A Model to Assess the Mobility of the National Airspace System (NAS).

(Total number of Words: 3300 (text) + 3500 (12 figures, 2 tables) = 6974)

Anand Seshadri
Via Department of Civil Engineering
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061
Tel. (540) 231-3363
Fax. (540) 231-7352
aseshadr@vt.edu

Antonio Trani
Via Department of Civil Engineering
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061
Tel. (540) 231-3363
Fax. (540) 231-7352
vuela@vt.edu

Hojong Baik
Via Department of Civil Engineering
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061
Tel. (540) 231-3363
Fax. (540) 231-7352
hbaik@vt.edu

Myunghyun Lee
Via Department of Civil Engineering
Virginia Polytechnic Institute and State University
Falls Church, VA 22081
Tel. (703) 538-8457
Fax. (703) 538-7352
mylee@vt.edu
Abstract

One of the ways to define mobility in a transportation system is total travel time for all travelers using the transportation network. A good assessment of the mobility is essential for knowing the points of congestion in the network and the factors responsible for the congestion. Also the change in mobility from the baseline to the horizon year would give the modeler an idea of the effectiveness of the various transportation systems. One of the applications of the mobility measurement is the evaluation of aviation technologies proposed by FAA to ease the congestion. This paper addresses a method to estimate the mobility of the air transportation network in the baseline year (2000). Also presented is a method to estimate the mobility to the horizon year by considering congestion on the roadway.
Seshadri, Trani, Baik and Lee

INTRODUCTION

The air transportation system is an essential part of the transportation infrastructure of the United States. The transportation system has played a major role in the economic expansion of the US. This expansion has in turn placed increasing demand on the transportation system, which is quickly becoming saturated. This will lead to increasing delays and lower level of service across the National Airspace System (NAS). To ease this congestion the Federal Aviation Administration (FAA) has proposed a set of new aviation technologies like User Request Evaluation Tool (URET) (12), Controller Pilot Datalink Communication (CPDLC) (15) etc. To determine the impact and worthiness of these new technologies, one must be able to compare the efficiencies of the air transportation network with and without the new technologies. The comparison will enable us to decide whether it is feasible to implement the proposed technologies.

Mobility is defined in various ways: 1) Number of trips made between any two nodes on the network 2) Delays on the network measured in passenger-hours. 3) Travel speed on the network. 4) Travel time on the network.

Measuring mobility in the present and future years would give one an idea of the efficiency of the system. The objective of this paper is to suggest a method to measure the mobility of air travelers for the year 2000 given airport-to-airport passenger O-D tables for General Aviation (GA) and commercial airline. Consequently, we can understand the factors, which lead to congestion and delays in the network. We also suggest a method to extend the model to the horizon year by considering roadway congestion. This paper is organized as follows: in the next section, the previous studies will be briefly reviewed. In the following section, the methods to estimate door-to-door travel time are suggested along with various types of data sources. The computational results are presented. In the last section, the conclusions and scope for further research are discussed.

PREVIOUS STUDIES

The total travel time by air transportation mode can be split into three components: 1) access and egress time to and from the airport, 2) flying time between airports, and 3) processing time which is the time required to complete security and other procedures and slack time which is the idle time that the passenger spends at the airport. Few studies can be found for measuring flying and slack times. Processing time is quite sensitive to the security policies, which is very difficult to quantify. On the other hand, quite a few studies have been done on measuring ground travel time, which are summarized below.

1) Artificial neural networks (1), (3)

One approach for measuring ground travel time is neural networks. One can think of a neural network as a “black box” that relates a set of inputs to a set of outputs. However neural networks differ from traditional statistical data-fitting techniques, since they do not assume any predetermined functional relationship between the input and output variables. Neural networks consist of one or more layers each consisting of one or more neurons and transfer functions, which relate the output of one layer to input of another layer. The number of layers and transfer functions are typically determined by trial and error. The neural network is first trained by using a large trial data set and the results from the training are then used to predict the output given the input variables. However for the above problem the neural network is not suitable, since most of the independent variables are binary leading to a loss of their explanatory power. The neural network approach also makes it difficult to predict the travel times for the horizon year, since there would be no growth factor in the modeling process.

