USDOT Region V Regional University Transportation Center Final Report

NEXTRANS Project No. 039PY02

System Methods for Uncovering Economic, Technological, and Policy Enablers of an "On-Demand Air Service" Regional Passenger Transportation Solution

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TECHNICAL SUMMARY

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Title

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Introduction

On-Demand Air Service (ODAS) is an emerging potential new mode of transportation, which commonly utilizes the Very Light Jet (VLJ) class of aircraft (maximum occupancy of 6 persons and range around 1000 nm). The mature and often stressed hub-and-spoke system of the commercial airlines and capacity constraints on the major hub airports; combined with a steady rise in air transportation demand over long term, has resulted in an increase in average trip time for random origin-destination pairs. Unlike scheduled air service (operated by today's airlines), ODAS will be similar to a taxi service in that it would be: 1) available for use when a customer needs it, 2) accessible at more locations (e.g. local airports) closer to where people live and work, and 3) operate from point-to-point (no stops). The development of widely available, affordable ODAS in a regional setting could have profound effects on regional economies, demographics, land use, quality of life, and shifts in business activity.

The objectives of the research are the following:

- Establish a framework that can study different service models (characterized by different aircraft performance, network topologies and price models) for an ODAS in the larger context of a Regional Transportation System (RTS).
- Extract the following aggregate properties for the RTS that can help the decision-makers to understand the effect of ODAS on the existing infrastructure:
  - Changes in overall network mobility
  - Fraction of the total demand that may potentially shift to ODAS
  - Effect on ground transport near ODAS service points
  - Effect on air transportation by the changes in demand
- Present case studies that compare different service models for the ODAS in order to prove the effectiveness of the framework.

Findings

The major findings of the research:

- From a ODAS analysis perspective, for the given price structure, most of the demand for ODAS comes from medium-range trips (100-300 miles) which were using automobile transport in the absence of ODAS. For these ranges, ODAS offers significant timesaving over automobile transport. Therefore price is the important factor, and indeed the model shows intuitive sensitivity of market share to ODAS price. ODAS does not capture a significant portion of long-range trips from commercial air transportation, owing to high costs. Even a limited ODAS service network could relieve congestion at large airports by servicing demand in urban areas close to where people work.

- From a methodological perspective, the work describes a viable analytical model for studying transportation systems in an integrated manner. While analysis modules for road and commercial air networks are based on standard models, a significant innovation of the integrated model lies in the integration of ODAS and especially the formulation of a "composite network". Once an origin-destination demand is generated, the network assignment is done on the composite paths, which may involve more than one mode. The use of composite network enables capturing multi-modal interactions more effectively than the existing methods. This is especially important given the increasing emphasis on seeking integrated analyses and solutions in transportation engineering. With additional levels of complexity, the framework can be modified to study factors other than demand forecasting, such as emission levels, simulations of daily operations and newer transportation modes.

Recommendations

Some major future research directions are the following:

- The commercial air transportation modeling needs to be improved in order to incorporate individual route choice and level-of-service factors such as flight frequency. This improved model can be expected to show better fit to the statistical data than the current model.

- Additional stated preference surveys for ODAS will be helpful in identifying if there are any level-of-service parameters that differentiate ODAS significantly from other established modes. The logit model can then be accordingly adjusted to reflect these additional parameters.

- New modes of transportation such as high-speed rail can be added to the framework, in order to study the evolution of the regional transportation system with their inclusion. Care needs to be taken in modeling these modes in terms of identifying correct level-of-service parameters and obtaining appropriate data sources to calibrate the model.

- Capacity constraints and supply dynamics should be included to analyze the evolution of the transportation system in more detail. If the network assignment step is carried out simultaneously with mode choice, the feedback mechanism in demand and supply can be readily modeled. Agent based modeling and simulation tools will be helpful in making such improvements in the model.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

1.1 Background and Motivation

On-Demand Air Service (ODAS) is a term that refers to transportation services that operate small aircraft (4-6 passengers) flying in and out of small public-use airports and providing on-demand or near on-demand service to the passengers. Such operations are alternatively called ‘air taxi’, as they are envisioned to provide non-scheduled service as opposed to the scheduled airlines. Small aircraft used for ODAS can access the smaller airports, which exist in much larger number than commercial airports (BTS, 2009). Since these airports are also geographically better distributed, the time taken to access the nearest airports to passenger’s origin and destination is less than that for a comparable commercial air trip. Additionally, the ground time associated with a trip by scheduled airline such as security checks, baggage check-in, connection time at a hub airport etc is saved when making a point-to-point trip with a much smaller aircraft. For these reasons, ODAS is expected to provide quicker (but not necessarily cheaper) service than commercial air travel for origin-destination pairs that lie within the small aircraft’s range.

However, the implementation of this concept so far has seen only mixed success. There are dividing opinions on feasibility of integrating this new mode into the national transportation system. The issues raised include economic feasibility of operating the Very Light Jet (VLJ) aircraft on an air-taxi basis (Mane and Crossley, 2006), the potential demand for such a service (Ashiabor, Baik, and Trani, 2007; Dollyhigh, 2002) and integrating the VLJ operations into the National Airspace System (NAS) (Trani, et.al, 2006; Bonnefoy, and Hansman, 2006). Since ODAS is a new mode of transport, many relevant aspects are still unknown. On the technology readiness level, VLJ aircraft have shown advancements in propulsion and avionics that result in significantly lower acquisition and maintenance costs compared to the next class of aircraft (the light business jets) (Bonnefoy, and Hansman, 2006). But the economic feasibility of the service depends on many other factors, such as the demand distribution, price structure, operating frequency etc.

1.2 Research Objectives

The research objectives are the following:

- Establish a framework that can study different service models (characterized by different aircraft performance, network topologies and price models) for an ODAS in the larger context of a Regional Transportation System (RTS).
- Extract the following aggregate properties for the RTS that can help the decisionmakers to understand the effect of ODAS on the existing infrastructure:
    - Changes in overall network mobility
    - Fraction of the total demand that may potentially shift to ODAS
    - Effect on ground transport near ODAS service points
    - Effect on air transportation by the changes in demand
- Present some case studies that compare different service models for the ODAS in order to prove the effectiveness of the framework.

1.3 Organization of the Report

Chapter 2 motivates the system-of-system perspective as a framework to understand and formulate relevant issues within the transportation system. The chapter includes a literature review on the previous tools that have been developed especially for multi-modal transport demand forecast. Chapter 3 describes a composite model that includes commercial air, road transport and ODAS. Chapter 4 is dedicated to document the verification and validation efforts of the model. Chapter 5 presents three case studies to illustrate different future scenarios for ODAS. Chapter 6 provides some conclusions and discusses future work.

CHAPTER 2. CONCEPTUAL FOUNDATION AND PRIOR TOOLS

This chapter introduces the conceptual foundation of the study and literature review on existing tools for forecasting transport demand.

2.1 System-of-systems Perspective

Systems engineering has been increasingly challenged as individual systems become more and more complex in all engineering domains. Lately, there has been a fundamental shift in how engineers and businesses approach the designing of new systems. Rather than designing an individual system and evaluating its performance, the emphasis has increased on setting the *requirements* for the design of a system properly, in the context of the larger scenario within which the system is expected to perform.

Efforts also have gone into providing a feedback loop in which one can evolve and refine the requirements for a given system by evaluating its design under different operational scenarios. For example, Lewe (2005) proposes a framework under which a new design for a Personal Air Vehicle (PAV) can be evaluated by simulating its use in the NTS and analyzing how it performs. A look at the historical efforts to bring air travel into personal domain reveals that tremendous amount of efforts and resources have been spent in formulating concepts that find no footing at all in the real market. Lewe therefore argues that it is the understanding of the *requirements* for a new PAV concept that is more important than the technical details of the design itself, because the requirements define the operational scenarios in which the PAV is expected to exist. Similarly, there have also been efforts to tie the process of designing a new aircraft for a commercial airliner to the process of fleet allocation and resource management for the airline, so that an estimate of how the aircraft will perform in the airline fleet can be made (Crossley and Mane 2005).

System-of-systems provides a good framework for understanding the problem of system design in the larger context. Under its lexicon, a given system usually occupies a single block within a hierarchy that includes elements from infrastructural resources, operations, economics and policy. Different entities relating to these elements interact with each other, and the performance of the single system is evaluated within this context of larger collection. Figure 1 shows how the NTS can be represented as a system-of-systems. Going upwards from the bottom, the first series of blocks represent the actual service models, including within themselves the performance of the vehicular systems and other service factors. A grouping of these services based on their nature forms the next tier – the type of service.

