Development of an Airport Choice Model for General Aviation Operations

by

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(ABSTRACT)

The General Aviation Airport Choice model is an attempt to model General Aviation (GA) travel patterns in the US in order to provide a means of assessing the impact of General Aviation activities on the National Air Space system. The model will also serve as part of transportation planning tool to help assess the viability of deploying NASA’s Small Aircraft Transportation Systems (SATS) aircraft as a competitive mode of transportation for intercity travel.

The General Aviation Airport Choice model developed estimates General Aviation (GA) person-trips and number of aircraft operations given trip demand in the form of GA person trips from counties. A pseudo-gravity model is embedded in the model to distribute the inter-county person-trips to a prescribed set of airports in the US. The airport-to-airport person-trips are split into person-trips by three aircraft modes (single, multi and jet engine) using an attractiveness factor based on average occupancy, utilization and a distance distribution factor for each aircraft type and the number of aircraft based at each airport. The person-trips by aircraft type are then converted to aircraft operations using occupancy factors for each aircraft type.

The final output from the model are aircraft operations trip-tables by aircraft type between the airports in the model. The GA trips are estimated in order to provide a means of assessing the impact of GA activities on the National Airspace System. The model output may be used to assess the viability of GA aircraft serving as a competitive mode of transportation for intercity travel.
DEDICATION

To you ‘Mama’ - for your unconditional love, support through the ‘hard times’.
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I especially want to thank Dr. Trani who has been not just an advisor but has been concerned with my welfare throughout my stay in Blacksburg. Special thanks to Dr. Baik for all your counsel and encouragement.

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# Table of Contents

**ABSTRACT** ........................................................................................................................................................................ ii

**DEDICATION** ........................................................................................................................................................................ iii

**ACKNOWLEDGEMENTS** .......................................................................................................................................................... iv

**LIST OF FIGURES** ................................................................................................................................................................. viii

**LIST OF TABLES** ................................................................................................................................................................. x

Chapter 1 : Introduction ................................................................................................................................................................. 1

Purpose of Research ........................................................................................................................................................................... 7

Overview of Transportation Systems Model ................................................................................................................................. 8

An Integrated SATS Transportation System Model ...................................................................................................................... 8

Methodology (SATS Model) ............................................................................................................................................................ 9

Relationship of Transportation Analysis and SATS Technical Capabilities ...................................................................................... 11

Scenario Definition ....................................................................................................................................................................... 13

Motivations Behind Demand Analysis ..................................................................................................................................... 15

Scope of Demand Analysis .......................................................................................................................................................... 15

Analysis Tools ............................................................................................................................................................................. 17

Chapter 2: Literature Review ............................................................................................................................................................ 18

Airport Choice Models ................................................................................................................................................................. 18

Metropolitan/Regional Airport Choice Models ............................................................................................................................ 20

General Aviation Demand and Airport Choice Models .................................................................................................................. 22

General Aviation Airport Choice Model .................................................................................................................................... 25

Gravity Model .............................................................................................................................................................................. 26

Chapter 3: Methodology ................................................................................................................................................................. 29

Methodology .............................................................................................................................................................................. 29

Data Source and Model Data Structures .................................................................................................................................... 30
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport Data</td>
<td>30</td>
</tr>
<tr>
<td>County data</td>
<td>32</td>
</tr>
<tr>
<td>Data Preparation</td>
<td>32</td>
</tr>
<tr>
<td>Airport-County Allocation</td>
<td>32</td>
</tr>
<tr>
<td>Trip Lenghts</td>
<td>32</td>
</tr>
<tr>
<td>Trip Distribution (Pseudo-Gravity Model)</td>
<td>33</td>
</tr>
<tr>
<td>Aircraft Based Factor</td>
<td>35</td>
</tr>
<tr>
<td>Relative Distance Factor</td>
<td>35</td>
</tr>
<tr>
<td>Splitting Person-trips (by aircraft type)</td>
<td>37</td>
</tr>
<tr>
<td>Utilization and occupancy Factors</td>
<td>38</td>
</tr>
<tr>
<td>Development of Distance Probability Density Function</td>
<td>38</td>
</tr>
<tr>
<td>Converting Person-trips to Aircraft-trips</td>
<td>42</td>
</tr>
<tr>
<td>Model Calibration</td>
<td>44</td>
</tr>
<tr>
<td>Pseudo Code for Airport Choice Model</td>
<td>45</td>
</tr>
<tr>
<td>Chapter 4: Discussion</td>
<td>46</td>
</tr>
<tr>
<td>Model Output</td>
<td>46</td>
</tr>
<tr>
<td>Summary of Output</td>
<td>46</td>
</tr>
<tr>
<td>Airport Estimates</td>
<td>53</td>
</tr>
<tr>
<td>Towered Airports</td>
<td>53</td>
</tr>
<tr>
<td>Non-Towered Airports</td>
<td>58</td>
</tr>
<tr>
<td>Chapter 5: Recommendations and Conclusions</td>
<td>61</td>
</tr>
<tr>
<td>Recommendations</td>
<td>62</td>
</tr>
<tr>
<td>Logit Models</td>
<td>63</td>
</tr>
<tr>
<td>Small Aircraft Cost Model</td>
<td>65</td>
</tr>
<tr>
<td>Conclusions</td>
<td>66</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Figure 1.1</td>
<td>Commercial Airline Delay Data</td>
</tr>
<tr>
<td>Figure 1.2</td>
<td>Multi-step Process of Trip Demand Analysis</td>
</tr>
<tr>
<td>Figure 1.3</td>
<td>Conversion from Person Trip to Aircraft-Trip Tables</td>
</tr>
<tr>
<td>Figure 1.4</td>
<td>Generalized Intercity Transportation Systems Analysis Methodology</td>
</tr>
<tr>
<td>Figure 1.5</td>
<td>Transportation Systems Analysis Implementation Strategy</td>
</tr>
<tr>
<td>Figure 1.6</td>
<td>Relationship between Transportation Systems Analysis and Other Analyses</td>
</tr>
<tr>
<td>Figure 1.7</td>
<td>Public Airports in the Virginia Regional Transportation Study Area</td>
</tr>
<tr>
<td>Figure 1.8</td>
<td>Final Outputs for Trip Demand Analysis</td>
</tr>
<tr>
<td>Figure 2.1</td>
<td>Layout of Airport Choice Model</td>
</tr>
<tr>
<td>Figure 3.1</td>
<td>Overview of Airport Choice Model</td>
</tr>
<tr>
<td>Figure 3.2</td>
<td>Gravity Model: Converting County-to-County Person trips to Airport-to-Airport Person-trips Attractiveness Factor</td>
</tr>
<tr>
<td>Figure 3.3</td>
<td>Illustration of Attractiveness Factor</td>
</tr>
<tr>
<td>Figure 3.4</td>
<td>Output of Gravity Model</td>
</tr>
<tr>
<td>Figure 3.5</td>
<td>Second Step: Splitting Airport-to-Airport Person-trip Table by mode</td>
</tr>
<tr>
<td>Figure 3.6</td>
<td>Modified PDF (Weibull Distribution) used in deriving Attractiveness Factor to split person-trips by mode</td>
</tr>
<tr>
<td>Figure 3.7</td>
<td>Cumulative Density Function of Distance Distribution</td>
</tr>
<tr>
<td>Figure 3.8</td>
<td>Output of Trip-split Process</td>
</tr>
<tr>
<td>Figure 3.9</td>
<td>Third Step: Converting Aircraft type Airport-to-Airport Person-trips to Airport-to-Airport Aircraft Operations</td>
</tr>
<tr>
<td>Figure 3.10</td>
<td>Final Output of GA Airport Choice Model</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>Model Output: Percentage of Aircraft Operations by Aircraft type</td>
</tr>
<tr>
<td>Figure 4.2</td>
<td>Model Output: Percentage of Distance Traveled by Aircraft Type</td>
</tr>
<tr>
<td>Figure 4.3</td>
<td>Distance Probability Density Function (using Estimated values from the Model)</td>
</tr>
<tr>
<td>Figure 4.4</td>
<td>Estimated Cumulative Density Function (from Model Output)</td>
</tr>
<tr>
<td>Figure 4.5</td>
<td>Plot of Estimated Operations versus Observed Operations from NTAD Database (Towered Airports)</td>
</tr>
<tr>
<td>Figure 4.6</td>
<td>Estimated Operations for GAACM versus Observed Operations from NTAD Database (Large Hub Airports)</td>
</tr>
<tr>
<td>Figure 4.7</td>
<td>Plot of Estimated Operations versus Observed Operations from NTAD Database (Towered Airports without Large Hub Airports)</td>
</tr>
<tr>
<td>Figure 4.8</td>
<td>Estimated Operations for GAACM versus Observed Operations from NTAD Database (Medium Hub Airports)</td>
</tr>
<tr>
<td>Figure 4.9</td>
<td>Estimated Operations for GAACM versus Observed Operations from NTAD Database (Small Hub Airports)</td>
</tr>
<tr>
<td>Figure 4.10</td>
<td>Estimated Operations for GAACM versus Observed Operations</td>
</tr>
</tbody>
</table>
Figure 4.11 Comparison of Model Operations Estimates with NTAD Data for Non-Towered Airports 59
Figure 4.12 Model Operations Estimates versus NTAD Estimates 60
LIST OF TABLES

Table 1.1  Comparison of Statistics for Two Possible Regional Studies ..........14
Table 4.1  Aircraft Utilization and Occupancy Factors .............................38
Table 4.2  Model Output: Estimated Values by Aircraft mode ......................48
Table 4.3  Operations by Aircraft type through Towered and
            Non-towered Airports ..................................................................49
Table 4.4  Model Estimates (Selected Airports) .......................................52
Transportation plays a critical role in the economic development of nations and the more developed a nation the more critical the role of transportation in its development and economic activities. The United States is no exception to this and the effect is well reflected in comments in the 2000 Transportation Statistics Annual Report (TSAR) issued by the Bureau of Transportation and Statistics. The contribution of transportation related goods and services to the gross domestic product is put at 10.6% coming fourth after housing, healthcare and food.

The 1999 version of the report put the figure at 11.2% and singles out air transportation as the fastest growing transportation mode with domestic passenger-miles more than doubling and tonne miles of freight by air increasing threefold from 1980 to 1999. The number of airports increased more than 20% over the same time period with the increase being attributed to the addition of more than 3,200 general aviation (GA) airports bringing the total number of general aviation airports to 17,685 of 18,345 airports in the US (TSAR 1999). Current GA aircraft use statistics show 60% of trips made are for personal activities, 14% for business, 8% for flight instruction and 5% for corporate activities. Over the same timeline the number of commercial airports decreased from 760 in 1980 to 660 in 1997. However considering the fact that the 60 commercial aviation airports account for 98% of aviation trips it is clear that the level of utilization of GA airports is very low.
The rapid growth in demand for air transportation service has not been matched by an equivalent growth in capacity leading to increased delay and congestion in the air transportation system. Though a sizeable portion of the delay has been attributed to weather conditions (Fig. 1.1) it is noteworthy that the volume of delays continues to increase annually suggesting that weather cannot solely be blamed for the delays.

![Chart showing flight delays from 1995 to 2000](chart.png)

**Figure 1.1  Commercial Airline Delay data (TSAR 2000)**

The air transport sector in the US is loosing ‘speed, accessibility, flexibility and efficiency’ and if nothing is done soon in the near future to improve and address capacity issues the National Airspace System (NAS) may be headed for gridlock (*Long et al - LMI SATS Demand Model*). The National Aeronautical Space Agency (NASA) in an attempt to contribute to addressing the above issues has proposed a program that seeks to tap into the latent potential of the vast number of general aviation airports by drawing on new developments in aircraft and airframe technology to help ease congestion in the air transportation system and speed movement of goods and travelers. This program named the Small Aircraft Transportation System (SATS) seeks to develop a new generation of general aviation (GA) aircraft that will harness new developments in aircraft engine and airframe technology, communications and navigation (GPS, Highway In the Sky HITS), to produce an ‘enhanced general aviation vehicle.
with near all-weather operations capability and the ability to utilize airports with minimally equipped landing facilities (Strawnan SATS program). This new mode of SATS’s aircraft seeks to fill a niche in the long distance transportation market and help reduce travel times and increase the utilization of the huge network of airports in the US.

As a first stage in the development of this mode congress has mandated NASA to prove four technical capabilities of the new mode to:

1) Improve lower landing minima,

2) Allow high volume operations at non-towered airports,

3) Improve single pilot safety and

4) Allow seamless integration in the en-route airspace system.

Though the capabilities may be proved by developing the requisite technology it also imperative to investigate the existence of demand for the mode of transport being proposed and its impact on the National Airspace System (NAS). Air transportation systems consist of vehicles (aircraft), infrastructure (airports, access roads, air traffic control devices) and the personnel that manage the system to ensure its smooth and safe operation. The development, operation and maintenance of the vehicles, infrastructure and personnel are interrelated and one cannot be developed without considering its impact on the others. In developing the SATS mode there is also the need to consider the substantial capital investment needed to develop such a the program, and the impact of the provision of the service on society and the environment (airspace conflicts, airport delays, noise levels around airports etc).

The field of transportation planning and design is concerned with addressing some of the issues raised above. There is the need to conduct a transportation systems (demand) analysis to help identify requirements for the SATS initiative in order to harness the most appropriate available technology to provide the services needed in catering for both current and future demand. Implicit to the process is the issue of paying for the cost of the provision of the service. It is crucial in the development of a new mode or transport or service to consider both the demand and supply characteristics in a holistic manner. This implies the need to adopt a systems-based approach to the analysis.
Most transportation infrastructure investment projects are large and expensive to implement and to help justify costs and analyze the system the approach in engineering has been to develop models (simplified representations of the real system) that can be used to give an indication of a systems’ behavior. The models developed allow the real life system to be studied under different scenarios at a reasonable cost before implementation/construction in order to evaluate the feasibility of the project and help avoid implementing costly projects that may later turn out to be inappropriate. In some cases models can be used as a monitoring tool during the implementation and life cycle of projects.

The purpose of travel is to conduct business, visit friends, attend conferences etc. This implies that an intercity trip represents a means to achieve a certain activity. This further implies that in order to forecast trip demand, we should understand the relationships between activities and travel behavior. In transportation planning the standard modeling tool/concept used has been the urban transportation planning model generally known as the 4step planning model. It involves the definition of a scenario, followed by inventory and travel studies. The traditional multi-step modeling process to study travel behaviors includes: 1) trip generation, 2) trip distribution, 3) mode choice, and 4) trip assignment (Meyer and Miller, 1994; Morlok, 1984). A brief description of each process is presented in the following paragraphs. The process is shown schematically in Figure 1.2.

The trip generation is used to predict the number of trips by trip purpose produced by each zone of activity and attracted to each zone. Figure 1.2 illustrates that the output of this procedure is a simple Origin-Destination matrix with two vectors: one for productions and one for attractions.

In the trip distribution, we predict origin-destination (O-D) flows, that is, we link the trip ends predicted by the trip generation model to form trip interchanges between zones. This results in a large trip interchange matrix (or sometimes called an origin-destination, O-D, table) showing the number of trips between an origin to a destination county (see Figure 1.2). Note that the units of the trip interchange matrix are person-trips per year between counties.
Figure 1.2 Multi-step Process of Trip Demand Analysis.
**Mode Choice** predicts the percentage of person-trips selecting each mode of transportation while traveling between two zones in the region of interest. The general aviation mode competes with automobile, commercial airline, bus, train, etc. Figure 1.2 illustrates that in the mode choice model we decompose the trip interchange matrix obtained in the trip distribution step into a number of trip interchange matrices consistent with the number of modes studied. In our analysis we show five O-D matrices representing: 1) ground modes (called “others”), 2) general aviation single-engine aircraft, 3) general aviation multi-engine, 4) general aviation jet, and 5) commercial aircraft. Note that the output matrices of the mode choice step shown in Figure 1.2 are defined at the county level.

**Trip Assignment** places the O-D flows for each mode on specific routes of travel through the respective networks. In this step the we are interested in studying the airport-airspace network interactions to assess the impact of SATS operations in NAS. In this last step our goal is to convert airport-to-airport person-trip O-D table by aircraft type to an airport-to-airport aircraft O-D table using average occupancy rate. Figure 1.3 illustrates graphically the conversion procedure.

![Figure 1.3 Conversion from Person-Trip to Aircraft-Trip Tables.](image-url)
1.1 Purpose of Research

Basically in the trip distribution and generation stage the demand is being generated, during mode split demand is feed to modes and the network analysis determines the capacity of existing infrastructure to absorb the demand generated. The output of the model gives an indication of the capacity constraints and can be used to determine if there is a need for additional infrastructure and a cost benefit analysis can be performed at this stage. This process was used to model the NASA Small Aircraft Transportation System.

1.1 Purpose of Research

The General Aviation Airport Choice model was initially developed within the framework of a transportation systems analysis study for NASA. It seeks to model current U.S. National General Aviation travel patterns in order to provide a tool to help assess the viability of implementing SATS as a competitive mode of transportation for intercity travel. The model comes between the mode choice and network analysis stage.

The input to the general aviation airport choice model is a [3091 x 3091] origin destination table of general aviation person-trips from the centroids of 3091 counties in the continental US (this is the output from the mode choice process).

The model seeks to generate the demand (in GA aircraft operations) through a database of 3346 selected airports in the US. The first step in the model is to convert the person-trips between county centroids to person trips through airports. The person-trips through airports are then split into trips by three aircraft modes and then converted to aircraft trips by applying an occupancy factor. The baseline for this analysis is the year 2000.

The output of the model when fed into a network analysis model/tool (e.g. TAAM, AOM/AEM) will provide a means of assessing the current impact of General Aviation activities on the National Air Space and the implications of deploying SATS as a transportation system. The output will serve as a starting point to estimate future behaviors of various transportation modes when competition exists among them (multi-mode analysis).
1.2 Overview of Transportation Systems Model

Provided in the rest of this chapter is an extract form a Transportation Systems Baseline Assessment Study carried out by the Virginia SATS Alliance (of which the author was a contributor) to help give the reader a perspective of the complete transportation modeling framework within which the airport choice model was developed. It contains a brief description of the modeling framework, including details on how the transportation regional analysis ties with other analytical modeling techniques pursued in parallel by the Virginia SATS Alliance.

The output from the mode choice section of the transportation systems analysis is in the form of two tables of business and non-business trips from the 3091 counties in the US. The two tables are combined to obtain general aviation trips from the 3091 counties and this serves as the initial input to the airport choice model implemented in this research study.

