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Modeling destination choice and measuring the transferability of hurricane evacuation patterns

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MODELING DESTINATION CHOICE AND MEASURING THE TRANSFERABILITY OF HURRICANE EVACUATION PATTERNS

A Thesis

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Abstract

In this study a gravity model was used to model destination choice during a hurricane evacuation. Hurricane Floyd data was used to calibrate and apply the gravity model. Two different models were generated for different destination types; home of friends/relative and hotels and motels are the two different destination types for which the models were generated. The performance of the gravity model was tested by comparing the observed and estimated OD matrices using the chi-squared test. The results have indicated that gravity model developed in this study can successfully reproduce the observed trip destinations during a hurricane evacuation The Floyd model developed was then tested for transferability by applying the model on the hurricane Andrew data. It was observed that the gravity model developed on Floyd data can be transferred and used on the Andrew data.

1. Introduction

1.1 Background

Hurricanes are damaging and potentially deadly events that occur relatively frequently in the United States. These immense storms pose a number of threats to the coastal residents including storm surge flooding from excessive rainfall, and damage from high winds. On average, 10 tropical storms, 6 of which become hurricanes, develop in the Atlantic Ocean, Caribbean Sea or Gulf of Mexico each year. In a typical 3-year span, the U.S. coastline is struck five times by hurricanes, two of which will be designated as major hurricanes.

Hurricanes are usually steered by weak and erratic winds, making the forecasting of their track a challenge. However the warnings issued by the National Hurricane Center and local Offices of Emergency Preparedness continue to improve and greatly reduce fatalities due to hurricanes in the United States (Mei, 2002). At the same time, despite the improved warnings, there is an increase in the property damage, due to the growing population in the areas affected by hurricanes. The federal agencies and organizations such as the American Red Cross have combined with the state and local agencies to improve the preparedness efforts.

The process of evacuation from a natural disaster like a hurricane involves moving a large population that may grow or change, onto a highly congested and possibly damaged road network, towards numerous destinations that may alter as to their ability to serve the needs of the evacuees as the evacuation process progresses. While managing the evacuation process is not easy, it is imperative that it will be successful since lives are often at stake and the need for more effective and efficient evacuation is increasing as the populations of coastal regions grow and the possibility of expanding the infrastructure is limited. Therefore, a comprehensive and a well conceived evacuation plan must be developed to anticipate the unexpected problems and identify those management decisions that would allow the most efficient use of the existing infrastructure.

An important component for evacuation planning is the ability to estimate the number and time that trips will be generated (*trip generation*), the destinations of the trips (*trip distribution*), and the route chosen by the evacuees (trip assignment). While several studies have addressed the first and third aspects of evacuation travel demand estimation (i.e. trip generation and trip assignment), none have addressed the issue of trip distribution or destination choice in the context of hurricane evacuation. This study is aimed at testing whether trip distribution in evacuation modeling can be successfully conducted using a trip distribution procedure commonly used in modeling urban travel demand, and whether the model established is transferable from one area to another. The latter test of transferability is to identify whether a model is likely to function in other settings than the one in which it was calibrated, so that there is assurance that the model will function accurately in estimating destination choice in a variety of storm scenarios.

The main purpose of creating a trip distribution or destination choice model is to use the model to test alternative policies and strategies as a means of identifying optimum evacuation plans for a variety of storm scenarios. The model will be used to identify evacuation routes and departure times which will maximize system performance, allowing evacuation of the largest number of people within the least amount of time and under the safest possible conditions.

1.2 Purpose of Study

The specific objectives of this study are:

- To model hurricane evacuation trip destination choices by estimating gravity model on data from hurricane Floyd.
- To test the transferability of the model by applying the model estimated above on data from hurricane Andrew.

2. Literature Review

2.1. Hurricanes

The term hurricane has its origin in the indigenous religions of old civilizations. The Mayan storm god was named *Hunraken* (NOAA 2001). A god considered evil by the Taino people of the Caribbean was called *Huracan* (NOAA 2001). Hurricanes may not be considered evil but they are one of the nature's most powerful storms. Their potential for loss of life and destruction of property is tremendous. According to Herbert et al., hurricanes resulted in annual average damages of $1.6 billion between the years of 1950 and 1989, and of $6.2 billion between 1989 and 1995 (Herbert et al., 1996). For example, the damage caused by hurricane Andrew in 1992 was estimated at $26 billion. Over the past 40 years, the population of metropolitan areas along the US Atlantic and Gulf coasts has grown significantly. More people now live along these coasts than ever before in history. As a result of the increase in population in coastal areas, development along these areas has also increased, producing more damage in property when disasters occur (NOAA 2001). According to the Office of Ocean Resources Conservation and Assessment (ORCA), the region with the largest coastal population is the Atlantic Coast followed by the Pacific Coast and then the Gulf of Mexico region (Culliton et al., 1990). In addition to the permanent residents, these coastal areas attract holiday, weekend, and vacation populations during the hurricane season. Many of the Nation's most popular vacation spots are located on or near the coast; this together with the growing coastal population intensifies the risk of fatalities during a hurricane.

Over the past several years, the hurricane warning system has provided adequate time for people on the barrier islands and the immediate coastline to move inland when hurricanes threaten. However, it is becoming more difficult to evacuate people from the barrier island areas and other coastal areas because the roads have not kept pace with the rapid population growth.

The *Saffir-Simpson Hurricane Scale* is a 1 to 5 rating based on the intensity of the hurricane as measured by wind speed within the hurricane (Simpson and Riehl, 1981). Hurricanes reaching Category 3 and higher are considered major hurricanes because of their potential for loss of life and damage. The classification of hurricanes based on the wind speed is shown in table 1.

Table 1: Saffir - Simpson Scale

Category	Wind Speed	Damage
I	74-95 mph	Minimal
II	96-110 mph	Moderate
III	111-130 mph	Extensive
IV	131-155 mph	Extreme
V	> 155 mph	Catastrophic

In 1999, roughly three million people were evacuated during Hurricane Floyd. Traffic and emergency management agencies at local, state and federal level coordinated to move residents from coastal areas in Florida, Georgia, North Carolina and South Carolina.

2.2. Hurricane Floyd

Hurricane Floyd was a large and intense storm that roughly paralleled the Atlantic US coastline remaining offshore from Miami, Florida to its landfall near Cape Fear, North Carolina as a category 2 hurricane. Only a year after hurricane Georges, Floyd precipitated the largest evacuation in the US history. For the United States, nearly the entire Atlantic coast from Miami to Plymouth, Massachusetts was put under a hurricane warning (PBS&J, 2000b). The figure1 below shows the track of the Hurricane Floyd. It can be observed from the color-coding in the figure that the hurricane was a category 2 to category 3 storm as it approached North Carolina. However it was a much stronger storm shortly before that. It was also a very large storm and was moving slowly, making the threat of flooding much greater.

