures by time of day for the sum of all access/egress modes

(Table C-5 cont.) **Passenger waiting times (cont.)**	$PWT_{8t} = 0$, t = 1,2,3 $PWT_{9t} = 0$, t = 1,2,3 $PWT_{10t} = 0$, t = 1,2,3 $PWT_{11t} = 0$, t = 1,2,3 $PWT_{12t} = \frac{1}{60} \cdot e_{34t} \cdot P_{12t} \quad , \quad t = 1,2,3$ *Result:* 36 measures by access/egress mode and time of day	
Passenger transfers *Note:* **(1)** Number of transfers within public transit-bus service are unknown	***By access/egress mode:*** $PTR_{1t} = 0$, t = 1,2,3 $PTR_{3t} = P_{2t}$, t = 1,2,3 $PTR_{3t} = 2P_{3t}$, t = 1,2,3 $PTR_{4t} = P_{4t}$, t = 1,2,3 $PTR_{5t} = P_{5t}$, t = 1,2,3 $PTR_{6t} = 0$, t = 1,2,3 $PTR_{7t} = 0$, t = 1,2,3 $PTR_{8t} = 0$, t = 1,2,3 $PTR_{9t} = 0$, t = 1,2,3 $PTR_{10t} = 0$, t = 1,2,3 $PTR_{11t} = 0$, t = 1,2,3 $PTR_{12t} = P_{12t}$, t = 1,2,3 *Result:* 36 measures by access/egress mode and time of day	$PTR_t = \sum_{m=1}^{12} PTR_{mt} \ \forall$ t=1,2,3 *Result:* 3 measures by time of day for the sum of all access/egress modes
Connectivity-production cost (Waiting-time, transfer time, on-board travel time and average combined veh-hr operating cost)	***By access/egress mode:*** $CPC_{1t} = e_{39} \cdot PTT_{1t} + e_{40}^{1} VHT_{1t}, \quad t = 1,2,3$ $CPC_{2t} = e_{37} \cdot PWT_{2t} + e_{38} \cdot PTR_{2t} + e_{39} \cdot PTT_{2t} + e_{40}^{1} \cdot \sum_{i \in I_{2t}} e_{1it} + \frac{t'}{2e_{5t}} \cdot e_{6} \cdot e_{40}^{3}, \quad t = 1,2,3$ $CPC_{3t} = e_{37} \cdot PWT_{3t} + e_{38} \cdot PTR_{3t} + e_{39} \cdot PTT_{3t} + e_{40}^{1} \cdot \sum_{i \in I_{3t}} e_{26it} + e_{40}^{R} \cdot \sum_{i \in I_{3t}} e_{24it} + \frac{t'}{2e_{30t}} \cdot e_{31} \cdot e_{40}^{3}, \quad t = 1,2,3$ $CPC_{4t} = e_{37} \cdot PWT_{4t} + e_{39} \cdot PTT_{4t} + e_{40}^{4} \cdot VHT_{4t}$, t = 1,2,3	$CPC_t = \sum_{m=1}^{12} CPC_{mt} \ \forall$ t=1,2,3 *Result:* 3 measures by time of day for the sum of all access/egress modes

(Table C-5 cont.) **Connectivity-production cost (cont.)** ***Note:*** **(1)** The use of mode R (BART, Caltrain, etc.) is shown in e_{409}^{R}	$CPC_{5t} = e_{37} \cdot PWT_{5t} + e_{38} \cdot PTR_{5t} + e_{39} \cdot PTT_{5t} + e_{40}^{1} \cdot \sum_{i \in I_{5t}} e_{16it} + \frac{t'}{2e_{15t}} \cdot e_{13} \cdot e_{40}^{5}, \quad t = 1,2,3$ $CPC_{6t} = e_{39} \cdot PTT_{6t} + e_{40}^{6} \cdot VHT_{6t}, \quad t = 1,2,3$ $CPC_{7t} = e_{39} \cdot PTT_{7t} + e_{40}^{7} \cdot VHT_{7t}, \quad t = 1,2,3$ $CPC_{8t} = e_{39} \cdot PTT_{8t} + e_{40}^{8} \cdot VHT_{8t}, \quad t = 1,2,3$ $CPC_{9t} = e_{39} \cdot PTT_{9t} + e_{40}^{9} \cdot VHT_{9t}, \quad t = 1,2,3$ $CPC_{10t} = e_{39} \cdot PTT_{10t} + e_{40}^{10} \cdot VHT_{10t}, \quad t=1,2,3$ $CPC_{11t} = 0, \quad t = 1,2,3$ $CPC_{12t} = e_{37} \cdot PWT_{12t} + e_{38} \cdot PTR_{12t} + e_{39} \cdot PTT_{12t} + e_{40}^{1} \cdot \sum_{i \in I_{12t}} e_{1it} + \frac{t'}{2e_{34t}} \cdot e_{35} \cdot e_{40}^{3}, \quad t = 1,2,3$ *Result:* 36 measures by access/egress mode and time of day	

Appendix D: IAPT Data Table Specifications and Data Preparation

This appendix documents the initial implementation of the Intermodal Airport Ground Access Planning Tool (IAPT) air party and transportation service data tables. These tables need to include the relevant variables for the mode choice model implemented in the IAPT, and thus may need to be modified to correspond to the variables included in the mode choice model.

D-1 Air Party Data

The variables needed from the ***air party data*** table are as follows:

Data Table	Name:	**AIRPAX_xxx_yyyy**		
	Description:	Air passenger data for airport XXX for year YYYY (*e.g.* AIRPAX_OAK_2001)		
	Rows:	Air parties		
	Variables:	PartyID	I	Air party case ID number
		TAZ	I	Ground origin zone
		PartySize	I	Air party size
		ParkDur	N	Trip duration (days parked)
		TripType	I	Trip type code (1=res/bus, 2=res/nonbus, 3=vis/bus, 4=vis/nonbus)
		OriginType	I	Ground origin type (survey codes)
		TimeDay	I	AM peak (1), midday (2), PM peak (3), or off-peak (4)
		Inc2000	N	Household income in year 2000 ($000)
		ModeUsed	I	Ground access mode used (1=drop, 2=park, 3-11 as survey codes, 12=rental car)

D-2 Transportation Service Data

Creating the ***transportation service data*** table is a key step in computing the utilities for each mode in the mode choice model. This table contains the values of the transportation service variables for each air party in the ***air party data*** table. The values of most of these will be obtained from the data tables defined in the **Project_Data** table. However, whereas the rows in the data tables defined for the zonal variables in the **Project_Data** table give values for each analysis zone, the rows in the ***transportation service data*** table give the values for each air party in the ***air party data*** table. Thus the ***transportation service data*** table is a *K* by *M* table, where there are *M* transportation service variables defined for each air party. The process of creating this table involves looking up the relevant value of each zonal variable for the trip origin analysis zone of each air party, as well as selecting the correct variable to use where different variables are defined for different time periods (*e.g.* AM peak versus off-peak travel times).

Data Table

Name: **ServiceData_xxx_yyyy**

Description: Transportation service data for airport XXX for year YYYY (*e.g.* ServiceData_OAK_2001)

Rows: Air parties (corresponding to the rows of AIRPAX_xxx_yyyy)

Variables:

PartyID	I	Air party case ID number
DriveTime	N	Zone to airport driving time (min)
DriveDist	N	Zone to airport highway distance (miles)
DropCost	N	Access cost for auto drop trips ($)
ParkCost	N	Total cost for auto park trips ($)
TaxiFare	N	Taxi fare ($)
VanWait	N	Wait time for door-to-door van (min)
VanFare	N	Total fare for door-to-door van ($)
SchBusTime	N	Travel time by scheduled airport bus (min)
SchBusWait	N	Wait time for scheduled airport bus (min)
SchBusAcc	N	Auto access time to scheduled airport bus stop (min)
SchBusFare	N	Total fare for scheduled airport bus ($)
BusTime	N	Transit bus ride time to airport (min)
BusWait	N	Wait time for transit bus to airport (min)
BusWalk	N	Walk distance to transit bus (miles)
BusFare	N	Total fare for transit bus to airport ($)
RailTime	N	Ride time on rail system to airport (min)
RailAcc	N	Auto access time to rail station (min)
RailWait	N	Wait time for rail trip to airport (min)
RailFare	N	Total fare for rail trip to airport ($)
RentalCost	N	Assumed cost for rental car access trip ($)