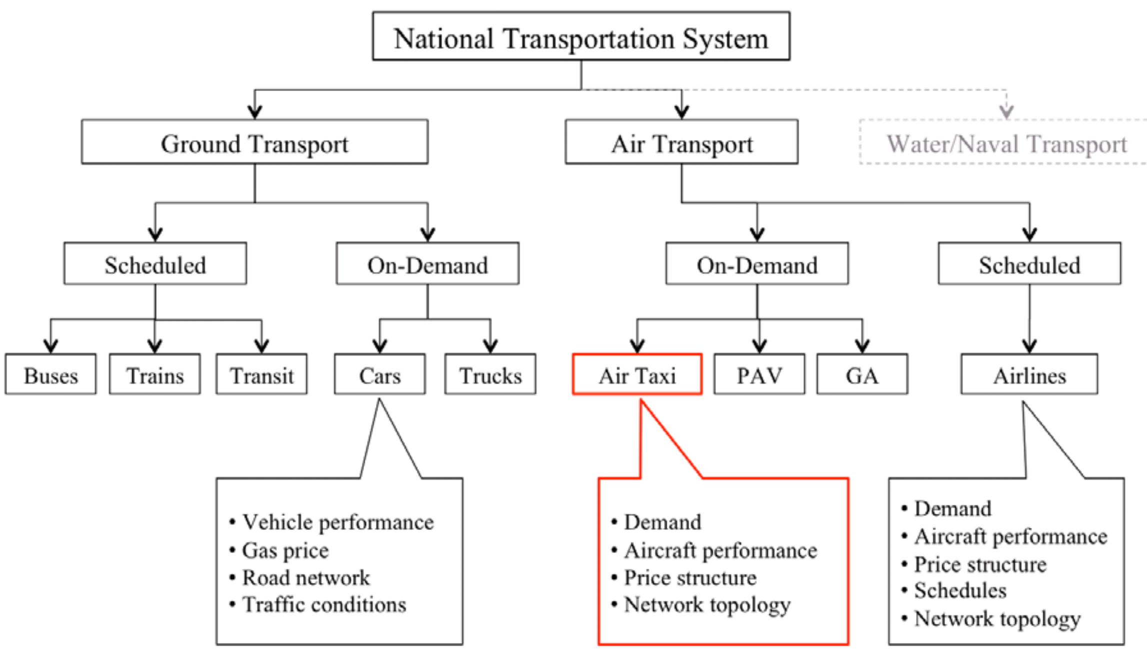

Figure 1. National Transport System as a system-of-systems

There are some factors, which are common to all the members of a block in this tier –performance of all the scheduled systems is dependent on the factors affecting their schedules. The next tier forms the modal transportation system – comprising of its own infrastructure and network topology. And finally a collection of all the modes forms the National Transportation System. These tiers are commonly named as alpha, beta, gamma etc starting from the bottom tier. Figure 1 also shows the factors included in a single alpha level system for some representative systems. For example, the performance of the airlines depends upon factors such as their revenue models, the aircraft fleet performance (in addition to their interaction with the rest of the SoS) etc.

Therefore, looking from a SoS perspective, the performance of an ODAS service model should be evaluated within the larger context of a regional transportation system. This provides another motivation for developing a framework in which there would be some design parameters which, when changed, would produce different ODAS service models, and these different models could then be evaluated in a multi-modal transportation system.

2.2 Intercity Travel Demand Forecast Models

Intercity travel demand forecast models are models that study the socio-economic factors of a region to determine the overall travel demand in the region, and then compare different modes of transportation available for travel in the region to determine their relative demand. The main components of such a model are a macroscopic model of the transportation networks, a socio-economic model of the demand, and an analytical or empirical model of how a traveler chooses a transportation mode for a given trip. There have been a handful of efforts to estimate inter-city travel demand across the entire US since 1970s. Ashiabor, Baik, and Trani (2007) provide a broad overview of such national inter-city travel demand models. Most of these models employ the same basic structure, although the analytical and simulation tools involved in each step of the process have evolved. In addition, better and more comprehensive travel surveys have been generated over time, which enable such frameworks to be calibrated more accurately. Major differences in these models typically occur in the way they estimate the split of demand across different modes. Various theoretical tools rooted in Discrete Choice Theory are used, which model the human process of choosing from a set of discrete alternatives given their perception of the utility of each alternative. Most of these existing models include a combination of road, transit, rail and commercial air transport.

However, few models have looked into the General Aviation (GA) or the newly emerging ODAS segment. In a model called 'Integrated Air Transportation System Evaluation Tool (IATSET)' developed for NASA, Dollyhigh (2002) develops a tool for predicting the total number of potential person trips that can be attracted by various GA operations, such as self-piloted single-piston engine aircraft, fractional ownership business jets and air taxi. In another similar attempt, model developed by Mane and Crossley (2009) investigate the effect of different pricing strategies for air taxi and fractional ownership GA operations on the potential demand captured. Both these models provide excellent references for comparing any demand analysis done with Small Aircraft Transportation Service.

However, both models focus on demand prediction for GA operations, and do not necessarily stress on integrating an analysis of these models into a larger regional transportation system. There are two recent models that do include such analysis– the TSAM model developed at Virginia Tech (Ashiabor, Baik, and Trani, 2003) and the ***Mi*** simulation tool developed at Georgia Tech (Lewe, 2005). Both of these build a model of National Transportation System including road, commercial air and GA transport, and attempt to predict the demand for each mode of transportation, while considering the multi-modal interactions. In addition, the TSAM model is also tied to the more elaborate NAS simulations such as ACES, in order to simulate average daily traffic patterns given the demand input.

The present work builds on the methods in the existing demand forecast models with two key additional capabilities. First, the network modeling uses a *composite network* which encapsulates all the modal networks. This addresses the multi-modal interactions directly in the modeling. Secondly, the ODAS mode is introduced as a hypothetical mode, with fully configurable parameters. Therefore, it is possible to perform case studies that compare different ODAS models in the context of a regional transportation setting.

2.3 Demand Forecasting and Logit Models

The present work uses the classical four step forecasting process for intercity travel demand. The sequential steps involved are as follows: Trip generation, where based on the economic and demographic data, the total number of trips originating or ending in every geographic unit in a certain time span (a year, a month, a day etc) are estimated. Trip distribution, where these trips are divided into origin-destination pairs, using gravity model functions that involve parameters such as the distance between two units, connectivity, perceived attractiveness of the origin and destination. The mode choice step, the trips are divided between each origin-destination pair by the modes of transportation available. Common mechanisms include direct surveys and discrete theoretic tools such as logit models. And finally network assignment, where the aggregate demand data is converted into actual assignment on network and compute network-wide parameters such as average daily traffic on roads, average daily flight operations etc.

Logit models are used for modeling the disaggregate travel mode choice behavior. Ashiabor, Baik, and Trani (2007) provide an overview of the logit models developed for intercity travel. These models use socio-economic data of a region from sources such as the U.S. Census to obtain the traveler attributes (such as household income, education level etc.) and integrate these with data about transportation modes to calibrate the attributes of the mode (such as travel time and cost). Naturally, the logit models need credible statistical data for calibration. Historically, as the disaggregate travel surveys evolved, so did the logit models. All the models used versions of National Travel Surveys (NTS) conducted by the Bureau of the Census and the Bureau of Transportation Statistics (BTS). Ranging from earlier, simple multinomial logit models mentioned in Ashiabor, Baik, and Trani (2007) to modern nested and mixed logit models of TSAM, extensive work has been conducted in forming and calibrating these models.

CHAPTER 3. MODEL DESCRIPTION

The objective of the framework is to form a composite model consisting of commercial air, road transport, and the hypothetical ODAS modes. Stated preference surveys conducted to gauge the traveler response to ODAS suggest that this mode is competitive in ranges up to 650 miles (Peeta, Paz, and DeLaurentis, 2008). For longer ranges, the time savings offered by ODAS compared to commercial air travel are counterbalanced by high costs. Thus, the research studies a regional transportation system (in which maximum distance between any origin-destination pair is less than 650 miles) instead of the entire national transportation system. The geographical extent of the regional transportation system studied includes the three Midwestern states of Illinois, Indiana and Ohio. This geographical region well represents the continental US in terms of a mix of big cities, large and medium hub airports and a large number of small communities. The region covers 282 counties spread across the 3 states.

3.1 Network Model

Since the framework is intended to be a planning tool, the network models do not include the operational details like actual flow dynamics or network feedback. The road network is modeled by using GIS data about highway links, obtained from the National Transportation Atlas Database (NTAD) 2009 (BTS, 2009). An intersection of any two highway links is defined as a highway node. The highway links consist of interstate highways, US highways and state highways. Since every airport is also connected to the road network, it is also a node on the road network. NTAD also includes the Annual Average Daily Traffic (AADT) data for highway links, which is useful for calculating driving times on them. The highway network thus modeled consists of 3145 nodes connected by 5070 links. Figure 2 shows the highway network for the study region with AADT.

The commercial air network (operated by scheduled airlines) is extracted using the Air Carrier Statistics data reported by Bureau of Transportation Statistics (BTS). Form T100D (segment) of BTS consists of monthly data reported by air carriers about aircraft type, passenger capacity, ramp-to-ramp time, and enplanements on all of the origin- destination routes served by the carrier. All the airports with at least one daily flight, and located within the geographical area of the study region, were included in the regional commercial air network to begin with.

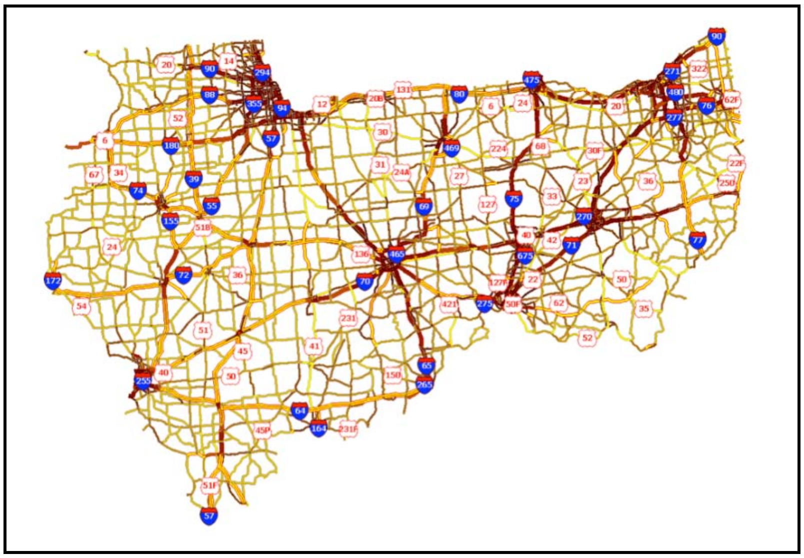

Figure 2. Highway network for the study region with AADT

However, because of the hub-and-spoke nature of the commercial air network, many itineraries are routinely routed through a major hub situated far from the direct origin-destination path. According to BTS data, more than 88% of all flight itineraries involve a connection at a hub airport. Therefore, simply selecting the airports situated in the geographical area of the study region does not truly represent the network available to passengers in this area. For example, Detroit is a major hub and may serve as a connection point for an itinerary involving origin in Illinois and destination in Ohio. But since Michigan is not a part of study region, Detroit is not included in the regional commercial air network. To overcome this shortcoming, the following potential hubs located near the study region were included in the regional network: Detroit, MI (DTW), Saint Louis, MO (STL), Louisville, KY (SDF), and Pittsburgh, PA (PIT).