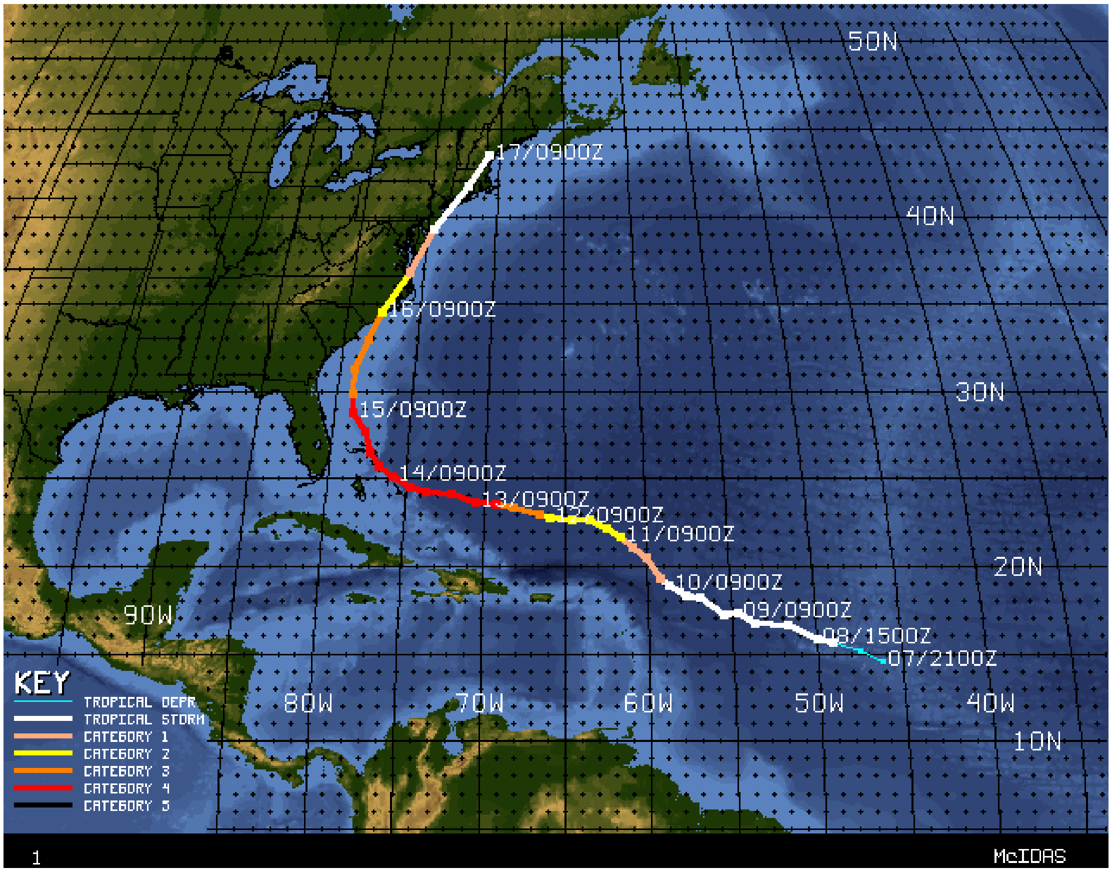

Figure 1: Hurricane Floyd Track (Source: CIMSS/University of Wisconsin)

During Hurricane Floyd mandatory and voluntary evacuations were issued in almost every state from Florida to New York. In Florida, an estimated 2 million people evacuated, while in Georgia after evacuation orders were given an estimated 300,000 people left Georgia's coast. In South Carolina, a voluntary evacuation was closely followed by a mandatory evacuation in the State's six coastal counties. In response to these two evacuations orders, over 400,000 people evacuated. Evacuation orders were also issued in North Carolina where Floyd made landfall (PBS&J, 2000b). The figures below show the evacuation traffic during Hurricane Floyd.

Figure 2: Hurricane Floyd Evacuation Traffic (Source: Transportation Analysis by PBS&J)

The massive evacuation from Hurricane Floyd was partly the result of the uncertainty regarding the landfall of Floyd. State officials also reported traffic problems such as diversions of evacuees from other jurisdictions, inadequate roadway signage, uncoordinated traffic lights, inadequate traffic control, and roadway flooding among others (PBS&J, 2000b). During Floyd, evacuation methods such as contra flow operations were first implemented by Georgia and South Carolina and ITS systems were used to disseminate information (e.g. exit ramps, road closures) to the public during the evacuation. In addition, mid Atlantic states such as Virginia, Maryland, Delaware and New Jersey were declared states of emergency, setting the stage for storm evacuations and putting state police, National Guard, and other essential employees on alert (NOAA 2001). In Virginia, mandatory evacuations were authorized in the most flood-prone areas of Hampton Roads and other coastal counties, while in Maryland voluntary evacuations were issued to residents along the Chesapeake Bay and Atlantic Coast. The rest of the mid Atlantic coastal states also urged evacuations in low-lying and coastal areas; such as the case in New York City, where Governor Rudy Guiliani issued a voluntary evacuation.

2.3. Trip Distribution

The choice of an evacuation destination under threat to life tends to be modeled in one of the following ways (Southworth, 1991):

• Evacuees will choose the closest destination (in terms of distance or travel time) beyond the at-risk area.

• Evacuees will head for pre-specified destinations, according to an established evacuation plan.

• Evacuees will display some degree of dispersion in their selection of destinations, depending on such factors as location of friends and relatives, the characteristics of the hazard, and the traffic conditions on the network at the time they are evacuating.

The first assumption may work effectively in modeling small urban areas or rural evacuations when the hazard is intense and is approaching rapidly. Some large cities within the US have well-publicized evacuation routes which may favor the second approach above. For example, the Tampa Bay – St. Petersburg conurbation published a newsletter showing residents in different communities how to evacuate in case of hurricanes. A good evacuation plan supplemented by effective policing of traffic flow can make this option the best method for evacuation (Southworth, 1991). The third option is more complicated because the selection of destination is influenced by more factors with higher uncertainty. However, this option is closer to the reality, especially for hurricane evacuation.

Almost all hurricane evacuation behavioral studies conducted in the past have recorded the destination of evacuated respondents. It has been found that relatives or friends are the most common destinations during hurricanes: 64% in Southwest Louisiana (Irwin et al, 1995), 68.8% in North Carolina (RDS et al, 1999), and 55-68% in Alabama (Corps of Engineers, 2001). Hotels or motels are the next most popular destination: roughly 13% in Southwest Louisiana, 16.2% in North Carolina, and 17-26% in Alabama. The percentage of the evacuees who went to public shelters was only 12%, 6.4%, and 3-8% respectively in these states. The Corps of Engineers (2001) found that the severity of risk and income are the two most consistent predictors of public shelter demand: evacuees from more hazardous locations tend to use public shelters less than those from less hazardous areas. Poorer people tend to use public shelters more than wealthier people.

The spatial distribution of hurricane evacuation trips has been studied in the past (NCDOT). The implicit assumption was that trip distribution patterns derived from historical data are good indicators of trip distribution patterns that would result from future hurricanes. However, no model of trip distribution appears to have been developed so far to model the process of destination selection in emergency evacuation settings (Mei, 2002). One exception is the trip distribution model in the Oak Ridge Emergency

Management System (OREMS) package; developed by the Oak Ridge National Laboratory (ORNL) to simulate the traffic flow during various defense- oriented emergency evacuations (Wolshon et al.,). It is an integrated system consisting of three major components: a data input manager, a traffic simulation model, and an output data display manager.

The analytical core of OREMS is a FORTRAN program, ESIM (Evacuation SIMulation), which combines the trip distribution and traffic assignment submodel with a detailed traffic flow simulation submodel. The combined trip distribution and traffic assignment submodel was developed by the researchers at ORNL, and the traffic simulation model was derived primarily from the TRAF simulation system developed by FHWA and therefore has many similarities to that system (ORNL). The combined algorithm of trip distribution and trip assignment expands the original network by introducing super-destination nodes and adding a set of pseudo-links, which connect the super-destination nodes to the original destination nodes. Each super-destination node is connected to a subset of destination nodes. These subsets of destination nodes are designed in such a way that the flow needs to be assigned from any origin to a single super-destination node. The algorithm then solves the problem by using the assignment model on the expanded network. The flows on the expanded network are converted into flows on the original network by deleting the super-destination and the pseudolinks (ORNL).

After establishing the overall link flows, ESIM performs a detailed simulation of vehicular traffic operations on the evacuation network given these projected flows and routes under prevailing roadway and traffic conditions. The model can identify evacuation routes, estimate service rates in the evacuation network by location and by time, identify traffic operational characteristics and bottlenecks, estimate evacuation times across various categories (link, sector, or region- specific estimates by time), and provide information on other elements of an evacuation plan. It also allows the analyst to experiment with alternative routes and destinations, various alternative traffic control and management strategies, and different evacuee participation rates (ORNL 1999). The OREMS and other computer software models developed so far, are focused on the assignment of the given traffic demand, the simulation of traffic operations on the road network, and the estimation of the evacuation clearance time.