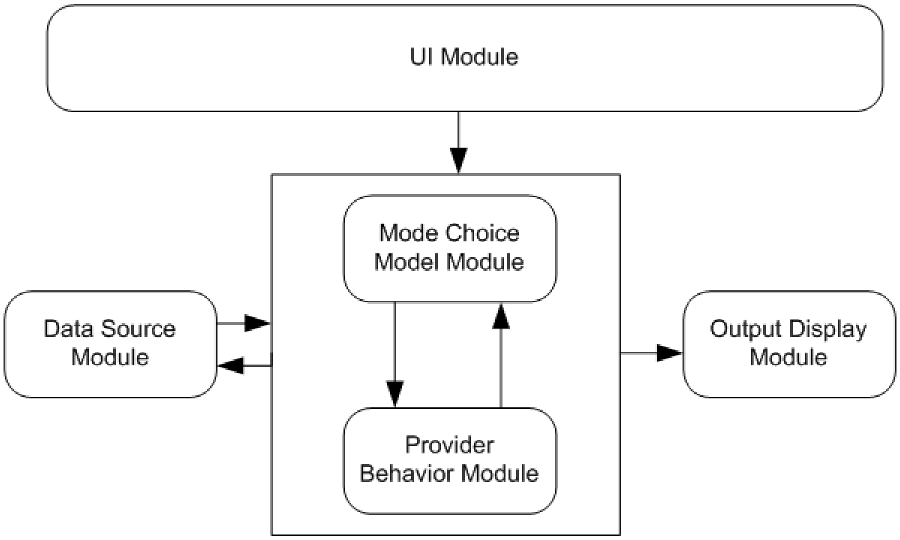
While assembling the service data table can be done by hand initially (*e.g.* by using the *vlookup* function in Excel), this process is tedious and error-prone and thus it will be highly desirable to develop a utility routine to automate the process as soon as possible in the IAPT development.

In cases where a service parameter involves a cost or time component that is identical for all air parties (*e.g.* walk from parking or shuttle bus ride time from the rental car return facility), this need not be explicitly included in the ***transportation service data*** table variables, but can be added to the modal utility as a separate term (in fact this simply changes the mode-specific constant for that mode, which is the simplest way to account for these components).

Appendix E: Technical Aspects of the IAPT

E-1 Program Structure

The Intermodal Airport Ground Access Planning Tool (IAPT) has been developed using C++ running on the Microsoft .NET platform. The system is divided into modules, each responsible for a major function, as shown in the diagram below.



The user interface (UI) module:

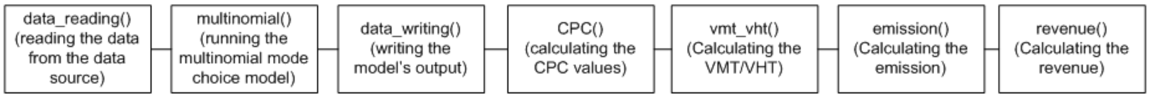
This module is responsible for handling all the interaction with the user.

The data source module:

This module is responsible for reading data files into the system and updating data files.

The mode choice model module:

The mode choice model is the core of IAPT, and is responsible for analyzing the proportion of passengers choosing each mode and subsequent system performance calculations. The following flow chart shows the sequence of routines that perform the analysis within the IAPT.

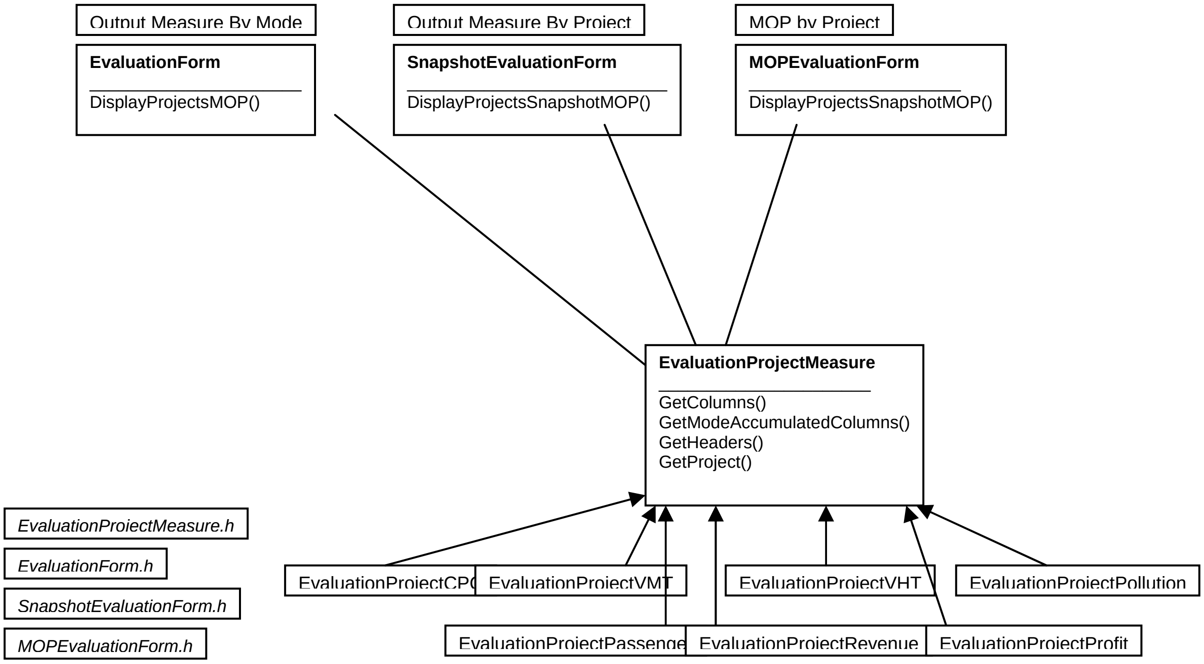


The provider behavior module:

This module implements the Generalized Nash Game to reflect the competitive behaviors of transportation providers for different modes in responding to changes in market share.

The output display module:

This module is responsible for displaying different outputs of the system performance evaluation. It also allows future software developers to add or modify system performance measures easily. The following diagram illustrates the relationship between the various components of the module.



E-2 Data File Formats

The IAPT reads in varies data tables from input files. This section describes the structure of these input files. All data files are tab-delimited text files.

Airpax data file: (AIRPAX_XXX_NNNN.txt)

This file contains the air party characteristics for a sample of air parties using the airport, typically obtained from an air passenger survey. The first row of the data file must contain the column names. The file name should include the airport three-letter code (XXX) and the year for which the data was obtained (NNNN). Definitions of the columns for the initial implementation of the IAPT are given in Appendix D.

Service data file: (ServiceData_XXX_NNNN.txt)

This file contains the transportation service data for each mode included in the mode choice model (up to 20 modes in the initial implementation) for each air party. Each row of the data file provides the transportation service data for one of the air parties in the Airpax data file. Thus the Service Data file must have the same number of rows as the Airpax data file. The first row of the data file must contain the column names. Two columns, “PartyID” and “DriveDist” must be present, and users can add a variable numbers of columns. The mapping between column and each mode’s service data is contained in the Service Data Name mapping file described below.

The file name includes the airport code and year for the data values, corresponding to the Airpax data file discussed above. Definitions of the columns for the Service Data file in the initial implementation of the IAPT are given in Appendix D.

Service data name mapping file: (ServiceDataNameMap_XXX_NNNN.txt)

This file contains the mapping between each mode’s transportation service data and the corresponding column in the Service Data file. The file name includes the airport code and year for the data values, corresponding to the Airpax data file discussed above. Each row represents a mode, with the row order corresponding to the mode number in the mode choice model. The first row of the data file must contain the column names, as follows:

FareName: The column name of mode’s fare data; ‘None’ if such column doesn’t exist.
TravelTimeName: the column name of the mode’s travel time data; ‘None' if such column doesn’t exist.
WaitTimeName: the column name of the mode’s wait time data; ‘None' if such column doesn’t exist.

AccTimeName: the column name of the mode's access time data; 'None' if such column doesn't exist.

Mode choice model coefficients data file (Coeff_XXX.txt)

This file contains the coefficients for the mode choice model. In the initial implementation of the IAPT this is a multinomial logit model with a linear utility function containing a mode-specific constant and four continuous variables: fare, travel time, waiting time, and access time to the mode. There are 20 columns and 20 rows, with each row representing a mode. The row number corresponds to the mode number in the mode choice model. The first row does **not** contain the column names. Thus the column names shown below are only to indicate the order of the data in successive columns and do not appear in the file.