1.2.1 An Integrated SATS Transportation System Model

The purpose of this modeling process is to develop a systems engineering methodology to study the Small Aircraft Transportation System (SATS) concept as a feasible transportation system. The approach proposed by the Virginia SATS Alliance is, an improvement over traditional intercity transport models by characterizing demand-supply causal links of the proposed SATS transportation system over the complete life cycle using a model with continuous state variables. By comparison, traditional approaches in transportation planning characterize the behavior of the system at two discrete points in time, namely the initial state (baseline) and the horizon year (end state). This approach might be suitable to model well-understood and well-established modes of transportation. However, SATS as proposed by NASA, could create a natural evolution in intercity travel if a series of social and technology factors are met over time. The time gap between the initial and end states is critical for SATS because there are many uncertainties in the development of this technology and more so in the deployment strategy associated with such a system. Therefore, it is critical to model intermediate points in the life-cycle of the SATS system and in the national decisions needed to foster a suitable implementation strategy. The approach adopted permits this modeling while preserving all the strengths of more traditional
intercity multi-modal analyses.

1.2.2 Methodology (SATS Model)

The proposed approach to study the deployment of SATS, in the presence of other competing forms of transportation (including electronic commerce and information technologies) is shown in Figure 1.4. Ultimately, the method proposed yields macroscopic measures of effectiveness such as travel time benefits, noise impacts, fuel and energy usage, non-user economic benefits, air transportation system congestion and delays etc.
The diagram shown in Figure 1.4 includes several important proven feedback loop structures that are characteristic of existing transportation systems and shows their effect on the regional and national economies. The reader should understand that the blocks depicted in Figure 1.4 have two implicit attributes: 1) time dependencies and 2) spatial dependencies. Figure 1.4 depicts the following critical steps to study the SATS transportation concept from a life cycle point of view. These steps are:

a) Inventory of existing NAS infrastructure including current and future concept of operations (for both SATS and non-SATS aircraft),
b) Intercity trip generation analysis (including in all modes),
c) Intercity trip distribution,
d) Intercity modal split,
e) Air transportation network analysis and
f) Air transportation system performance assessment.

In Figure 1.4 there are implicit connections between these blocks that make the life-cycle analysis process possible. For example, once an evaluation of airspace conflicts among SATS aircraft (or between SATS and their airline counterparts as shown in Block 10 in Figure 1.4) is performed it will be necessary to adjust the intercity travel times assumed in the Trip Generation and Trip Distribution Analyses (Blocks 4 and 5). When all the modeling blocks are completed, and equilibrium points reached (to determine how many people travel on each mode and how many new flights are generated through the NAS) the process is then repeated to every time point in the life cycle. This process is shown graphically in Figure 1.5.
The outputs of these models feed the regional transportation analysis in several ways. For instance, the models can provide data on the number of conflicts, delays at airports, and the target level of safety. These outputs can be used to enhance the relationship between the transportation system and the four technical capabilities to be studied for SATS, as illustrated in Figure 1.6. The Virginia SATS Alliance is developing design and analysis tools to: a) predict human performance metrics, b) provide safety improvements to the system in low visibility airport conditions and in the en-route airspace system, and c) enhance the ability to operate higher volumes at non-towered airports. The human performance models feed three critical technical models: 1) the SATS airport model, 2) a SATS en-route analysis model, and 3) the SATS Terminal Area Procedures (TERP) model that produce airport and terminal area metrics such as the number of conflicts, delays at airports, target level of safety among others, for every concept of operations investigated. The outputs of these models feed the regional transportation analysis in several ways. For
example, added low landing minima capabilities and improved safety with single pilot operations, make the SATS mode more reliable and, in general, could increase its mode share (i.e., ridership). At the same time, enhanced operations at non-towered airports could expand the capacity of the National Airspace System (NAS) and improve opportunities for intercity travel across the country.

Figure 1.6  Relationship Between Transportation Systems Analysis and Other Analyses.
On the demand side, the transportation system analysis described here provides the best chance to measure the potential demand function that would result from reliable and safe SATS operations. This analysis includes multiple SATS ownership operations including: a) full SATS aircraft owners, b) fractional ownership, c) air taxi services, and d) airline-style scheduled operations. These operating scenario costs are captured in the cost model included as appendix B. All these sub-modes are factored in the intercity modal split analysis carried out in Block 9 of Figure 1.4. The modal split analysis is critical in the demand estimation for SATS services. In turn the demand eventually influences the measures of mobility, accessibility, safety and capacity of the system (shown in the right most block in Figure 1.6).
1.2.4 Scenario Definition

Any transportation study starts with the definition of the scenario to be studied. In the analysis by the Virginia SATS Alliance a Cordon Line (CL) was established around the area of interest and all activities outside this region are modeled as exogenous inputs to the model (see Figure 1.7). **The airport choice model however encompasses the whole US including Hawaii and Alaska.** The region includes states, counties, public airports with hard runways (greater than 3,000 ft.). Table 1.1 shows a summary of the statistics about this scenario. This approach is primarily adopted to study airports and their characteristics. However, to determine travel demand functions, all 3091 counties in the country were considered in the analysis. This is done to account for a complete Origin-Destination matrix across the U.S.

The transportation analysis is not trivial as it involves thousands of counties, public airports, and millions of intercity trips per year. According to the 1995 American Travel Survey (ATS, 1995), the average intercity business trip distance was 448 statute miles. Non-business trips average 361 statute miles. The smallest unit considered in this analysis is the county. Counties range in size from a few to several hundred square miles and their socio-economic properties are well documented in the literature (United States Census, 1990; Woods and Poole, 2001). High fidelity of socio-economic characteristics inside each county are modeled using trip-rate tables that vary with income and education levels. In this way, the analysis can approximate travel behaviors specific to each county based on specific socio-economic characteristics of the county. This approach achieves a balance between computational efficiency (so that not every person is modeled individually) and yet allows a stratification of behaviors within a county. In other words, not everyone living in a county behaves the same way from a travel standpoint. The analytical techniques explained in this study can be applied to any number of counties in
1.2 Overview of Transportation Systems Model

the country.

Figure 1.7 Public Airports in the Virginia Regional Transportation Study Area (1,000 mile Envelope).

Table 1.1 Comparison Statistics for Two Possible Regional Studies.

<table>
<thead>
<tr>
<th>Item</th>
<th>500-mile Contour</th>
<th>1000-mile Contour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Airports</td>
<td>1,296</td>
<td>2,221</td>
</tr>
<tr>
<td>Counties</td>
<td>1,627</td>
<td>2,261</td>
</tr>
<tr>
<td>States</td>
<td>29</td>
<td>37</td>
</tr>
<tr>
<td>Households</td>
<td>55,555,625</td>
<td>76,076,753</td>
</tr>
<tr>
<td>Total U.S. Area (sq. miles)</td>
<td>826,706</td>
<td>1,642,009</td>
</tr>
</tbody>
</table>
1.2 Overview of Transportation Systems Model

1.2.5 Motivations Behind Demand Analysis

In the study of SATS as a feasible transportation system it is imperative to demonstrate that a demand function exists to support the system. Without a careful demand estimation for SATS it will be impossible to estimate cost-benefits of the system and the influence that four technical capabilities have in the life-cycle of the program. In fact, it can be argued that identifying the demand function for SATS is the first necessary step to demonstrate the practicality of the overall concept.

The ultimate goal of trip demand analysis in this research is to estimate how many flights, by aircraft type, including SATS flights, will operate from thousands of public airports into the National Airspace System (NAS) at specific times of the day today and into the future. The resulting trip demand will eventually be used to measure broader impacts of SATS on society. Some examples of these are: airspace conflicts, airport delays, noise levels around airports, air pollution, and regional and national economic benefits. In other words, all the secondary effects resulting from the deployment of SATS are intrinsically tied to SATS traffic demand.

Trip demand analysis attempts to answer the following question:

\[
\text{Find the number of total intercity generated trips (n) by a center of activity \(i\) (i.e., city or a region) and the number of m trips attracted to center of activity \(j\) given some demand and supply characteristics associated with each center of activity.}
\]

1.2.6 Scope of Demand Analysis

A long-distance trip is defined as a journey longer than 100 miles considering a one-way traveled distance for any purpose such as conducting business, visiting relatives, attending a conference, etc. In this research project, we set year the 2000 as the baseline year and consider only base year demand initially. In other words, future demands beyond year 2000 will be handled in the full implementation of the Systems Dynamics model to be developed later. The models developed in this research are designed to be easily extented to future years and algorithmically all source code can execute the complete demand analysis in 4-5 hours considering all the continental U.S. in a high-end PC workstation (i.e., Pentium 4 and 1.7 Ghz system).
Geographically, our demand analysis covers all U.S. territory including Alaska and Hawaii in county level. It should be noticed that the number of counties in Census data and Woods-and-Poole data are slightly different. In particular, Woods-and-Poole (2001) data uses an aggregated county system considering socio-economic influence effect. In W&P data, for example, Montgomery county (VA) and Radford (VA) merged into one county. In this modeling framework, we adopt the W&P county system for computational convenience. This means the continental U.S. consists of 3091 counties. It is assumed that there are no long distance trips within the same county.

In conclusion, the goal of trip demand analysis in this research is to estimate the total number of long distance trips (person-trips) between 3091 counties in the year 2000, and induce airport-to-airport aircraft trips from the county-to-county person trips.
1.3 Analysis Tools

Off-the-shelf software was employed to expedite the numerical computations depicted graphically in Figure 1.4. MATLAB - a software developed by the MathWorks Inc.– is used as a computational engine in the multi-step planning process. For statistical analysis, the SAS software package is employed. We also used ArcView 3.2 and ArcGIS 8.1 developed by ESRI Inc. to study geographical data and to help in the production of maps. Standard office applications such as Microsoft Excel, Microsoft Access, and Microsoft Visio were also used to process data and in the preparation of figures.
CHAPTER 2  

Literature Review

A substantial amount of research work and studies have been conducted to model the behavior of travelers in selecting airports for travel. These studies aim at identifying factors that influence travelers’ decisions in the selection of origin and destination airports in order to assist planners predict traffic volumes through airports. This chapter gives an overview of regional and national airport choice models developed so far, modeling techniques used in the models and provides an explanation of the basis for the methodology adopted in developing the general airport choice model in this study.

2.1 Airport Choice Models

Once the destination for a trip has been selected the next decision confronting the air traveler is the selection of an appropriate origin destination airport pair. A wide variety of factors influence the travelers’ airport selection decision process including ground access and egress times/costs, line-haul travel time/cost, number of flights and flight frequencies from airports, aircraft type, facilities and level-of-service at airports (e.g. parking, delays, quality of baggage handling systems, congestion etc).

Airport choice models try to use these factors as variables to capture the travelers’ behavior. The application of Random Utility Models (RUM) developed from economic theory to study the “disutilities”
associated with choosing from various alternatives has been applied in many airport choice models. These RU models in the form of Logit and Probit mode choice models have long been quite popular in transportation analyses to assess how users make decisions when comparing travel mode disutilities (Kanafani, 1983; Sheffi, 1985). More recently, the application of Fuzzy Logic to transportation modal and route choice models by Teodorovic and Vukanovic (1998) extends this analysis incorporating uncertainty and allowing linguistic variables in the model.

In addition to frequencies, travel costs and travel times from airports, mode travel choice depends on a variety of factors whose influence cannot be easily quantified without a survey of the travel population (sense of safety, sense of comfort, and others). Travelers decide on a particular transportation mode according to the perceived travel times, perceived sense of safety and comfort as well as the approximately known rates, numbers of daily departures, and departures times.

Discrete choice models have become the preferred tool for mode choice analysis because of certain attributes they possess. Otuzar (1994) summarized some of these attributes as,

- They are based on theories of human behavior unlike conventional models that use physical analogies.
- They are also more likely to be stable over time and space.
- Discrete choice models are data efficient compared to conventional models as each individual choice in the model is an observation (due to aggregation in conventional models sometimes the average of hundreds of individual observations are needed for one observation).
- The use of individual choices instead of aggregates makes these models less susceptible to suffer from bias due to correlation between aggregate units (in aggregate models individual characteristics may be masked by unidentified characteristics associated with a zone during the aggregation process).
- As individual data are used, all the inherent variability in the information can be utilized
- The explanatory variables included in the model can have explicitly estimated coefficients, this allows for more flexible representation of the policy variables considered relevant for the study.
- The above also means the coefficients of the explanatory variables have a direct marginal utility interpretation (i.e. they reflect the relative importance of each attribute).

In general, discrete choice models postulate that “the probability of individuals choosing a given option is a function of their socioeconomic characteristics and the relative attractiveness of the option”.
2.1 Airport Choice Models

2.1.1 Metropolitan/Regional Airport Choice Models
The choice behavior of travelers when faced with the option of selecting from multiple origin and destination airport sets within the same region usually referred to as Multiple-Airport Systems (MAS) has also been investigated extensively.

Studies involving metropolitan areas served by multiple airport systems have been conducted in the San Francisco Bay area by Kanafani (1977), Harvey (1987) and Mark Hansen (1996); in the Washington D.C./Baltimore area by Skinner (1978), Windle & Dresner (1995); and in New York City by Augustinus and Demakopoulos (1978). The studies have tried to estimate the fraction of passengers captured by competing airports within the same metropolitan area.

Other airport choice studies have also been conducted by Ashford and Benchemam (1987) for airports in Britain; Innes and Doucet (1990) for airports in rural New Brunswick, Canada; and Furuichi (1994) for four major Japanese airports (Windle & Denser).

A study by Skinner (1978) using a multinomial logit model in the Washington D.C./Baltimore area showed that the most significant factors influencing the utility of a passenger’s choice of airports are ground access cost and flight frequency. Skinner concluded that ‘improvements in airport access are a more important factor in shifting airport choice among passengers than is improvement in flight frequencies’. Windle and Drener (1995) in a later study of the Washington D.C./Baltimore area in addition to considering variables such as access time and flight frequencies investigated the effect of different ground access modes and parking on airport selection behavior of passengers. Travelers were grouped into four segments based on their trip purpose (business/non-business) and residential status (resident/nonresident) in the metropolitan area. A multinomial logit formulation was used and the coefficients determined by maximum likelihood estimation. The study agreed with previous studies that ‘airport access time and flight frequencies from area airports are the major determinants of airport choice’. Other conclusions were that

- A passenger’s experience with an airport is generally an important determinant of airport choice and should be considered for future airport choice models.
- In competitive airport aviation zones, the importance of airport access time decreased dramatically while the importance of flight frequencies increased.
Innes and Doucet (1990) studied airport-choice behavior of individuals in rural areas with access to multiple departure airports. They used a binary logit model formulation in the study. The aim of the study was to evaluate the importance of proximity of airports to the traveler in the selection of airports. The study attempted to determine the impact of Level-of-Service (LOS) variables such as, ticket type (full fare or discount), trip purpose, person paying for ticket (passenger or another person), type of aircraft (jet or non-jet), route type (direct flight or not), and difference in flight times between alternatives. Efforts to ‘calibrate the disaggregate model for the distance variable yielded anomalous results’ hence the analysis focused mainly on the LOS variables. The best-fit LOS model had two variables, aircraft type and flying time difference. This model was able to predict the decision of over 89% of individuals in the survey. Two significant conclusions from the study were

- Air travelers were willing to travel significant ground distances in order to reach an airport where jet service was offered.
- The study also showed among other factors that passengers prefer jet aircraft to propeller-driven aircraft and direct flights to flights with connections.

Though the former conclusion may seem counterintuitive similar travel patterns have been observed by other authors (De Neufville, 1939).

Furuichi (1994) in his study of airport choice characteristics of international travelers from four major airports in Japan used a nested logit model. He concluded that both business and non-business international travelers place a higher value on access cost/time than line haul cost/time. The study results also indicated that air travelers placed a high value on flight frequency.

Mark Hansen (1994) proposed a positive feedback logit model for allocating traffic in multiple-airport-systems (MAS). The study was undertaken in the San Francisco Bay area which is served by San Francisco International (SFO), Oakland (OAK) and San Jose (SJC) airports. The model was based on three propositions concerning preferences of air traveler in an MAS

- Travelers prefer airports closer to their trip origins.
- Travelers prefer airports with higher levels of traffic in their ‘market’ (market traffic along their route) with the strength of this effect increasing with market length of haul.
- Travelers prefer airports with higher levels of traffic in other markets.

The predictive power of the feedback model proposed was compared with a model that had no feed-
back effect and considered only access time. The predictive power of the later was found to be inferior for all the three airports considered.

Kanafani (1977) calibrated a logit route choice model for airports between the San Francisco and Los Angeles metropolitan areas. Separate models were calibrated for business and non-business trips. The utility expressions had variables for total travel time (access + egress + in-vehicle time), schedule frequency on routes (measured as total weekly flights) and travel cost (coach air fare). Output from the model indicates business travelers are sensitive to schedule frequency and less sensitive to travel costs (fare).

From the above review it is clear that the preferred method for airport choice models at the ‘regional’ level have been logit models. Also among the various variables available for modeling air traveler choice decisions studies indicate that access cost (measured either as time or distance) and flight frequency seem to be the strongest predictors and preferred variables for use in the utility or regression expressions.

A comprehensive literature review of “Airport choice and ground access choice models” undertaken Mark Lunsford (1992) is available as a working paper from the Institute of Transportation Studies at UC Berkeley.

2.1.2 General Aviation Demand and Airport Choice Models

The models discussed above have mainly been developed and applied in specific areas or regions in the US. Most of the models have concentrated on estimating traffic flows of airports with air carrier services for which there is an extensive pool of data to calibrate and validate the models. However, there are currently very few studies to estimate operations at GA airports on regional or nationwide basis. One of the biggest constraints in developing such models is the lack of accurate and reliable historical data on GA operations. Without such data is difficult to calibrate or validate models developed.

Despite this constraint a few models have been developed. Ghobrial (1997) developed an econometric regression model to forecast GA operations. The model was an improvement on an earlier model developed for 20 airports in Florida by Ghobrial and Ramdass. The socioeconomic variables in the model
were population and employment the other variables in the model were dummy variables and include runway length (>4000), presence of air traffic control towers, presence of avionic services etc. Issue of high levels of correlation between variables was partly addressed by developing different sets of regression expressions. The dependent variable GA operations included both itinerant and local GA operations. The model was developed using data for 82 general aviation airports in Georgia. Four regression expressions were developed with $R^2$ values ranging from 0.650 - 0.658. However, the regression models were not tested with other airports outside the data set or the state of Georgia and hence much cannot be said about the applicability of the model to other states.

GRA Inc. (2001) also developed a regression model for the Statistics and Forecast Branch of the FAA Office of Aviaton and Policy and Plans. This model was also an improvement on an earlier model developed by Hoekstra. Various regression expressions were developed and the independent variables included population count with 50 and 100 mile radius of the airport, a dummy variable indicating whether the airport was towered or not, presence or absence of flight schools, proportion of single engine based aircraft, whether the airport was within a specified region (i.e. CA, OR, WA, AK) or not etc. The final regression expression selected had eight variables (including the tower specific dummy variable) and an $R^2$ value of 0.743 which is indicates that 74% of the time the regression expression is able to explain the variation in the number of GA operations.