2.4. Gravity Model

To date, the most widely used trip distribution model in urban transportation planning has been the *gravity model* (Miller and Meyer, 2000). Gravity models rely on historical origin destination information for calibration. This means that future trip distribution is assumed to be based on the same behavioral principles as those used in calibration of the model. Gravity models are founded on the notion that trip patterns are primarily determined by the amount of activity at the origin, the relative attractiveness of the destination and the difficulty of making the trip between the origin and destination (USDOT, 1983). In regular urban transportation planning, the gravity model can use any measure of the three assumed determinants of trip distribution that are represented by productions, attractions, and travel time respectively. However, this paradigm does not transfer in to the evacuation studies directly because the productions and attractions in the evacuation conditions are going to be considerably different to those in regular urban conditions, and choice of location is likely to be influenced by other factors rather than impedance on the network alone.

3. Methodology

3.1. Introduction

The main objective of this research was to test whether a gravity distribution model can successfully model the destination choice of evacuees from a hurricane. The gravity model postulates that the number of trips from zone i to zone j is proportional to the product of the number of trips produced in a origin zone, attracted to a destination zone, and inversely proportional to the impedance of moving between the zones. Gravity model calibration and gravity application are the two major steps involved in the trip distribution by gravity model. The main inputs are the observed OD matrix and the impedance.

Different measures of impedance can be used, such as travel distance, travel time, or travel cost. In the gravity model, impedance is expressed as a mathematical function of these measures. Sometimes, continuous functions such as exponential, power, or gamma functions are used. More commonly, discrete expressions, described in terms of friction factors are used to describe the impact of the measure on trip distribution. In the present study, travel time is taken as the impedance.

3.2. Urban Travel Demand Modeling and Hurricane Evacuation Modeling

In classical urban travel demand modeling, trip distribution models are developed for different trip purposes. This is because the choice of a trip destination varies depending on the purpose of the trip that is made in urban travel. A common classification of trip purposes used in urban travel is Home Based Work, Home Based School, Home Based Other and Non Home Based trips. Different models are generated for each of these trip purposes in urban travel modeling studies. On the other hand, for hurricane evacuation modeling, it is not appropriate to classify trips based on trip purpose because the sole purpose is to evacuate from the hurricane. On the other hand, in hurricane evacuation trips differ in their trip length characteristics by the type of destination that is chosen by the evacuee.

The trip length distributions for the three most common destinations are shown in figure 3, using the data from hurricane Floyd. The distributions in the figure 3 below were drawn using the travel times that were reported by the respondents during the survey. The graph was drawn to compare the trip length distributions of the three prominent destination types during the hurricane evacuation.

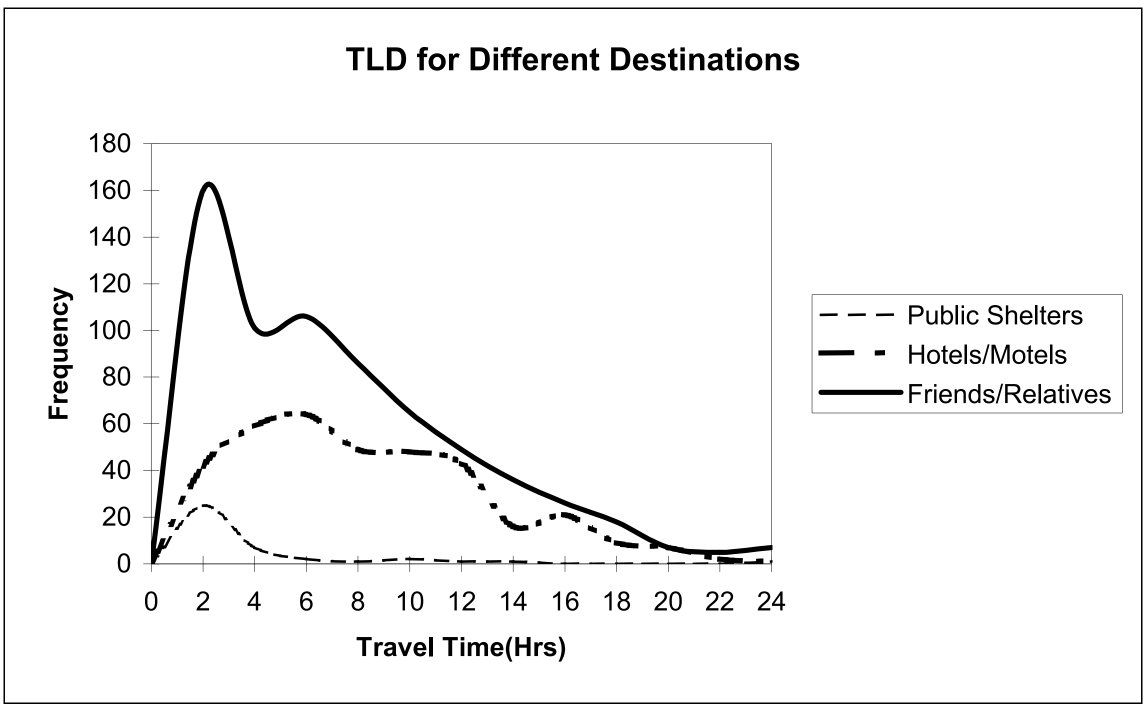

Figure 3: TLD for different destination types

From the graph it can be observed that the trip length distributions are different for the three types of trip destinations; distances to public shelters are typically short while trips to hotels and motels are typically longer than those to shelters and to friends and relatives. Therefore three different models for the above mentioned three destination choices were generated. However, since the data available for the trip destination of public shelters is comparatively low, only two different models for the house of friends and relatives; and hotels and motels were generated for this present study.

4. Analysis and Results

4.1. Data

4.1.1. Evacuation Data

The Hurricane Floyd evacuation data were obtained from a survey conducted by Prof. Earl J. Baker for the U.S. Army Corps of Engineers. About 1800 telephone interviews were conducted in Charleston, Myrtle Beach and Beaufort cities in South Carolina. Figure 4 below shows the study area for the present study. The stars on the map are the three origins in the study.

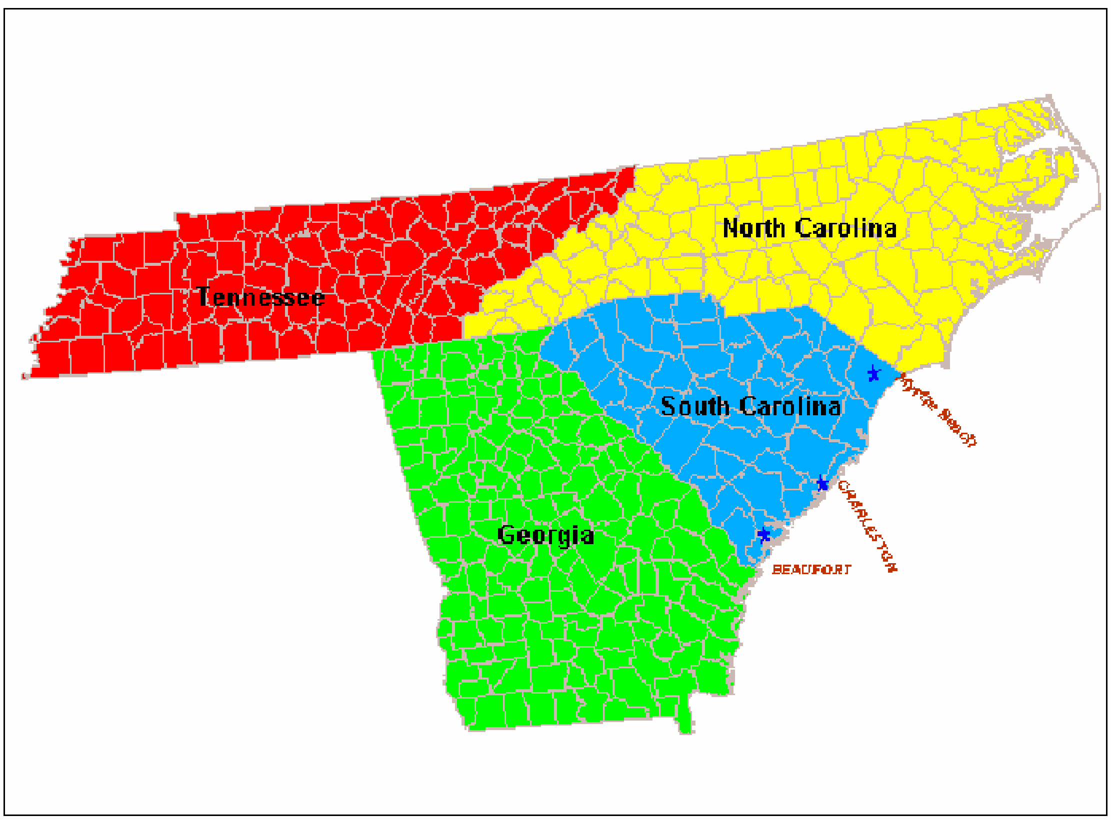

Figure 4: Study Area for the Present Study

The survey data consists of information such as the number of vehicles owned by the household, household income, destination place and also the type of destination etc. The raw data obtained by the survey was cleaned so that the data was free of errors, and invalid responses were deleted from the data set. Since the destination type is the most important feature in the present study, the data set after cleaning was again divided based on the destination type.