Columns:

ResBizFare: The fare coefficient for resident business trips
ResBizTravel: The travel time coefficient for resident business trips
ResBizWait: The wait time coefficient for resident business trips
ResBizAcc: The access time coefficient for resident business trips
ResBizConstant: The mode-specific constant for resident business trips

ResPerFare: The fare coefficient for resident personal trips
ResPerTravel: The travel time coefficient for resident personal trips
ResPerWait: The wait time coefficient for resident personal trips
ResPerAcc: The access time coefficient for resident personal trips
ResPerConstant: The mode-specific constant for resident personal trips

VisBizFare: The fare coefficient for visitor business trips
VisBizTravel: The travel time coefficient for visitor business trips
VisBizWait: The wait time coefficient for visitor business trips
VisBizAcc: The access time coefficient for visitor business trips
VisBizConstant: The mode-specific constant for visitor business trips

VisPerFare: The fare coefficient for visitor personal trips

VisPerTravel: The travel time coefficient for visitor personal trips

VisPerWait: The wait time coefficient for visitor personal trips

VisPerAcc: The access time coefficient for visitor personal trips

VisPerConstant: The mode-specific constant for visitor personal trips

It Is not strictly necessary for the terms in the mode choice model utility function to be the transportation characteristics indicated by the above names, since the Service Data Name mapping allows any variable to be assigned to a particular term. Thus for example, the “access time” term for public transit bus could instead be the walking distance to access the nearest bus stop, provided that the appropriate value was used for the mode choice model coefficient for access time for that mode. This provides some flexibility in specifying the mode choice model structure.

Appendix F: Sample Data Files Used for the Development of the IAPT

This appendix contains a selection of representative data files that were prepared for testing the current version of the Intermodal Airport Ground Access Planning Tool (IAPT) or provide supporting information that was used in the development of the tool. For those files that contain too many rows to show in their entirety, only the first few rows are shown..

Service Data Variable Definitions

This table defines the variables used in the transportation service data file for Oakland International Airport shown on the following two pages.

OAK TAZ Data File

1. Name	2. Unit	3. Variable Definition	4. Notaion
TAZ	TAZ	TAZ number	
DistTerm	miles	Distance to airport terminal	Obtained from MTC highway zone-to-zone travel file
DrvTAM	minutes	Driving time to airport in AM peak	Obtained from MTC highway zone-to-zone AM peak travel file
DrvTOP	minutes	Driving time to airport in off-peak	Obtained from MTC highway zone-to-zone off-peak travel file
DrvTPM	minutes	Driving time to airport in PM peak	we assume this as same as AM peak
FareTaxi	dollars	Taxi fare	We use airport egress taxi rate and calculate the fair by cost per mileage multiple by distance, waiting time cost and airport access fee are not considered
FareDDV1	dollars	Door-to-door van fare (first person)	
FareDDV2	dollars	Door-to-door van fare (additional person)	
FreqDDV	minutes	Door-to-door van service interval between scheduled pick-up times	
CircDDV	minutes	Additional door-to-door van travel time to pick up other parties	
TazBART	TAZ	TAZ of the nearest BART station	
AccBART	minutes	Auto access time to nearest BART station	We assume OAK is connected by BART only
DistBART	miles	Distance to nearest BART station	
HeadBART 1	minutes	Headway on BART	
HeadBART 2	minutes	Headway on BART	If there is not direct service, Headway2 is the second headway
RideBART	minutes	Ride time on BART	
FareBART	dollars	Fare on BART	
StoptazSchB	TAZ	Nearest scheduled bus stop TAZ	
StopnameSchB		Nearest scheduled bus stop name	
OperatorSchB		Nearest scheduled bus service operator	
AccSchB	minutes	Auto access time to nearest scheduled airport bus stop	
DistSchB	miles	Distance to nearest scheduled airport bus stop	
HeadSchB	minutes	Headway on scheduled bus	
RideSchB	minutes	Ride time on scheduled bus	
FareSchB	dollars	Fare on scheduled bus	
HeadTran	minutes	Headway on public transit bus	Off-peak travel on transit, walk access
RideTran	minutes	Ride time on public transit bus	Off-peak travel on transit, walk access
FareTran	dollars	Fare on public transit bus	in 1990 dollars

Sample Ground Transportation Service Data

Oakland International Airport

(2005)

TAZ	DistTerm	DrvTAM	DrvTOP	DrvTPM	FareTaxi	FareDDV1	FareDDV2	FreqDDV	CircDDV	TazBART	AccBART	DistBART	HeadBART 1	HeadBART 2	RideBART	FareBART
1	18.53	29		29	46.472			30	10	14	1.2	0.2	8	0	18	3.15
2	18.64	29.8		29.8	46.736			30	10	12	2.2	0.41	8	0	20	3.15
3	18.8	30.4		30.4	47.12			30	10	12	2.8	0.56	8	0	20	3.15
4	18.47	29.2		29.2	46.328			30	10	12	1.2	0.15	8	0	20	3.15
5	19.02	30.2		30.2	47.648			30	10	11	2	0.38	8	0	22	3.15
6	19.11	31.1		31.1	47.864			30	10	11	3	0.61	8	0	22	3.15
7	19.3	30.8		30.8	48.32			30	10	11	2.2	0.5	8	0	22	3.15
8	19.37	30.7		30.7	48.488			30	10	11	2	0.37	8	0	22	3.15
9	19.71	30.9		30.9	49.304			30	10	10	1.2	0.15	8	0	23	3.15
10	19.57	30.1		30.1	48.968			30	10	10	1	0.15	8	0	23	3.15
11	19	29.3		29.3	47.6			30	10	11	0.9	0.17	8	0	22	3.15
12	18.43	28.7		28.7	46.232			30	10	12	0.6	0.11	8	0	20	3.15
13	18.2	28		28	45.68			30	10	12	0.8	0.06	8	0	20	3.15
14	18.26	28		28	45.824			30	10	14	0.5	0.09	8	0	18	3.15
15	18.46	28.6		28.6	46.304			30	10	14	0.8	0.14	8	0	18	3.15
16	17.9	26.8		26.8	44.96			30	10	14	1.1	0.24	8	0	18	3.15
17	18.07	27		27	45.368			30	10	14	3.4	0.61	8	0	18	3.15
18	18.45	28.3		28.3	46.28			30	10	11	2.7	0.62	8	0	22	3.15
19	18.95	29.2		29.2	47.48			30	10	10	3.4	0.74	8	0	23	3.15
20	19.33	29.4		29.4	48.392			30	10	10	1.6	0.25	8	0	23	3.15
21	18.74	28.5		28.5	46.976			30	10	11	1.4	0.26	8	0	22	3.15
22	18.65	29.7		29.7	46.76			30	10	14	1.9	0.33	8	0	18	3.15
23	19.01	31.2		31.2	47.624			30	10	14	3.5	0.74	8	0	18	3.15
24	18.93	31		31	47.432			30	10	12	3.4	0.7	8	0	20	3.15
25	18.95	31.1		31.1	47.48			30	10	12	3.5	0.72	8	0	20	3.15
26	18.96	31.1		31.1	47.504			30	10	12	3.5	0.73	8	0	20	3.15
27	19.11	31.8		31.8	47.864			30	10	12	4.2	0.88	8	0	20	3.15
28	19.14	31.6		31.6	47.936			30	10	11	4	0.87	8	0	22	3.15
29	18.95	30.8		30.8	47.48			30	10	11	3.2	0.68	8	0	22	3.15
30	19.58	31.8		31.8	48.992			30	10	10	2.7	0.54	8	0	23	3.15
31	19.32	32.1		32.1	48.368			30	10	10	3.9	0.81	8	0	23	3.15
32	19.51	32.8		32.8	48.824			30	10	10	4.6	1	8	0	23	3.15
33	19.77	34.4		34.4	49.448			30	10	10	6.2	1.27	8	0	23	3.15
34	20.12	36.1		36.1	50.288			30	10	10	7.9	1.61	8	0	23	3.15
35	19.42	33.3		33.3	48.608			30	10	11	5.7	1.15	8	0	22	3.15
36	19.13	32.6		32.6	47.912			30	10	12	5	0.9	8	0	20	3.15
37	19.01	32		32	47.624			30	10	12	4.4	0.8	8	0	20	3.15
38	19.58	33.5		33.5	48.992			30	10	14	5.7	1.43	8	0	18	3.15
39	19.57	35.4		35.4	48.968			30	10	12	7.8	1.34	8	0	20	3.15

Sample Ground Transportation Service Data

Oakland International Airport (cont.)