2) Time series (2), (4)

Time-series use the previously known values to predict the same variable into the future. The shortcoming of the time series approach is that the causes for the change in the variable are unknown. This means that for the above problem we would not know what caused the change in travel time over the years. This is undesirable because as transportation modeler one would like to know what factors affect travel time.
A METHOD TO ESTIMATE DOOR-TO-DESTINATION TRAVEL TIME

As aforementioned, the door-to-door travel time for air travelers are calculated as the sum of time spent in traveling from door-to-airport and airport-to-destination (groundside part), the time spent in flying (airside part), and the slack and processing times at the airport.

Depending on the transportation mode, two sub modules for the airside part are: 1) A flight trajectory model to determine the flying time of passengers taking the General Aviation (GA) mode, 2) A commercial aviation model to determine the flying time of passengers taking commercial flights which includes the waiting time at the transfer airport(s). For the landside part, a network analysis model is developed to determine the door-to-airport and airport-to-destination travel times for the present year. The model is extended for the future year. Due to lack of data, the slack and processing times are assumed to be about 70 minutes for commercial air travelers.

Model for Airside part

1) General aviation mobility model

The flight trajectory model uses the Base of aircraft data (BADA) (11) model to calculate the fuel consumed and travel time for an aircraft flying a great circle route. Precisely speaking, the flight trajectory model uses the Performance Table File (PTF) of the BADA model, which gives rate of climb, true airspeed (TAS) and fuel consumption at various altitudes. The general aviation mobility model consists of nine sub-modules as summarized in Table 1.

First, we read the given airport-to-airport passenger O-D table for General Aviation (GA) into the memory. Then the various other modules described in Table 1 work in conjunction to give the fuel and time consumed required to complete each trip. The entire process is depicted in detail in Figure 1.

2) Commercial aviation mobility model

Unlike the GA mode, the flight trajectory model would not give a good assessment of travel time. This is because commercial flights from origin to destination rarely follow a great circle path, but are routed through a hub, thus increasing the travel time. Therefore, the mobility for commercial aviation for the baseline year is measured with the help of the Airline Origin and Destination Survey (DB1B) (7) and Official Airline Guide (OAG) (8). The DB1B gives us the hub-and-spoke structure for all commercial flights as well as number of passengers on each spoke. The OAG provides information on the flight schedule from which the time for each passenger to complete the trip, including stopover time at intermediate airports is calculated.

The commercial aviation model consists of two steps. In the first step, a module determines the hub-and-spoke structure of the NAS using the Coupon file of the DB1B. The output of this module is an array where each cell $(i,j)$ contains the number of passengers from airport $i$ to airport $j$ and all the intermediate airports that the passengers are routed through. The next step is to determine the total travel time for passengers traveling from airport $i$ to airport $j$.

The travel time is obtained by combining the network topology derived from DB1B and flight schedule from OAG. This is explained more clearly with an example. Consider 1,000 passengers traveling from Roanoke, VA (ROA) to San Francisco (SFO). Let us assume that from the DB1B, we know that 700 passengers are routed through Chicago O’ Hare (ORD) and 300 through Baltimore-Washington international (BWI). The OAG database is searched for flights from ROA-ORD and ORD-SFO and their schedules are obtained. Here it should be noted that neither DB1B nor OAG give information about the connecting flights. Therefore, it is assumed that two flights with minimum time differential are the ones that the passenger most likely takes for the trip. For example if a flight from ROA to ORD is scheduled to depart at 8:30 am and arrives at 10:30 am and the earliest flight after 10:30 am from ORD-SFO is scheduled to depart 11:45 am and arrives at SFO at 3:00 pm, then total travel time for all passengers on the ROA-ORD-SFO route is $700 \times 6.5 = 4,550$ passenger-hours. The same procedure is repeated for all the O-D pairs across NAS and mobility for commercial air travelers across NAS is calculated.
Seshadri, Trani, Baik and Lee