The main types of destinations considered in the survey are home of friends and relatives and hotels and motels. A total of 427 households evacuated to a home of friend or relative and 270 households evacuated to a hotel or a motel.

The evacuation trips were aggregated by county. For example if the destination reported was "Atlanta, GA", then the destination was aggregated to the county in which Atlanta is located. Since Atlanta is located in the "Fulton,GA" County, the destination was aggregated to "Fulton,GA", i.e. "Fulton,GA" was considered as the destination for Atlanta. The counties in which the corresponding destination cities were present are selected and were located on a map to create a county layer. This county layer consists of all the origin and destination counties of the cities listed in the survey by the survey respondents. This county layer was prepared using TransCAD. Each county was considered a zone in the present study. Two different county layers were prepared for the two trip destination types. The county layer for the home of friends and relatives as destination type consisted of 92 zones and the county layer for the hotels and motels as the destination type consisted of 50 zones. The county layers for both the destination types are shown in the figures 5 and 6 below.

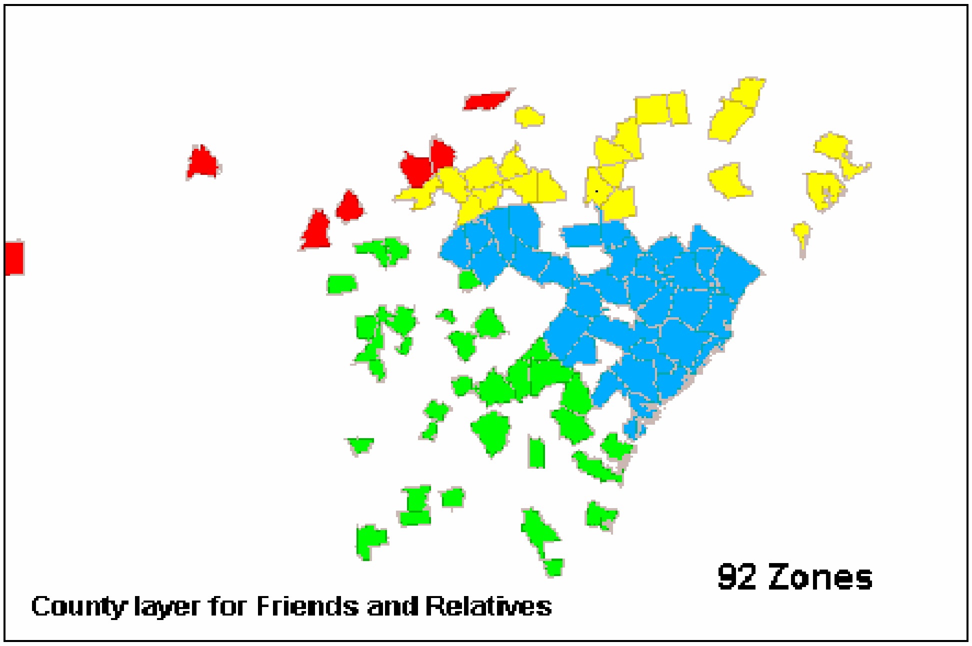

Figure 5: County Layer for Friends/Relatives

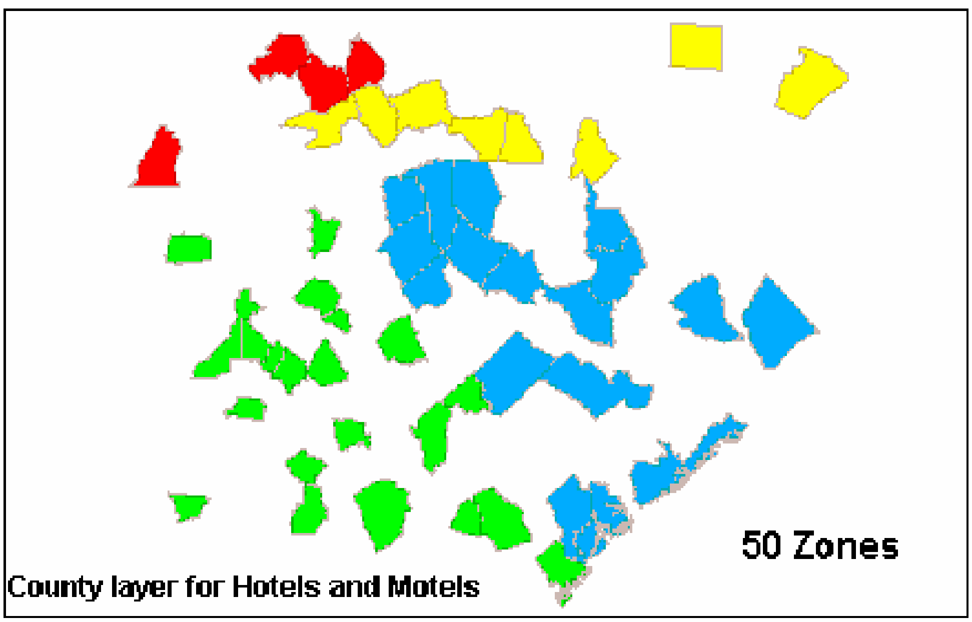

Figure 6: County Layer for Hotels/Motels

4.1.2. O-D Matrix

An O-D matrix, which represents the origin-destination information, was prepared in TransCAD It shows the number of trips made from each origin to the individual destinations in the study area. Charleston, Beaufort and Myrtle Beach cities of South Carolina are the three origins for the study. The destinations in the OD matrix are the selected counties in the study area, which contain the destinations made during the hurricane evacuation. North Carolina, South Carolina, Tennessee and Georgia are the states that were considered as the study area for the present study. Two different OD matrices were created for the two different types of trip destinations i.e. home of friends and relatives and for the hotels and motels. The output of the observed OD matrices is shown in Appendix. The matrix for the destination type of friends and relatives consists of all the 92 zones from the county layer and the matrix for the destination type of hotels and motels consists of all the 50 zones from the county layer. County ID or the names of the county were assigned as labels to the matrix. These IDs or the county names were obtained from the county layer prepared from the survey data. The labels assigned were used as a reference for each individual county. The OD matrix prepared was a square matrix; therefore all the cells in the matrix other than for the three origins were filled with zeros. The numbers of trips made from each of the three origins were entered in the respective matrix cells.

It was observed that Fulton, GA; Richland, SC; Greenville, SC; and Mecklenburg, NC are the four major destination counties for friends and relatives as the destination type. It was observed that these four destination counties have fifty percent of the destinations for the home of friends and relatives as destination type. Also Buncombe, NC and Richmond, GA were the two destination counties that had fifty percent of the destinations for hotels and motels as destination type. The distance traveled to reach the main destinations for both the destination types ranged from 150 miles to 250 miles.