(2005)

TAZ	StoptazSch	StopnameS	OperatorSc	AccSchB	DistSchB	HeadSchB	RideSchB	FareSchB	HeadTran	RideTran	FareTran
1	1430	San Rafael	Sonoma Co	34.7	19.51	120	60	20	22.5	34.17	2.02
2	1430	San Rafael	Sonoma Co	33.8	19.23	120	60	20	22.5	34.17	2.02
3	1430	San Rafael	Sonoma Co	33.3	18.97	120	60	20	22.5	35.57	2.02
4	1430	San Rafael	Sonoma Co	34.6	19.43	120	60	20	22.5	35.57	2.02
5	1430	San Rafael	Sonoma Co	34.2	19.36	120	60	20	22.5	35.57	2.02
6	1430	San Rafael	Sonoma Co	32.8	18.89	120	60	20	26.5	39.47	3.49
7	1430	San Rafael	Sonoma Co	33.4	19.07	120	60	20	22.5	36.97	2.02
8	1430	San Rafael	Sonoma Co	33.9	19.19	120	60	20	22.5	36.97	2.02
9	1430	San Rafael	Sonoma Co	33.2	18.87	120	60	20	22.5	38.67	2.02
10	1430	San Rafael	Sonoma Co	34.5	19.34	120	60	20	22.5	38.67	2.02
11	1430	San Rafael	Sonoma Co	35.4	19.57	120	60	20	22.5	36.97	2.02
12	1430	San Rafael	Sonoma Co	34.9	19.56	120	60	20	22.5	35.57	2.02
13	1430	San Rafael	Sonoma Co	35.5	19.73	120	60	20	22.5	35.57	2.02
14	1430	San Rafael	Sonoma Co	35.3	19.71	120	60	20	22.5	34.17	2.02
15	1430	San Rafael	Sonoma Co	35.4	19.61	120	60	20	22.5	34.17	2.02
16	1430	San Rafael	Sonoma Co	36.1	19.95	120	60	20	22.5	34.17	2.02
17	1430	San Rafael	Sonoma Co	37.5	20.34	120	60	20	32	53.53	2.56
18	1430	San Rafael	Sonoma Co	37.5	20.2	120	60	20	25.5	41.98	2.75
19	1430	San Rafael	Sonoma Co	37.1	20	120	60	20	30	43.21	2.75
20	1430	San Rafael	Sonoma Co	35.7	19.59	120	60	20	22.5	38.67	2.02
21	1430	San Rafael	Sonoma Co	36.2	19.83	120	60	20	22.5	36.97	2.02
22	1430	San Rafael	Sonoma Co	34.8	19.43	120	60	20	22.5	34.17	2.02
23	1430	San Rafael	Sonoma Co	32.6	18.67	120	60	20	30	50.29	4.21
24	1430	San Rafael	Sonoma Co	33.6	19.11	120	60	20	25	49.82	2.56
25	1430	San Rafael	Sonoma Co	32.5	18.73	120	60	20	25	52.33	2.56
26	1430	San Rafael	Sonoma Co	33.5	19.04	120	60	20	25	51.51	2.56
27	1430	San Rafael	Sonoma Co	32.1	18.64	120	60	20	26.5	41.97	3.49
28	1430	San Rafael	Sonoma Co	32.1	18.58	120	60	20	25	55.69	2.56
29	1430	San Rafael	Sonoma Co	32.4	18.77	120	60	20	26.5	40.47	3.49
30	1430	San Rafael	Sonoma Co	31.9	18.58	120	60	20	27	54.84	2.56
31	1430	San Rafael	Sonoma Co	31.5	18.41	120	60	20	34.5	41.58	2.75
32	1430	San Rafael	Sonoma Co	31	18.2	120	60	20	25	58.29	2.56
33	1430	San Rafael	Sonoma Co	30.2	18	120	60	20	30.5	46.47	3.49
34	1430	San Rafael	Sonoma Co	29.6	17.67	120	60	20	30.5	52.97	3.49
35	1430	San Rafael	Sonoma Co	31.6	18.46	120	60	20	26.5	43.57	3.49
36	1430	San Rafael	Sonoma Co	32.6	18.29	120	60	20	26.5	42.97	3.49
37	1430	San Rafael	Sonoma Co	33.2	18.36	120	60	20	25	50.69	2.56
38	1430	San Rafael	Sonoma Co	32.8	18.39	120	60	20	32.5	46.96	2.75
39	1430	San Rafael	Sonoma Co	30.2	17.87	120	60	20	30.5	46.97	3.49

Transportation Provider Cost Function Data

Oakland International Airport

Transportation Provider Cost Function Date

Mode ID	Revised Mode Name	Definition/comment	Traffic Units	Freq Change?	Price Change?	Op Cost 1: $/veh/mi	Op Cost 2: $/veh/hr	Avg party size	Avg trip distance (mi)	
									Total	On Mode
1	Auto Drop-off	Private vehicle		N	N (No)	0.562	--	1.95	22.28	22.28
2	Rental Car	Modeled separately for visitors	air parties	N	Y (Yes)	0.69	2.16	2.19	26.69	1.00
3	Scheduled Airport Bus		air pax	N	Y	3.97	118	1.79	64.01	52.40
4	Public Transit Bus			N	N	8.65	101	1.75	28.10	28.10
5	Charter Bus	Modeled separately		N	N	7.42	187.15	0.00	0.00	0.00
6	Door-to-Door Van		air pax	N	Y	2.19	40.12	1.88	25.51	25.51
7	Hotel Courtesy Shuttle	Modeled separately (visitors only)		N	N	1.67	26.81	2.78	5.27	5.27
8	Taxi			N	N	--	--	1.47	14.53	14.53
9	BART			N	N	--	--	1.56	24.37	3.00
10	Amtrak/Caltrain			N	N	--	--	--	--	--
11	Short term Parking		air parties	N	Y	N/A	0.43722	2.25	23.23	0.00
12	Long term Parking		air parties	N	Y	N/A	0.43722	1.83	26.49	0.50
13	Off Airport Parking		air parties	N	Y	N/A	N/A	1.77	30.89	0.50
14	Limousine		air parties	N	Y	2.32	45.36	2.52	23.69	23.69

Note:
1. N/A indicates data are not available for analysis
2. " -- " indicates item does not apply to this mode

Transportation Provider Cost Function Data

Oakland International Airport (cont.)

Transportation Provider Cost Function Date

			Avg trip duration (min)		Fixed cost		Variable cost	
Mode ID	**Revised Mode Name**	**Definition/comment**	**Total trip**	**On mode**	**$**	**Traffic Unit**	**$**	**Traffic Unit**
1	Auto Drop-off	Private vehicle	*40.79*	*40.79*	--	--		
2	Rental Car	Modeled separately for visitors	*63.57*	*17.27*	--	--	#REF!	Rental
3	Scheduled Airport Bus		*110.42*	*89.12*	191.89	Veh Trip	--	--
4	Public Transit Bus		*41.79*	*41.79*	--	--		
5	Charter Bus	Modeled separately	*0.00*	*0.00*	N/A	Veh Trip		
6	Door-to-Door Van		*54.56*	*54.56*	20.55	Veh Trip	17.52	Veh-Hour
7	Hotel Courtesy Shuttle	Modeled separately (visitors only)	*11.86*	*11.86*	#REF!	Veh Trip		
8	Taxi		*25.99*	*25.99*	--	--		
9	BART		*58.54*	*21.89*	--	--		
10	Amtrak/Caltrain		--	--	--	--		
11	Short term Parking		*41.63*	*0.00*	437.22	1000 Stall	0	Vehicle
12	Long term Parking		*58.85*	*11.77*	438.22	1001 Stall	0	Vehicle
13	Off Airport Parking		*67.63*	*11.88*	N/A	N/A	0	Vehicle
14	Limousine		*42.59*	*42.59*	16.85	--	54.15	Veh-Hour

Note:

1. N/A indicates data are not available for analysis
2. " -- " indicates item does not apply to this mode

Summary of Air Party Characteristics by Mode

Oakland International Airport

(2001 MTC Air Passenger Survey)