Figure 3 shows the commercial air network for the study region. The choice of external hubs was subjective determined by observing the annual airport traffic at these airports and their proximity with the study region. It is not possible to truly isolate a regional commercial network from the entire national network. The service network for ODAS forms a design variable for this study. All the public use airports, which have a hard runway at least 3000 feet long, are deemed accessible for a possible ODAS business using VLJ's. Assuming that any ODAS business will utilize current airport infrastructure, locations of such airports were extracted from NTAD.

There are a total of 357 eligible airports in the study region, with fairly uniform geographic distribution. During simulation case studies, a subset of these airports is chosen to represent the ODAS service network. The ODAS network is considered a complete network in order to represent the on-demand nature. In other words, in contrast to the commercial air network, there are no scheduled links in the ODAS network, and any origin-destination demand can be met with a direct link.

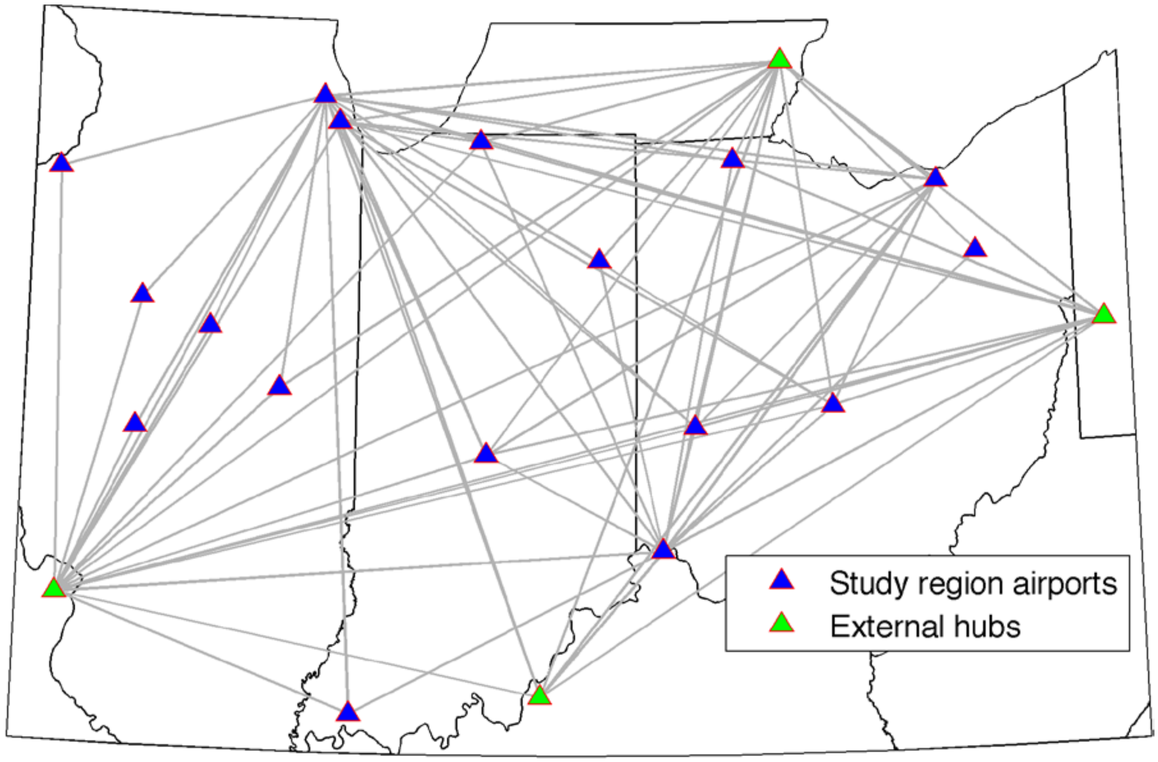

Figure 3. Commercial air network for the study region

3.2 Demand Model

As explained before, the traditional four-step demand forecast process is used in the framework. Before using the network models to estimate the demand for each network, an overall demand is needed. This overall travel demand is expressed in the form of an origin-destination matrix. Since the present study focuses mainly on the mode choice process, the overall demand data from other similar previous studies can be used. Colleagues working with the TSAM model provided the overall demand forecast data for this study (see Acknowledgements). TSAM uses a county as the smallest geographical unit, and a year as the time unit. The only socio-economic parameter used to distinguish the travelers is the annual household income. Hence the travelers are divided into 5 groups according to their annual household incomes: \$30,000 or less; \$30,000-\$60,000; \$60,000-\$100,000; \$100,000-\$150,000 and \$150,000 or more (hereafter referred to as IC1 to IC5). The trips are divided according to their purpose into business and non-business trips. Therefore, demand forecast is obtained in the form of 10 O-D matrices, each matrix of the size 282 x 282 (the total number of counties in the study region being 282). Each matrix *Dxy* corresponds to an income group *x* (1-5) and a trip purpose *y* (indicating business or personal trip); and the element (*i*, *j*) in each matrix represents the annual number of person trips taken from county *i* to county *j*.

An important characteristic of the intercity trips forecast in TSAM is that all the trips are at least 100 miles long. This is necessary to keep out the commuter trips. Forecasting commuter trips within metropolitan areas is a completely different task with its own separate methodologies. Therefore, the trips included in the data are only intercity trips that would not qualify as commuter trips. The demand numbers used in this study correspond to year 2002. The demand for future years can be estimated using demographic projection data such as Woods and Poole. Figure 4 shows the summary of demand.

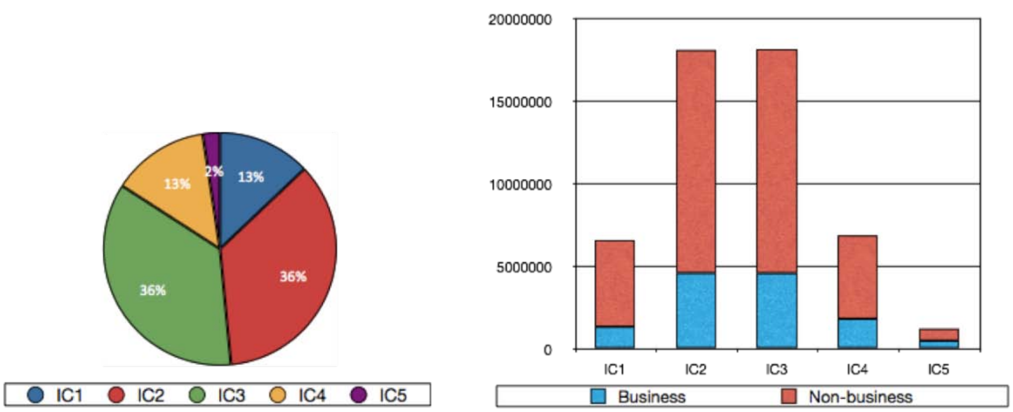

Figure 4. Summary of TSAM annual intercity demand forecast for the study region

As expected, the total number of personal trips exceeds the number of business trips across all income brackets. One of the major reasons for this is that personal trips often consist of an average trip party of more than one person, while business trips are often taken solo. Income brackets 2 and 3 include the most number of trips since a relatively large fraction of total population lies in these income brackets. The total number of annual intercity trips equals approximately 50 million. The total population of the study region according to Census 2000 is around 30 million and the total number of households around 12 million. That corresponds to approximately 4 trips per household annually.

The county demand matrix imported from the TSAM model has to be modified since the current study uses a node on the highway network as a basic unit. Compared to the county, which is a basic unit in TSAM, our model affords a higher resolution. In order to form the demand matrix for highway nodes instead of counties, Census data about *population centroids* is used. Population centroids are areas of high population density in a county. All the population centroids in the Census database with population >5000 are chosen. Each population centroid is assigned to the highway node nearest to it. Then the demand is simply distributed across the population centroids in a county according to the population distribution. Because the demand representation is distributed across several population centroids instead of a single point, the intermodal dynamics such as effect of dense highway traffic can be better studied. Figure 5 shows the demand expansion process. Note that all the points in the right panel are nodes on the highway network.

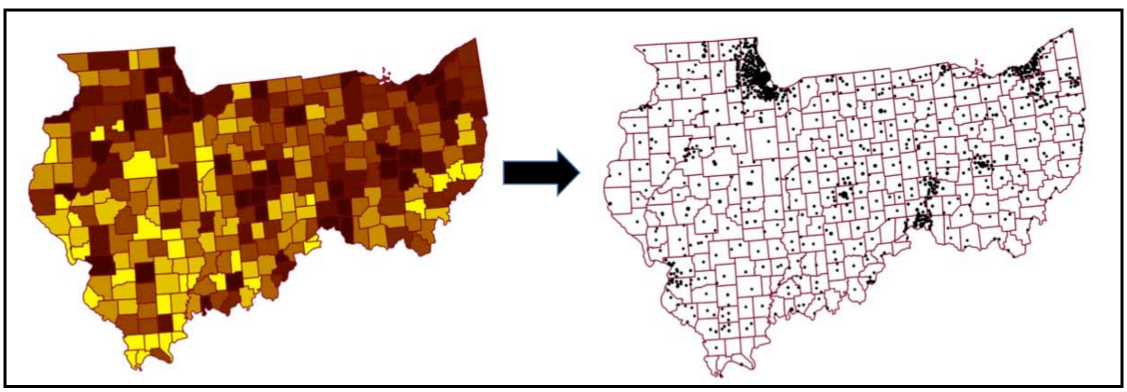

Figure 5. Demand expansion process. (Left) demand density imported from TSAM; (Right) demand as implemented

The original demand matrix has 282 rows and columns. The expanded demand matrix now has 1015 rows and columns. The mode choice process then takes this intercity demand matrix as an input and produces demand matrices for each transportation mode. A quick analysis of this overall intercity demand offers two major insights – most of the demand is for short-range trips (average trip distance is 143 miles) and the demand shows scale-free characteristics (meaning there are some origin-destination pairs for which there is overwhelmingly large demand while a large number of origin-destination pairs have very small demand). We expect the demand for different modes of transportation to also show these characteristics. Also, since the number of long-range trips is low, commercial air, which has a natural advantage in long-range trips, is not expected to attract a significant fraction of total trips.