Model for groundside part

1) Ground mobility model

The ground mobility model calculates the travel time to access an airport or egress from an airport on the ground network. The process consists of three steps: In the first step, cumulative density functions (CDF’s) for travel speed are derived from the Nationwide Personal Transportation Survey (NPTS) (5) data. Next, CDF’s for travel distance to airport are developed from the American Travel Survey (ATS) (6) data. The final step is the convolution of the CDF’s obtained from the NPTS and the ATS to obtain the travel time CDF’s.

a. Travel speed profiles

To derive the travel speed CDF’s, the raw data is classified into different categories. This is because developing a single CDF from the raw data would have not been meaningful as different parts of the US behave differently. The explanatory variables considered for classifying the travel speed data are population, population density, road density, travel distance, MSA/non-MSA characteristics and peak/non-peak characteristics. After performing statistical analysis, population density is adopted as a final explanatory variable. It is also found that road density can be dropped since population density and road density would be highly correlated especially in a developed country like the US. To test this hypothesis, the road density for each county is extracted from the Highway Performance Monitoring System (HPMS) (9) and compared against the population density obtained from the Census data (14). It is revealed that the correlation coefficient was 0.97, which proves that the hypothesis is correct. Therefore the three explanatory variables taken for travel speed are population density, peak/non-peak characteristic and MSA/non-MSA characteristic.

The raw data has to be separated into categories using some statistical test of significance. The various tests that are commonly used are the t-test and F-test. However in this case the raw speed data is not found to be normally distributed at a 95% level of significance. Therefore a non-parametric test called the ‘Wilcoxon rank sum’ test is used to separate the raw data into categories. The MSA data is first divided into two groups based on peak and non-peak hour characteristic. Then each of these groups is further divided into five subgroups based on population density. The classifications for travel speed in MSA areas is shown in Table 2.

Unlike MSA areas, all the non-MSA area is grouped into a single category since the peak and non-peak characteristics for non-MSA areas are found to be the same within a 95% level of significance. The resulting travel speed CDFs for MSA and non-MSA regions are depicted in Figures 3 and 4.

Another factor, which has to be considered, is travel distance to the airport. This is because travel distance and travel speed are found to be positively correlated, that is longer trips were faster than short ones. Another reason is that people cannot live very close to an airport because of noise and other concerns. Therefore a lower limit for travel distance has to be found. This is done by collecting all the airport-specific trips from NPTS and determining the lower limit at 95% significance. This value is found to be 2 miles. The upper limit is set at 100 miles since it was highly likely that trips greater than 100 miles are intercity trips. Thus all trips less than 2 miles and greater than 100 miles are eliminated. The final outputs of the model are 11 CDF’s- 5 for peak MSA characteristics, 5 for non-peak characteristics and 1 for non-MSA areas. The CDF’s are given as table function since no suitable interpolating function was found.

b. Travel distance profiles

In order to derive CDF’s for travel distances in MSA areas, two independent approaches are adopted. The first method is a macroscopic approach generating a single travel distance CDF from NPTS data. The second approach is a microscopic approach extracting travel distance CDF’s from ATS data. In this case, the explanatory variable used is the number of airports within a 40-mile radius from the centroid of the MSA. This idea comes from the assumption that, if there were more airports within a certain distance of the MSA, the travel distance to the airports would be less. Due to the fact that ATS data has very limited geographic information for the non-MSA areas, a single CDF for travel distance is extracted.

c. Access time profiles

The final step is to convolute travel speed CDF’s with the travel distance CDF’s to derive travel time CDF’s. The convolution process involves generating a random number between 0 and 1 and interpolating the random number with the access speed and access distance CDFs to get the corresponding speed and distance. The distance is
Seshadri, Trani, Baik and Lee

divided by the speed to get the access time. The process is repeated a large number of times to get the access time CDFs. The access time CDFs from the macroscopic approach are shown in figures 5, 6, 7 and 8. The result from the microscopic approach is presented in Figure 10.