Oakland Airport

Mode Used	Access	Total Distance	# of Trips	# of Passenger	Average Party	Average Distance (Total)	Average Distance (On Mode)	Average Travel Time (On Mode)	Average Travel Time (OffMode)	Average Total Trip Time	Average Trip Duration (day)	Average Service Duration (day)
1	Auto Drop-off	8913.9	400	778	1.95	22.28	22.28	40.79	0.0	40.8	32.25	--
2	Rental Car	5018.0	188	411	2.19	26.69	1.00	17.27	46.3	63.6	31.53	4.3
3	Scheduled Airport Bus	2176.5	34	61	1.79	64.01	52.40	89.12	21.3	110.4	34.47	--
4	Public Transit Bus	224.8	8	14	1.75	28.10	28.10	41.79	0.0	41.8	26.25	--
5	Charter Bus	0.0	0	0	0.00	0.00	0.00	0.00	0.0	0.0	0.00	--
6	Door-to-Door Van	867.3	34	64	1.88	25.51	25.51	54.56	0.0	54.6	66.47	--
7	Hotel Courtesy Shuttle	142.4	27	75	2.78	5.27	5.27	11.86	0.0	11.9	80.59	--
8	Taxi	493.9	34	50	1.47	14.53	14.53	25.99	0.0	26.0	10.65	--
9	BART	2705.2	111	173	1.56	24.37	3.00	21.89	36.7	58.5	13.80	--
10	Amtrak/Caltrain	--	--	--	--	--	--	--	--	--	--	--
11	Short term Parking	1184.5	51	115	2.25	23.23	0.00	0.00	41.63	41.6	1.00	1.00
12	Long term Parking	7019.6	265	486	1.83	26.49	0.50	11.77	47.07	58.8	3.06	3.06
13	Off Airport Parking	3613.9	117	207	1.77	30.89	0.50	11.88	55.75	67.6	7.62	7.62
14	Limousine	544.9	23	58	2.52	23.69	23.69	42.59	0.0	42.6	6.30	--

Ground Transportation Service Data

Oakland International Airport
(2001)

Airport Ground Transportation Information

	Service	P/OP	Headway (min)	Wait (min)	Ride Time (min)	Trip Distance (mi)	Service Time	Note
Airport parking-shuttle[1]	Free Shuttle	P	10	5	5	0.5	24 Hour/day	PH: F, Sa night, Mon Morning
		OP	15	7.5				
Rail-shuttle (min) [2]	AirBart	P	10	5	20	3	M-Sa 6-12am,Su 8-12am	
		OP	10	5	15			
Rental car-shuttle[1]	Free Shuttle	P	20	10	20	1	1:30am - 4:30am On demand	PH: F Sa night, M morning, noon everyday
		OP	10	5	8.5			

1. For airport shuttle info: 510-569-8310 ext 21
2. BART website: http://www.bart.gov/guide/airport/oak.asp accessed:12/13/06

Air Party Data Variable Definitions and Codes

OriginType	Trip origin type	
	1	Own home
	2	Someone else's home
	3	Place of business
	4	Hotel, motel or inn
	5	Restaurant
	6	Convention center
	7	School or college
	8	Other type of place
TimeDay	Time of day of airport access trip	
	1	AM peak
	2	PM peak
	3	Off peak
Inc2000	Household income in 2000 ($000)	
ModeUsed	Ground access mode used	
	1	Auto drop
	2	Auto park (for trip duration)
	3	BART
	4	Transit bus
	5	Scheduled airport bus
	6	Taxi
	7	Hotel courtesy shuttle
	8	Limousine
	9	Shared ride van
	10	Chartered bus
	11	Other
	12	Rental car

Sample Air Party Data

Oakland International Airport
(MTC 2001 Air Passenger Survey)

ID	PartyID	TAZ	Party Size	ParkDur	TripType	Origin Type	Time of Day	Mode Used	Distance Traveled (OnMode)	Distance Traveled (Off Mode)	TraTime (OnMode)	TraTime (OffMode)
1	4370	741	1	3	1	1	3	1	21.48	0	36.6	0
2	4469	1079	2	32	1	1	3	1	26.16	0	50	0
3	4720	911	1	3	1	3	3	1	8.77	0	20.6	0
4	4918	1137	1	6	1	1	1	1	28.17	0	50.1	0
5	4920	840	1	3	1	1	1	1	8.71	0	18.8	0
6	4984	1133	1	2	1	1	1	1	23.72	0	40.8	0
7	4992	40	1	3	1	1	1	1	20.31	0	35.6	0
8	5189	1159	3	4	1	1	1	1	16.76	0	38.1	0
9	5194	836	3	4	1	1	3	1	7.06	0	15.6	0
10	5195	1163	1	8	1	1	3	1	27.94	0	44.9	0
11	5243	1062	1	6	1	1	1	1	22.19	0	39.3	0
12	5251	1083	2	4	1	3	3	1	26.07	0	51.1	0
13	5337	736	9	2	1	3	3	1	18.99	0	33.6	0
14	5341	926	1	8	1	1	3	1	5.5	0	12.7	0
15	5345	1150	1	5	1	1	3	1	22.69	0	38.2	0
16	5400	84	1	4	1	1	3	1	21.64	0	35.8	0
17	5557	1332	1	2	1	3	3	1	53.18	0	103.5	0
18	5564	918	1	2	1	1	3	1	11.52	0	23	0
19	5660	1168	1	91	1	3	3	1	19.43	0	40.4	0
20	5680	1039	1	6	1	1	3	1	16.72	0	32	0
21	6501	918	3	4	1	1	2	1	11.52	0	23	0
22	6528	871	2	3	1	1	3	1	3.79	0	10.3	0
23	6718	776	1	4	1	1	3	1	17.93	0	31.9	0
24	6720	609	7	8	1	1	3	1	28.77	0	42.8	0
25	15121	45	2	4	1	1	3	1	20.92	0	38	0
26	29183	956	2	1	1	1	3	1	5.99	0	16.7	0
27	29194	1178	2	3	1	1	3	1	44.82	0	99.1	0
28	29195	737	4	3	1	1	3	1	18.67	0	30.8	0
29	29379	20	2	5	1	1	1	1	19.33	0	29.4	0
30	29433	1085	2	5	1	1	1	1	28.41	0	54.9	0
31	29441	1141	1	3	1	1	1	1	27.84	0	49.5	0
32	29605	883	1	15	1	1	1	1	5.9	0	16.3	0
33	29632	949	3	7	1	1	1	1	5.23	0	13	0
34	29801	1075	3	6	1	1	3	1	21.67	0	42	0
35	29978	934	1	2	1	1	3	1	7.99	0	17.7	0
36	30038	846	2	2	1	3	3	1	9.9	0	19.5	0
37	30232	29	4	4	1	2	3	1	18.95	0	30.8	0
38	30252	194	1	4	1	1	3	1	28.53	0	45	0
39	30615	970	7	4	1	3	2	1	9.21	0	19.1	0

Service Data Variable Definitions

This table defines the variables used in the transportation service data file for San Francisco International Airport shown on the following two pages.

SFO TAZ Data File

1. Name	2. Unit	3. Variable Definition	4. Notaion
TAZ	TAZ	TAZ number	
DistTerm	miles	Distance to airport terminal	Obtained from MTC highway zone-to-zone travel file
DrvTAM	minutes	Driving time to airport in AM peak	Obtained from MTC highway zone-to-zone AM peak travel file
DrvTOP	minutes	Driving time to airport in off-peak	Obtained from MTC highway zone-to-zone off-peak travel file
DrvTPM	minutes	Driving time to airport in PM peak	we assume this as same as AM peak
FareTaxi	dollars	Taxi Fare	we use airport egress taxi rate and calculate the fair by cost per mileage multiple by distance, waiting time cost and airport access fee are not considered
FareDDV1	dollars	Door-to-door van fare (first person)	
FareDDV2	dollars	Door-to-door van fare (additional person)	
FreqDDV	minutes	Door-to-door van service interval between scheduled pick-up times	
CircDDV	minutes	Additional door-to-door van travel time to pick up other parties	
TazBART	TAZ	Nearest BART station TAZ	
AccBART	minutes	Auto access time to nearest BART station	we assume SFO is connected by Caltrain and BART only
DistBART	miles	Distance to nearest BART station	
HeadBART 1	minutes	Headway on BART	
HeadBART 2	minutes	Headway on BART	If there is not direct service, Headway 2 is the second train headway
RideBART	minutes	Ride time on BART	
FareBART	dollars	Fare on BART	
TazCALTRAIN_AM	TAZ	Nearest Caltrain station TAZ in AM peak	
AccCALTRAIN_AM	minutes	Auto access time to nearest Caltrain station in AM peak	
DistCALTRAIN_AM	miles	Distance to nearest Caltrain station in AM peak	
HeadCALTRAIN_AM	minutes	Headway of Caltrain in AM peak	
RideCALTRAIN_AM	minutes	Ride time on Caltrain in AM peak	
FareCALTRAIN_AM	dollars	Fare on Caltrain in AM peak	
TazCALTRAIN	TAZ	Nearest Caltrain station TAZ outside AM peak	
AccCALTRAIN	minutes	Auto access time to nearest Caltrain station outside AM peak	
DistCALTRAIN	miles	Distance to nearest Caltrain station outside AM peak	
HeadCALTRAIN1	minutes	Headway of Caltrain in PM peak hours, weekday	
HeadCALTRAIN2	minutes	Headway of Caltrain in off-peak hours, weekday	
HeadCALTRAIN3	minutes	Headway of Caltrain in weekend	
RideCALTRAIN	minutes	Ride time on Caltrain outside AM peak	
FareCALTRAIN	dollars	Fare on Caltrain outside AM peak	
StoptazSchB	TAZ	Nearest scheduled bus stop TAZ	
StopnameSchB		Nearest scheduled bus stop name	
OperatorSchB		Nearest scheduled bus service operator	
AccSchB	minutes	Auto access time to nearest scheduled airport bus stop	
DistSchB	miles	Distance to nearest scheduled airport bus stop	
HeadSchB	minutes	Headway on scheduled bus	
RideSchB	minutes	Ride time on scheduled bus	
FareSchB	dollars	Fare on scheduled bus	
HeadTran	minutes	Headway on public transit bus	Off-peak travel on transit, walk access
RideTran	minutes	Ride time on public transit bus	Off-peak travel on transit, walk access
FareTran	dollars	Fare on public transit bus	in 1990 dollars