The model was developed for using 232 GA airports of which 127 were towered and 105 were not. The model was then validated by testing the regression expression with estimates of GA operations for larger dataset of 2,789 non-towered GA airports derived from Form 5010. The model produces higher estimates for 35% of the airports used for validation and lower estimates for 65%. The model also produced negative estimates for a small proportion of the airports.

The Logistics Management Institute (LMI - June 2001) also developed an aircraft utilization model to generate demand at 2,865 GA/SATS airports in the US. An initial attempt to develop an econometric model using population and average housing income was abandoned due to very low $R^2$ values and the difficulty of obtaining accurate GA data for all airports. The aircraft utilization model was developed using reported FAA regional utilization rates, landing rates, number of aircraft in region and number of based aircraft at each airport (for single, multi and jet engine aircraft types). LMI computed local
operations by multiplying the local airport fleet by the regional utilization rates. Total operations by ‘visiting aircraft’ (i.e. aircraft not based at the airport) is derived by subtracting local operations from reported (TAF) itinerant operations. Visiting aircraft operations by aircraft type is derived by applying factors related to the regional distribution of aircraft types. Local operations by aircraft type is derived using the reported data on aircraft based at the airport. The operations by aircraft type for both visiting and based aircraft are then combined to obtain operations by aircraft type from each airport. The model estimated a total of approximately 11 million operations and 14 billion Transported Passenger miles for the baseline year 2000.

All the large scale models mentioned have used some form of regression analysis in trying to model demand for GA airports. All the three models identified the need to include airport specific characteristics in the models. The biggest constraint as mentioned earlier has been the lack of a credible database of historical data on GA operations nationwide. The major data source have been data compiled in FAA’s TAF and reported data in Form 5010 but the accuracy of these for non-towered airports was called into question in most of the reports reviewed. LMI in their report also noted that the trends in GA traffic demand are very dependent on government policy. This makes it difficult to adopt the regression approach for forecasting purposes as deriving credible estimates for the independent variables for future years poses a big challenge.
2.2 General Aviation Airport Choice Model

The general aviation airport choice model estimates the number of travelers taking specific modes of aircraft while performing an intercity trip. This process is represented in Figure 2.1. The question to be answered in this analysis is:

Given volumes of trips $v_{ij}$ originating at the center of activity $i$ (i.e., centroid of a county or region) and ending at a center of activity $j$ find the most likely origin/destination airport pair $(k$ and $l)$ and the most likely mode of transportation (aircraft type) $m$ selected by the traveler.

![Figure 2.1 Layout of Airport Choice Model](image)

The deciding factors behind the choice of mode and path on intercity transportation networks are travel time, price of transportation on the paths, flight frequency, number of stopovers, perceived safety, mode accessibility, etc. Kanafani (Transportation Demand Analysis) in discussing suitable variables for city-pair models enumerated air fare, travel time, travel distance, frequency of service and level-of-service as supply variables that could be considered in selecting variable for city-pair models.
The airport choice model developed aimed at predicting all general aviation trip volumes in the continental US during the baseline year (2000). Currently, detailed data on variables such as access and egress times, fares and flight frequency are not available on a national level for GA operations. In order to calibrate a discrete choice model there would be the need to conduct an extensive survey to capture general aviation travel patterns and costs not only for business and non-business trips but also for people living in metropolitan and non-metropolitan areas in the US. It was not feasible to conduct the survey at this stage due to logistical, financial and time constraints hence a different modeling approach was adopted. The model used for estimation had a gravity type formulation.

2.3 Gravity Model

In converting the inter-county person-trip table (3091 x 3091 matrix) to GA aircraft operations between airports a model based on principles similar to the ‘gravity model’ used in trip distribution was embedded in the GA airport choice model. The gravity model is a synthetic model deriving its name from its analogy to Newton’s law of gravity. It has been used extensively in travel demand modeling as a trip distribution tool. In its most basic form it can be expressed mathematically as

$$Q_{ij} = \frac{k P_i A_j}{W_{ij}^c}$$  \hspace{1cm} (2.1)

where $P_i$ is the trip production from origin zone $i$ and $A_j$ represents the attractiveness of the destination zone. $W_{ij}^c$ is the impedance between the zones. The underlying assumption of the model is that for a given volume of trips from an origin zone $i$ the proportion of trips attracted to a destination zones is directly correlated to the trip production and attractiveness of the origin and destination zones respectively, and inversely correlated to distance between the zones. The attractiveness variable can be quantified as population, number or shopping centers etc., depending on the scenario being analyzed, the impedance can be represented as cost or drive time. The model has a more general form
2.3 Gravity Model

\[ Q_{ij} = P_i \frac{A_j F_{ij} K_{ij}}{\sum_j A_j F_{ij} K_{ij}} \]  

(2.2)

where \( F_{ij} \) is a travel time friction and factor \( K_{ij} \) is a socioeconomic adjustment factor (Papacostas 2001).

In the pseudo gravity model in the GA airport choice model origin-destination county pairs may be viewed as origins (from which trips emanate) and the sets of airport pairs associated with the origin/destination count pairs as destinations (to which the trips are distributed). The volume of trips attracted to airport pairs is assumed to be directly correlated to volume of aircraft based at the airport pairs under consideration and the impedance is characterized by the total trip distance. The model is calibrated by comparing estimated trip volumes of towered airports from the model with reported values.

Two attractiveness factors were developed to distribute trips from origin-destination county pairs through selected airport pairs in the origin-destination counties.

- The first factor was a distance/route attractiveness factor that aims at distributing more trips to routes that had a shorter length for a selected county pairs (travelers are assumed to making a choice based on door-to-door route length).
- The second factor is an airport attractiveness factor that distributes more trips to origin-destination airport pairs that have ‘more services’ (the variable used to capture level of service or potential flight frequency is based aircraft at airports).

The two attractiveness factors are based on assumptions that general aviation travelers will tend to take the shortest route and will travel from airports that are well equipped (availability of aircraft, Fixed-base- Operators etc.). To a limited extent the model seeks to mimic the effect of access time/distance and flight frequency (level of service) that have been identified in earlier studies.

As there is currently no adequate database with data on flight frequency for GA trips from airports the variable used as an indicator of flight frequency was number of based aircraft at each airport. This data was extracted from the NTAD 2000 CDROM for the 3346 airports in the model. The trip distance was computed in the model as the sum of the great circle access and egress distance(s) and the great circle distance between airports.

The aircraft operations between airports need to be further split by aircraft mode (single, multi and jet
engine). The split is performed based on the factors average occupancy, availability of aircraft, utilization of aircraft type and a trip distance distribution profile. The complete methodology is further explained in chapter 3.
CHAPTER 3  **Methodology**

This section describes the procedure used to estimate General Aviation aircraft trips through airports. The General Aviation airport choice model is the second stage in the process to understand modal choice phenomena in the baseline year. The first stage described in Chapter 1 involved the development of diversion curves to split the trip distribution. The airport choice model estimates general aviation aircraft operations by single, multi and jet engine aircraft through public use airports (included in the database) in the continental US.

3.1 **Methodology**

During the mode split stage of the baseline study a stratified diversion curve was developed to split the output of the trip-distribution process into person-trips by three modes: Commercial Aviation, General Aviation (GA) and Others (Auto, Rail etc). The trips were further separated into business and non-business travelers for each mode. The output for GA business and non-business trips was however combined before being used as input to the airport choice model.

The initial input to the model is therefore an inter-county person-trip table (3091 x 3091 matrix) of GA trips from the centroid of each county. Also a database of airports and their attributes is required as
3.2 Data Source and Model Data Structures

input to the model. The aim of the model is to convert the inter-county person-trip table obtained from the stratified diversion curve to GA aircraft operations by aircraft mode between airports as shown in Figure 3.1. There are 3,646 airports in the current model as explained earlier.

![Diagram of Airport Choice Model]

Figure 3.1 Overview of Airport Choice Model.

3.2 Data Source and Model Data Structures

3.2.1 Airport Data

In the development of the model there is the need to specify airports through which travelers would route their trips. Currently there are 19,793 aviation facilities in the National Transportation Atlas Database published compiled by the Bureau of Transportation Statistics (2001) using information from USDOT and other Federal agencies. These facilities include airports, heliports, balloon ports, glider ports, seaplane bases, STOL-ports and ultra-light ports. In order to perform a consistent analysis for GA operations for the baseline year and into the future, a simple criteria was developed to create a database of airports through which these trips will be made. From the tables in FAA Advisory Circular 150/5325-4A on a normal day 95% of aircraft in the US fleet can be accommodated at airports with runway lengths greater than or equal to 3000 feet. The criteria used was to select airports that are
3.2 Data Source and Model Data Structures

1) Designated as Public Use (PU) Airports

2) Have Paved Runways and

3) Have usable runway length of more than 3,000 ft.

Information about the airports and other aviation facilities is available from the National Transportation Atlas Database CD-ROM which is available on request from BTS. The airport data was parsed from the CD-ROM using ArcGIS, Microsoft Access and Excel. Data on the airports and runway information was first extracted separately and then merged using the ‘Site Nos.’ field as the ‘Primary Key’. The runway and airport data are for the years 1998 and 2000 respectively. After merging the two datasets records that did not meet the criteria (i.e. PU, Hard surface runway & Runway Length > 3000ft) specified above were purged from the dataset.

Relevant fields extracted for use in the airport choice model include airport ID, airport coordinates (latitude & longitude), aircraft based at the airport by engine type (single, multi and jet engine), annual itinerant General Aviation operations, and a field indicating whether the airport is a towered or non-towered. It was noted that some of these airports did not have any based aircraft in any of the three categories. These airports were still left in the final data set as it is expected that as GA/SATS traffic grows there will be some activity at these ports.

In order to get the code to run efficiently MATLAB ‘struct’ arrays had to be utilized extensively and a sample array for the airports is shown below:

```
airport =
1x3613 struct array with fields:
    locID
    longAirports
    latAirports
    ctrlTower
    singleEngine
    multiEngine
    jetEngine
    totGA
```
3.3 Data Preparation

Data for the county included the coordinates (latitude/longitude) of the weighted centroids and county area was obtained from the Census Bureau website (www.bts.gov).

3.3.2 County data

Due to the large size of matrices being handled in the code it was necessary to preprocess some portions of the model in order to optimize it. Look-up tables for inter-county distance, inter-airport distance and access and egress distances were first developed in separate programs using information on the longitude and latitude of the counties and airports.

3.3.1 Airport-County Allocation

The first stage in the airport choice model is to ‘distribute’ the trip makers from the centroids of counties to the airports in the model. It is intuitive to state that trip makers make their decision from a ‘perceived’ set of available airports and it was necessary to define this ‘perceived’ choice set of airports prior to the distribution process. In the model an influence area was defined for each county centroid based on the radius of the county. The radius was estimated as $R = \sqrt{\frac{A}{\pi}}$ where $A$ is the area of the county.

For computational purposes the initial influence area is defined as 120% of the equivalent county Radius. All airports within that circumference measured from the county centroid are associated with the county centroid (even if they were outside the county). The attributes of the airports are also extracted and stored as MATLAB ‘struct’ arrays. If there was no airport within this area of influence for a particular county the factor 1.2 is increased until an airport is associated with that county. All the output from this module is stored in as a database.

3.3.2 Trip Lenghts

The access distance from each county to all the airports associated with is it computed and stored in a
in the struct array format in the database above.

The inter-county distance for all counties is computed and stored as a 3091 x 3091 matrix. The inter-airport distance (distance between each airport pair) computed and stored as a 3346 x 3346 matrix. Other pertinent data such as the distance probability distribution, occupancy and utilization factors related to the three aircraft categories are all read and stored in the model database.

### 3.4 Trip Distribution (Pseudo-Gravity Model)

The methodology to distribute the trips between the airports uses a pseudo gravity model to distribute trips from county centroids to airports. The model process is shown in Figure 3.2.

![Gravity Model: Converting County-to-County Person-trips to Airport-to-Airport Person-trips using Attractiveness Factor.](image)

This formulation is based on the assumption that travelers faced with a choice of different routes will tend to take the route with the shortest travel time and would travel through facilities with higher levels of travel services (e.g. number of aircraft based at the airport, frequency of trips to destination, availability of a fixed-base operator etc.). Given an origin and a destination county pair and a set of airports (within an influence area based on a county influence radius) associated with the origin and destination.
counts the volume of trips made through each airport pair will be directly correlated with the current volume of general aviation operations at the airport and inversely correlated to the door-to-door travel time (or door-to-door travel time) for the given airport pair under consideration. An attractiveness factor can be defined related to the level of service for the airports and another one related to the door-to-door travel time. These two attractiveness factors are then combined to derive a single attractiveness factor for that route.

It is difficult to obtain data on the variables access/egress times and to overcome this difficulty, the access and egress distances are used in place of times. The variable used to capture level of service at the airport was number of aircraft based at airport. Due to difficulty in obtaining reliable GA data it was decided to employ only two variables in the first iteration of the model. Also as the model will need to be re-run for future years the inclusion of too many variables could create problems when those variables had to be estimated for future years.

In the pseudo-gravity model in the GA airport choice model the origin county serves as the origin zone (from which trips emanate) and the sets of airport pairs associated with each the origin/destination county pairs as destinations (to which trips are distributed). Given an origin county $i$ with $k$ airports associated with it, a destination county $j$ with $l$ airports associated with it, and given a trip volume of $t_{ij}$ person-trips between the two counties. An attractiveness factor $A_{ijkl}$ is postulated such that

$$T_{ijkl} = t_{ij} \times \frac{A_{ijkl}}{\sum \sum_{k, l} A_{ijkl}}$$  \hspace{1cm} (3.1)

where $T_{ijkl}$ is the trip volume between airport $k$ and airport $l$ from the county pair $i$ and $j$.

The attractiveness factor is further decomposed into two factors Relative Distance ($RD$) and Aircraft Based ($ABsd$) at airport. The expression has the form

$$A_{ijkl} = \frac{(ABsd_{ijkl})^{\alpha_1}}{(RD_{ijkl})^{\alpha_2}}$$  \hspace{1cm} (3.2)
where $\alpha_1$ and $\alpha_2$ are parameters used in calibrating the model.

**Aircraft Based Factor**

The volume of trips attracted to airport pairs is assumed to be directly correlated to number of aircraft based at the airport pairs under consideration and the factor is expressed as

$$ABsd = ABsd_{ik} \times ABsd_{jl}$$

(3.3)

where $ABsd_{ik}$ and $ABsd_{jl}$ represent number of aircraft based at airport $k$ and airport $l$ associated with the origin and destination counties $i$ and $j$ respectively.

**Relative Distance Factor**

For every origin-destination county pair $(i,j)$ there are a set of airports $(1..k; 1..l)$ and hence a set of routes from which the traveler makes choices (see illustration in Figure 3.5). For a given set of routes (between the two county pairs) the volume of trips along a selected route will be inversely correlated to the **relative trip length** for that route. The Relative Trip Distance factor is formulated as

$$RD_{ijkl} = \frac{IntCounty_{ij}}{AccessDist_{ik} + EgressDist_{jl} + IntAir_{kl}}$$

(3.4)

where

$IntCounty_{ij}$ is the great circle distance (GCD) between weighted centroids of counties $i$ and $j$.

$AccessDist_{ik}$ is the GCD from weighted centroid of origin county $i$ to airport $k$ under consideration.

$EgressDist_{jl}$ is the GCD from weighted centroid of destination county $j$ to airport $l$ under consideration.

$IntAir_{kl}$ is the GCD between the two airport pairs.

in the destination county.
This implies that as the total trip length gets longer than the great circle distance between the airport pairs fewer travelers will opt to use the route under consideration.

To a limited extent the model seeks to mimic the effect of access time/distance and flight frequency (level of service) that have been identified in earlier studies. The relative distance attractiveness factor aims at distributing more trips to routes that had a shorter length for a selected county pairs. The airport attractiveness factor distributes more trips to origin-destination airport pairs that have ‘more services’.

The output from the ‘gravity’ model is person-trips between each airport in the database and is in the form of a 3346 x 3346 table (see Figure 3.4).
3.4 Trip Distribution (Pseudo-Gravity Model)

3.4.1 Splitting Person-trips (by aircraft type)

The table of aircraft person-trips between airports is further split by aircraft type (single, multi and jet engines). Factors considered in splitting the trips between the various aircraft types include the number of each aircraft type based at the airport, reported average annual utilization rates and occupancy values for the different aircraft types and the trip distance (which is characterized by a distribution profile). This step yields three 3346 x 3346 person-trip tables for each aircraft type and is illustrated in Figure 3.5).

Figure 3.5 Second Step: Splitting Airport-to-Airport Person-trip Table to Person-Trip table by mode.

The form of the expression used for the distribution is defined mathematically as

\[ T_{ijkl}^m = T_{ijkl} \times \frac{ABsd_{ik} \times UtI^m \times Occ^m \times Dist^m}{\sum_{k} ABsd_{ik} \times UtI^m \times Occ^m \times Dist^m} \] (3.5)

the subscript \( m \) represents aircraft type (i.e. single, multi or jet engine).

\( T_{ijkl}^m \) is the number of person-trips by aircraft type \( m \) from county \( i \) to county \( j \) through airport \( k \) and \( l \) associated with the respective counties.
3.4 Trip Distribution (Pseudo-Gravity Model)

\( ABsd_{ik} \) the number of based aircraft at the origin airport \( k \),

\( Util^m \) is the level of utilization of the aircraft (source GAATA, explained below),

\( Occ^m \) is the average occupancy of each of the aircraft types (source GAATA, explained below),

and \( DDist^m \) is a value obtained from the distance probability distribution for model \( m \) (the derivation of this distribution is outlined below).

Utilization and occupancy Factors

Aircraft Occupancy and Utilization factors were obtained by adjusting values derived from those reported by the General Aviation and Air Taxi Activity (GAATA) at the FAA website. Table 3.1 shows the aircraft factors employed in our analysis.

**TABLE 3.1. Aircraft Utilization and Occupancy Factors**

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>Average Occupancy (Persons)</th>
<th>Average Annual Utilization (hours) MODEL</th>
<th>Average Annual Utilization (hours) GAATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Engine</td>
<td>1.7</td>
<td>128</td>
<td>133</td>
</tr>
<tr>
<td>Multi Engine</td>
<td>2.4</td>
<td>170</td>
<td>170</td>
</tr>
<tr>
<td>Jet Engine</td>
<td>3</td>
<td>320</td>
<td>385</td>
</tr>
</tbody>
</table>

Development of Distance Probability Density Function

According to data published in the General Aviation and Air Taxi Activity Survey the U.S. general civil aviation fleet consists of about 185,000 fixed wing aircraft made up of approximately 172,000 piston-engine aircraft, 6,000 turboprops and 7,000 jets. Each of these aircraft groupings have different range and performance features that makes them unique as modes of travel. Single engine aircraft cruise at 120 to 175 mph within a range of 500 to 1,200 miles, turboprops and multi engines cruise between 200 to 350 mph and have ranges of 600 to 1,500 miles. Turbojets have cruise speeds ranging from 400 to 600 mph. (National Research Council Special Report 263). Obviously, there are overlaps in the performance and use of these aircraft that warrants the development of a stochastic model to assign trips
generated by the airport choice model.