4.1.3. Highway Network

A highway-network layer for the study region was prepared using TransCAD. The highway and the interstate data available from TransCAD were used to prepare the network. The network for the study area was prepared by clipping the entire highway network of USA with the layer that contain the counties for the present study i.e. the highway layer was clipped such that the entire highway network layer was made available for the states of North Carolina, South Carolina, Tennessee and Georgia. The network layer consists of "links" and "nodes". Each link in the network system contained information regarding distance, number of lanes and functional classification. Two new fields named "Centroids" and "Travel time" were added to the dataview of the highway layer. A field named "Centroid Nodes" was added to the dataview of the highway node layer. The fields "Centroids" and "Centroid Nodes" were added to be able to verify that the IDs on the network were consistent with the actual zone ID's.

A constant speed of 25mph was assumed on all the links of the highway network. This assumption was based on calculations conducted on the data using the reported travel time and distance. The results showed that speed varied from 22mph to 29mph. The travel time on each link was calculated by using the distance of each link divided by the speed. The centroids of the highway layer were selected and were connected to the centroids of the zones or the counties in the county layer. The figure 7 below shows the highway network on the study area.

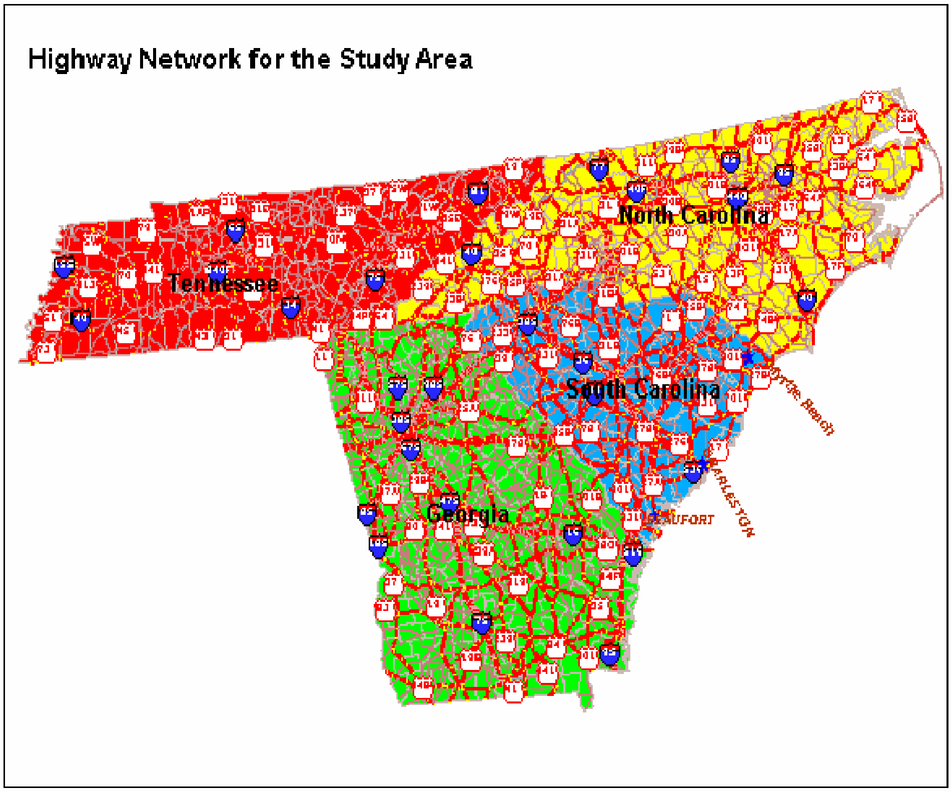

Figure 7: Highway Network for the Study Area

4.2. Calibrating the Gravity Model

The main objective in calibrating a gravity model is to make sure that the model accurately describes the travel pattern of the study area and it is usually accomplished by adjusting the parameters within the model until the modeled trip length frequency distribution adequately reproduces the observed trip length frequency distribution. The trip length frequency distribution is a graph plotted between the time interval and the frequency or the number of trips made.

In regular urban transportation planning, the following inputs are required to estimate or calibrate a gravity model:

- Productions

- Attractions
- O-D matrix
- Travel time matrix

However, in evacuation modeling, some of the inputs will be different because of the different conditions in the two settings.

4.2.1. Productions and Attractions

The productions and attractions are usually fixed in urban travel demand modeling. They mostly depend on the trip purpose, but the productions and attractions for evacuation modeling are not the same when compared to the urban travel demand modeling, because there will be no classification of trips like the work trips, school trips and others. The trips in evacuation modeling are only classified on the type of destination. In evacuation modeling, the productions are defined as the number of households evacuating from each zone and the attractions are replaced by number of safe destinations reached in each zone by the households during the evacuation. These productions and attractions were developed for the two different destination types. The productions and attractions are entered in the respective fields that are added to the dataview of the county layer. Productions are the total number of trips from each individual origin. The three origins Beaufort, Charleston and Myrtle Beach are the production ends in the present study. The productions for the remaining zones were filled with Zero. Attractions are the total number of trips attracted to each individual destination zone in the study area. There are 92 attraction zones for the house of friends and relatives as destination type and 50 attraction zones for hotels and motels as the destination type.

4.2.2. Travel Time Matrix

The travel time matrix is the matrix of shortest path travel time between zones. The time reported in the matrix is the shortest time taken to travel from one zone to the other zone using the highway network in the present study. Since travel time is assumed as the impedance in the present study, the travel time matrix is considered as the impedance matrix to run the gravity model. Travel time is taken as the impedance because the main objective of the evacuees is to reach a safe destination in a short period of time. Hence travel time is the main cost function in the evacuation process. The travel time matrices for both the destination types were shown in Appendix.

Friends/Relatives: The observed travel times from the three origins to the destinations in the study area ranged from 1.27 hours to 29.83 hours. The mean travel times from the three origins ranged from approximately 9 hours to 11 hours. A travel time between 27.14 hours and 29.23 hours was observed from the three origins to reach Shelby, TN as the most distant destination observed for those going to the house of friends or relatives.

Hotels and Motels: The observed travel times from the three origins to the destinations in the study area ranged from 1.75 hours to 17.69 hours. The mean travel times from the three origins ranged from approximately 9 to 10 hours. A travel time between 15.56 hours and 17.69 hours was observed from the three origins to reach Hamilton, TN as the most distant destination observed for those going to hotels and motels.

4.2.3. Trip Length Distribution

Trip length distribution (TLD) is a graph plotted between the travel time interval and the frequency or the number of trips made during the travel time interval. The shortest path matrix and the observed OD matrix are the required inputs to calculate the observed TLD. The output is a matrix (shown in Appendix), which describes the frequency or number of trips in a fixed travel time interval. This output is used to plot the TLD, which is represented in a graph. This TLD is known as the observed TLD, which shows the original travel pattern of the hurricane evacuation. Different TLD's were drawn for the two different types of trip destinations. A travel time interval of 1 hr was used and a graph was plotted with the time interval starting from two hours. The first two hours of travel time were neglected in the TLD because most of the trips in the first two hours of the evacuation were intrazonal trips. Since the maximum time reported by the respondents to evacuate to a safe place is 24 hours, the maximum TLD was taken as 24 hours.

4.2.3.1. Observed TLD for Friends and Relatives

This TLD is a curve drawn with the observed OD matrix and shortest path matrix for friends and relatives as inputs. The TLD curve is shown in the figure 8 below. It can be observed that the curve is not a smooth curve like the normal TLD for urban planning. We can observe intermittent peaks in the curve. The peak number of trips was observed during the 8 to 9 hours of travel time with 58 trips in the interval.