Sample Ground Transportation Service Data

San Francisco International Airport

2001

TAZ	DistTerm	DrvTAM	DrvTOP	DrvTPM	FareTaxi	FareDDV1	FareDDV2	FreqDDV	CircDDV	TazBART	AccBART	DistBART	HeadBART 1	HeadBART	RideBART	FareBART	TazCALTR
1	13.29	31.4		31.4	32.7525			30	10	14	1.2	0.2	7.85	0	22	2.25	109
2	13.19	31.3		31.3	32.5275			30	10	12	2.2	0.41	7.85	0	21	2.25	109
3	14.01	31.7		31.7	34.3725			30	10	12	2.8	0.56	7.85	0	21	2.25	109
4	12.93	30.4		30.4	31.9425			30	10	12	1.2	0.15	7.85	0	21	2.25	109
5	12.66	29.8		29.8	31.335			30	10	11	2	0.38	7.85	0	19	2.25	109
6	13.64	30.4		30.4	33.54			30	10	11	3	0.61	7.85	0	19	2.25	109
7	13.53	29.6		29.6	33.2925			30	10	11	2.2	0.5	7.85	0	19	2.25	109
8	13.4	29.5		29.5	33			30	10	11	2	0.37	7.85	0	19	2.25	109
9	13.41	29.7		29.7	33.0225			30	10	10	1.2	0.15	7.85	0	18	2.25	109
10	13.39	29.2		29.2	32.9775			30	10	10	1	0.15	7.85	0	18	2.25	109
11	13	27.9		27.9	32.1			30	10	11	0.9	0.17	7.85	0	19	2.25	109
12	12.64	30		30	31.29			30	10	12	0.6	0.11	7.85	0	21	2.25	109
13	12.79	30.3		30.3	31.6275			30	10	12	0.8	0.06	7.85	0	21	2.25	109
14	13.03	31		31	32.1675			30	10	14	0.5	0.09	7.85	0	22	2.25	109
15	13.23	31.6		31.6	32.6175			30	10	14	0.8	0.14	7.85	0	22	2.25	109
16	12.55	30.7		30.7	31.0875			30	10	14	1.1	0.24	7.85	0	22	2.25	109
17	13.09	28.3		28.3	32.3025			30	10	14	3.4	0.61	7.85	0	22	2.25	109
18	12.56	26.8		26.8	31.11			30	10	11	2.7	0.62	7.85	0	19	2.25	109
19	12.56	27.2		27.2	31.11			30	10	10	3.4	0.74	7.85	0	18	2.25	109
20	12.93	27.9		27.9	31.9425			30	10	10	1.6	0.25	7.85	0	18	2.25	109
21	12.93	27.7		27.7	31.9425			30	10	11	1.4	0.26	7.85	0	19	2.25	109
22	13.47	32.3		32.3	33.1575			30	10	14	1.9	0.33	7.85	0	22	2.25	109
23	14.59	33.9		33.9	35.6775			30	10	14	3.5	0.74	7.85	0	22	2.25	109
24	13.48	32.5		32.5	33.18			30	10	12	3.4	0.7	7.85	0	21	2.25	109
25	13.49	32.7		32.7	33.2025			30	10	12	3.5	0.72	7.85	0	21	2.25	109
26	14.07	32		32	34.5075			30	10	12	3.5	0.73	7.85	0	21	2.25	109
27	14.04	32.1		32.1	34.44			30	10	12	4.2	0.88	7.85	0	21	2.25	109
28	13.9	31.4		31.4	34.125			30	10	11	4	0.87	7.85	0	19	2.25	109
29	13.71	30.6		30.6	33.6975			30	10	11	3.2	0.68	7.85	0	19	2.25	109
30	13.68	30.5		30.5	33.63			30	10	10	2.7	0.54	7.85	0	18	2.25	109
31	13.94	31.7		31.7	34.215			30	10	10	3.9	0.81	7.85	0	18	2.25	109
32	14.12	32.4		32.4	34.62			30	10	10	4.6	1	7.85	0	18	2.25	109
33	14.39	34		34	35.2275			30	10	10	6.2	1.27	7.85	0	18	2.25	109
34	14.73	35.7		35.7	35.9925			30	10	10	7.9	1.61	7.85	0	18	2.25	109
35	14.18	33.1		33.1	34.755			30	10	11	5.7	1.15	7.85	0	19	2.25	109
36	14.29	33.6		33.6	35.0025			30	10	12	5	0.9	7.85	0	21	2.25	109
37	13.57	33.6		33.6	33.3825			30	10	12	4.4	0.8	7.85	0	21	2.25	109
38	14.38	35.7		35.7	35.205			30	10	14	5.7	1.43	7.85	0	22	2.25	109

Sample Ground Transportation Service Data

San Francisco International Airport (cont.)