From the above, it is clear that the trip length will be a deciding factor in selecting which mode of aircraft to use for a trip. The use of a distance distribution variable in the aircraft attractiveness seeks to account for this phenomenon. Generally more jet aircraft will be used for longer trips and more single engine types for shorter trips.

A Weibull distribution developed by LMI and George Mason University for the LIMNET-SATS model was modified and used in the analysis. The distribution was constructed by selecting twelve samples from the Enhanced Traffic Management System (ETMS) from FAA’s Consolidated Operational Delay Database, which contains flight plan information for IFR flights in the National Airspace System. Data collected was used to construct a histogram that had the form of a Weibull distribution. The form of the probability and cumulative density function can be expressed mathematically as (Long et al, 2001),

\[
f(x; (\delta, \lambda)) = \delta \left(\frac{x}{\delta}\right)^{\lambda-1} e^{-\left(\frac{x}{\delta}\right)^{\lambda}}, \quad x \geq 0, \quad \delta > 0
\] (3.6)

\[
f(x; (\delta, \lambda)) = 1 - e^{-\left(\frac{x}{\delta}\right)^{\lambda}}, \quad x \geq 0, \quad \delta > 0
\] (3.7)

where \(\delta\) and \(\lambda\) are the Weibull scale and shape parameters, respectively.

Estimated parameters for each single, multi and jet engine aircraft types are as follows,

\[
f(x; (\delta_s, \lambda_s)) = \frac{1.15}{237} \left(\frac{x}{237}\right)^{0.15} e^{-\left(\frac{x}{237}\right)^{1.15}}
\] (3.8)

\[
f(x; (\delta_m, \lambda_m)) = \frac{1.16}{289} \left(\frac{x}{289}\right)^{0.16} e^{-\left(\frac{x}{289}\right)^{1.16}}
\] (3.9)
3.4 Trip Distribution (Pseudo-Gravity Model)

\[
f(x; (\delta_j, \lambda_j)) = \frac{1.14}{826} \left(\frac{x}{826}\right)^{0.14} e^{-\left(\frac{x}{826}\right)^{1.14}}
\]

The modified probability and cumulative density functions are shown in Figures 3.6 and 3.7 respectively.

Figure 3.6 Modified PDF (Weibull Distribution) used in deriving Attractiveness Factor to split person-trips by mode (Original Distribution Developed by LMI).
3.4 Trip Distribution (Pseudo-Gravity Model)

Figure 3.7 Cumulative Density Function of Distance Distribution.
3.5 Converting Person-trips to Aircraft-trips

This aircraft split process yields three 3346 x 3346 airport-to-airport person-trip tables for each aircraft type (see Figure 3.8).

Figure 3.8 Output of Trip-split Process.

3.5 Converting Person-trips to Aircraft-trips

After deriving the table for person-trips aircraft type the person-trips are then converted to airport-to-airport person-trips to aircraft operations. This analysis is done using the occupancy factor the expression can be written as:

\[
AirOps_{ijkl}^m = \frac{T_{ijkl}^m}{Occ_i^m}
\]  

(3.11)

where \(AirOps_{ijkl}^m\) is the number of aircraft operations by aircraft type \(m\) from the origin county \(i\) to destination county \(j\) through airport \(k\) and \(l\) associated with the origin and destination counties respectively. The process is illustrated in Figure 3.9.
3.5 Converting Person-trips to Aircraft-trips

The operations by aircraft type are one-way trips. A return-trip table is generated by adding trips departing and arriving at each airport. The total aircraft operations can be obtained by doubling the number of return trips since we assumed that all trips have a return portion to their originating county. The cells in the arrays ‘Production’ (last row) and ‘Attraction’ (last column) in Figure 3.10 represent the number of operations from and to each airport in the model, respectively. The output from the model is three 3346 x 3346 airport-to-airport aircraft operations trip tables for each aircraft type (Figure 3.10).
3.6 Model Calibration

The airport choice model was calibrating parameters are $\alpha_1$ and $\alpha_2$. The model is calibrated by comparing estimated trip volumes of towered airports from the model with reported values by from the NTAD 2001. This calibration only considers for towered airports because reported statistics GA operations are in general not very reliable for non-towered airports.

Once a pair of values is selected for the calibrated parameters the main MATLAB script is run and the estimated aircraft operations for towered airports from the model is compared with the reported operations from TAF data. The Root Mean Square Error (RMSE) is computed and saved. The model is then re-run for pairs of values of the calibrating parameters and the pair of values with the minimum RMSE is selected.

Upon selecting the final calibration parameter pair, the model is re-run to obtain the airport-to-airport person-trip table and aircraft operation trip table. The final output is the three 3346 x 3346 airport-to-airport aircraft operations tables. This will serve as an input for the network analysis stage of the transportation modeling process.
3.6 Model Calibration

3.6.1 Pseudo Code for Airport Choice Model

The outline of computations in the model is presented below

for $\alpha_1 = 0:0.01:2$
for $\alpha_2 = 0:0.01:2$
for $i = 1:3091$
for $j = 1:3091$
for $k = 1:k(\text{origin airports})$
for $l = 1:l(\text{destination county airports})$

Compute $ABsel_{ijkl}$
Compute $RD_{ijkl}$
Compute $A_{ijkl}$

Next $k$
Next $l$
Compute $T_{ijkl} = t_{ijkl} \times \sum_k \sum_l A_{ijkl}$
Compute $T_{ijkl}^m = T_{ijkl} \times \frac{ABsd_{kl} \times Ut^m \times Occ^m \times DDist^m}{\sum_k \sum_l ABsd_{kl} \times Ut^m \times Occ^m \times DDist^m}$
next $j$
next $i$
Sum $T_{ijkl}^m$
Compute RMSE for towered Airports
Save $\alpha_1$, $\alpha_2$, and RMSE$_{\alpha_1\alpha_2}$
next $\alpha_1$
next $\alpha_2$
Select best RMSE$_{\alpha_1\alpha_2}$
Re-run model to estimate operations at airports.

The complete MATLAB code for the model is available in Appendix C.
This section describes the General Aviation Airport Choice Model (GAACM) output and results. During the calibration stage, the model was run for $\alpha_1$ and $\alpha_2$, each running from 0 to 2 with a step-size of 0.1. The minimum root mean square error was obtained for values of ‘0.8’ and ‘0’ for $\alpha_1$ and $\alpha_2$ respectively. As $\alpha_1$ is associated with the factor related to aircraft based and $\alpha_2$ is related to ‘relative distance’, the implication is that in the model the choice of trip makes is more sensitive to the Aircraft Based factor than the Relative Distance factor.

### 4.1 Model Output

#### 4.1.1 Summary of Output

A summary of the total aircraft operations estimated from the model is shown in Table 4.1. The results show high trip volumes for single engine aircraft (as expected) compared to other modes. Nevertheless, jet aircraft show some gain in number of total operations an flights.

The number of person-trips in the GAACM for the year 2000 was 6 million and the total number of aircraft operations is 15 million. These numbers agree with results of a top-down analysis performed by LMI using TAF data for the same year.
A Transported Passenger Mile (TPM) was computed by multiplying the cells of the person-trip tables and the aircraft operations table $TPM = (\text{Number of Operations} \times \text{Stage Length})_{\text{Airport}}$.

The estimated TPM of 3 billion however differed from the estimate of 15 billion from the LMI model. The difference may be attributed to different aircraft utilization and occupancy factors used in both models.

**TABLE 4.1. Model Output: Estimated Values by Aircraft mode**

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>Average Stage Length (mi)</th>
<th>Total Hours Flown</th>
<th>Total Trip Distance (mi)</th>
<th>Total Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Engine</td>
<td>447</td>
<td>6,980,000</td>
<td>1,030,000,000</td>
<td>8,318,000</td>
</tr>
<tr>
<td>Multi Engine</td>
<td>587</td>
<td>2,760,000</td>
<td>759,000,000</td>
<td>4,776,000</td>
</tr>
<tr>
<td>Jet Engine</td>
<td>1,084</td>
<td>1,210,000</td>
<td>652,000,000</td>
<td>2,302,000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>10,950,000</strong></td>
<td><strong>2,441,000,000</strong></td>
<td><strong>15,396,000</strong></td>
<td></td>
</tr>
</tbody>
</table>

Figures 4.1 and 4.2 show percentage of operations and distance traveled by aircraft type. The results show high trip volumes for single engine aircraft (as expected) compared to the two other modes. Nevertheless, jet aircraft show some gain in the total distance traveled given their longer stage lengths (see Table 4.1).

![Figure 4.1 Model Output: Percentage of Aircraft Operations by Aircraft Type.](image)
4.1 Model Output

Figure 4.2 Model Output: Percentage of Distance Travelled by Aircraft Type.

From Table 4.2, close to 60% of current GA traffic is routed through the 474 control-towered airports (that account for only 14% of airports in the model). An estimate of the proportion of trips through towered airports from the NTAD database yielded a value of 53%.

<table>
<thead>
<tr>
<th></th>
<th>% GA Operations (Model Estimates)</th>
<th>% GA Operations (NTAD 2001)</th>
<th>Number of Airports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Towered Airports</td>
<td>59%</td>
<td>53%</td>
<td>474</td>
</tr>
<tr>
<td>Non-towered Airports</td>
<td>41%</td>
<td>47%</td>
<td>2872</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td></td>
<td>3346</td>
</tr>
</tbody>
</table>
From Table 4.3 for all aircraft types towered airports attract a higher volume of traffic. A very high proportion of jet aircraft operations is (70%) routed through towered airports.

**TABLE 4.3. Operations by Aircraft types through Towered and Non-Towered Airports**

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>% of Operations</th>
<th>Control Towered Airports</th>
<th>Non-towered Airports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Engine</td>
<td>49%</td>
<td>51%</td>
<td></td>
</tr>
<tr>
<td>Multi Engine</td>
<td>58%</td>
<td>42%</td>
<td></td>
</tr>
<tr>
<td>Jet Engine</td>
<td>70%</td>
<td>30%</td>
<td></td>
</tr>
</tbody>
</table>

Using the aircraft operations estimated by the model the probability density function for the Weibull distribution was reconstructed. The shape of the plot is the form of a Weibull distribution. The irregular pattern for jet aircraft operations can be attributed to insufficient data points as relatively few GA trips (15%) are made using that mode. Nevertheless, the expected values of the obtained distributions (see Table 4.1) are 447, 587, and 1084 miles for single-engine, multi-engine, and jet aircraft, respectively.

The plots below shows the probability density function of the theoretical distribution used in the model and that for the estimated operations from the model.
4.1 Model Output

Figure 4.3 Distance Probability Density Function (using Estimated Values from the Model).
4.1 Model Output

Figure 4.4 Estimated Cumulative Density Function (from Model Output).
4.1 Model Output

Table 4.4 is a sample output from the model showing operations by aircraft types for \( \alpha_1 = 0.8 \) and \( \alpha_2 = 0 \).

**TABLE 4.4. Model Estimates - Selected Airports**

<table>
<thead>
<tr>
<th>AIRPORT INFORMATION</th>
<th>ESTIMATED OPERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCID</td>
<td>ST_NAME</td>
</tr>
<tr>
<td>-------</td>
<td>---------</td>
</tr>
<tr>
<td>79J</td>
<td>ALABAMA</td>
</tr>
<tr>
<td>BHM</td>
<td>ALABAMA</td>
</tr>
<tr>
<td>DHN</td>
<td>ALABAMA</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>6V3</td>
<td>VIRGINIA</td>
</tr>
<tr>
<td>OFP</td>
<td>VIRGINIA</td>
</tr>
<tr>
<td>FCI</td>
<td>VIRGINIA</td>
</tr>
<tr>
<td>SFQ</td>
<td>VIRGINIA</td>
</tr>
<tr>
<td>AKQ</td>
<td>VIRGINIA</td>
</tr>
<tr>
<td>W97</td>
<td>VIRGINIA</td>
</tr>
<tr>
<td>OKV</td>
<td>VIRGINIA</td>
</tr>
<tr>
<td>LNP</td>
<td>VIRGINIA</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>UUO</td>
<td>ALASKA</td>
</tr>
<tr>
<td>CYT</td>
<td>ALASKA</td>
</tr>
<tr>
<td>YAK</td>
<td>ALASKA</td>
</tr>
<tr>
<td>HNM</td>
<td>HAWAII</td>
</tr>
<tr>
<td>UFP</td>
<td>HAWAII</td>
</tr>
<tr>
<td>MUE</td>
<td>HAWAII</td>
</tr>
<tr>
<td>LNY</td>
<td>HAWAII</td>
</tr>
<tr>
<td>HDH</td>
<td>HAWAII</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
\text{TOTAL} & = 8,317,832.00 \\
\text{TOTAL} & = 4,776,024.00 \\
\text{TOTAL} & = 2,301,928.00 \\
\text{TOTAL} & = 15,395,784.00
\end{align*}
\]
4.1 Model Output

4.1.2 Airport Estimates

Towered Airports

A plot of estimated (Model) versus observed (NTAD) aircraft operations for towered airports in the model (shown below) yielded an $R^2$ value of 23%. This value is very low. Upon scrutiny of the towered airport data it was noticed there was very little correlation between the model estimates and NTAD estimates for large hub towered airports (Figure 4.6). Upon deleting the large hub towered airports the $R^2$ value increased considerably to 38.4% (see Figure 4.6).

![Figure 4.5 Plot of Estimated Operations for GAACM versus Observed Operations from NTAD Database (All Towered Airports).](image)

$y = 0.6856x + 35482$

$R^2 = 0.2323$
There is very little correlation between the model estimates and reported data in the NTAD database for large hub airports.
4.1 Model Output

Figure 4.7 Plot of Estimated Operations for GAACM versus Observed Operations from NTAD Database (Towered Airports without Large Hub Airports).

The correlation for medium, small and non-hub towered airports were much better with $R^2$ values of 67%, 22% and 47% respectively.
Figure 4.8 Estimated Operations for GAACM versus Observed Operations from NTAD Database (Medium Hub Airports).
4.1 Model Output

Figure 4.9 Estimated Operations for GAACM versus Observed Operations from NTAD Database (Small Hub Airports).

\[ y = 1.1475x + 30039 \]
\[ R^2 = 0.2211 \]
4.1 Model Output

Figure 4.10 Estimated Operations for GAACM versus Observed Operations from NTAD Database (Non-Hub Airports).

Non-Towered Airports
A plot of the model estimates for non-towered airport operations and NTAD operations is shown in Figure 4.11. The estimates from the model are ranked from left to right. The model overpredicts GA operations (from NTAD) 14% of the time and underestimates NTAD operations 86%. There is a wide variation between the model and NTAD output for non-towered airports as shown by the low $R^2$ value of 19% in Figure 4.12.
Figure 4.11 Comparison of Model Operations Estimates with NTAD Data for Non-Towered Airports.
Figure 4.12 Model Operations Estimates versus NTAD Estimates.
This research begun initially as part of an initial attempt to model NASA’s SATS aircraft program as a feasible transportation system. The first stage (called an initial transportation systems analysis assessment) focuses in the analysis of baseline transportation systems conditions (year 2000) to understand today’s travel behaviors by the population of the U.S. This stage defines the initial conditions in order to estimate future behaviors of various transportation modes when competition exists among them (multi-mode analysis).

The second stage will (called an intermediate transportation system analysis assessment) will focus on the development and limited-scope calibration of a realistic modal split (a mathematical model) model to estimate how SATS could attract users over a 20-year modeling life cycle. This analysis will be complemented with the formulation of a large-scale, Systems Dynamics-based computer simulation model (called SATS decision Support Model) to execute modal split analysis in an evolving time framework. The third stage, will focus on a final assessment of the SATS state based on outputs derived from other analyses including flight simulation, human factors, etc. for proposed concept of operations.

The airport choice model developed was part of the analysis of the first stage and seeks to predict general aviation trip volumes from 3346 selected airports in the US. The ability of the model to also predict
both person-trips and aircraft operations makes it a valuable tool to for Airport planners and developers. The person-trips can be used in development of plans for airport terminal facilities whilst the aircraft operations can be used in the development of plans for runways, taxiways and apron areas etc.

The current output of the model is in the form of annual person-trips and annual operations from airports. Upon further modification (explained later on) it may be used as input to aircraft network analysis models to help assess the impact of general aviation and later SATS aircraft operations on the National Airspace.

The current model was calibrated using data reported for towered airports for the NTAD database. The model estimated 59% of current GA aircraft activity is routed through 474 towered airports, which is reasonably close to 53% derived from the NTAD database (see Figure 4.2). In a similar analysis for GA operations using a different database LMI arrived at the same figure. These 474 towered airports that account for only 14% of airports in the database. These two values are reasonably close and seem to indicate that though GA aircraft can operate from non-towered airports currently a high volume operations are conducted from towered airports.

There is the need to investigate this trend further as part of the vision of NASA in developing SATS is to increase access and use of the non-towered airports.

5.1 Recommendations

This first attempt to characterize airport choice travel behavior produced many interesting questions that deserve study.

1) There is the need to investigate different formulations for the gravity model as the value of 0 obtained for \( \alpha_2 \) suggests trip length and access time is not critical in the travelers’ decision making process. This is counterintuitive.

2) The model assigns trips to aircraft without considering aircraft performance and travelers behavior. For example an inspection of the Airport-to-Airport O/D table reveals trips with ranges greater 500 miles for single engine aircraft. It is unlikely that such a trip will be make with one takeoff an landing.
5.1 Recommendations

There is therefore a need to further modify the output. Based on a selected range for each aircraft type such trips can be split into two or more stages with the stopover portion being assigned to the closest airport along the route. The values in the aircraft tables for the affected airport pairs will then be readjusted.

3) There is the need to investigate the use of other variables (instead of the Aircraft Based factor) in the gravity formulation of the model as there is very little correlation between this variable and operations for some airports. For example in at Los Angeles airport (LAX) the NTAD database reports 18,000 operations but there is only 1 aircraft based at the airport. This caused the model to allocate very few operations (240) to LAX.

4) In order to use the output for the model in aircraft network models (such as TAAM, AOM/AEM and LIMNET SATS see Bibliography) the annual trips first need to be converted to daily trips and a time-of-day departure schedule needs to be developed for each airport. Currently LMI and George Mason University have developed conversion routines and are feeding the output of this model into LIMNET SATS and TAAM respectively.