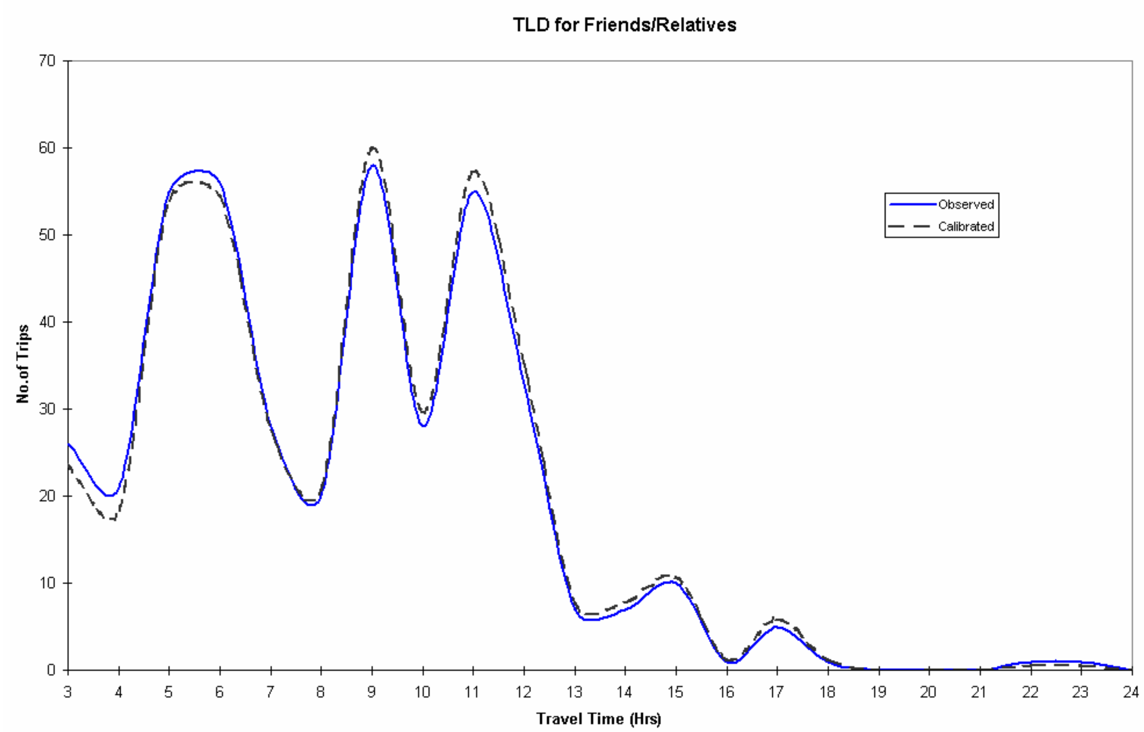

Figure 8: Observed TLD for Friends/Relatives

Figure 9 below shows the cumulative count of the number of trips made during the corresponding travel times. It can be observed that the curve remains constant after the 12-hour travel time. About 380 trips were made up to the travel time of 12 hours, which is more than 90% of the total number of trips made. Thus most of the evacuees had to travel up to 12 hours to reach a safe destination during the evacuation process. Also it can be seen that given a total of 427 trips to a house of friends and relatives, the median travel time was 10 hours.

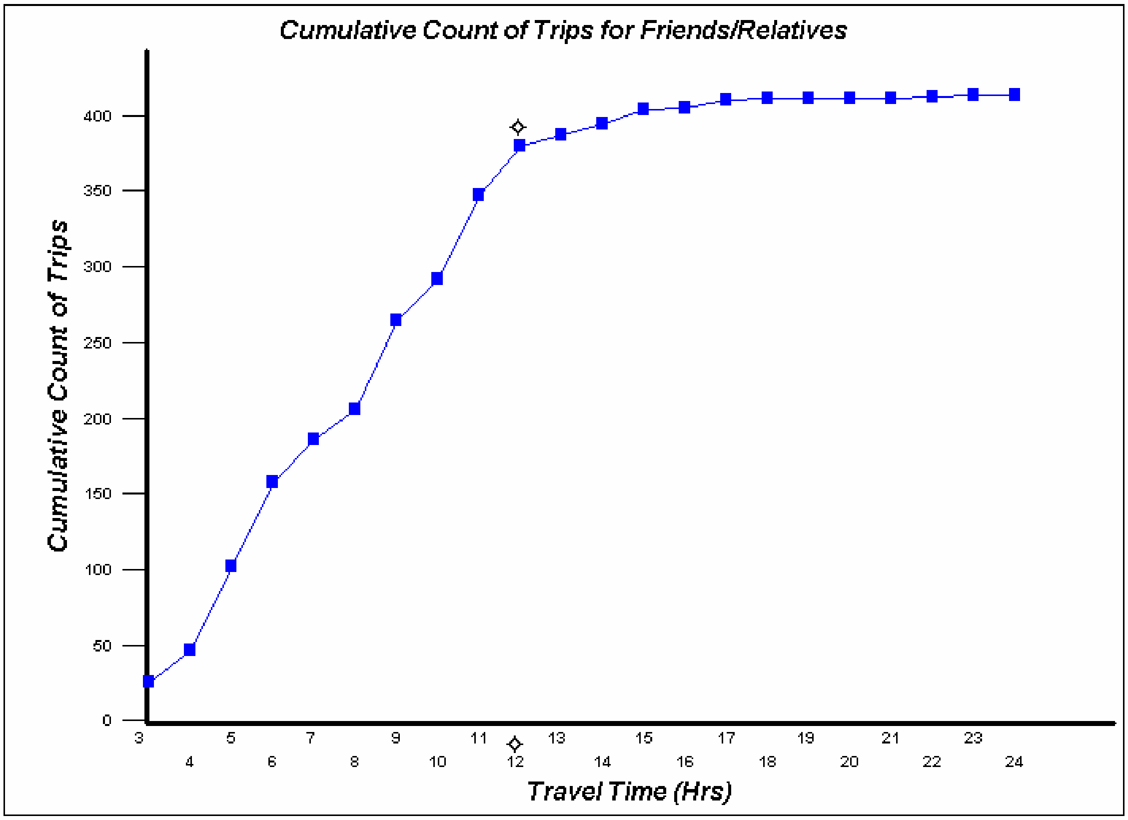

Figure 9: Cumulative Count of trips for Friends/Relatives destination type

4.2.3.2. Observed TLD for Hotels and Motels

Figure 10 below shows the observed TLD for evacuation trips to hotels and motels. It can be observed that the peak number of trips occur during the 8 to 9 hours travel time interval. The TLD plot is similar to the observed TLD for friends and relatives with peaks occurring at approximately the same travel time. The maximum travel time observed is about 18 hours. It was observed that there was a peak of 41 trips observed during the 5 to 6 hours of travel time. This peak may be due to the availability of rooms in the hotels in the city that is of 5 to 6 hours of travel time from the origins.