3.3 Mode Choice Model

A multinomial logit model is developed to represent the mode choice behavior of travelers. In this particular study, a traveler has a choice of three modes: road transport, commercial air travel or ODAS. To model this discrete choice problem, the simplest form of multinomial logit model is used. Under this model, the probability of choosing the road transport for a given origin-destination trip is given by

$$\Pi(road) = \frac{e^{U_{road}}}{e^{U_{road}} + e^{U_{air}} + e^{U_{ODAS}}} \qquad (1)$$

where Umode is the utility value of the mode for a given traveler for the given origin-destination trip. Ideally, a traveler would have multiple route options for any of the three modes. Each route can be looked upon as a distinct alternative within a given mode. Therefore a nested logit model, with the modes as nests and corresponding available routes as alternatives within the nests, would be a more appropriate choice for representing overall route choice behavior. However in the current model only the best route from each mode is considered as a representative of that mode. A nested logit model can be expected to improve the accuracy of the mode choice model.

The first step in using Eq. 1 is to define the utility of an alternative. Considerable prior research has been done to identify the attribute space for intercity travel mode choice behavior. This utility depends upon the attributes of the individual as well as attributes of the mode. Koppelman (1989) led the early efforts in modeling, and identified key variables such as travel time, travel cost and level-of-service for the alternative; income, education level and region type for the individual; and the trip type (business, personal or personal business). Many logit models formed in the past have used these key variables to calculate utility and have given satisfactory results when calibrated with statistical data (Ashiabor, Baik, and Trani, 2007) .

Since logit models are disaggregate (individual) decision models, they are best calibrated using statistical surveys conducted using disaggregate trip choice data. The 1995 American Travel Survey (ATS) is one of the most comprehensive datasets available for this purpose, and was used in this study. Since ATS includes the household income values, it was used as the defining attribute of the traveler. Therefore the travelers were divided into 5 groups according to their household income, similar to the TSAM model (Ashiabor, Baik, and Trani, 2007). ATS does not include parameters such as travel time and cost for the trips. Therefore these parameters were calculated synthetically using the network model.

The utility of the mode *m* for a trip from origin *i* to destination *j*, and an individual of type *p* is given by

$$U^{p}_{m,i,j} = \alpha^{p}_{t}.t_{m,i,j} + \alpha^{p}_{c}.c_{m,i,j} \qquad (2)$$

Where $t_{m,i,j}$ and $c_{m,i,j}$ are respectively the time and cost for traveling from *i* to *j* by mode *m*. The coefficients α^{p}_{t} and α^{p}_{c} are essentially calibration parameters. Since the travelers are divided into 5 income groups, and the trips are divided into business and non-business, there are 10 distinct types of traveler trips. Hence p varies from 1 to 10, and there are 10 pairs of calibration parameters $\left(\alpha_t^p, \alpha_c^p\right)$.

3.4 Travel Time and Travel Cost Estimation

The travel time and cost for each mode in a given origin-destination trip are calculated for the best route involving that mode. To calculate these values on a route, a *composite network* is created. Since both ODAS and commercial airports are also nodes on the highway network, the composite network consists of the highway nodes and all the links including highway, commercial air, and ODAS links. When the best route between an origin and destination is calculated, it may consist of links of more than one mode, including the highway links from origin to the origin airport, air links between the origin airport and destination airport (also including the connecting airport, if applicable), and the highway links from the destination airport to the final destination. Such a composite network automatically includes the multi-modal interactions. For example, if the origin airport is situated in a metropolitan area such as Chicago, the time taken to reach it from the origin by highway will be long, because of the heavy urban traffic. This time is included in the overall time for the commercial air route, therefore potentially decreasing its attractiveness. In the stated preference survey conducted by Peeta et. al.(2008), it was found that one of the biggest incentives for ODAS is the availability of airports near origin and destination points, reducing the access time. The composite network also captures this characteristic, because longer distance from the origin to the nearest airport means longer composite route.

Once the travel time and cost is calculated for a single link for each transportation mode, the composite route values are calculated by simply adding the time and cost for each link included in the route. The Transportation Research Board's Highway Capacity Manual (HCM, 2000) is a widely used source of acceptable methodologies to calculate performance attributes of highway links. The publication describes empirical methods of estimating highway capacities and average travel times. For planning models such as the present work, simple empirical models exist that can predict these parameters fairly well as long as traffic on a highway is below a certain fraction of the highway capacity.

Beyond this fraction, the traffic flow is interrupted and more elaborate methods that use vehicle queuing and traffic signal modeling have to be used. We use uninterrupted traffic flow modeling to estimate the average travel times. It has been empirically determined that travel time has a non-linear relationship with the traffic volume on a highway links. Various functions have been developed to determine the exact nature of this relationship. Davis and Xiong (2007) present a review of these functions and compare their relative performances in different conditions. We use the Bureau of Public Records (BPR) function here for three reasons: it has been proven to give reasonable estimates for uninterrupted flow that is not close to the saturation conditions, it needs the least amount of data, and it has fixed parameters, thus there is no need to re-calibrate it for every different application.

The BPR function states that for a highway link,

$$T_{avg} = T_{ff}\left(1+\alpha\left(\frac{V}{C}\right)^{\beta}\right) \qquad (3)$$

Where

T_{avg} : Average travel time on the link

T_{ff} : Free flow travel time on the link

V : Average traffic volume on the link

C : Traffic volume capacity of the link

α : Model parameter (default value = 0.15)

β : Model parameter (default value = 4)

Free flow travel time is related to the free flow travel speed, *vff*. This is the speed an average driver chooses on a given road when there are no immediate distractions in terms of traffic or traffic signals. Traffic volume and traffic volume capacity is commonly measured in terms of number of passenger vehicles per hour (including all lanes in one direction), denoted by pc/hr. The Highway Performance Measurement Systems (HPMS) data is available in the NTAD. It includes information regarding the length, functional class (as defined by the Department of Transportation), number of lanes and Annual Average Daily Traffic (AADT). This information can be effectively used to calculate the traffic volume and traffic capacity. Free flow travel time is calculated by using free flow velocities given in Table 1 below. These values are based on recommendations given in HCM.

Table 1. Free-flow speed on highway links by functional class (mph)

	Urban	Rural
Interstate	70	75
Principal Arterial	55	60
Minor Arterial	55	60
Freeway/ expressway	70	N/A

The travel time for each highway link is calculated using peak hour conditions. The peak hour capacity for a highway link is calculated by multiplying its basic capacity by a Peak Hour Factor (PHF). The basic capacity for each functional class is given in Table 2 below.

Table 2. Highway link capacity (pc/hour/lane)

	Urban	Rural
Interstate	2400	2400
Principal Arterial	2100	1900
Minor Arterial	2100	1600
Freeway/ expressway	2400	N/A

In accordance with HCM recommendations, a value of 0.92 is used for PHF for urban links, and 0.88 for rural links. The value of C in Eq. (3) for any highway link is given by multiplying its basic capacity (Table 2) with PHF. The value of *V* in Eq. (3) is calculated using the AADT. While AADT is measured in pc/day, *V* is measured in pc/hr/lane. This conversion is done using a parameter called the K-factor, which is an empirical parameter defined in the HCM directly as the ratio of peak hour traffic to average daily traffic. Default values for K-factor are 0.093 for urban links and 0.095 for rural links. Thus the value of *V* for a link is obtained by multiplying AADT with K-factor. With these parameters, average travel time on each highway link is calculated using Eq. (3). Average travel cost is calculated simply by multiplying the link length by BTS estimated average cost of owning and operating a personal vehicle in the United States. The value of 20 cents/mile was used in this study, according to the BTS recommendation.

Calculating the total travel time on a commercial air link is made up of three parts – the processing and wait time at the origin airport, the ramp-to-ramp aircraft travel time, and the exit time at the destination airport. Further, if a path involves two air links (signifying a connection), the wait time at the connecting airport (called the connection time) is added. The processing, connection and exit time of an air trip together is termed the *ground time* for that trip.

Data about ramp-to-ramp travel time on airline segments are available in the Bureau of Transportation Statistic's (form 41 traffic) T-100 (segment) dataset. It is the monthly data reported by certificated U.S. air carriers on passengers, freight and mail transported. From this dataset, the data about total annual passenger volume and average ramp-to-ramp travel time was extracted for every link of the commercial air network in the study region.

The process of calculating travel time between all pairs of (Midwest) airports in this network is as follows:

1. For each pair, compute all the possible air routes in the network that involve at most one connection (meaning routes consisting of either a direct link or a connection at a hub airport). Routes involving two or more connections are discarded for obvious reasons in a regional transportation context.

2. For each route thus computed, calculate the total travel time, including process time at the origin airport, ramp-to-ramp time, connection time (if applicable) and the exit time at the destination airport.
3. Compute the average travel time between the origin and destination, weighted by the passenger volume on each route.