2) Extension of the ground mobility model

If we assume that the reduction in travel speed over the years is caused by an increase in the population density, the model can easily be extended to predict the access time to airport in the future. Historical trend in travel speeds are obtained from the Urban Mobility study (10) that gives the mean value of travel speeds for 75 MSAs from 1980 to 2000. The population trends of these MSAs with time are obtained from Woods and Poole (13), which predicts the population of each MSA, County and state till 2025. The population densities of the 75 MSAs from 1980 to 2025 is found by dividing the population of each MSA by the area of the MSA in the year 2000. It is assumed that the areas of MSAs do not significantly change with time. Next the speeds of each of the 75 MSAs from 1980 to 2000 are regressed against the corresponding population densities. The regression equations whose R-square value fell below 0.6 are rejected. A sample regression for Atlanta MSA is shown in figure 9. The remaining equations are used to obtain the travel velocities in the year 2020. The travel velocities in the year 2020 are divided by the travel velocities in the year 1995 to get the correction factors for the horizon year. Then the correction factors are classified depending on the population density of the corresponding MSA in the year 2000 and average correction factors for each of the population density categories are obtained. For the non-MSA regions the correction factor is assumed to be the same as the correction factor for the MSAs having the lowest population density since no historical trends in travel speeds for non-MSA areas are available. Finally the 1995 speed CDF’s are multiplied by the corresponding correction factors to get travel speed distributions in the year 2020. The travel speed CDFs for MSAs and non-MSAs are shown in figures 11 and 12.

COMPUTATIONAL RESULTS

The final output of the model is: 1) the total passenger-hours that air travelers spent traveling in the year 1995, 2) set of access time CDF’s for the present (1995) and access speed CDF’s for the future year (2020), and 3) Proportion of the total time that was spent in flying, on the ground and waiting at the airport as shown in Figure 10.

The total door-to-door passenger hours for air travelers (commercial airline + GA) are estimated to be about 3.7 billion in the year 2000. From the horizon year analysis, it has been observed that the average reduction in speeds to access airports from 1995 to 2020 is expected to be about 20%, which is an appreciable reduction in mobility.

CONCLUSION AND RECOMMENDATIONS

In this paper, a set of methods to estimate total door-to-door passenger hours using various sources is introduced. The suggested methods are based on several assumptions. In the flight trajectory model, for example, it is assumed that all the flights take place at International Standard atmosphere (ISA) conditions, which is seldom true. One possible enhancement is to solve the equations of motion under non-ISA condition to obtain a more realistic value of flight time. Another assumption used in the flight trajectory model for GA is that the intermediate airport in the case where the distance between the two airports was greater than the maximum range of the aircraft was selected based solely on the nearest distance criterion. Nevertheless, this assumption may not always be correct since if the airport is a small airport then it is highly likely that it will not have facilities for refueling and other maintenance. Therefore the nearest airport should be chosen based on the distance and the number of operations since the number of operations from the airport is a direct indication of the facilities available at the airport. In the ground model, it is assumed that the slack and processing times are deterministic. This also may not be true since it is likely that hub airports will have higher slack and processing times than non-hubs. Therefore the model can be enhanced by collecting data on slack and processing times from different airports.

Nevertheless, the method suggested in the paper can be used to measure of the mobility of the air transportation network in the present and future years. Then, the mobility measured can provide a quick indication on the system efficiency to system planner and final decision makers.
Seshadri, Trani, Baik and Lee

REFERENCES

(5) ______, Bureau of Transportation Statistics, “Nationwide Personal Transportation Survey”,
(12)_______, MITRE Center for Advanced Aviation System design, “User request evaluation tool”,
http://www.mitreaas.org/proj/uret/
(15)_______, Federal Aviation Administration, “Controller Pilot Data link Communications”,
http://ffp1.faa.gov/tools/tools_cpdlc.asp
Seshadri, Trani, Baik and Lee

LIST OF TABLES

Table 1 Modules of the general aviation mobility model.
Table 2 Classification of the raw NPTS MSA data