2001

AccCALTR	DistCALTR	HeadCALT	HeadCALT	HeadCALT	RideCALT	FareCALT	StoptazSch	StopnameS	OperatorSch	AccSchB	DistSchB	HeadSchB	RideSchB	FareSchB	HeadTran	RideTran	FareTran
1.8	6	28	39	60	24	2	12	Palace Hot	SFO Airporte	2.3	0.51	60	50	13	30	43.2	2.2
1.71	5.9	28	39	60	24	2	12	Palace Hot	SFO Airporte	2.2	0.41	60	50	13	30	43.2	2.2
1.57	6.3	28	39	60	24	2	5	Crowne Pl	SFO Airporte	2.1	0.26	60	40	13	30	41.7	2.2
1.45	4.9	28	39	60	24	2	12	Palace Hot	SFO Airporte	1.2	0.15	60	50	13	30	42.3	2.2
1.17	4.4	28	39	60	24	2	5	Crowne Pl	SFO Airporte	0.8	0.16	60	40	13	30	41.7	2.2
1.56	5.7	28	39	60	24	2	7	Westin St.	SFO Airporte	1.2	0.13	60	35	13	42	38.79	2.93
1.45	5	28	39	60	24	2	7	Westin St.	SFO Airporte	0.8	0.15	60	35	13	42	37.66	2.93
1.11	4.8	28	39	60	24	2	7	Westin St.	SFO Airporte	0.9	0.13	60	35	13	30	39.1	2.2
1.3	5.6	28	39	60	24	2	8	Renaissan	SFO Airporte	2	0.34	60	25	13	30	35.34	2.2
1.28	5.1	28	39	60	24	2	11	San Franci	SFO Airporte	2.4	0.3	60	20	13	30	34.48	2.2
0.74	3.4	28	39	60	24	2	11	San Franci	SFO Airporte	0.9	0.17	60	20	13	30	39.1	2.2
1.16	4.5	28	39	60	24	2	12	Palace Hot	SFO Airporte	0.6	0.11	60	50	13	30	41.7	2.2
1.3	4.9	28	39	60	24	2	12	Palace Hot	SFO Airporte	0.8	0.06	60	50	13	30	42.3	2.2
1.43	5.6	28	39	60	24	2	12	Palace Hot	SFO Airporte	1.4	0.3	60	50	13	30	43.2	2.2
1.4	5	28	39	60	24	2	22	Hyatt Rege	SFO Airporte	2.2	0.43	60	55	13	30	43.2	2.2
1.29	4.8	28	39	60	24	2	12	Palace Hot	SFO Airporte	2.2	0.54	60	50	13	30	43.2	2.2
0.58	2.5	28	39	60	24	2	12	Palace Hot	SFO Airporte	3	0.77	60	50	13	42	43.14	2.93
0.12	1.7	28	39	60	24	2	11	San Franci	SFO Airporte	2.7	0.62	60	20	13	38	37.44	2.93
0.46	3.2	28	39	60	24	2	11	San Franci	SFO Airporte	3	0.77	60	20	13	33.16	31.48	2.93
0.82	3.8	28	39	60	24	2	11	San Franci	SFO Airporte	2	0.41	60	20	13	30	33.08	2.2
0.48	2.6	28	39	60	24	2	11	San Franci	SFO Airporte	1.4	0.26	60	20	13	30	39.1	2.2
1.98	6.9	28	39	60	24	2	22	Hyatt Rege	SFO Airporte	0.8	0.13	60	55	13	30	43.41	2.46
1.83	7.2	28	39	60	24	2	22	Hyatt Rege	SFO Airporte	2.3	0.35	60	55	13	42	45.16	2.93
1.99	7.1	28	39	60	24	2	22	Hyatt Rege	SFO Airporte	2.4	0.45	60	55	13	35	48	2.93
2.01	7.3	28	39	60	24	2	5	Crowne Pl	SFO Airporte	3.1	0.45	60	40	13	35	50.51	2.93
1.63	6.6	28	39	60	24	2	5	Crowne Pl	SFO Airporte	2.3	0.32	60	40	13	33	45.41	2.93
1.78	7.3	28	39	60	24	2	5	Crowne Pl	SFO Airporte	3.1	0.47	60	40	13	34	44.1	3.67
1.82	6.8	28	39	60	24	2	7	Westin St.	SFO Airporte	2.2	0.39	60	35	13	35	53.87	2.93
1.63	5.9	28	39	60	24	2	7	Westin St.	SFO Airporte	1.4	0.2	60	35	13	42	39.14	2.93
1.73	6	28	39	60	24	2	7	Westin St.	SFO Airporte	1.4	0.28	60	35	13	37.5	42.8	2.93
1.99	7.1	28	39	60	24	2	7	Westin St.	SFO Airporte	2.5	0.54	60	35	13	37.5	45.17	2.93
2.17	7.8	28	39	60	24	2	7	Westin St.	SFO Airporte	3.2	0.72	60	35	13	42	41.64	2.93
2.44	9.4	28	39	60	24	2	7	Westin St.	SFO Airporte	4.8	0.99	60	35	13	38	44.34	2.93
2.78	11.1	28	39	60	24	2	7	Westin St.	SFO Airporte	6.5	1.33	60	35	13	37.5	54.2	2.93
2.1	8.4	28	39	60	24	2	7	Westin St.	SFO Airporte	3.9	0.67	60	35	13	34	45.7	3.67
2.19	8.8	28	39	60	24	2	22	Hyatt Rege	SFO Airporte	4.1	0.65	60	55	13	33	52.05	2.93
2.09	8.2	28	39	60	24	2	22	Hyatt Rege	SFO Airporte	3.3	0.54	60	55	13	42	48.31	2.93
2.59	9.5	28	39	60	24	2	7	Westin St.	SFO Airporte	6.5	1.05	60	35	13	40	55.13	2.93

Transportation Provider Cost Function Data

San Francisco International Airport

Transportation Provider Cost Function Date

Mode ID	Revised Mode Name	Definition/comment	Traffic Units	Freq Change?	Price Change?	Op Cost 1: $/veh/mi	Op Cost 2: $/veh/hr	Avg party size	Avg trip distance (mi)	
									Total	On mode
1	Auto Drop-off	Private vehicle		N	N (No)	0.562	--	2.13	24.10	24.10
2	Rental Car	Modeled separately for visitors	air parties	N	Y (Yes)	0.61	1.91	2.48	26.72	1.00
3	Scheduled Airport Bus		air pax	N	Y	3.97	118	1.54	39.37	32.58
4	Public Transit Bus			N	N	N/A	N/A	1.44	18.49	18.49
5	Charter Bus	Modeled separately		N	N	7.42	187.15	10.83	26.96	26.96
6	Door-to-Door Van		air pax	N	Y	2.19	40.12	1.60	19.16	19.16
7	Hotel Courtesy Shuttle	Modeled separately (visitors only)		N	N	1.67	26.81	2.71	7.13	7.13
8	Taxi			N	N	--	--	1.77	14.11	14.11
9	BART			N	N	--	--	1.81	22.43	0.40
10	Caltrain			N	N	--	--	1.56	58.25	0.40
11	Short term Parking		air parties	N	Y	N/A	0.3588	1.80	26.23	0.40
12	Long term Parking		air parties	N	Y	N/A	0.3588	1.92	25.51	0.60
13	Off Airport Parking		air parties	N	Y	N/A	N/A	2.20	32.09	0.60
14	Limousine		air parties	N	Y	2.69	45.36	2.07	21.53	21.53

Note:

1. N/A indicates data are not available for analysis
2. " -- " indicates item does not apply to this mode

Transportation Provider Cost Function Data

San Francisco International Airport (cont.)

Transportation Provider Cost Function Date

			Avg trip duration (min)		Fixed cost		Variable cost	
Mode ID	**Revised Mode Name**	**Definition/comment**	**Total trip**	**On mode**	**$/Unit**	**Traffic Unit**	**$**	**Traffic Unit**
1	Auto Drop-off	Private vehicle	*50.15*	*50.15*	--	--		
2	Rental Car	Modeled separately for visitors	*63.84*	*7.00*	--	--	#REF!	Rental
3	Scheduled Airport Bus		*79.06*	*65.08*	128.85	Veh Trip	--	--
4	Public Transit Bus		*33.74*	*33.74*	--	--		
5	Charter Bus	Modeled separately	*53.73*	*53.73*	#REF!	Veh Trip		
6	Door-to-Door Van		*52.05*	*52.05*	19.60	Veh Trip	17.52	Veh-Hour
7	Hotel Courtesy Shuttle	Modeled separately (visitors only)	*18.34*	*18.34*	#REF!	Veh Trip		
8	Taxi		*32.54*	*32.54*	--	--		
9	BART		*45.33*	*5.00*	--	--		
10	Caltrain		*80.40*	*5.00*	--	--		
11	Short term Parking		*1.00*	*5.00*	358.8	1000 Stall/hou	--	--
12	Long term Parking		*3.06*	*12.00*	358.8	1001 Stall/hou	N/A	Vehicle
13	Off Airport Parking		*7.28*	*12.00*	N/A		NA	Vehicle
14	Limousine		*46.74*	*46.74*	17.82	--	54.15	Veh-Hour

Note:
1. N/A indicates data are not available for analysis
2. " -- " indicates item does not apply to this mode

Summary of Air Party Characteristics by Mode

San Francisco International Airport
(2001 MTC Air Passenger Survey)

San Francisco Airport

Mode Used	Access	Total Distance	# of Trips	# of Passenger	Average Party	Average Distance (Total)	Average Distance (On Mode)	Average Travel Time (On Mode)	Average Travel Time (OffMode)	Average Total Trip Time	Average Trip Duration (day)	Average Service Duration (day)
1	Auto Drop-off	16768.2	657	1399	2.13	25.52	25.52	52.51	0.00	52.51	110.10	--
2	Rental Car	7552.1	290	718	2.48	26.04	1.00	7.00	54.71	61.71	78.05	7.52
3	Scheduled Airport Bus	#N/A	123	189	1.54	#N/A	#N/A	57.24	13.77	71.00	49.65	--
4	Public Transit Bus	338.9	16	23	1.44	21.18	21.18	14.13	0.00	14.13	12.19	--
5	Charter Bus	181.1	6	65	10.83	30.19	30.19	56.97	0.00	56.97	336.67	--
6	Door-to-Door Van	3604.2	183	292	1.60	19.70	19.70	53.15	0.00	53.15	56.01	--
7	Hotel Courtesy Shuttle	815.3	69	187	2.71	11.82	11.82	25.33	0.00	25.33	78.90	--
8	Taxi	3393.6	216	382	1.77	15.71	15.71	35.01	0.00	35.01	67.15	--
9	BART	#N/A	29	54	1.86	#N/A	0.40	5.00	35.42	40.42	77.52	--
10	Caltrain	#N/A	22	36	1.64	#N/A	0.40	5.00	55.85	60.85	100.77	--
11	Short term Parking	135.8	5	9	1.80	27.16	0.40	5.00	61.52	1.00	1.00	1.00
12	Long term Parking	2321.6	96	184	1.92	24.18	0.60	12.00	57.13	3.06	3.06	3.06
13	Off Airport Parking	2703.8	87	191	2.20	31.08	0.60	12.00	66.81	7.28	7.28	7.28
14	Limousine	1566.4	67	139	2.07	23.38	23.38	50.16	0.00	50.16	70.43	--