This average time is then used as the travel time for the origin-destination airport pair. Here it must be noted that by using the average time, we are destroying the possibility of presenting the traveler a choice of multiple air routes. Ideally this distinction between air routes needs to be retained, as it reflects the real life scenario. For example, business travelers would choose direct routes, even if they were more expensive. On the other hand, personal trips and trips for travelers in lower income brackets may choose indirect routes; they likely take longer, but cost less. However, because of the decision to use simple multinomial logit model instead of nest logit model, this extra dimension of the problem was left unexplored.

At the regional level, the effect of this decision is not as pronounced as at the national level, where there is a much wider variety of air routes and fare combinations to choose. Data about average processing and connection times for airports is not readily available. Therefore some reasonable assumptions have to be made. BTS definitions about airport hubs were used for this purpose. According to these definitions, any airport that handles at least 1% of the national air passenger volume is classified as a large hub, airports handling between 0.25% and 1% are classified as medium hubs and other airports are classified as small hub or non-hubs. Based on aggregate trends, the values in Table 3 were used. There values are less than the national averages used in transportation models such as TSAM (Trani, et. al., 2006). However since these values are essentially based on some assumptions, it is important to study their impact on the model. For this reason one of the simulation experiments involves a sensitivity study for changes in these values.

Table 3. Airport processing, connection and exit time (min)

Airport type	Processing time	Connection time	Exit time
Large hub	45	30	20
Medium hub	30	45	15
Non hub	20	N/A	15

It must also be noted here that the above values, which together make the ground time of an air trip, make up a significant part of the total trip time. A quick analysis of the segment ramp-to-ramp times reported in T100 data and the above values shows that on an average about 30% of the total trip time consists of the ground time. This fraction decreases as the trip distance increases. This significant ground time is one of the major disadvantages of commercial air transportation for short distances.

For calculating the average ticket price for a given airport pair, the BTS Airline Origin and Destination survey, called the DB1B survey, was used. It is a 10% sample of airline tickets from reporting carriers. Data includes origin, destination and other itinerary details of passengers transported. Unlike the T100 data, DB1B is not an aggregate data reported by the airline. It is a sample of individual traveler itineraries. As such, this data includes a lot of unwanted and unnecessary elements. Following filters were used while using this data:

- Some of the itineraries were found to report unusually small airfares. Assuming these fares represent promotion fares, frequent flyer rewards or other such unusual instances, they were removed. Any fare less than $50 was removed in this process.
- Some of the itineraries had unusually large travel party sizes. In many cases it was found that the fares in such cases did not show normal trends. Such instances were removed.
- Some of the itineraries were found to report unusually large airfares. This typically occurred when the aircraft seating capacity was low. These were probably instances of chartered flights, aircraft rentals or other such unusual cases. Such itineraries were removed.

It is possible with further statistical analysis to separate average economy fare and average business fare. However since the travel times for all the air routes were averaged, it was decided to average the fares as well. Because travel fare essentially provides a trade-off to the travel time, in the absence of multiple options for travel time, options for fare were deemed unnecessary.

Both the service network and aircraft performance for the ODAS mode form design variables in the present study. Therefore no available datasets are used to define any parameters for this mode. The typical operating conditions and the potential impacts of using VLJ in an ODAS mode have been studied in Trani, et al. (2006). and Bonnefoy, and Hansman (2006). The values for design variables during the experiments were used based on the trends highlighted in these sources. The design variables are explained below.

The first design variable is the price per passenger mile (*ppm*) for the service. The ticket price for an ODAS seat between a pair of airports is simply the great circle distance between them multiplied by *ppm*. The value of *ppm* for an ODAS operator depends upon various factors, including the type of aircraft, its acquisition cost, operating cost, typical load factor (number of passengers) for a trip, personnel cost etc. Dollyhigh (2002) includes life-cycle cost analysis for Eclipse 500, and assuming 4 passengers for a typical trip, calculates the *ppm* to be \$1.72. This value is obviously sensitive to the load factor used. In their air taxi feasibility study, Mane and Crossley (2009) estimate the direct operating cost of the Eclipse 500 to be \$937 per hour. Assuming 2 passengers per trip, and using the nominal performance characteristics of Eclipse 500, this translates to a *ppm* of approximately \$2.25. A detailed life-cycle cost analysis for a typical VLJ, including expected operational factors for a typical ODAS operator (such as 10-20% repositioning or empty flights) performed for the TSAM model, estimates that the *ppm* for a typical ODAS service will range from \$1.85 to \$2.25 (Trani, et al.,2006).

The aircraft performance is represented by maximum cruise velocity (*vcruise*) and maximum rate of climb (*rclimb*). More detailed aircraft dynamics are avoided for the sake of simplicity. For any given origin-destination airport pair, the flight profile of the aircraft is assumed to be simple climb-cruise-descent. The cruise altitude (*hcruise*) is in general a function of the distance between the airports. Using these parameters, it is possible to calculate the ramp-to-ramp travel time for a give pair of airports using ODAS, as simply the sum of time taken for the climb, cruise and descent segments. Figure 6 summarizes the model as described in this section. The end result is the time and cost for the best route on each mode (which potentially involves more than one type of link). These values are then used to calculate the utility of a particular mode using Eq. (2).

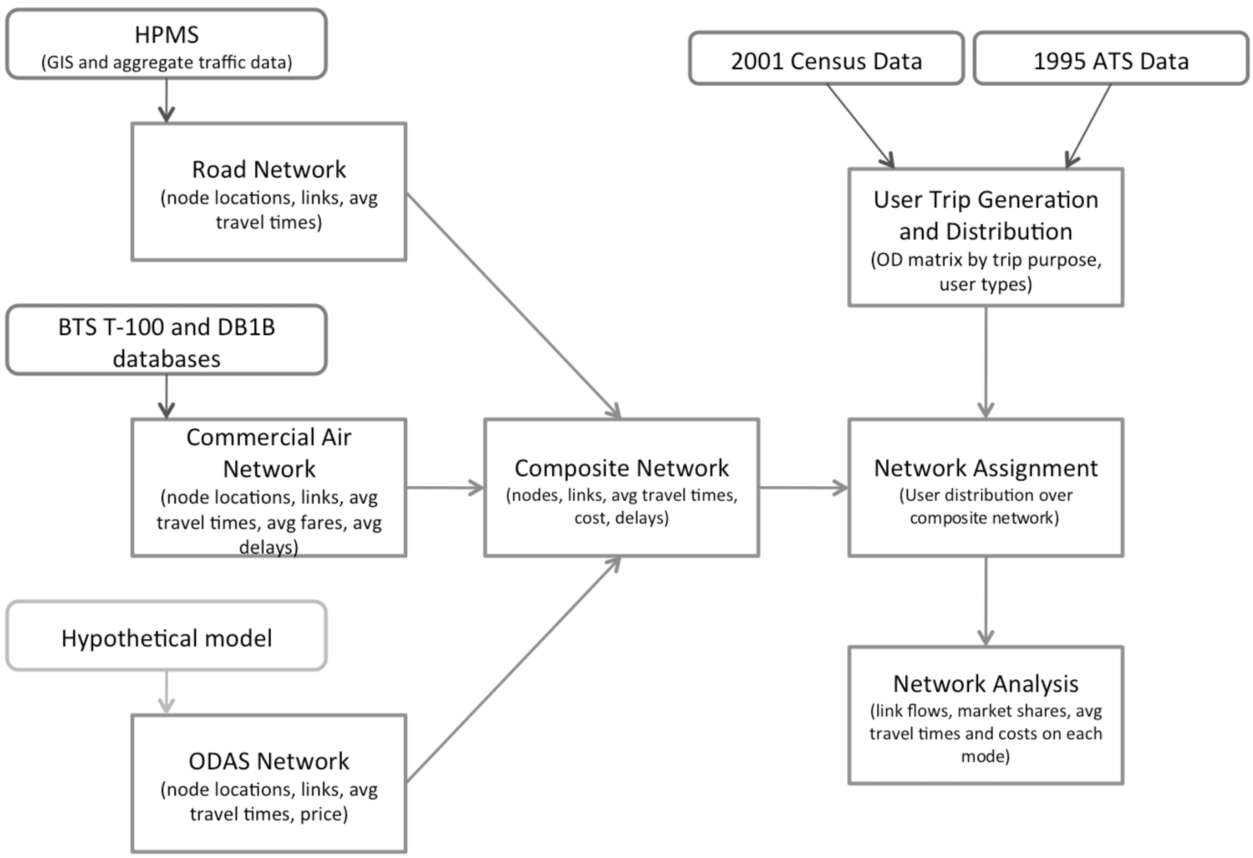

Figure 6. Model Overview

CHAPTER 4. MODEL CALIBRATION AND VALIDATION

4.1 Calibration

The coefficients in Eq. (2) need to be calibrated with available data from surveys before the utility of an alternative can be calculated. The 1995 American Travel Survey (ATS) is used for this purpose. It is one of the most comprehensive surveys conducted in the US for the purpose of analyzing the long-distance travel preferences of Americans. The data in ATS was collected by randomly choosing households across the entire US to fill out a form requesting details about long distance trips (>100 miles) each person in the household has taken in the previous year.

The factors collected include, among other things, the household income, number, age and gender of the persons in the household, trip origin and destination, and the mode chosen for the trip. There are over 554,000 individual records in the survey. For each record, the information about origin-destination in ATS includes the origin state, the destination state, the origin and destination Metropolitan Statistical Area (MSA), and the distance between origin and destination. The United States Office of Management and Budget defines MSA as one or more adjacent counties or county equivalents that have at least one urban core area of at least 50,000 population, plus adjacent territory that has a high degree of social and economic integration with the core as measured by commuting ties (Wikipedia, 2010).