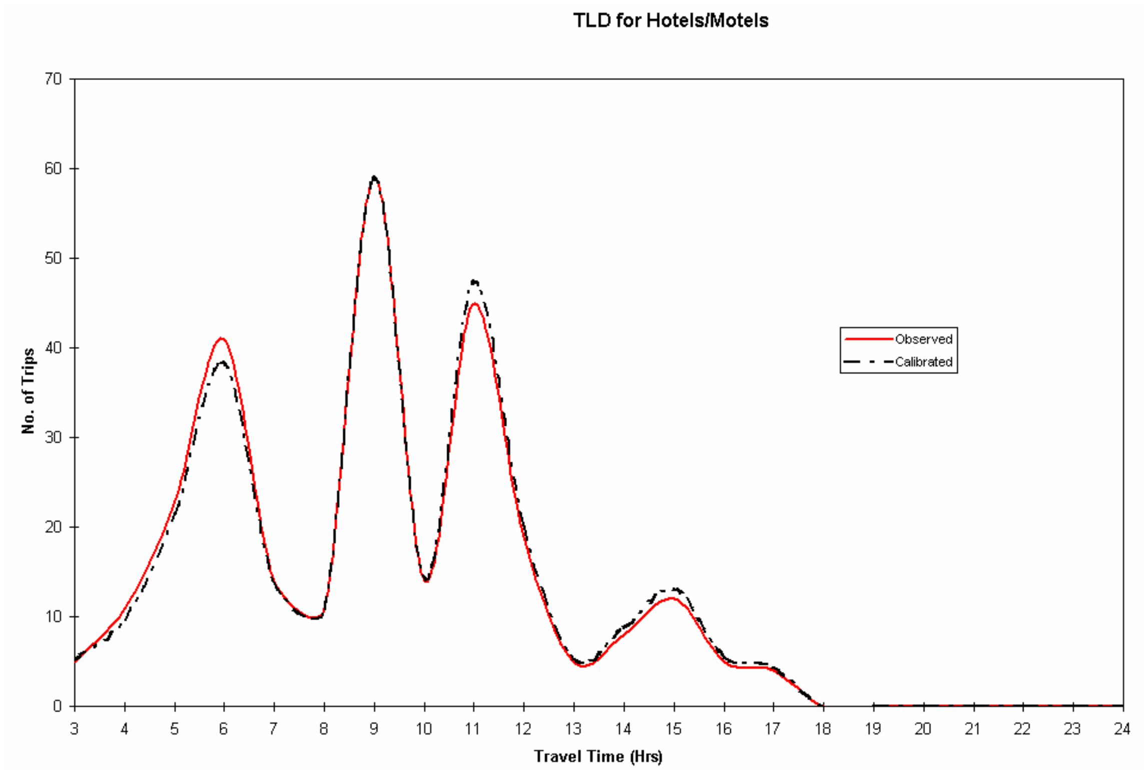

Figure 10: Observed TLD for Hotels/Motels

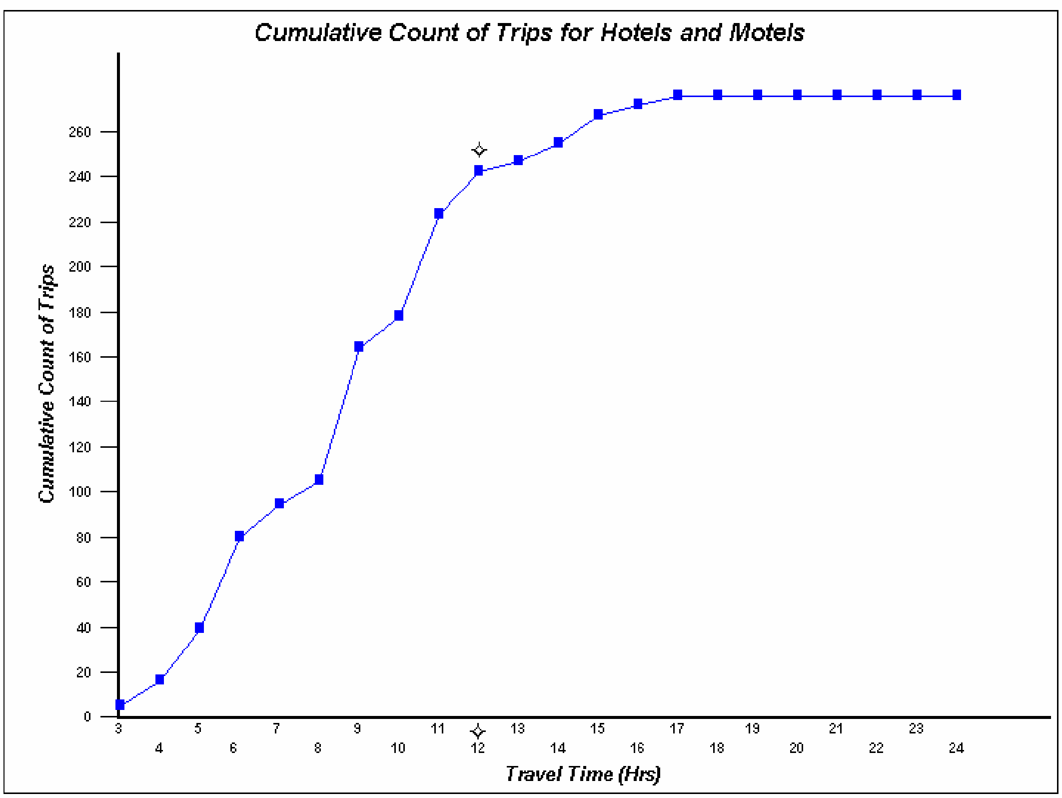

Figure 11: Cumulative Count of trips for Hotels/Motels destination type

Figure 11 above shows the cumulative count of the number of trips made during the corresponding travel times. It can be observed that the curve remains constant after the 12-hour travel time. About 242 trips were made up to the travel time of 12 hours, which was more than 90% of the total number of trips made. Also it can be seen that given a total of 270 trips to hotels and motels, the median travel time was 10 hours.

4.2.4. Friction Factors

Friction factors represent the effect that various levels of travel time have on travel between zones. These factors are determined in the model calibration process.

A friction factor matrix contains the friction factor for travel between each pair of zones. The friction factor matrices are created either from a continuous impedance function or a discrete function described by values in a friction factor lookup table. A friction factor look up table was used in the present study. This friction factor look up table is an output (Shown in Appendix) from TransCAD when the observed OD matrix, shortestpath matrix (impedance) and the county layer are given as inputs.

For the discrete friction factors, the trip lengths, $d_{ij,}$ are broken into discrete intervals and a value of the impedance, f, is obtained for each interval to ensure that the modeled trip length frequency distribution closely matches the observed trip length frequency distribution.

The friction factors for friends and relatives and for hotels and motels are plotted in figures 12 and 13. It can be observed that the friction factors are high during the first two hours of travel time. This is because there is a preference to evacuate to closer destinations, although destinations closer than one hour are less preferred. The high friction factors may result because of very less number of attractions in the first two hours. The graphs shown in the figures 12 and 13 below are drawn using the friction factors and the bins that were obtained by the gravity calibration. The output, which was in the form of a matrix, was shown in the Appendix