5) Access and Egress distances are used in place of access and egress times and number of aircraft based at airports is used in place of GA operations due to difficulty of obtaining drive times. In subsequent studies there will be the need to look at the possibility of considering other predictive variables and also incorporating drive-times by employing GIS based tools.

6) For validation purposes it is proposed that analysis presented here be further reviewed by appropriate and cognizant agencies to provide feedback on the methods employed and the credibility of the numbers. Further Study

5.1.1 Logit Models

From the literature review it is clear that the predominant means of studying travel choice behavior has been through the use of Logit models. There is a need to conduct a follow-up study needs to quantify the socio-economic factors and travel model related parameters (and their weights) that characterize travel behavior at the individual level. This follow-up study should use actual surveys to assess how
people would react to SATS as a mode with a carefully orchestrated survey that presents an objective SATS mode (with both weaknesses and strengths). It is proposed that a survey be conducted to obtain cross-classified data of GA travelers’ trips in selected metropolitan and non-metropolitan areas in order to calibrate a nested multinomial logit model.

1) It is proposed that a nested multinomial logit model calibrated for the study. A variety of techniques have been used in the past to address this issue in the random utility modeling framework - (Ben Akiva, 1997). It should also be mentioned here that specifying the proper form of a utility function to study modal split, in the presence of SATS aircraft, would require a separate study including a survey using a hybrid of revealed and state preference techniques (Herriges, 199; Adamowicz, 1994).

2) A calibration process would also be required to ensure the correct specification of the utility function has been selected. This process is extremely critical in the analysis of SATS as a feasible mode of transportation, as it will dictate the viability of SATS as a regular mode of operation. Moreover, any SATS technology investments should be tied to cost-benefit analyses considering the user population of the mode. This implies a knowledge of the demand function for the mode.

3) Another issue to be addressed is the determination the alternatives in the choice set that are available to the individual. In the case of a national model of this scale for all modes it is obvious that certain modes may not be available in all zones (e.g. rail is not available in certain areas). Also factors such as weather may make it impossible to use some available modes (SATS and Commercial Aviation) during certain times of the year. The solution to the problem of mode availability is not trivial, however a variety of techniques have been used in the past to address this issue in the random utility modeling framework. Ben Akiva (1997) used a methodology that considered only subsets of options that are effectively chosen in the sampling framework. However if realistic alternatives are excluded there is the probability that the model may produced unreliable results.

The other method is to assume all alternatives are available to all individuals and let the model decide the choice probabilities of unrealistic options are zero. This also has a drawback if the discriminatory powers of the model are not strong enough. Ben Akiva and Watanatada (1980) proposed a method that assumes continuity across all alternatives. Harvey and Hwa-Wu (1992) have also developed software
that aims at capturing the space-time accessibility measures in the context of Transportation Systems and Planning.

The approach proposed to address the implicit accessibility problem in the modal split analysis for SATS operations is a variation of that developed by Casseta and Papola (2001). This approach is based on the concept of intermediate degrees of availability/perception of each alternative simulated through an inclusion function which, is introduced in the systematic utility expression of the random utility model. The utility expression has the form shown in Equation 4.1. This model is a hybrid logit model with implicit availability and perception.

$$ U_j^i = V_j^i + E[\ln\mu_i^j(j)] + \eta_j^i + \varepsilon_j^i $$  (4.1)

The critical step in the development of this model is the calibration step. This will require an extensive survey of random populations to calibrate the weights assigned to various populations to individual travel choices.

### 5.1.2 Small Aircraft Cost Model

A small aircraft cost model was developed in this analysis (explained in detail in Appendix B) points out some interesting fact about the competitiveness required for SATS in the future. Many high performance turboprop aircraft today have total operating costs that range from $1.50 to $3.00 dollars per mile (this factors all costs associated with the operation, service and amortization of the equipment). Small to medium business jets range from $2.70 to $5.50 per mile. This translates into a range of 25-50 cents per Available Seat-Mile (ASM) for turboprops and 45-95 cents ASM for business jets. Current cost figures per ASM for modern regional airline turboprops (i.e., Embraer 120, ATR 72, Saab 340) are 9.2-11.5 cents per ASM. Regional jets (i.e., Bombardier CRJ-200 and Embraer 145) have cost factors ranging from 9.5 to 14.0 cents per ASM (from DOT data). The statistics for larger aircraft improve a bit more. These numbers are perhaps good initial indicators of the efficiency that SATS has to achieve as a mode to be competitive with commercial operations.
5.2 Conclusions

There are significant conclusions derived from the airport choice model:

1) The number of trip-persons using the GA mode in the year 2000 amounted to 6 million. This equates to about 3 billion Transported Passenger Miles (TPM) via GA in 2000. This number differs from a top-down analysis performed by LMI using the ATS data. The differences, are primarily driven by the average trip length of flights and the different values of aircraft occupancies used in the separate studies.

2) Based on a study of various transportation data sets, the amount of GA travel in the U.S constitutes a small fraction (<0.6%) of the total trip-persons done in the year 2000. This states that while SATS has good potential, the economic (i.e., cost) and performance variables have to be very competitive for the system to thrive in the presence of other modes of transportation like the automobile and commercial aircraft.

3) The model estimated that 59% of current GA aircraft activity is routed through 474 towered airports which is reasonably close to 53% derived from the NTAD database. These 474 towered airports that account for only 14% of airports in the database. These two values are reasonably close and seem to indicate that though GA aircraft can operate from non-towered airports a currently high volume operations are from towered airports. There is the need to investigate this trend further as part of the vision of NASA in developing SATS is to increase access and use of the non-towered airports.

4) The methodology used in developing the model can be said to be reasonable. The model output may be used in further analysis to derive macroscopic measures of effectiveness such as travel time benefits, noise impact studies, fuel and energy usage, and air transportations systems delays etc.

Given the current low level of modeling work undertaken for GA operations nationwide it is believed the current model will be a major contribution to help in the task to further study and characterize the airport choice behavior of GA travelers.

In concluding it must be stated that there is the need to improve and invest in more detailed data collection with regard to the GA travel mode in order to model new modes like SATS more effectively. The numbers of trips for GA in the baseline year is very consistent with the data derived by LMI in a
previous SATS demand study. However, the TPM metric is not consistent and thus needs further investigation.

As the model stands at the macro level it is able to reasonably estimate GA trip volumes in the US. Output from the model may be aggregated at various levels (FAA regions, State, County etc) to give an indication of the level of general aviation aircraft (GA) activity for various planning and decision making purposes at various levels.

All the analyses presented in this report have been integrated into a standard numerical computing environment called MATLAB. MATLAB is an off-the-shelf computer environment suitable to handle the large matrices and complex manipulations of the data presented in this report. A detailed output of the model is attached and available on the CD-ROM attached to this document.
Bibliography


Appendix A  Sample Airport Database

This appendix contains relevant information on a sample of the 3,346 airports considered in the region of interest. The database has been extracted from the Federal Aviation Administration archives (FAA, 2000). All airports in Virginia are shown in the table.

Table A.1. Relevant Airport Data (source FAA).

<table>
<thead>
<tr>
<th>Airport Name</th>
<th>State Name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (ft)</th>
<th>Runway Length (ft.)</th>
<th>Annual Local GA Operations</th>
<th>Annual Itinerant GA Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHELBY COUNTY</td>
<td>ALABAMA</td>
<td>-86.783</td>
<td>33.178</td>
<td>584</td>
<td>3797</td>
<td>6048</td>
<td>14600</td>
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<tr>
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This appendix contains information about a small aircraft cost model. As part of the modal split analysis it is necessary to estimate the cost of travel along different routes by different modes. The average cost of commercial airline operations can be obtained either by using explicit functions of cost components derived from Department of Transportation (DOT) data reported by the airlines or derived from queries of commercial airline reservation systems like the Sabre Database. As the small aircraft transportation technology is deployed it is likely that the initial travellers to switch to this mode would be full-fare paying coach and first-class airline travelers. The attractiveness of the mode to travellers will be determined to a large extent by the cost of travel.

The exact state of the SATS aircraft has yet to be determined but it is envisaged that cost and will be between those of current general aviation and commercial airlines. The small aircraft cost model attempts to model current operating cost of general aviation aircraft that will serve as an input in the development of costs for the random utility model and also serve as a framework from which SATS aircraft costs may be derived.

The modeling of SATS aircraft operation costs is an activity that requires careful examination because the utility functions employed in RUT are very sensitive to the cost of travel. The attempt here has been to develop a cost model to realistically predict the operating costs of this class of vehicles based on
existing and anticipated trends in the industry.

The model predicts the total operation costs of turboprop and jet aircraft. The operation costs of aircraft are influenced by the number of hours the aircraft is operated and the stage length of the trips. The model developed is able to predict the total operating cost in dollars per seat mile given the annual number of hours the aircraft is operated and an average stage length.

The model estimates the annual Acquisition cost, annual Fixed Operating Costs and annual Variable Operating Costs. The sum of these cost are then divided by the total number of miles the aircraft is flown per year to obtain the Total Operating Cost per mile (number of miles flown per year is obtained by multiplying the average speed of the aircraft by the annual hours of operation). The current model output is for 400, 600 and 800 hours of operations per year with average stage lengths of 300, 600 and 1000 nautical miles for all aircraft except the Ultra Long Range Jets which have output for 1000, 3000 and 6000 nautical miles.

It is envisaged that the mode of operation of SATS (Fractional Ownership, Air Taxi or Personal Ownership) will greatly influence the number of hours flown annually and the aim of determining the operating cost for different annual hours of operation is to capture this variation in cost.

The number of seats on the aircraft is multiplied by a load factor (currently this is input is set at 70% but can be easily changed to reflect different operating policies) and this figure is used to derive the cost per seat mile of the class of aircraft. The load factor is to cater for the fact that most of these aircraft are not operated at full capacity most of the time.

Methodology
Linear regression models were developed to predict the Acquisition cost and various components of the Fixed and Variable costs. The aim of the regression analysis was to select as input independent variables that were easily obtainable from aircraft manufacturers and operators for both aircraft that are in production and those in the design stage. This would then make it easy to model the cost of SATS vehicles in the future once these variables are estimated.
Data

The regression models were developed using multivariate analysis and correlation analysis techniques to select the most appropriate variables. The data used to develop the model was from the ‘2001 Purchasing and Planning Handbook’ and the ‘2001 Operations and Planning Guide’ of Business & Commercial Aviation.

There were twenty five aircraft used to derive realistic values in the jet model. These are shown below.

- Bombardier LR31A
- Cessna CJ1 CE525
- Cessna CJ2 CE525A
- Cessna Citation Bravo
- Cessna Citation Encore
- Premier RA390
- Raytheon Beechjet
- Bombardier LR45
- Bombardier LR60
- Bombardier CL601RJ
- Bombardier CL604
- Bombardier CL601SE
- Cessna Citation Excell
- Cessna Citation X
- Dassault Falcon 2000
- Dassault Falcon 50EX
- Dassault Falcon 900C
- Dassault DA900EX
- Fairchild Envoy 3 Corporate
- Gulfstream IV
- Airbus A319
- Boeing 737700IGW
- Boeing Business Jet 2
- Global Express
- Gulfstream V

The Jet aircraft are categorised into three groups

- Ultra Long Range
- Jets with Maximum Takeoff Weight Greater than 20,000 lb
- Jets with Maximum Takeoff Weight Less than 20,000 lb
The eleven aircraft used in the turboprop model are,

- New Piper Meridian
- Pilatus PC12
- Socata TBM SA 700
- Cessna Caravan I
- Cessna Grand Caravan
- Raytheon King Air C90
- Raytheon King Air C90B
- Raytheon King Air B200CSE
- Raytheon King Air B200SE
- Raytheon King Air B350

The turboprop aircraft are categorised in two groups

- Multi Engine turboprops
- Single Engine turboprops

**Model Structure**

Typically airline accounts are classified into Operating (items directly related to airlines services) and Non-Operating (items such as gains or losses from retirement of property, interest on loans, foreign exchange transactions etc not directly related to the airlines services. The operating items may be costs or revenues. The costs are further classified into direct and indirect operating cost.

Under ICAO’s classification direct costs include

- Flight Operations
- Maintenance & Overhaul
- Depreciation & Amortization

The indirect cost include

- Station and ground expenses
- Passenger services
- Ticketing, sales and promotion
- General Administrative
- Other Operating costs

The model uses a similar structure but omits some of the cost such as ticketing and sales that are not a significant part of current general aviation operating costs.
Model Input Variables

Input variables to the models can be grouped into two categories, those used to derive regression expressions and those used directly as input to the model. All data for these two models was derived from Business and Commercial Aviation annual FBO and aircraft manufacturer surveys (2001).

Variables used in computing the operating costs are

- Acquisition cost of aircraft (Depreciated over 10 years)
- Variable operating costs
- Hull Insurance
- Liability Insurance
- Maintenance Software
- Miscellaneous Expenses
- Mid-Life Hot-section Inspection
- Engine Overhaul
- Painting
- Refurbishment
- Modernisation
- Periodic Maintenance
- Pilot Training
- Maintenance Training
- Hanger & Facilities
- Other Miscellaneous costs
- Salaries

Variables used to derive regression equations are: Operating Empty Weight (lb.), Fuel Flow rate (lb./hour), Engine Power (horsepower), Interior Area / Seat (sq. ft.), Purchase Price of aircraft ($). Other variables used directly as input to the model include the Liability Insurance ($), Software Maintenance Costs ($), Hangar Costs ($), Miscellaneous Costs ($) and Salaries. A sample of the regression cost expressions and their corresponding $R^2$ values are shown in Figures D.2 through D.5.

Where it was not possible to obtain good fit or reasonable regression expressions for variables, the average or actual costs in the Business and Commercial Aviation publication was used.

Acquisition Costs

The aircraft is assumed to be operated over a lifecycle of 10 years. The independent variable used to estimate the acquisition cost was the operating empty weight and area per seat for the jets and operat-
ing empty weight for turboprop aircraft. The estimated costs are in dollars and represent the market value of the aircraft in 2001. The value used in computations is the depreciated value over 10 years.

In order to depreciate the aircraft acquisition cost salvage values had to be estimated. Business and Commercial Aviation contains data acquisition cost of aircraft when they were manufactured and their used prices in 2001. An analysis of the data shows that single engine aircraft are losing only 10% of their value over a 10 year period with turboprops losing 50% and jets 15%. The salvage values used were 90%, 50% and 85% for single engines multi engines and jets respectively.

The rapid drop in value of the multi engine turboprops may be due to the steady drop in jet aircraft prices. Though single engine aircraft prices seem to retain their value it should be noted that they are relatively inexpensive relative to other aircraft types with acquisition cost well below a million dollars. Turboprops range from one to four million, while general aviation jets range from two to twenty million and over.

**Variable Operating Costs**
For the variable costs the direct operating cost in seat per mile was estimated using operating empty weight, area per seat and power of the engine the engine as independent variables.

The direct operating cost in dollars per mile (dependent variable) obtained from the regression expression is then multiplied by the speed and hours flown per year to obtain the annual cost in dollars. The variable operation costs are those related to operating the aircraft and include maintenance, fuel, parts and trip related expenses.

**Fixed Operating Costs**
The Indirect operation cost is categorised as fixed costs, periodic maintenance costs, flight and crew costs and facilities costs. The fixed costs were made up of hull and liability insurance, maintenance and software costs, miscellaneous service costs. The periodic cost were made up of engine overhaul, mid-life hot-section inspection, painting, interior refurbishment and modernization and upgrade costs.

Costs in the other cost categories include the pilot and crew salaries, training and salary costs and the facilities cost included hanger costs and other miscellaneous expenditure. Regression fits were derived
for some of the dependent variables but in most cases it was difficult to obtain a good fit and the values provided in the Business and Commercial Aviation database was used directly in the model.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Cost per Mile ($) - Business Jet Aircraft {MTOW &lt; 20,000lb}</th>
<th>Cost per Mile ($) - Business Jet Aircraft {Ultra Long Range}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cessna</td>
<td>CJI CE525</td>
<td>2.976 2.786 2.716 2.583 2.383 2.333 2.402 2.192 2.142</td>
<td>2.583 2.383 2.333 2.402 2.192 2.142</td>
</tr>
</tbody>
</table>
Figure B.3 Business Jets - Area per Seat vs Acquisition Cost

![Figure B.3 Business Jets - Area per Seat vs Acquisition Cost](image)

\[ y = 636.95x + 5264.94 \]
\[ R^2 = 0.74 \]

Figure B.4 Business Jet Aircraft Fuel Flow vs. Acquisition Cost.

![Figure B.4 Business Jet Aircraft Fuel Flow vs. Acquisition Cost](image)

\[ y = 11.797x + 207.51 \]
\[ R^2 = 0.9066 \]
Figure B.5 Acquisition Cost vs. Yearly DOC (Business Jets) [400hrs 300nm].

Figure B.6 Acquisition Cost vs. Yearly Indirect Cost (Business Jets) [400hrs 300nm].
Figure B.7 Predicted Annual Costs for Business Jet Aircraft \(\text{MTOW} < 20,000 \text{ lb}\).

Figure B.8 Predicted Annual Costs for Business Jet Aircraft \(\text{MTOW} > 20,000 \text{ lb}\).
Figure B.9 Predicted Annual Costs for Business Jet Aircraft (Ultra Long Range).
Figure B.10 Cost per Mile - Business Jets { MOTW > 20,000 lb}.

Figure B.11 Cost per Seat Mile - Business Jets { MOTW > 20,000 lb}. 
Figure B.12 Cost per Mile - Business Jets (Ultra Long Range).

Figure B.13 Cost per Seat Mile - Business Jets (Ultra Long Range).
Turboprop Aircraft

The table below shows a sample output for the aircraft cost model for 400 and 600 hours of annual operations and average stage lengths of 300, 600 and 1000 nautical miles for turboprop aircraft. The output of this model was used in estimating travel costs by general aviation, fractional ownership, air-taxi, and personal operations.

Figure B.14 Turboprop Aircraft - Cost per Seat-Mile
Figure B.15 Turboprop Aircraft - Cost per Mile

Figure B.16 Turboprop Aircraft - Annual DOC
Figure B.17 Turboprop Aircraft - Annual IOC
Figure B.18 Cost per-mile Variation with Stage Length and Annual Utilization (Pilatus PC-12).
Figure B.19 Cost per-seat-mile Variation with Stage Length and Annual Utilization (Pilatus PC-12).