In order to calculate the travel time and cost using the model, the origin and destination have to be mapped onto the network nodes. This is done as follows. First, the ATS records are filtered to only include the trips within the study region. It is also filtered to include only the records pertaining to mode of choice as either road or commercial air transportation. This reduces the total data size to 18,500 records. If either the origin or destination happens to be in a MSA, it is identified by the name of the MSA in the ATS. However, a MSA typically has many counties included. Thus all the highway nodes lying in these counties form the *origin (or destination) set* for this particular record. If, on the other hand, either origin or destination is identified simply as non-MSA, then all the highway nodes lying in the non-MSA counties in the corresponding state form the origin (or destination) set. This way, a set of nodes each for origin and destination is obtained. Then the distance information in the ATS record is used to select the ordered pair of nodes from these two sets. The pair of nodes (one each from origin and destination set) with the distance closest to that mentioned in the ATS record is chosen. This way the origin and destination are now mapped on the highway network. More than 95% of the mappings thus obtained result in the difference of less than 30 miles in the origin-destination distance in ATS and the distance on network.

After trying multiple utility models for the calibration purpose, the following model was selected. For a given origin-destination pair, the utility of mode *p* (either road transport or commercial air transport) is given by:

$$U_p = \alpha_t t_p + \left(\alpha_c^1 + \alpha_c^2 + \alpha_c^3 + \alpha_c^4 + \alpha_c^5\right)c_p \qquad (4)$$

Where α_t is the time coefficient, t_p is the travel time for mode *p*, c_p is the travel cost for mode *p*, and α_c^i is the cost coefficient for the traveler from income group *i* (*i* = 1,2…5). For a traveler of income group *i*, all the cost coefficients except *i* are set to zero. Thus effectively these coefficients act as dummy variables for any given record. This procedure is carried out separately for business trips and personal trips.

NLOGIT software by Econometric Software Inc was used to calibrate the coefficient values using this data and equation. Table 4 shows the results of the calibration process.

Table 4. Model Coefficients

Coefficient	Value	Std Error	Value/Std Error	P (|Z|>Z)
Business Trips				
α_t	-0.03513	0.00224	-15.68303	<0.0001
α_c^1	-0.01182	0.00105	-11.25714	<0.0001
α_c^2	-0.00755	0.00177	-4.26553	<0.0001
α_c^3	-0.00563	0.00113	-4.98230	<0.0001
α_c^4	-0.00494	0.00108	-4.57407	<0.0001
α_c^5	-0.00448	0.00291	-1.53951	0.0003
Personal Trips				
α_t	-0.04675	0.00282	-16.57801	<0.0001
α_c^1	-0.01581	0.00128	-12.35156	<0.0001
α_c^2	-0.01256	0.00105	-11.96190	<0.0001
α_c^3	-0.00892	0.00267	-3.34082	<0.0001
α_c^4	-0.00739	0.00172	-4.29651	<0.0001
α_c^5	-0.00715	0.00343	-2.08454	0.0006

The calibration results, while satisfactory, do not provide a uniformly good fit, as evidenced by the relatively low value/std. error. This was also confirmed by a R-squared value of ~0.5 for both business and personal trips. The quality of the fit especially deteriorates for the high-income groups due, primarily, to the fact that the ATS data volume is insufficient for high-income group. A more focused travel survey, with more data on regional trips taken by high-income groups, will be helpful in calibrating the model better. Another reason for a relatively poor fit is the relatively low fidelity of the commercial air network. The inclusion of choice for routes and fares will result in time and cost estimations for the air network that are better representations of reality.

4.2 *Validation*

The model thus calibrated is run in the absence of a hypothetical ODAS mode. The only available modes are road and commercial air. Once the model is run, aggregate network data is analyzed for relative trip volumes on both modes. This data is then compared to ATS in ordered to validate the results. Figure 7 shows the validation results. All the records were divided according to the trip distance into brackets of 50 miles. The fraction of trips that chose the commercial air for each bracket was calculated. The X-axis in the figure corresponds to a distance bracket and the Y-axis corresponds to the market fraction of commercial air for that distance. As the figure shows, the market fraction increases as the distance increases and in the range of ~600 miles, over half of total trips are taken by commercial air.

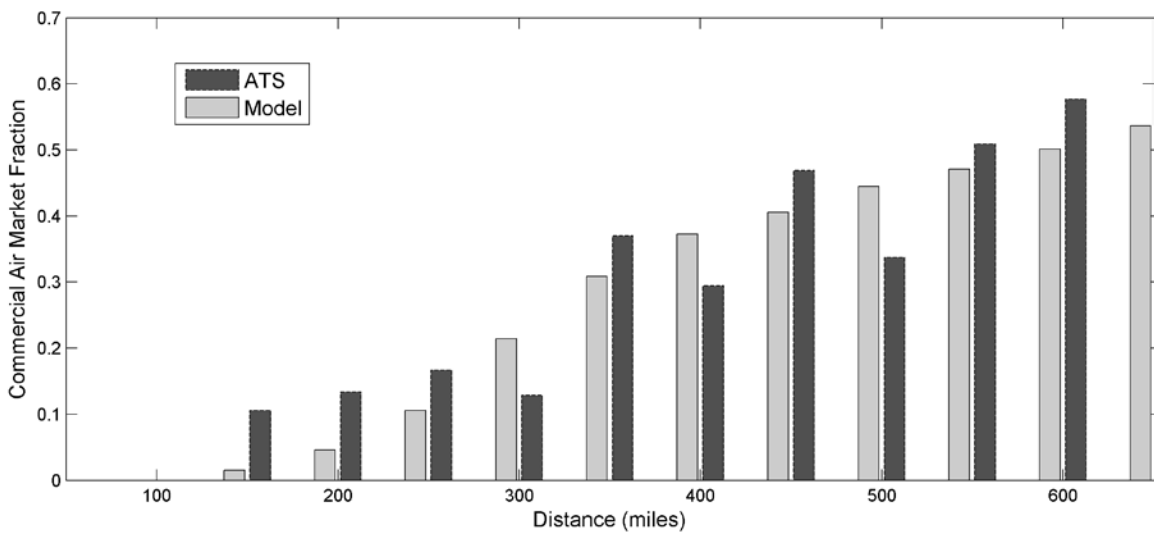

Figure 7. Model validation with ATS

The model also computes the traffic volume on all the links on modal networks. Using this data, total annual number of enplanements at the commercial airports was calculated. These numbers were compared to the annual enplanements as reported in T-100 (market) database. The T-100 market data describes the total number of person trips taken between an origin destination airport pair. This data is filtered to include only the air links present in the model network. Figure 8 shows the results.

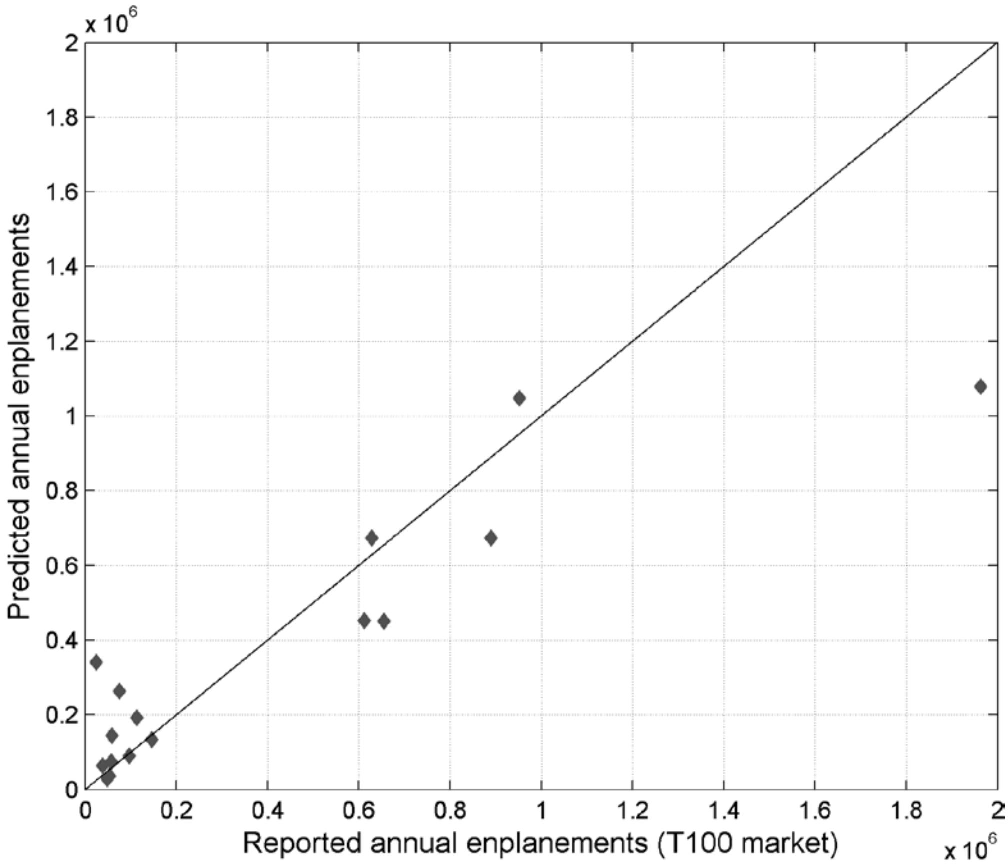

Figure 8. Model validation with T100 data

On the whole, the model underpredicts the total number of enplanements by about 16% (5.5 million computed by model as against 6.5 million reported in T-100). From the figure, it can also be seen that the model over-predicts the number of enplanements for smaller airports, and generally under-predicts them for the larger airports. This can be attributed to the relatively low level of fidelity of the commercial air network model. As described before, many details about the commercial air network are dropped for the sake of simplicity. For example, there is no information about flight frequency for a given route in the model, thus making even routes with less frequency appear as attractive as routes with higher frequency, as long as the travel time and price are similar.

These two validation results prove that the mode choice and network assignment process models show correct trends. The validation results also help in understanding where the models fail to capture the real dynamics properly, and predict where the accuracy of the model will be limited, as well as the possible reasons for it.