LIST OF FIGURES

Figure 1. Flowchart of the general aviation mobility model.
Figure 2. Flowchart for the ground mobility model
Figure 3 CDF of peak urban travel speeds in 1995.
Figure 4 CDF of non-urban travel speeds in 1995
Figure 5 CDF of peak urban access times in 1995 for commercial air travelers
Figure 6 CDF of non-urban access times for commercial air travelers in 1995
Figure 7 CDF of urban access times for general aviation air travelers
Figure 8 CDF of non-urban access times for general aviation air travelers.
Figure 9 Variation of travel speed with time for some MSAs.
Figure 10 Pie chart of total door-to-door travel time in 2000.
Figure 11 CDF of peak urban travel speed in 2020.
Figure 12 CDF of non-urban travel speed in 2020.
Table 1. Modules in the general aviation mobility model

<table>
<thead>
<tr>
<th>Module</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Climb</td>
<td>Computes the fuel and time consumed to reach desired height</td>
</tr>
<tr>
<td>2) Cruise</td>
<td>Computes the fuel and time consumed for an aircraft in cruise</td>
</tr>
<tr>
<td>3) Descent</td>
<td>Computes the fuel and time consumed for an aircraft in the descent mode</td>
</tr>
<tr>
<td>4) Optimization</td>
<td>Computes the optimal cruise height so that fuel and time consumed are minimized</td>
</tr>
<tr>
<td>5) Randomize</td>
<td>Randomly chooses aircraft from a list and assigns them to complete the trip</td>
</tr>
<tr>
<td>6) Parser for O-D table</td>
<td>Loads the O-D Table into memory</td>
</tr>
<tr>
<td>7) Parser for BADA PTF file</td>
<td>Extracts the aerodynamic constants from the BADA PTF file</td>
</tr>
<tr>
<td>8) Subflight module</td>
<td>Assigns the intermediate airport when the distance to be flown is greater than the aircraft range</td>
</tr>
<tr>
<td>9) Maximum range</td>
<td>Calculates the maximum range of the aircraft</td>
</tr>
</tbody>
</table>
Table 2. Classification of speed data from NPTS (MSA data)

<table>
<thead>
<tr>
<th>Population density (people/mi²)</th>
<th>Time of day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak</td>
</tr>
<tr>
<td>&lt;250</td>
<td>See Figure 3.</td>
</tr>
<tr>
<td>&lt;500</td>
<td>Not shown.</td>
</tr>
<tr>
<td>&lt;750</td>
<td>Not shown.</td>
</tr>
<tr>
<td>&lt;1000</td>
<td>Not shown.</td>
</tr>
<tr>
<td>&gt;=1000</td>
<td>Figure 3.</td>
</tr>
</tbody>
</table>
Figure 1. General aviation mobility model
Figure 2. Flowchart for the ground mobility model

1. **Input Data**
   - NPTS speed data
   - Census population density data
   - ATS travel distance data
   - MSA travel time CDF's

2. **Data Processing**
   - Extract speeds for distance < 100 and speed < 100
   - Separate into MSA and non-MSA
   - Set a lower limit for trip distance at 95% significance
   - Check for differences between peak and non-peak characteristics
   - Develop 1995 Speed CDF's
   - Check for differences between peak and non-peak characteristic
   - Develop 1995 Speed CDF's
   - ATS travel distance data
   - Non-MSA travel time CDF's

3. **Decision Points**
   - Bin according to the population density
   - Is data MSA?
     - Yes: Set a lower limit for trip distance at 95% significance
     - No: Check for differences between peak and non-peak characteristic

4. **Output**
   - MSA travel time CDF's
   - Non-MSA travel time CDF's
Figure 3. CDF for travel speeds in 1995 (MSA areas, peak hour)

Figure 4. CDF for travel speeds in 1995. (non-MSA areas)
Figure 5. CDF for access times in 1995 for commercial air travelers
(from macroscopic analysis)(MSA areas)

Figure 6. CDF of non-MSA access times for commercial air travelers in 1995
Figure 7. CDF of MSA access times for general aviation air travelers in 1995

Figure 8. CDF of non-MSA access times for general aviation air travelers in 1995
Figure 9. Variation of travel speed with population density for an MSA

Figure 10. Pie chart of total door-to-door travel time in 2000 (from microscopic analysis)
Figure 11. CDF of peak MSA travel speed in 2020

Figure 12. CDF of non-MSA travel speed in 2020.