The source code for the model is included in Appendix.
Appendix C

Airport Choice Model Code (Matlab)

This appendix source code written in Matlab for the GA airport mode choice model. In the first few lines of each script there is description of the function of the script and any Matlab functions that call or are called by the script. (Scripts are also available on the CD-ROM attached)

Script 1: Function to create inter-county distance table

function createDistC2C();

%------------------------------------------------------------------

% This script computes the great circle distance between the 3091 county pairs

%
% calling:
% called: createAttractTable

%------------------------------------------------------------------

% Load .xls files and rename fields

%------------------------------------------------------------------

[FIPS1, FIPS2, cName, long, lat] = textread('county_centroid.txt', '%d %d %s %f %f');
totCounty = size(FIPS1, 1);
distC2C = zeros(totCounty, totCounty);
for i= 1 : totCounty;
    disp(‘ createDistC2C, totCounty =’, num2str(i));
    for j= i + 1 : totCounty
        % Compute Great Circle distance between two points
        distC2C(i, j) = distance(lat(i), long(i), lat(j), long(j));
        distC2C(j, i) = distC2C(i,j);
    end;
end;

% Convert values from deg to nautical miles & save
distC2C = deg2sm(distC2C);
save distC2C distC2C;

Script 2: Create County to Airport distance table
function createDistC2A();
%-------------------------------------------------------------------------------
% This script computes the great circle distance between the 3091 county pairs
%-------------------------------------------------------------------------------
% calling:
% called: createAttractTable
%-------------------------------------------------------------------------------

[FIPS1, FIPS2, cName, longCounty, latCounty] = textread(‘county_centroid.txt’,’%d %d %s %f %f’);
[locID, longAirport, latAirport, ctrlTower, sEngine, mEngine, jEngine, airTaxi, itinerant] ... = textread(‘Airports_Haw_Alas1.txt’,’%s %f %f %d %d %d %d %d’);
totCounty  = size(FIPS1, 1);
totAirport = size(locID, 1);

distC2A = zeros(totCounty, totAirport);
for i = 1 : totCounty;

disp([' createDistC2A, totCounty = ', num2str(i)]);
for j = 1 : totAirport
    % Compute Great Circle distance between two points
    distC2A(i, j) = distance(latCounty(i), longCounty(i), latAirport(j), longAirport(j));
end
end

% Convert deg to nautical miles & save
distC2A = deg2sm(distC2A);
save distC2A distC2A;

---

Script 3: Create Airport to Airport table
function createDistA2A();

% This script computes the great circle distance between the 3346 airports in the database
% calling:
% called: createAttractTable
%------------------------------------------------------------------------------------------

[locID, longAirport, latAirport, ctrlTower, sEngine, mEngine, jEngine, airTaxi, itinerant] ...

    = textread('Airports_Haw_Alas1.txt', '%s %f %f %d %d %d %d %d %d');

totAirport = size(locID, 1);

distA2A = zeros(totAirport, totAirport);

for i = 1 : totAirport
    disp(['   createDistA2A, totAirport = ', num2str(i)]);
    %airport Data
    airport(i).locID    = locID(i);
    airport(i).latAirport   = longAirport(i);
    airport(i).latAirport   = latAirport(i);
    airport(i).ctrlTower    = ctrlTower(i);
    airport(i).singleEngine = sEngine(i);
    airport(i).multiEngine  = mEngine(i);
    airport(i).jetEngine    = jEngine(i);
    airport(i).totGA        = sEngine(i) + mEngine(i) + jEngine(i);
    airport(i).airTaxi      = airTaxi(i);
    airport(i).itinerant    = itinerant(i);
    for j= i + 1 : totAirport
        % Compute Great Circle distance between two points
        distA2A(i, j) = distance(latAirport(i), longAirport(i), latAirport(j), longAirport(j));
    end;
end;

% Convert deg to nautical miles & save

distA2A = deg2sm(distA2A);

save airport airport;
save distA2A distA2A;
Script 4: Develop Struct arrays to associate airports with counties.
function dummy = createAprts4C(multipleOfRadius)

%--------------------------------------------------------------------------------------------
% Find Airports around each county within (multipleOfRadius * countyRadius(countyIndex))
%If there is no airport for a county, then find closest airport from the center of the county
%
%calling:
%called: createAttractTable
%--------------------------------------------------------------------------------------------
load distC2A;              % Count to Airport distance table
load countArea.txt         % County attribute table
countyRadius = multipleOfRadius .* sqrt(countArea ./ pi); %mile
for countyIndex   = 1 : size(distC2A, 1)     % for all county
    disp(['   createAprts4C, county = ' , num2str(countyIndex)]);
    totAirports4County = 0;
    county(countyIndex).airports = [];
    for airportIndex = 1 : size(distC2A, 2) % for all airports
        if distC2A(countyIndex, airportIndex) <= (multipleOfRadius * countyRadius(countyIndex))
            totAirports4County = totAirports4County + 1;
            county(countyIndex).airports(totAirports4County) = airportIndex;
        end
    end
    if(isempty(county(countyIndex).airports))
        %for non-airport county like 205
end
function dummy = createAttractTable()
% This script splits struct arrays into smaller units and computes attractiveness factors
% called:
% calling:
% createDistA2A; createDistC2A
% createDistC2C; createAprts4C
% computeAttractiveness
% clear all
% createDistA2A; save distA2A distA2A; % save airport airport;
% createDistC2A; save distC2A distC2A;
% createDistC2C; save distC2C distC2C;
% createAprts4C(1.2); % multipleOfRadius = 1.2. save aprts4C aprts4C;
load distA2A; %dist between airports
load distC2A; %dist between county & airport
load distC2C; %dist between county & county
load county; %airports around county
load airport; %airport information such as total GA flight, etc...

% START preparing struct data

%-----------------------------
%county: aprtRelAtt_1_150
%-----------------------------
aprtRelAtt_1_150(200, 3091).att_1 = [];
aprtRelAtt_1_150 = ...
computeAttractiveness(aprtRelAtt_1_150, 1, 151, distA2A, distC2A, distC2C, airport, county)
save aprtRelAtt_1_150 aprtRelAtt_1_150;
clear aprtRelAtt_1_150;

%-----------------------------
%county: aprtRelAtt_151_300
%-----------------------------
aprtRelAtt_151_300(200, 3091).att_1 = [];
aprtRelAtt_151_300 = ...
computeAttractiveness(aprtRelAtt_151_300, 151, 300, distA2A, distC2A, distC2C, airport, county)
save aprtRelAtt_151_300 aprtRelAtt_151_300;
clear aprtRelAtt_151_300;

%-----------------------------
%county: aprtRelAtt_301_500
%-----------------------------
aprtRelAtt_301_500(300, 3091).att_1 = [];
aprtRelAtt_301_500 = ...
computeAttractiveness(aprtRelAtt_301_500, 301, 500, distA2A, distC2A, distC2C, airport, county)
save aprtRelAtt_301_500 aprtRelAtt_301_500;
clear aprtRelAtt_301_500;

%-------------------------------
%county: aprtRelAtt_501_750
%-------------------------------
aprtRelAtt_501_750(250, 3091).att_1 = [];
aprtRelAtt_501_750 = ...
computeAttractiveness(aprtRelAtt_501_750, 501, 750, distA2A, distC2A, distC2C, airport, county)
save aprtRelAtt_501_750 aprtRelAtt_501_750;
clear aprtRelAtt_501_750;

%-------------------------------
%county: aprtRelAtt_751_1000
%-------------------------------
aprtRelAtt_751_1000(250, 3091).att_1 = [];
aprtRelAtt_751_1000 = ...
computeAttractiveness(aprtRelAtt_751_1000, 751, 1000, distA2A, distC2A, distC2C, airport, county)
save aprtRelAtt_751_1000 aprtRelAtt_751_1000;
clear aprtRelAtt_751_1000;

%-------------------------------
%county: aprtRelAtt_1001_1300
%-------------------------------
aprtRelAtt_1001_1300(300, 3091).att_1 = [];
aprtRelAtt_1001_1300 = ...
computeAttractiveness(aprtRelAtt_1001_1300, 1001, 1300, distA2A, distC2A, distC2C, airport, county)
save aprtRelAtt_1001_1300 aprtRelAtt_1001_1300;
clear aprtRelAtt_1001_1300;

%-------------------------------
%county: aprtRelAtt_1301_1600
aprtRelAtt_1301_1600(300, 3091).att_1 = []; 
aprtRelAtt_1301_1600 = ... 
computeAttractiveness(aprtRelAtt_1301_1600, 1301, 1600, distA2A, distC2A, distC2C, airport, county) 
save  aprtRelAtt_1301_1600 aprtRelAtt_1301_1600; 
clear aprtRelAtt_1301_1600; 

aprtRelAtt_1601_2000(400, 3091).att_1 = []; 
aprtRelAtt_1601_2000 = ... 
save  aprtRelAtt_1601_2000 aprtRelAtt_1601_2000; 
clear aprtRelAtt_1601_2000; 

aprtRelAtt_2001_2500(500, 3091).att_1 = []; 
aprtRelAtt_2001_2500 = ... 
save  aprtRelAtt_2001_2500 aprtRelAtt_2001_2500; 
clear aprtRelAtt_2001_2500; 

aprtRelAtt_2501_3091(591, 3091).att_1 = []; 
aprtRelAtt_2501_3091 = ... 
computeAttractiveness(aprtRelAtt_2501_3091, 2501, 3091, distA2A, distC2A, distC2C, airport, county) 
save  aprtRelAtt_2501_3091 aprtRelAtt_2501_3091; 
clear aprtRelAtt_2501_3091;
Script 6: Compute distance attractiveness factors

function airportRelativeAtt = computeAttractiveness(airportRelativeAtt, bOrgCounty, eOrgCounty, distA2A, distC2A, distC2C, airport, county)

%-----------------------------------------------------------------------
% This is a function to compute distance attractiveness factor
% called: createAttractTable
%-----------------------------------------------------------------------

%-------------------------------
%county: bOrgCounty -> eOrgCounty
%-------------------------------

for orgCnty = bOrgCounty : eOrgCounty
    if(mod(orgCnty, 5) == 0)
        disp(['   airportRelativeAtt, orgCnty = ', num2str(orgCnty)]);
    end
    for destCnty = orgCnty + 1 : 3091 %Symmetric !!!
        if(orgCnty == 135 & destCnty == 2439) end
        distorgCnty2destCnty = distC2C(orgCnty, destCnty);
        totAptInOrgCnty = size(county(orgCnty).airports, 2);
        totAptInDestCnty = size(county(destCnty).airports, 2);
    end
end
att_1 = zeros(totAprtInOrgCnty, totAprtInDestCnty);  % on the based aircraft
att_2 = zeros(totAprtInOrgCnty, totAprtInDestCnty);  % on the distance
relativeAtt_1 = zeros(totAprtInOrgCnty, totAprtInDestCnty);
relativeAtt_2 = zeros(totAprtInOrgCnty, totAprtInDestCnty);

% orgCnty -> destCounty;
for orgAprt = 1 : totAprtInOrgCnty
    for destAprt = 1 : totAprtInDestCnty
        orgAprtId  = county(orgCnty).airports(orgAprt);
destAprtId = county(destCnty).airports(destAprt);

        % attraction 1: based on aircraft based
        att_1(orgAprt, destAprt) = (airport(county(orgCnty).airports(orgAprt)).totGA ... 
*  airport(county(destCnty).airports(destAprt)).totGA);

        % attraction 2: based on distance
        orgCounty2orgAprt_Dist = distC2A(orgCnty, orgAprtId);
destAprt2destCounty_Dist = distC2A(destCnty, destAprtId);
tourDist = orgCounty2orgAprt_Dist ... 
+ orgAprt2destAprt_Dist ... 
+ destAprt2destCounty_Dist;
att_2(orgAprt, destAprt) = tourDist;
    end %for destAprt = 1: size(county(destCnty).airports)
end %for orgAprt = 1: size(county(orgCnty).airports)

% total Attractiveness of this airport pair

maxAttract_1 = max(max(att_1));
if(maxAttract_1 <= 0)
    airportRelativeAtt(orgCnty - bOrgCounty + 1, destCnty).att_1 = zeros(totAprtInOrgCnty, totAprtInDestCnty);
else
airportRelativeAtt(orgCnty - bOrgCounty + 1, destCnty).att_1 = round(att_1 / maxAttract_1 * 100);
end

airportRelativeAtt(orgCnty - bOrgCounty + 1, destCnty).att_2 = round(distC2C(orgCnty, destCnty) / att_2 * 100);
end %for orgCnty = 1 : 3091
end %for destCnt = 1 : 3091
return

Script 7: Main file
function dummy = airportChoiceModel()
%---------------------------------------------------------------------
% Main function of GA airport mode choice model
% Programmed By Hojong Baik & Senanu Ashiabor
% March, 2002
%
% Called: None
% Calling:
% distanceDistributionCDF
% compute_wholeProcesses
% summing
% computeRMSE
%---------------------------------------------------------------------
clear all
%
%Declaration
%---------------------------------------------------------------------
global airport county distC2C c2cPersonTripTable
global annualUtilz Occpn
%---------------------------------------------
%Load releavant data
%---------------------------------------------
load airport % for airport detail information
load county % for airports in each county
load distC2C % distance
load c2cPersonTripTable % for c2cPersonTripTable

%---------------------------------------------
%Weibul Distribution for aircraft choice
%---------------------------------------------
%Utilization
annualUtilz = [128 170 320];
Occpn = [1.7 2.4 3.0];
% cdf, pdf market share (ms) over distance using Weibul distance
% For example, singleEngineStatOverDist = [31x4]
% 1st Column = dist by 100
% 2nd Column = cfd
% 3rd Column = pdf
% 4th Column = frequency

[dist, singleEngineStatOverDist, multiEngineStatOverDist, jetEngineStatOverDist] = distanceDistributionCDF(0, 100, 3000);
% market share for three aircraft types over distance

singleEngineStatOverDist(1,4) = singleEngineStatOverDist(2,4);
multiEngineStatOverDist(1,4) = multiEngineStatOverDist(2,4);
jetEngineStatOverDist(1,4) = jetEngineStatOverDist(2,4);
totFreq = singleEngineStatOverDist(:,4) + multiEngineStatOverDist(:,4) + jetEngineStatOverDist(:,4);
ms_singleEgine = singleEngineStatOverDist(:,4) ./ totFreq;
ms_multiEgine = multiEngineStatOverDist(:,4) ./ totFreq;
ms_JetEgine = 1 - ms_singleEgine - ms_multiEgine;

%------------------------------------
% Initialization
%------------------------------------

bestRMSE = inf;
bestAlpha1 = inf;
bestAlpha2 = inf;

startAlpha_1 = 0; stepSizeForalpha_1 = 1; limitAlpha_1 = 2;
startAlpha_2 = 0; stepSizeForalpha_2 = 0.001; limitAlpha_2 = 0.01;
totAirports = size(airport,2);

sizeAlpha1 = round((limitAlpha_1 - startAlpha_1 + 1) / stepSizeForalpha_1);
sizeAlpha2 = round((limitAlpha_2 - startAlpha_2 + 1) / stepSizeForalpha_2);
totOperationEst(sizeAlpha1, sizeAlpha2) = struct('alpha1', [], 'alpha2', [], 'RMSE', [], 'ops', [], 'ratio', []);

%------------------------------------
% Calibration
%------------------------------------

alpha1_index = 0;
for alpha1 = 0.8 %startAlpha_1 : stepSizeForalpha_1 : limitAlpha_1
alpha1_index = alpha1_index + 1;
alpha2_index = 0;
for alpha2 = startAlpha_2 : stepSizeForalpha_2 : limitAlpha_2

alpha2_index = alpha2_index + 1;

if(alpha1 > 0 | alpha2 > 0)

    a2aPersonTripTable_tot = sparse(totAirports + 1, totAirports + 1); %unit = persons
    a2aPersonTripTable_SE = sparse(totAirports + 1, totAirports + 1); %unit = persons
    a2aPersonTripTable_ME = sparse(totAirports + 1, totAirports + 1); %unit = persons
    a2aPersonTripTable_JE = sparse(totAirports + 1, totAirports + 1); %unit = persons

    a2aAircraftTripTable_tot = sparse(totAirports + 1, totAirports + 1); %unit = aircraft
    a2aAircraftTripTable_SE = sparse(totAirports + 1, totAirports + 1); %unit = aircraft
    a2aAircraftTripTable_ME = sparse(totAirports + 1, totAirports + 1); %unit = aircraft
    a2aAircraftTripTable_JE = sparse(totAirports + 1, totAirports + 1); %unit = aircraft

    airportRelativeAtt = [];

tic

%------------------------------------------------
%Start Computing a2aAircraftTripTable by Mode
%------------------------------------------------

load aprtRelAtt_1_150;  bOrgCnty = 1;    eOrgCnty = 150;
airportRelativeAtt = aprtRelAtt_1_150;
clear aprtRelAtt_1_150;
compute_wholeProcesses(bOrgCnty, eOrgCnty, alpha1, alpha2);

load aprtRelAtt_151_300;  bOrgCnty = 151;  eOrgCnty = 300;
airportRelativeAtt = aprtRelAtt_151_300;
clear aprtRelAtt_151_300;
compute_wholeProcesses(bOrgCnty, eOrgCnty, alpha1, alpha2);

load aprtRelAtt_301_500; bOrgCnty = 301; eOrgCnty = 500;
airportRelativeAtt = aprtRelAtt_301_500;
clear aprtRelAtt_301_500;
compute_wholeProcesses(bOrgCnty, eOrgCnty, alpha1, alpha2);

load aprtRelAtt_501_750; bOrgCnty = 501; eOrgCnty = 750;
airportRelativeAtt = aprtRelAtt_501_750;
clear aprtRelAtt_501_750;
compute_wholeProcesses(bOrgCnty, eOrgCnty, alpha1, alpha2);

load aprtRelAtt_751_1000; bOrgCnty = 751; eOrgCnty = 1000;
airportRelativeAtt = aprtRelAtt_751_1000;
clear aprtRelAtt_751_1000;
compute_wholeProcesses(bOrgCnty, eOrgCnty, alpha1, alpha2);

load aprtRelAtt_1001_1300; bOrgCnty = 1001; eOrgCnty = 1300;
airportRelativeAtt = aprtRelAtt_1001_1300;
clear aprtRelAtt_1001_1300;
compute_wholeProcesses(bOrgCnty, eOrgCnty, alpha1, alpha2);

load aprtRelAtt_1301_1600; bOrgCnty = 1301; eOrgCnty = 1600;
airportRelativeAtt = aprtRelAtt_1301_1600;
clear aprtRelAtt_1301_1600;
compute_wholeProcesses(bOrgCnty, eOrgCnty, alpha1, alpha2);

load aprtRelAtt_1601_2000; bOrgCnty = 1601; eOrgCnty = 2000;
airportRelativeAtt = aprtRelAtt_1601_2000;
clear aprtRelAtt_1601_2000;
compute_wholeProcesses(bOrgCnty, eOrgCnty, alpha1, alpha2);

load aprtRelAtt_2001_2500; bOrgCnty = 2001; eOrgCnty = 2500;
airportRelativeAtt = aprtRelAtt_2001_2500;
clear aprtRelAtt_2001_2500;
compute_wholeProcesses(bOrgCnty, eOrgCnty, alpha1, alpha2);

load aprtRelAtt_2501_3091; bOrgCnty = 2501; eOrgCnty = 3091;
airportRelativeAtt = aprtRelAtt_2501_3091;
clear aprtRelAtt_2501_3091;
compute_wholeProcesses(bOrgCnty, eOrgCnty, alpha1, alpha2);

clear airportRelativeAtt;