CHAPTER 5. CASE STUDY

The purpose of simulation experiments is to observe the demand for each transportation mode as the nature of ODAS mode is changed. The first experiment assumes that ODAS can be provided between a pair of any two VLJ ready airports in the study region. All 357 public use VLJ-ready airports in the study region are considered as service airports. Thus, it assumes ODAS with infinite capacity (in terms of fleet size and flight frequency), in order to uncover the maximum demand possible for this mode. A baseline price per mile (*ppm*) of $2.25 is assumed and used in Experiment 1 and 3. It can be expected that the demand volume and distribution is very sensitive to this value. Therefore, Experiment 2 studies price sensitivity of demand on this same (infinite capacity) ODAS network. Experiment 3 conducts sensitivity studies for the ground times of commercial air and ODAS networks.

In order to calculate the travel time and cost for ODAS, the performance parameters of Eclipse 500 jet were used: cruise speed 425 mph, rate of climb 3314 feet per minute, and cruise altitude 24000 feet. In addition, a wait time of 15 minutes at the origin airport and an exit time of 15 minutes at the destination airport were added to the ODAS travel time. Therefore, the total ground time for an ODAS flight is 30 minutes. ODAS price was assumed to be *ppm* times the distance for distances greater than 100 miles and *ppm* times 100 for distances less than 100 miles.

5.1 Experiment 1: Maximum possible demand for ODAS

The first experiment consists of an ODAS with infinite capacity, and every VLJ-ready airport treated as an ODAS service airport. Figure 9 shows the market shares for the transportation modes by distance in this case. The tip of each bar in the figure is the combined share of commercial air and ODAS, and the rest is the market share for automobile. As the figure shows, most of the demand for ODAS lies in short distance brackets, and the total market share is less than 10%. Commercial air dominates for trips longer than 400 miles, and automobile transport dominates for shorter trips. This translates to approximately 2.5 million enplanements annually for ODAS in the study region (with note that the ubiquitous availability of ODAS represents the limiting value in case of infinite capacity). The average trip distance for ODAS is 107 miles, which is much shorter than what would be expected of a VLJ aircraft. The demand is very small for trip ranges of over 250 miles. It is worth noting that the typical VLJ has the capability to fly much longer ranges (e.g., the Eclipse 500 has a maximum range of 1300 miles). This is an indication of price, not the aircraft performance, being the limiting factor on the ODAS demand. The point-to-point nature of the service provides significant advantage in terms of time saved for a trip, but for longer-range trips, the cost offsets the timesaving.

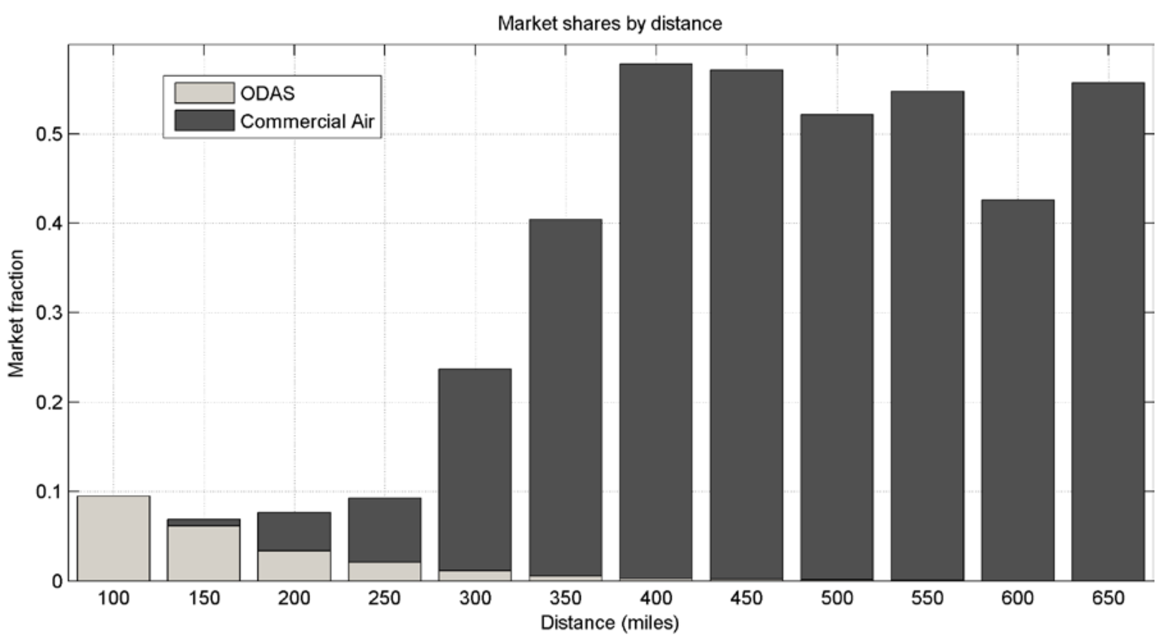

Figure 9. Market shares by trip distance for Experiment 1

5.2 Experiment 2: Price Sensitivity of ODAS demand

Since price is the most influential factor in ODAS demand, it is worthwhile to investigate the sensitivity of overall demand to ODAS price. In reality, the decisions about price will depend on the aircraft life-cycle analysis and higher prices will invariably show improvements in other ODAS level-of-service parameters. However in this case we assume that the performance parameters for ODAS remain otherwise the same, as we change the value of *ppm* to observe its impact on ODAS demand. The *ppm* was varied from $1.25 to $3.5 in increments of $0.25 while keeping other parameters constant. Figure 10 shows the market fractions of ODAS and commercial air for different ODAS prices.

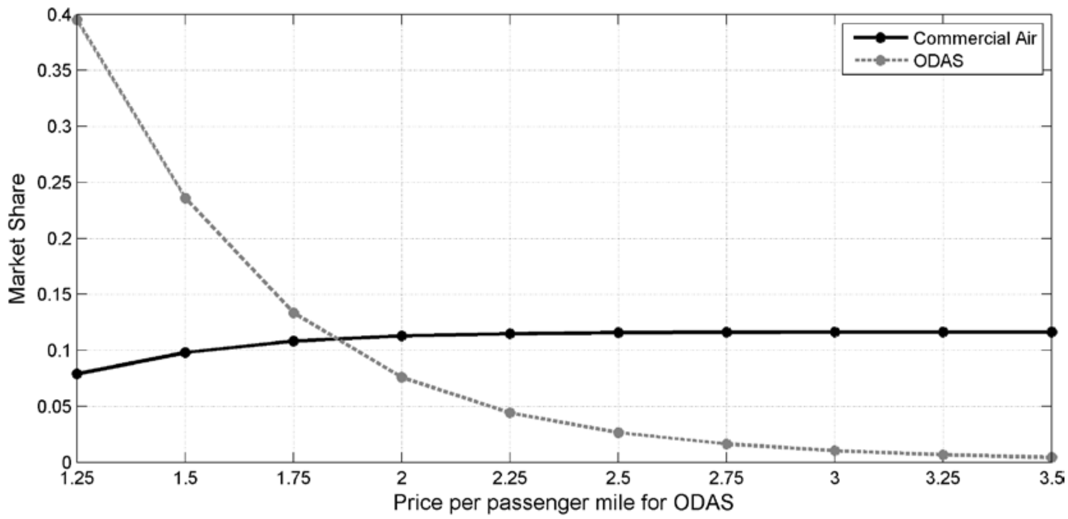

Figure 10. Price elasticity of ODAS demand

The demand for ODAS increases rapidly as *ppm* drops below $2. Also, the commercial air market fraction does not change for ODAS *ppm* above $2, indicating that above this price the ODAS cost for typical long-range trips is prohibitive, therefore commercial air travel retains significant fraction of these trips. Below $2, the commercial air market fraction decreases as ODAS prices drop. As Figure 11 shows, for $1.5 per passenger mile, a significant fraction of long-range trips are captured by ODAS, but as price increases, the average trip distance for ODAS begins to drop rapidly. At $2.5 per passenger mile, most of the trips are shorter than 200 miles.

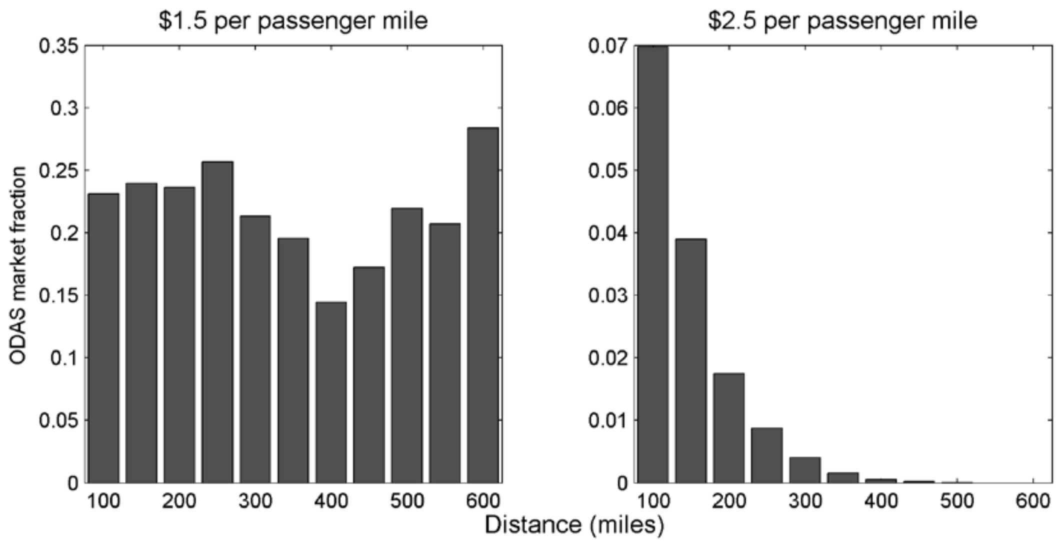

Figure 11. ODAS demand by distance for different prices

The overall demand analysis presented earlier indicated that much of the overall demand lies in short-range trips. Therefore, although a low ODAS price can effectively capture a significant portion of the long-range trips, the intrinsic nature of the regional transportation demand is such that there will always be a far greater demand (in terms of volume) for short-range trips.