Ground Transportation Service Data

San Francisco International Airport

(2001)

Airport Ground Transportation Information

	Service	Headway (min)	Wait (h/2) (min)	Trip Duration (min)	Trip Distance (mi)	Service Time	Note
Airport parking-shuttle	Air Train[1]	4	2	10	0.6	24 hr/day	International Garage A and G
		4	2	6	1.5		Long Term Parking D
	Walk	--	--	5	0.4	--	Central Garage
Rail (Caltrain to SFO)[2]	BART	15	7.5	6	1.3		
Rail Shuttle	Air Train[1]	4	2	5	0.4	24 hr/day	
Rental car-shuttle (on airport)		4	2	5	1		
Rental car-shuttle (off airport)	Free shuttle	--				Upon Request	Connects from rental car center

1. SFO website: http://www.flysfo.com/transport/services/gt_tsv_search.asp accessed: 12/13/06
2. BART website: http://www.bart.gov/index.asp accessed:12/13/06

Sample Air Party Travel Distance and Time Data

San Francisco International Airport
(2001 MTC Air Passenger Survey)

ID	PartyID	TAZ	PartySize	ParkDur	TripType	OriginType	TimeDay	ModeUsed	Distance Traveled (OnMode)	Distance Traveled (OffMode)	TraTime (OnMode)	TraTime (OffMode)
1	101	333	1	5	1	1	3	1	24.37	0	40.6	0
2	330	747	2	22	1	1	3	1	27.22	0	57.6	0
3	1121	1005	1	2	1	1	3	1	25.83	0	77	0
4	1526	320	1	2	1	1	3	1	21.81	0	35.7	0
5	1555	247	1	2	1	1	1	1	11.34	0	24	0
6	1584	266	1	4	1	1	1	1	13.94	0	26.6	0
7	1587	1175	1	3	1	2	1	1	45.82	0	109.7	0
8	1659	46	1	3	1	1	1	1	13.44	0	33.6	0
9	1738	131	1	4	1	1	1	1	10.8	0	25.6	0
10	1740	319	1	4	1	1	1	1	20.92	0	33.4	0
11	1746	105	2	6	1	1	1	1	9.56	0	25.6	0
12	1769	86	4	5	1	1	1	1	9.11	0	23.8	0
13	2176	789	4	61	1	1	3	1	22.39	0	54.1	0
14	2519	104	1	24	1	1	3	1	9.09	0	24.2	0
15	2665	856	1	5	1	1	3	1	31.67	0	66.5	0
16	3762	52	1	5	1	1	2	1	12.76	0	31.7	0
17	4273	956	1	3	1	1	3	1	21.66	0	65.1	0
18	9248	173	1	5	1	2	3	1	1.73	0	10.3	0
19	9289	252	1	7	1	1	3	1	12.6	0	21	0
20	9662	5	1	999	1	4	1	1	16.06	0	38	0
21	9802	494	1	6	1	1	1	1	43.61	0	61.1	0
22	9878	286	20	1	1	2	1	1	15.71	0	28.5	0
23	10893	239	1	4	1	3	3	1	9.01	0	17.9	0
24	10908	909	3	8	1	2	3	1	26.05	0	71.3	0
25	12215	258	1	11	1	1	3	1	33.29	0	58.6	0
26	12936	232	2	1	1	1	1	1	10.41	0	23.3	0
27	14303	760	1	5	1	1	3	1	26.44	0	58.5	0
28	17838	240	3	5	1	1	3	1	6.85	0	16.4	0
29	18883	911	1	6	1	2	1	1	33.31	0	70.1	0
30	18950	50	2	3	1	1	1	1	13.51	0	33.4	0
31	19302	312	2	8	1	1	3	1	22.5	0	36.8	0
32	19478	1106	1	5	1	1	3	1	35.77	0	87.2	0
33	19586	381	1	6	1	1	3	1	29.7	0	50.3	0
34	19926	821	2	15	1	2	3	1	26.42	0	61.4	0
35	20606	255	1	5	1	1	2	1	24.13	0	70.3	0
36	20680	171	1	2	1	1	3	1	2.4	0	9.6	0
37	20693	839	1	5	1	1	3	1	29.94	0	64.6	0

Transportation Provider Cost Function Data

San José International Airport

Transportation Provider Cost Function Date

									Avg trip distance (mi)	
Mode ID	**Revised Mode Name**	**Definition/comment**	**Traffic Units**	**Price Change?**	**Freq Change?**	**Op Cost 1: $/veh/mi**	**Op Cost 2: $/veh/hr**	**Avg party size**	**Total**	**On mode**
1	Auto Drop-off	Private vehicle		N (No)	N	0.562	--	1.87	36.50	36.50
2	Rental Car	Modeled separately for visitors	air parties	Y (Yes)	N	0.62	1.94	2.25	34.53	0.50
3	Scheduled Airport Bus		air pax	Y	N	3.97	118	15.40	101.06	36.40
4	Public Transit Bus			N	N	19.39	268	1.00	33.32	33.32
5	Charter Bus	Modeled separately		N	N	7.42	187.15	20.75	34.86	34.86
6	Door-to-Door Van		air pax	Y	N	2.19	40.12	2.47	31.00	31.00
7	Hotel Courtesy Shuttle	Modeled separately (visitors only)		N	N	1.67	26.81	2.88	34.94	34.94
8	Taxi			N	N	--	--	1.43	36.52	36.52
9	Metro Light Rail			N	N	--	--	1.44	37.43	1.00
10	Caltrain			N	N	--	--	1.00	38.89	1.50
11	Short term Parking		air parties	Y	N	--	N/A	1.26	36.62	0.00
12	Long term Parking		air parties	Y	N	--	N/A	1.41	35.71	0.50
13	Off Airport Parking		air parties	Y	N	--	N/A	1.71	35.33	0.50
14	Limousine		air parties	Y	N	1.85	46.37	4.14	36.10	36.10

Note:
1. N/A indicates data are not available for analysis
2. " -- " indicates item does not apply to this mode

Transportation Provider Cost Function Data

San José International Airport (cont.)

Transportation Provider Cost Function Date

			Avg trip duration (min)		Fixed cost		Variable cost	
Mode ID	**Revised Mode Name**	**Definition/comment**	**Total trip**	**On mode**	**$**	**Traffic Unit**	**$**	**Traffic Unit**
1	Auto Drop-off	Private vehicle	*57.20*	*57.20*	--	--		
2	Rental Car	Modeled separately for visitors	*64.44*	*11.48*	--	--	#REF!	Rental
3	Scheduled Airport Bus		*152.50*	*60.00*	131.41	Veh Trip	--	--
4	Public Transit Bus		*16.34*	*10.34*	--	--		
5	Charter Bus	Modeled separately	*52.78*	*52.78*	#REF!	Veh Trip		
6	Door-to-Door Van		*58.39*	*58.39*	21.99	Veh Trip	17.52	Veh-Hour
7	Hotel Courtesy Shuttle	Modeled separately (visitors only)	*52.62*	*52.62*	#REF!	Veh Trip		
8	Taxi		*56.62*	*56.62*	--	--		
9	Metro Light Rail		*43.94*	*7.00*	--	--		
10	Caltrain		*86.59*	*15.00*	--	--		
11	Short term Parking		*29.21*	*0.00*			0	Vehicle
12	Long term Parking		*36.28*	*7.00*			0	Vehicle
13	Off Airport Parking		*36.34*	*7.00*	N/A		0	Vehicle
14	Limousine		*56.55*	*56.55*	20.09	--	54.15	Veh-Hour

Note:

1. N/A indicates data are not available for analysis
2. " -- " indicates item does not apply to this mode