%------------------------------------------------
% End of computing a2aAircraftTripTable by Mode
%------------------------------------------------
toc

clear a2aPersonTripTable;

%------------------------------------------------
% Save
%------------------------------------------------
save a2aPersonTripTable_SE a2aPersonTripTable_SE
save a2aPersonTripTable_ME a2aPersonTripTable_ME
save a2aPersonTripTable_JE a2aPersonTripTable_JE

save a2aAircraftTripTable_SE a2aAircraftTripTable_SE
save a2aAircraftTripTable_ME a2aAircraftTripTable_ME
save a2aAircraftTripTable_JE a2aAircraftTripTable_JE

%------------------------------------------------
% Load
%------------------------------------------------
load a2aPersonTripTable_SE
load a2aPersonTripTable_ME
load a2aPersonTripTable_JE
load a2aAircraftTripTable_SE
load a2aAircraftTripTable_ME
load a2aAircraftTripTable_JE

%------------------------------------------------------
% Summing up, save and clear
%------------------------------------------------------
summing; % for a2aPersonTripTable_SE, a2aPersonTripTable_ME, a2aPersonTripTable_JE
a2aPersonTripTable_tot   = a2aPersonTripTable_SE   + a2aPersonTripTable_ME   + a2aPersonTripTable_JE;
save a2aPersonTripTables    a2aPersonTripTable_SE    a2aPersonTripTable_ME   a2aPersonTripTable_JE;
clear a2aPersonTripTable_SE    a2aPersonTripTable_ME   a2aPersonTripTable_JE;
save  a2aPersonTripTable_tot   a2aPersonTripTable_tot;
clear a2aPersonTripTable_tot

%------------------------------------------------------
% Doubly counting for (2-way trips table) - for LMI
%------------------------------------------------------
%aircraft trips
a2aAircraftTripTable_SE_2way  = a2aAircraftTripTable_SE + a2aAircraftTripTable_SE';
clear a2aAircraftTripTable_SE;
a2aAircraftTripTable_ME_2way  = a2aAircraftTripTable_ME + a2aAircraftTripTable_ME';
clear a2aAircraftTripTable_ME;
a2aAircraftTripTable_JE_2way  = a2aAircraftTripTable_JE + a2aAircraftTripTable_JE';
clear a2aAircraftTripTable_JE;
a2aAircraftTripTable_tot_2way = a2aAircraftTripTable_SE_2way + a2aAircraftTripTable_ME_2way + a2aAircraftTripTable_JE_2way;
save a2aAircraftTripTable_SE_2way  a2aAircraftTripTable_SE_2way;
%clear a2aAircraftTripTable_SE_2way;
save a2aAircraftTripTable_ME_2way  a2aAircraftTripTable_ME_2way;
%clear a2aAircraftTripTable_ME_2way;
save a2aAircraftTripTable_JE_2way  a2aAircraftTripTable_JE_2way;
%clear a2aAircraftTripTable_JE_2way;
save a2aAircraftTripTable_tot_2way a2aAircraftTripTable_tot_2way;
% clear a2aAircraftTripTable_tot_2way;

%------------------------------------------------------
% Operations for each airport
%  - for RMSE
%------------------------------------------------------

a2aAircraftTripTable_SE_ops = a2aAircraftTripTable_SE_2way * 2; % clear a2aAircraftTripTable_SE_2way;
a2aAircraftTripTable_ME_ops = a2aAircraftTripTable_ME_2way * 2; % clear a2aAircraftTripTable_ME_2way;
a2aAircraftTripTable_JE_ops = a2aAircraftTripTable_JE_2way * 2; % clear a2aAircraftTripTable_JE_2way;
a2aAircraftTripTable_tot_ops = a2aAircraftTripTable_SE_ops + a2aAircraftTripTable_ME_ops + a2aAircraftTripTable_JE_ops;

save a2aAircraftTripTable_SE_ops a2aAircraftTripTable_SE_ops; % clear a2aAircraftTripTable_SE_ops;
save a2aAircraftTripTable_ME_ops a2aAircraftTripTable_ME_ops; % clear a2aAircraftTripTable_ME_ops;
save a2aAircraftTripTable_JE_ops a2aAircraftTripTable_JE_ops; % clear a2aAircraftTripTable_JE_ops;
save a2aAircraftTripTable_tot_ops a2aAircraftTripTable_tot_ops; % clear a2aAircraftTripTable_tot_ops;

%------------------------------------------------------
% Compute RMSE (Root Mean Square Error)
%------------------------------------------------------

totOperationEst = computeRMSE(alpha1, alpha2, alpha1_index, alpha2_index, totOperationEst); % call function "computeRMSE"

save totOperationEst totOperationEst;

if(totOperationEst(alpha1_index, alpha2_index).RMSE < bestRMSE)
    bestRMSE = totOperationEst(alpha1_index, alpha2_index).RMSE;
    bestAlpha1 = alpha1;
    bestAlpha2 = alpha2;
    save output_bestTables a2aPersonTripTable_tot ...
        a2aPersonTripTable_SE ...
        a2aPersonTripTable_ME ...
        a2aPersonTripTable_JE ...
        a2aAircraftTripTable_tot ...
function [distNautMile, singleEngine, multiEngine, jetEngine] = distanceDistributionCDF(iniDistance, stepSizeDist, limitDist)
    distNautMile = iniDistance:stepSizeDist:limitDist;
    freqrow = zeros(3,(limitDist/stepSizeDist+1))';
    freq200 = [355 705 155];
    freqrow(3,:) = freq200;

    Script 8: Modification of LMI distance distribution function
    % Program to derive cdf for distance b/n counties for various aircraft type
    % By: Senanu Ashiabor, March, 2002
    % Called: airportChoiceModel_3

    format long
    distNautMile = iniDistance:stepSizeDist:limitDist;
    freqrow = zeros(3,(limitDist/stepSizeDist+1))';
    freq200 = [355 705 155];
    freqrow(3,:) = freq200;
scale = [237 289 826];
shape = [1.15 1.16 1.14];
for i = 1:3
    cdf(i,:) = (1 - exp(-(distNautMile./scale(i)).^shape(i)));
    differenceCDF(i,:) = [ 0 diff(cdf(i,:))];
end

factor           = freqrow(3,:) ./ differenceCDF(:,3)';
singleEngineFreq = (differenceCDF(:,1) .* factor(1))';
multiEngineFreq  = (differenceCDF(:,2) .* factor(2))';
jetEngineFreq    = (differenceCDF(:,3) .* factor(3))';

singleEngine   = [distNautMile'   cdf(1,:)'  differenceCDF(1,:)'  singleEngineFreq];
multiEngine    = [distNautMile'   cdf(1,:)'  differenceCDF(1,:)'  multiEngineFreq];
jetEngine      = [distNautMile'   cdf(1,:)'  differenceCDF(1,:)'  jetEngineFreq];

plot(distNautMile,cdf(1,:),' --' ,distNautMile,cdf(2,:),' o' ,distNautMile,cdf(3,:),' -' );
title(' CUMILATIVE DENSITY FUNCTION OF SINGLE, MULTI AND JET ENGINE AIRCRAFT')
ylabel('Cumulative Density (%)')
xlabel('Distance (Nautical Miles)')
legend('Single Engine','Multi-Engine','Jet Engine')

Script 9: Generates aircraft trip tables by aircraft type
function dummy = compute_wholeProcesses(bOrgCnty, eOrgCnty, alpha1, alpha2)
%-----------------------------------------------------------------------
% Receives from main file and passes files to functions (see lines below)
% computes relative attractiveness values and generates trips between airports
% Programmed By Hojong Baik,
% March, 2002
%Called: airportChoiceModel
%Calling:
%    compute_a2a_pTripTable
%    compute_a2a_pTripTable_type; compute_a2a_aTripTable_type
%    add_a2aPrsnTripTables_type; add_a2aAcftTripTables_type;
%-------------------------------------------------------------------------------

global airport county distC2C c2cPersonTripTable

global a2aPersonTripTable

global annualUtilz Occpn

global airportRelativeAtt

global ms_singleEgine           ms_multiEgine            ms_jetEgine

global a2aAircraftTripTable_SE  a2aAircraftTripTable_ME  a2aAircraftTripTable_JE

global a2aPersonTripTable_SE    a2aPersonTripTable_ME    a2aPersonTripTable_JE

a2a_assignedPerson_tot = 0;
c2c_assignedPerson_tot = 0;
c2cPersonTripTable_tot = 0;

for orgCnty  = bOrgCnty : eOrgCnty
    disp(
        ['(a_1, a_2) = (' , num2str(alpha1),' , ' , num2str(alpha2), '): (bCnty, cCnty, endCnty) = (' , num2str(bOrgCnty),' , ' , num2str(orgCnty), ' , ' , num2str(eOrgCnty), ' )']);
    for destCnty = orgCnty + 1 : 3091
        distC2C_this       = distC2C(orgCnty, destCnty); %Great Circle Distance from org- to dest county
        totAprtsInOrgCnty  = size(county(orgCnty).airports, 2);
        totAprtsInDestCnty = size(county(destCnty).airports, 2);
        relativeAtt_1   = [];
        relativeAtt_2   = [];

relativeAtt_tot = [];

relativeAtt_1 = airportRelativeAtt(orgCnty - bOrgCnty + 1, destCnty).att_1;
relativeAtt_2 = airportRelativeAtt(orgCnty - bOrgCnty + 1, destCnty).att_2;
relativeAtt_tot = round((relativeAtt_1 .^ alpha1) ./ (relativeAtt_2 .^ alpha2) .* 100);
sum_relativeAtt_tot = sum(sum(relativeAtt_tot));

c2cPersonTrip_org_dest = c2cPersonTripTable(orgCnty, destCnty);
c2cPersonTrip_dest_org = c2cPersonTripTable(destCnty, orgCnty);

%-----------------------
%Origin -> Destination
%-----------------------
if(c2cPersonTrip_org_dest > 0)
    % Step 1: compute a2a person trip table
    a2a_pTripTable = zeros(totAprtsInOrgCnty, totAprtsInDestCnty);
    a2a_pTripTable = compute_a2a_pTripTable(a2a_pTripTable, relativeAtt_tot, c2cPersonTrip_org_dest);
    a2a_pTripTable_SE = zeros(totAprtsInOrgCnty, totAprtsInDestCnty);
    a2a_pTripTable_ME = zeros(totAprtsInOrgCnty, totAprtsInDestCnty);
    a2a_pTripTable_JE = zeros(totAprtsInOrgCnty, totAprtsInDestCnty);
    [a2a_pTripTable_SE, a2a_pTripTable_ME, a2a_pTripTable_JE] = compute_a2a_pTripTable_type(orgCnty, a2a_pTripTable, distC2C_this, a2a_pTripTable_SE, a2a_pTripTable_ME, a2a_pTripTable_JE, c2cPersonTrip_org_dest);

    a2a_pTripTable_tot = a2a_pTripTable_SE + a2a_pTripTable_ME + a2a_pTripTable_JE;
    a2a_assignedPerson_tot = a2a_assignedPerson_tot + sum(sum(a2a_pTripTable_tot));
    a2a_pTripTable_SE = zeros(totAprtsInOrgCnty, totAprtsInDestCnty);
    a2a_pTripTable_ME = zeros(totAprtsInOrgCnty, totAprtsInDestCnty);
    a2a_pTripTable_JE = zeros(totAprtsInOrgCnty, totAprtsInDestCnty);
\[ \text{[a2a\_aTripTable\_SE, a2a\_aTripTable\_ME, a2a\_aTripTable\_JE]} = \text{compute\_a2a\_aTripTable\_type(a2a\_pTripTable\_SE, a2a\_pTripTable\_ME, a2a\_pTripTable\_JE, a2a\_aTripTable\_SE, a2a\_aTripTable\_ME, a2a\_aTripTable\_JE)}; \]

\text{add\_a2aPrsnTripTables\_type(\text{orgCnty, destCnty, a2a\_pTripTable\_SE, a2a\_pTripTable\_ME, a2a\_pTripTable\_JE});} \]

\text{add\_a2aAcftTripTables\_type(\text{orgCnty, destCnty, a2a\_aTripTable\_SE, a2a\_aTripTable\_ME, a2a\_aTripTable\_JE});} \]

\text{end \%if(c2cPersonTrip\_org\_dest > 0)}

%-------------------------------
%Destination -> Origin
%-------------------------------

\text{if(c2cPersonTrip\_dest\_org > 0)}

\text{temp} = \text{totAprtsInOrgCnty};
\text{totAprtsInOrgCnty} = \text{totAprtsInDestCnty};
\text{totAprtsInDestCnty} = \text{temp};

\text{orgCnty\_} = \text{destCnty};
\text{destCnty\_} = \text{orgCnty};

\text{relativeAtt\_tot = relativeAtt\_tot};

%\[ \text{[a2a\_aTripTable\_SE, a2a\_aTripTable\_ME, a2a\_aTripTable\_JE]} ... \]
\% \text{ = compute\_wholeProcesses(totAprtsInOrgCnty, totAprtsInDestCnty, orgCnty, ...}
\% \text{ relativeAtt\_tot, c2cPersonTrip\_dest\_org, distC2C\_this);} \]

\%Step 1: compute a2a person trip table
\text{a2a\_pTripTable} = \text{zeros(totAprtsInOrgCnty, totAprtsInDestCnty});
\text{a2a\_pTripTable} = \text{compute\_a2a\_pTripTable(a2a\_pTripTable, relativeAtt\_tot, c2cPersonTrip\_dest\_org)};

\text{a2a\_pTripTable\_SE} = \text{zeros(totAprtsInOrgCnty, totAprtsInDestCnty)};
\text{a2a\_pTripTable\_ME} = \text{zeros(totAprtsInOrgCnty, totAprtsInDestCnty)};
\text{a2a\_pTripTable\_JE} = \text{zeros(totAprtsInOrgCnty, totAprtsInDestCnty)};
\text{[a2a\_pTripTable\_SE, a2a\_pTripTable\_ME, a2a\_pTripTable\_JE]} = \text{compute\_a2a\_pTripTable\_type(orgCnty\_, a2a\_pTripTable, distC2C\_this, a2a\_pTripTable\_SE, a2a\_pTripTable\_ME, a2a\_pTripTable\_JE, c2cPersonTrip\_dest\_org);} \]
\[
a_{2a\_p\text{TripTable\_tot}} = a_{2a\_p\text{TripTable\_SE}} + a_{2a\_p\text{TripTable\_ME}} + a_{2a\_p\text{TripTable\_JE}}; \\
\text{a2a\_assignedPerson\_tot} = \text{a2a\_assignedPerson\_tot} + \text{sum}(\text{sum}(\text{a2a\_p\text{TripTable\_tot}})); \\
\]

\[
a_{2a\_a\text{TripTable\_SE}} = \text{zeros}(\text{tot\text{AprtsInOrgCnty}}, \text{tot\text{AprtsInDestCnty}}); \\
\text{a2a\_a\text{TripTable\_ME}} = \text{zeros}(\text{tot\text{AprtsInOrgCnty}}, \text{tot\text{AprtsInDestCnty}}); \\
\text{a2a\_a\text{TripTable\_JE}} = \text{zeros}(\text{tot\text{AprtsInOrgCnty}}, \text{tot\text{AprtsInDestCnty}}); \\
[a_{2a\_a\text{TripTable\_SE}}, a_{2a\_a\text{TripTable\_ME}}, a_{2a\_a\text{TripTable\_JE}}] = \text{compute\_a2a\_aTripTable\_type}(a_{2a\_p\text{TripTable\_SE}}, a_{2a\_p\text{TripTable\_ME}}, a_{2a\_p\text{TripTable\_JE}}); \\
\text{add\_a2aPrsnTripTables\_type}(\text{orgCnty\_}, \text{destCnty\_}, a_{2a\_p\text{TripTable\_SE}}, a_{2a\_p\text{TripTable\_ME}}, a_{2a\_p\text{TripTable\_JE}}); \\
\text{add\_a2aAcftTripTables\_type}(\text{orgCnty\_}, \text{destCnty\_}, a_{2a\_a\text{TripTable\_SE}}, a_{2a\_a\text{TripTable\_ME}}, a_{2a\_a\text{TripTable\_JE}}); \\
\text{end}
\]

\[
c_{2c\text{PersonTripTable\_tot}} = c_{2c\text{PersonTripTable\_tot}} + c_{2c\text{PersonTrip\_org\_dest}} + c_{2c\text{PersonTrip\_dest\_org}}; \\
\]

\[
\text{if}(c_{2c\text{PersonTripTable\_tot}} == \text{a2a\_assignedPerson\_tot}) \\
\text{end}
\]

\[
\text{end for orgCnty\_} = 1 : 3091 \\
\text{end for destCnty\_} = \text{orgCnty\_} + 1 : 3091 \\
\text{return}
\]

**Script 10: Sum Airport to Airport Person Trip Tables**

function dummy = add\_a2aPrsnTripTables\_type(\text{orgCnty\_, destCnty\_, } a_{2a\_p\text{TripTable\_SE}}, a_{2a\_p\text{TripTable\_ME}}, a_{2a\_p\text{TripTable\_JE}})

%--------------------------------------------------------------------------------------------
% Sums Airport to Airport Person Trip tables developed in compute\_wholeprocess
% Programmed By Hojong Baik,
% March, 2002
% Called: compute\_wholeProcesses
% Calling: None
%--------------------------------------------------------------------------------------------

global county

global a2aPersonTripTable\_SE a2aPersonTripTable\_ME a2aPersonTripTable\_JE
for orgAirport = 1: size(a2a_pTripTable_SE, 1) %totNoOfAirportsInOrgCounty
for destAirport = 1: size(a2a_pTripTable_SE, 2) %totNoOfAirportsInDestCounty

    orgAirportId  = county(orgCnty).airports(orgAirport);
    destAirportId = county(destCnty).airports(destAirport);