5.3 *Experiment 3: Sensitivity Analysis for Commercial Air Ground Times*

Earlier experiments bring out two important factors that influence the demand distribution for ODAS:

- ODAS price is the main limiting factor against a greater fraction of person trips switching from existing modes to ODAS. The time savings offered by ODAS should be significant in order to justify its high cost.
- Especially for commercial air travel, a significant part of the total travel time comprises of the ground time: time spent in the airports for check-in, security etc.

The ground times used for the commercial air travel, as mentioned in Table 3 do not have a well-established basis. They are based on some reasonable assumptions and looking at trends in existing literature. These values, however, are on the optimistic side (from the perspective of commercial air traveler). In reality, the ground times can be significantly higher than this. In such cases, the total travel time for commercial air transport increases. One of the key factors in favor of ODAS is that it can utilize the smaller airports, cutting down significantly on process times at these airports. It is therefore important to study if any increases in ground times for the commercial air travel result in additional demand for ODAS.

The values for ground times used in Experiment 1 are taken as the nominal values. In Experiment 3, the ground times are changed from their nominal values, and effects on overall demand distribution are analyzed. In the experiment, the ground time for each air trip is changed from its nominal value by a common factor f. Therefore, $f<1$ would mean a decrease in the ground time from nominal case, and $f>1$ would mean an increase in the ground time from nominal case. The value of f is changed from 0.5 to 2, in increments of 0.1, and the results are plotted as sensitivity analysis. Thus, $f = 0.5$ represents the most optimistic scenario for commercial air transportation, where all the ground times are cut in half (across the entire commercial air network) and $f = 2$ represents the worst-case scenario where the ground times are doubled across the entire network.

Figure 12 shows the overall market shares of commercial air travel and ODAS as f is changed. The commercial air market fraction drops as f is increased (from 16% to 5%). But the corresponding increase in ODAS market share is not very pronounced (from 4.3% to 4.5%). This implies that as average trip time for commercial air travel increases, demand shifts away from it, but ODAS does not capture a significant part of this demand. The most probable explanation is that the high price for ODAS acts as a deterrent even despite its timesaving.

These experiments prove one thing beyond doubt. Given current estimations of how much it would cost to own and operate a VLJ aircraft, the ODAS price is such that only short-range trips are affordable. These trips would normally be covered by automobile in the absence of ODAS. The commercial air transport dominates the market in long-range trips, and would continue to do so as long as it is not possible to drastically reduce the ODAS costs.

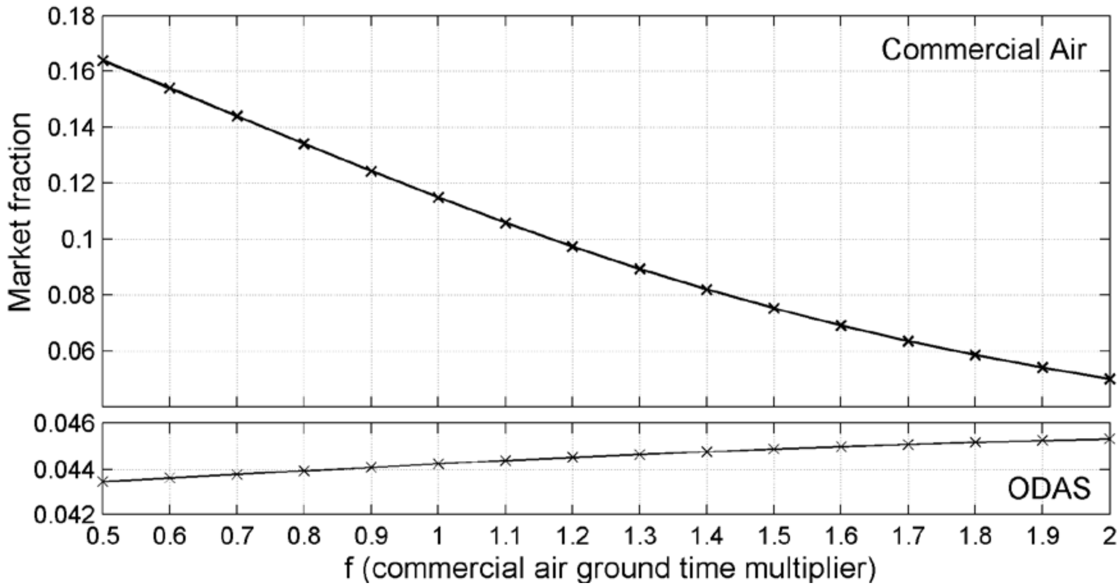

Figure 12. Commercial air and ODAS market shares sensitivity to commercial ground times

CHAPTER 6. CONCLUSIONS AND FUTURE WORK

This chapter summarizes the research, highlights its findings, and proposes directions for future research.

6.1 Summary

This study addresses the two primary objectives:

1. to develop an integrated framework that models in composite fashion a regional transportation system including three principal modes of transport – road transport, commercial air transport and a hypothetical On-Demand Air Service (ODAS) mode.

2. to explore the utility for such an on-demand, point-to-point air service in conjunction with other modes for efficiency of the regional system.

6.2 Major Findings

Road transport is inexpensive and convenient for short-range trips. It is also aided by an extensive highway infrastructure. For this reason, it is the mode of preference for all short-range trips (~100 miles). Commercial air transport, on the other hand, offers unparalleled benefits of speed and convenience for long-range trips (>500 miles). For trips between these two ranges, ODAS is envisioned to provide a more efficient service than these two modes.

Before discussing the experiments, it is important to note that the model is sensitive to the underlying assumptions while estimating the values of model parameters. The most important of these assumptions are the value of *ppm* for ODAS, the ground times (which include the processing times at origin, connection and destination airports) for commercial air and ODAS, the average traffic conditions on the road network, and the commercial air network available to the study region.

The results in Experiment 1, which was used to estimate the upper limit on the demand for ODAS in case of a wide-spread ODAS service network, showed that most of the demand is for relatively short-range trips (less than 150 miles). This can be attributed to two factors. First, an analysis of overall demand distribution for person trips in the study region shows that most of the transportation demand is for short-range trips. Figure 4.9 shows this fact. Therefore, it can be expected that for any mode of transportation, irrespective of its nature, a significant fraction of total demand will be for short-range trips. Second, the cost of ODAS is a deterrent for longer-range trips (greater than 300 miles). In this trip range, the timesaving offered by ODAS over commercial air transportation are offset by costs.

As explained in Experiment 2, this new ODAS mode also promises to relieve the pressure on major commercial airports, by diverting the demand for small and medium-range trips, for which the commercial air network is very inefficient. This is an important factor when considering the future of ODAS mode, not just as a new transportation mode in itself, but also as a potential part of the solution to the growing problem of congestion at major commercial airports.

Experiment 3 demonstrates the ability of the framework to evaluate the performance of the ODAS mode in case of a different aircraft and price structure. If directed research in aircraft technology produces an aircraft that is more appropriate for the ODAS demand than the current VLJ’s (an aircraft with shorter design range and less operating costs that a typical VLJ would fit this description), it will help capture a greater transportation demand.

Experiments 4 and 5 provide sensitivity analyses for changes in demand based on changes in ground time for commercial air and ODAS modes. This is important for two reasons. First, for these modes, ground time is a significant part of the total trip time, especially for the typical regional short-range trips. It is therefore important to analyze how this ground time affects the overall effectiveness of the transportation mode. Second, the values for ground time used in the model are based on some assumptions, and it is important to check if changing these values does not cause unexplainable changes in model outputs.

These sensitivity analyses offer some additional insights into the primary market for ODAS. It is noted that for the given price structure, most of the demand for ODAS comes from medium-range trips which were using automobile transport in the absence of ODAS. For these ranges, ODAS offers significant timesaving over automobile transport, therefore price is the important factor. Also, ODAS does not capture a significant portion of long-range trips from commercial air transportation, owing to high costs. Therefore any increase in the ground time for commercial air transportation results in that mode losing some demand to automobile transport.

From a methodological perspective, the work describes a viable analytical model for studying transportation systems in an integrated manner. The use of composite network enables capturing multi-modal interactions more effectively than the existing methods. This is especially important given the increasing emphasis on seeking integrated analyses and solutions in transportation engineering. With additional levels of complexity, the framework can be modified to study factors other than demand forecasting, such as emission levels, simulations of daily operations and newer transportation modes.

6.3 Future Research Directions

The current model implements all the basic factors needed to meet the study objectives laid out, but there are a number of additions that can be made without changing its basic nature. First of all, the commercial air transportation modeling needs to be improved in order to incorporate individual route choice and level-of-service factors such as flight frequency. This improved model can be expected to show better fit to the statistical data than the current model.

Also, additional stated preference surveys for ODAS will be helpful in identifying if there are any level-of-service parameters that differentiate ODAS significantly from other established modes. The logit model can then be accordingly adjusted to reflect these additional parameters. While American Travel Survey is an excellent database for national level demand forecasting models, a more comprehensive survey at the regional level would help in better calibration of the model. New modes of transportation such as high-speed rail can be added to the framework, in order to study the evolution of the regional transportation system with their inclusion. Care needs to be taken in modeling these modes in terms of identifying correct level-of-service parameters and obtaining appropriate data sources to calibrate the model.

A big step towards increasing the complexity of the model in order to analyze the evolution of the transportation system in more detail would be to model capacity constraints and supply dynamics. If the network assignment step is carried out simultaneously with mode choice, the feedback mechanism in demand and supply can be readily modeled. Agent based modeling and simulation tools will be helpful in making such improvements in the model.

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