    % cummulate
    a2aPersonTripTable_SE(orgAirportId, destAirportId) ... 
        = a2aPersonTripTable_SE(orgAirportId, destAirportId) ... 
            + a2a_pTripTable_SE(orgAirport, destAirport);

    a2aPersonTripTable_ME(orgAirportId, destAirportId) ... 
        = a2aPersonTripTable_ME(orgAirportId, destAirportId) ... 
            + a2a_pTripTable_ME(orgAirport, destAirport);

    a2aPersonTripTable_JE(orgAirportId, destAirportId) ... 
        = a2aPersonTripTable_JE(orgAirportId, destAirportId) ... 
            + a2a_pTripTable_JE(orgAirport, destAirport);

end
end
return
function dummy = add_a2aAcftTripTables_type(orgCnty, destCnty, a2a_aTripTable_SE, a2a_aTripTable_ME, a2a_aTripTable_JE)
%
%--------------------------------------------------------------------------------------------
% Sums Airport to Airport Aircraft Trip tables developed in compute_wholeprocess
% Programmed By Hojong Baik,
% March, 2002
% Called: compute_wholeProcesses
% Calling: None
%
%--------------------------------------------------------------------------------------------

global county

global a2aAircraftTripTable_SE a2aAircraftTripTable_ME a2aAircraftTripTable_JE

for orgAirport = 1: size(a2a_aTripTable_SE, 1) %totNoOfAirportsInOrgCounty
for destAirport = 1: size(a2a_aTripTable_SE, 2) %totNoOfAirportsInDestCounty

    orgAirportId = county(orgCnty).airports(orgAirport);
destAirportId = county(destCnty).airports(destAirport);

    a2aAircraftTripTable_SE(orgAirportId, destAirportId) ... = a2aAircraftTripTable_SE(orgAirportId, destAirportId) ... + a2a_aTripTable_SE(orgAirport, destAirport);

    a2aAircraftTripTable_ME(orgAirportId, destAirportId) ... = a2aAircraftTripTable_ME(orgAirportId, destAirportId) ... + a2a_aTripTable_ME(orgAirport, destAirport);

    a2aAircraftTripTable_JE(orgAirportId, destAirportId) ... = a2aAircraftTripTable_JE(orgAirportId, destAirportId) ... + a2a_aTripTable_JE(orgAirport, destAirport);

end
end

return
Script 12: Generate airport to airport person trip table from county to county trips

function a2a_pTripTable = compute_a2a_pTripTable(a2a_pTripTable, relativeAtt_tot, c2c_pTrip)

%---------------------------------------------------------------------------------
% Generate airport to airport person trip table from county to county trips
%
% Programmed By Hojong Baik,
% March, 2002
% Called: compute_wholeProcesses
% Calling: None
%---------------------------------------------------------------------------------
%---------------------------------------------------------------------------------
%Get a2aAcraftTripTable_SE, a2aAcraftTripTable_ME, a2aAcraftTripTable_JE.
% Via two steps
% Step 1) Split "c2cPersonTripTable" to "a2aPersonTripTable"
% Step 2) Split "a2aPersonTripTable" by a2aAircraftTripTable
% outputs: a2aAcraftTripTable_SE, a2aAcraftTripTable_ME, a2aAcraftTripTable_JE,
%---------------------------------------------------------------------------------
sum_relativeAtt_tot = sum(sum(relativeAtt_tot));
\[
\text{if}(\text{sum\_relativeAtt\_tot} > 0)
\]
\[
\text{att\_ratio} = \text{zeros(size(relativeAtt\_tot))};
\]
\[
\text{att\_ratio} = \text{relativeAtt\_tot} / \text{sum\_relativeAtt\_tot};
\]
\[
\text{att\_ratio} = \text{round(att\_ratio} \times 100000) / 100000;
\]
\[
a2a\_pTripTable = \text{round(c2c\_pTrip} \times \text{att\_ratio});
\]

% correct the diffTotTrip
\[
diffTotTrip = c2c\_pTrip - \text{sum(sum(a2a\_pTripTable))};
\]

if(diffTotTrip > 0)
\[
\text{att\_ratio\_} = \text{zeros(size(relativeAtt\_tot))};
\]
\[
\text{att\_ratio\_} = \text{att\_ratio} - \text{max(max(att\_ratio))} + 0.0001;
\]
\[
\text{sparse\_att\_ratio} = \text{sparse(att\_ratio\_)};
\]
\[
[\text{maxIndexRow maxIndexCol}] = \text{find(sparse\_att\_ratio} > 0);
\]

% tie break
\[
\text{tot\_fixed} = 0;
\]
for ii = 1:size(maxIndexRow, 1)
\[
a2a\_pTripTable(maxIndexRow(ii), maxIndexCol(ii)) ...
\]
\[
= a2a\_pTripTable(maxIndexRow(ii), maxIndexCol(ii)) ...
\]
\[
+ 1;
\]
\[
\text{tot\_fixed} = \text{tot\_fixed} + 1;
\]
if(tot\_fixed == diffTotTrip)
\[
\text{break};
\]
end
\]
end
if(tot\_fixed < diffTotTrip)
\[
a2a\_pTripTable(maxIndexRow(size(maxIndexRow, 1)), maxIndexCol(size(maxIndexRow, 1))) ...
\]
\[
= a2a\_pTripTable(maxIndexRow(size(maxIndexRow, 1)), maxIndexCol(size(maxIndexRow, 1))) ...
\]
\[
+ \text{diffTotTrip} - \text{tot\_fixed};
\]
end
\]
elseif(diffTotTrip < 0)
[iIndices, jIndices] = find(a2a_pTripTable);
for ii = 1:diffTotTrip
    a2a_pTripTable(iIndices(ii), jIndices(ii)) ...
    = a2a_pTripTable(iIndices(ii), jIndices(ii)) - 1;
end
end
else % i.e., sum_relativeAtt_tot = 0
a2a_pTripTable = round(c2c_pTrip * ones(size(relativeAtt_tot))./ (size(relativeAtt_tot, 1) * size(relativeAtt_tot, 2)));
att_ratio = ones(size(relativeAtt_tot)) + 1 / (size(relativeAtt_tot, 1) * size(relativeAtt_tot, 2));

% correct the diffTotTrip
diffTotTrip = c2c_pTrip - sum(sum(a2a_pTripTable));

% fixing difference
if(diffTotTrip > 0)
a2a_pTripTable(1, 1) = a2a_pTripTable(1, 1) + diffTotTrip;
elseif(diffTotTrip < 0)
    [iIndices, jIndices] = find(a2a_pTripTable);
    for ii = 1:diffTotTrip
        a2a_pTripTable(iIndices(ii), jIndices(ii)) ...
        = a2a_pTripTable(iIndices(ii), jIndices(ii)) - 1;
    end
end
end
if (sum(sum(a2a_pTripTable)) > c2c_pTrip | sum(sum(a2a_pTripTable)) < c2c_pTrip)
end
return

Script 13: Convert Airport to Airport Person trips to Person trips by Aircraft type
function [a2a_pTripTable_SE, a2a_pTripTable_ME, a2a_pTripTable_JE] = compute_a2a_pTripTable_type(orgCnty, a2a_pTripTable, distC2C_this,...
a2a_pTripTable_SE, a2a_pTripTable_ME, a2a_pTripTable_JE, c2c_pTrip)
%----------------------------------------------------------------------------------
% Convert Airport to Airport Person trips to Person trips by Aircraft type
% Programmed By Hojong Baik,
% March, 2002
% Called: compute_wholeProcesses
% Calling: None
%----------------------------------------------------------------------------------
%----------------------------------------------------------------------------------
% Split a2a persons to a2a persons by aircraft type.
% To get a2aAcraftTripTable_SE, a2aAcraftTripTable_ME, a2aAcraftTripTable_JE.
% via a2aPersonTripTable_SE, a2aPersonTripTable_ME, a2aPersonTripTable_JE.
%----------------------------------------------------------------------------------
% To get a2aPersonTripTable_SE, a2aPersonTripTable_ME, a2aPersonTripTable_JE
% global airport county
% global annualUtilz ms_singleEgine ms_multiEgine ms_jetEgine Occpn

for orgAirport = 1: size(a2a_pTripTable, 1)
    for destAirport = 1: size(a2a_pTripTable, 2)
        if(a2a_pTripTable(orgAirport, destAirport) > 0)
            orgAirportId = county(orgCnty).airports(orgAirport);

            indexForMS = ceil(distC2C_this/ 100);
            if(indexForMS > 31) indexForMS = 31; end

            attract_SE = airport(orgAirportId).singleEngine * annualUtilz(1) * ms_singleEgine(indexForMS) * Occpn(1);
            attract_ME = airport(orgAirportId).multiEngine * annualUtilz(2) * ms_multiEgine(indexForMS) * Occpn(2);
            attract_JE = airport(orgAirportId).jetEngine * annualUtilz(3) * ms_jetEngine(indexForMS) * Occpn(3);
            attract_tot = attract_SE + attract_ME + attract_JE;

            if(attract_tot > 0)
ratio_attract_SE = attract_SE / attract_tot;
ratio_attract_ME = attract_ME / attract_tot;
ratio_attract_JE = attract_JE / attract_tot;
else
    ratio_attract_SE = .6;
    ratio_attract_ME = .3;
    ratio_attract_JE = .1;
end

a2a_pTripTable_SE(orgAirport, destAirport) = round(a2a_pTripTable(orgAirport, destAirport) * ratio_attract_SE);
a2a_pTripTable_ME(orgAirport, destAirport) = round(a2a_pTripTable(orgAirport, destAirport) * ratio_attract_ME);
a2a_pTripTable_JE(orgAirport, destAirport) = round(a2a_pTripTable(orgAirport, destAirport) * ratio_attract_JE);

if(diffTotTrip > 0 | diffTotTrip < 0)
    att_ratio = [ratio_attract_SE ratio_attract_ME ratio_attract_JE];
    att_ratio_ = att_ratio - max(att_ratio) + 0.000001;
    sparse_att_ratio = sparse(att_ratio_);
    [maxIndexRow maxIndexCol] = find(sparse_att_ratio > 0);
    switch(maxIndexCol)
case 1,
    a2a_pTripTable_SE(orgAirport, destAirport) ... 
    = a2a_pTripTable_SE(orgAirport, destAirport) ... 
    + diffTotTrip;

case 2,
    a2a_pTripTable_ME(orgAirport, destAirport) ... 
    = a2a_pTripTable_ME(orgAirport, destAirport) ... 
    + diffTotTrip;

case 3,
    a2a_pTripTable_JE(orgAirport, destAirport) ... 
    = a2a_pTripTable_JE(orgAirport, destAirport) ... 
    + diffTotTrip;

end %switch(maxIndexCol)

% elseif()
%     [iIndices jIndices] = find(a2a_pTripTable);
%     for ii = 1: -diffTotTrip
%         a2a_pTripTable(iIndices(ii), jIndices(ii)) ... 
%         = a2a_pTripTable(iIndices(ii), jIndices(ii)) - 1;
%     end
% end
% (diffTotTrip > 0 | diffTotTrip < 0)
% end % if(a2aPersonTripTable(orgAirportId, destAirportId) > 0)

end % for orgAirport = 1: totNoOfAirportsInOrgCounty
end % for destAirport = 1: totNoOfAirportsInDestCounty

tot__ = sum(sum(a2a_pTripTable_SE)) + sum(sum(a2a_pTripTable_ME)) + sum(sum(a2a_pTripTable_JE));

if(tot__ > c2c_pTrip | tot__ < c2c_pTrip)
    asdads = 1;
end
return
**Script 14: Apply Occupancy factor to convert Person trips by Aircraft type to Aircraft trips**

function [a2a_aTripTable_SE, a2a_aTripTable_ME, a2a_aTripTable_JE] = compute_a2a_aTripTable_type(a2a_pTripTable_SE, a2a_pTripTable_ME, a2a_pTripTable_JE, a2a_aTripTable_SE, a2a_aTripTable_ME, a2a_aTripTable_JE)

%--------------------------------------------------------------------------
% Convert person trips to aircraft trips using occupancy factor
% Programmed By Hojong Baik, March, 2002
% Called: compute_wholeProcesses
% Calling: None
%--------------------------------------------------------------------------

global Occpn

for orgAirport = 1: size(a2a_pTripTable_SE,1)
    for destAirport = 1: size(a2a_pTripTable_SE,2)
        a2a_aTripTable_SE(orgAirport, destAirport) ...
            = ceil(a2a_pTripTable_SE(orgAirport, destAirport) / Occpn(1));

        a2a_aTripTable_ME(orgAirport, destAirport) ...
            = ceil(a2a_pTripTable_ME(orgAirport, destAirport) / Occpn(2));

        a2a_aTripTable_JE(orgAirport, destAirport) ...
            = ceil(a2a_pTripTable_JE(orgAirport, destAirport) / Occpn(3));

    end % for orgAirport = 1: totNoOfAirportsInOrgCounty
end % for destAirport = 1: totNoOfAirportsInDestCounty

return
Script 15: Sum Airport to Airport Person trip tables

function dummy = summingUp()

%--------------------------------------------------------------------------
% Sum Airport to Airport Person trip tables
%--------------------------------------------------------------------------

global a2aAircraftTripTable_SE a2aAircraftTripTable_ME a2aAircraftTripTable_JE

global a2aPersonTripTable_SE a2aPersonTripTable_ME a2aPersonTripTable_JE

[mSize1, mSize2] = size(a2aAircraftTripTable_SE);

% row sum

% aircraft Table
a2aAircraftTripTable_SE(1 : mSize1 - 1, mSize2)
    = sum(a2aAircraftTripTable_SE(1 : mSize1 - 1, 1 : mSize2 - 1), 2);

a2aAircraftTripTable_ME(1 : mSize1 - 1, mSize2)
    = sum(a2aAircraftTripTable_ME(1 : mSize1 - 1, 1 : mSize2 - 1), 2);

a2aAircraftTripTable_JE(1 : mSize1 - 1, mSize2)
    = sum(a2aAircraftTripTable_JE(1 : mSize1 - 1, 1 : mSize2 - 1), 2);

% person Table
a2aPersonTripTable_SE(1 : mSize1 - 1, mSize2)
= sum(a2aPersonTripTable_SE(1 : mSize1 - 1, 1 : mSize2 - 1), 2);

a2aPersonTripTable_ME(1 : mSize1 - 1, mSize2)
= sum(a2aPersonTripTable_ME(1 : mSize1 - 1, 1 : mSize2 - 1), 2);

a2aPersonTripTable_JE(1 : mSize1 - 1, mSize2)
= sum(a2aPersonTripTable_JE(1 : mSize1 - 1, 1 : mSize2 - 1), 2);

% column sum

% aircraft Table

a2aAircraftTripTable_SE(mSize1, :) = sum(a2aAircraftTripTable_SE(1 : mSize1 - 1, 1 : mSize2), 1);

a2aAircraftTripTable_ME(mSize1, :)
= sum(a2aAircraftTripTable_ME(1 : mSize1 - 1, 1 : mSize2), 1);

a2aAircraftTripTable_JE(mSize1, :)
= sum(a2aAircraftTripTable_JE(1 : mSize1 - 1, 1 : mSize2), 1);

% person Table

a2aPersonTripTable_SE(mSize1, :)
= sum(a2aPersonTripTable_SE(1 : mSize1 - 1, 1 : mSize2), 1);

a2aPersonTripTable_ME(mSize1, :)
= sum(a2aPersonTripTable_ME(1 : mSize1 - 1, 1 : mSize2), 1);

a2aPersonTripTable_JE(mSize1, :)
= sum(a2aPersonTripTable_JE(1 : mSize1 - 1, 1 : mSize2), 1);

return

Script 16: Compute Root Mean Square Error

function totOperationEst = computeRMSE(alpha1, alpha2, alpha1_index, alpha2_index, totOperationEst)

%---------------------------------------------------------------
% Computes the Root Mean Square error for towered airports
% called: compute_wholeprocess
%---------------------------------------------------------------

global airport
global a2aAircraftTripTable_tot
global a2aAircraftTripTable_tot_ops
global totOperationObs
global totOperationEst

currRMSE = 0;
totOperationObs = zeros(600,1);
totOperationEst(alph1_index, alph2_index).alph1 = alph1;
totOperationEst(alph1_index, alph2_index).alph2 = alph2;
totOperationEst(alph1_index, alph2_index).ops = zeros(600, 1);
totOperationEst(alph1_index, alph2_index).ratio = zeros(600, 1);
totAirports = size(a2aAircraftTripTable_tot, 2); % last column is the summation
for aprt = 1 : totAirports - 1
  if(airport(aprt).ctrlTower > 0) % if yes, this airport is a towered-airport.
    totOperationObs(aprt) = airport(aprt).itinerant; %+ airport(i).airTaxi; %From TAF
    totOperationEst(alph1_index, alph2_index).ops(aprt) ...
    = a2aAircraftTripTable_tot_ops(aprt, totAirports) ...
    + a2aAircraftTripTable_tot_ops(totAirports, aprt);
  end
end %for ii = 1 : size(totAcraftTripTable, 2)
totOperationObs_ratio = round(totOperationObs / sum(totOperationObs) * 10000);
totOperationEst(alph1_index, alph2_index).ratio = round(totOperationEst(alph1_index, alph2_index).ops / sum(totOperationEst(alph1_index, alph2_index).ops) * 10000);
currRMSE = sum((totOperationObs_ratio - totOperationEst(alph1_index, alph2_index).ratio).^2);
totOperationEst(alph1_index, alph2_index).RMSE = currRMSE;
return
subplot(2,2,1), plot([0 200], [0 200], ' -', totOperationObs.ratio, totOperationEst(1, 2).ratio, ' .');
xlabel('Obseration'); ylabel('Estimation');
subplot(2,2,2), plot([0 200], [0 200], ' -', totOperationObs.ratio, totOperationEst(1, 3).ratio, ' .');
xlabel('Obseration'); ylabel('Estimation');
subplot(2,2,3), plot([0 200], [0 200], ' -', totOperationObs.ratio, totOperationEst(2, 1).ratio, ' .');
xlabel('Obseration'); ylabel('Estimation');
subplot(2,2,4), plot([0 200], [0 200], ' -' , totOperationObs.ratio, totOperationEst(2, 2).ratio, ' .');

xlabel('Obseration'); ylabel('Estimation');
VITA

Senanu Ashiabor was born on July 6, 1972, in Ghana. In 1997 he graduated with a Bachelors degree in Civil and Structural Engineering from the Kwame Nkrumah University of Science and Technology in Ghana. After the program he worked for a year as a Research and Teaching Assistant with the Geothechnical Engineering Department of the University.

He went on to work for 2 years with Structeng Consultancy as a Civil Engineer before pursuing his masters program at in Transportation Engineering at Virginia Tech.

During his masters program he worked at the Virginia Tech. Air Transportation Laboratory as a Research Assistant. The position involved the development of Transportation models for NASA Small Transportation program and environmental impact modeling at airports using INM (FAA’s Integrated Noise Model). He completed his program in July, 2000.