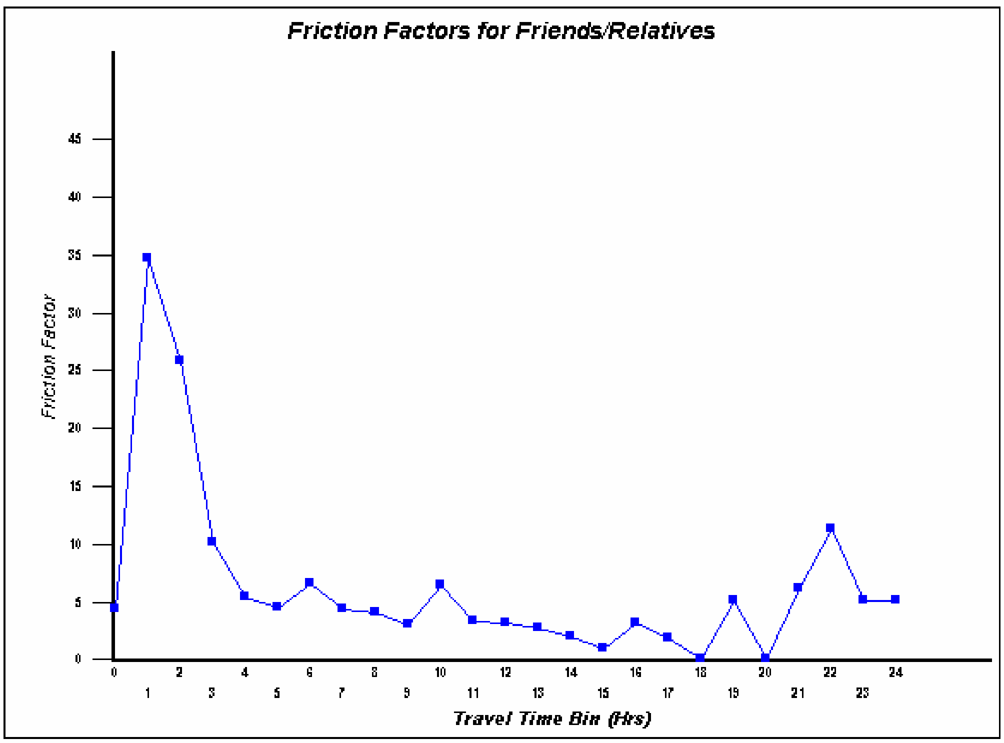

Figure 12: Friction Factors for Friends/Relatives destination type

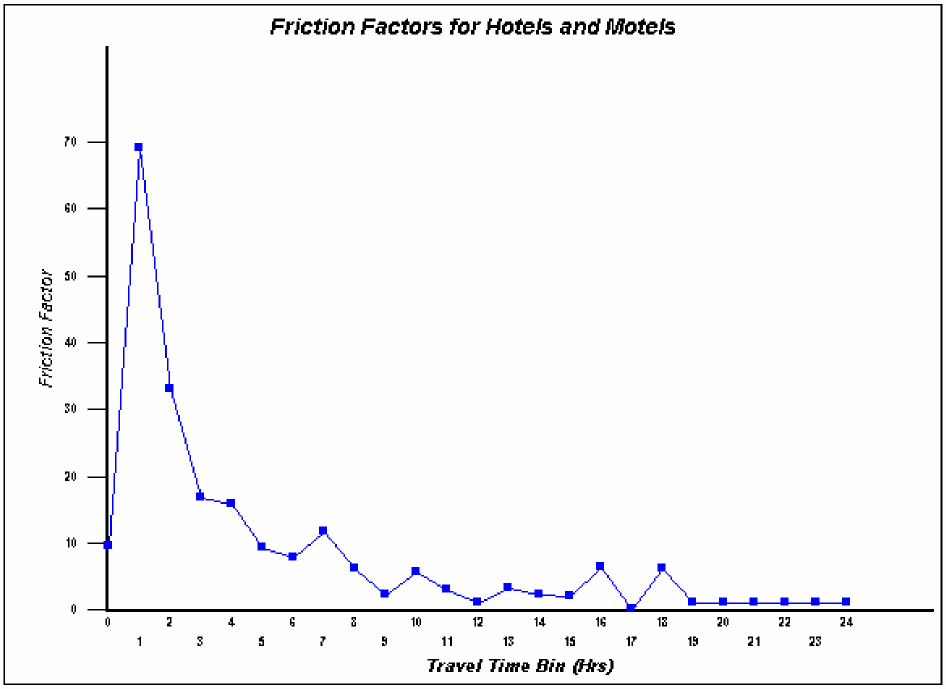

Figure 13: Friction Factors for Hotels/Motels destination type

4.3. Applying the Gravity Model

The following are the inputs given in TransCAD to apply the gravity model:

- Friction factors
- A county layer with productions and attractions
- Travel time matrix

The output of the gravity application process is the estimated or the modeled OD matrix (Shown in Appendix).

The estimated OD matrix for both trip destinations very well represented the observed OD matrix. The total number of trips from all the three origins remained the same as of that observed in the observed OD matrix.

The success of the model was measured by comparing the OD matrix, obtained after applying the model on the data on which it was calibrated with the observed OD matrix. The comparison of the OD matrices shows how well the model was able to reproduce the destinations actually chosen by the evacuees. The matrices were compared statistically using the Chi-Square test (**$\chi 2$**) with the proviso that the OD matrix cells are aggregated so that no cell contains an estimated frequency of less than 5. Hypothesis testing was conducted using the Chi-square test at the 5% level of significance. The null hypothesis was that the values in the observed OD matrix and the values in the estimated OD matrix are the same; while the alternative hypothesis is that they are different. In the chi-squared test, if the chi-squared value calculated is less than the critical value, we are unable to reject the null hypothesis, i.e. there is insufficient evidence that the estimated and observed values are different at the 5% level of significance. The chi-squared statistic is calculated using the following formula.

$$\chi^2_{k-1,m-1} = \sum_{i,j} \frac{\left(o_{ij} - e_{ij}\right)^2}{e_{ij}}$$

Where, O_{ij}= Observed frequency in the i^{th} row and j^{th} column of the observed OD matrix

e_{ij} = Estimated frequency (from the model) in the i^{th} row and j^{th} column of the estimated OD matrix

k = Number of rows in the matrix

m = Number of columns in the matrix

To apply the chi-square test, each cell value in the expected observations should be greater than 5. The cell values in the estimated matrix are aggregated such that each cell has a frequency greater than 5. A chi-squared value of 35.792 with 25 degrees of freedom was obtained for the friends and relatives destination type. A chi-squared value of 16.567 with 16 degrees of freedom was obtained for the hotels and motels as destination type. The critical values of chi-square for 25 and 16 degrees of freedom are 37.652 and 26.296 respectively. Based on the critical values we are unable to reject the null hypotheses that the observed and estimated OD matrices are the same for both the destination types at 5% level of significance i.e. there is insufficient evidence that the estimated and observed values are different at the 5% level of significance Therefore we can infer that the gravity model reproduced the destinations chosen by the evacuees.

4.4. Transferability

Transferability is the application of a model to a context different from which it was estimated in (Koppelman and Wilmot, 1982). Transfer of a model can be defined as the use of all or part of a model in another context than the one in which it was estimated. Transferability is invoked each time a model is applied to any other data than that on which it was estimated (Wilmot, 1983). Disaggregate models are most likely to be transferable because the disaggregate data (i.e., the individual observations of travel behavior) represents the average behavior of the individual traveler, and it is reasonable to expect the individual travel behavior to be essentially the same in one area as in another. The issue of transferability in this research is important because the need is to be able to use the model to test alternative strategies and policies.

Transferability can be done in two ways, full transfer and partial transfer. Full transfer is the transfer of an entire model while partial transfer is the transfer of any portion or aspect of the original model.

4.4.1Test of Transferability

In this study, an objective is to test the transferability of the model developed for Hurricane Floyd, by applying the model to Hurricane Andrew data. Hurricane Andrew data was obtained by a survey conducted by the Louisiana Population Data Center at Louisiana State University. The survey conducted was similar to the one conducted for Hurricane Floyd. The data collected contained information about the socio-economic characteristics, household size, location of residence, destination place, type of destination, etc. The data for the friends/relatives destination type was used to test the transferability of the trip distribution model estimated on the Floyd data.

Since gravity models are calibrated on trip length frequency, it seemed that comparing the trip length frequency that would be generated by a model transferred into an area with that of the local data, would be an effective measure of transferability. Another measure of transferability used in this study, was to compare the friction factors between the transferred model and a locally estimated model. Both these tests are described below.

4.4.1.1 Kolmogorov-Smirnov Test (KS test)

The trip length frequencies of the transferred model and the locally estimated model were compared using the Kolmogorov-Smirnov (KS) two- sample test. The model estimated on the Floyd data was applied to the Andrew data and the trip length frequencies are determined. The trip length frequency of the local model was assumed to be the same as the observed trip length frequency in the Andrew data. The test statistic 'T' in the two sample KS test is defined as the maximum difference between the two cumulative distribution functions of two distribution functions being tested. The two-sample KS test determines whether the two distributions belong to the same distribution or not. Thus the null hypothesis for this test is that the distributions of the transferred model and the locally estimated model are same and the alternate hypothesis is that they are different. The null hypothesis is rejected if the value of the T statistic calculated is greater than the critical value of T at a given level of significance. The value of T obtained was 0.1364 and the critical value of T at the 5% level of significance is 0.3636. Thus, the null hypothesis cannot be rejected suggesting that no statistical difference between the two trip length frequency distributions can be observed.

4.4.1.2 Paired Samples t - Test

The statistical similarity of the Floyd model and the Andrew model were tested using the t- test statistic. The test was conducted by using the friction factors of the Floyd model and the friction factors of the Andrew model.

Paired samples t –test in SPSS software was used to calculate the t-test statistic. The Paired Samples t - test compares the means of two variables. It computes the difference between the two variables for each case, and tests to see if there is any significant difference between the two variables. The null hypothesis is that there is no significant difference between the two variables and the alternate hypothesis was that there exists a significant difference between the two variables. The null hypothesis is rejected if the value of t calculated is greater than the critical value of t. The SPSS output for the paired samples t-test is shown in the figure 14 below.

t-test for friction factors of Floyd model and Andrew Model

Paired Samples Statistics

	Mean	N	Std. Deviation	Std. Error Mean
FLOYD	6.37272	25	7.756048	1.551210
ANDREW	4.33584	25	10.643932	2.128786

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	FLOYD & ANDREW	25	-.071	.736

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	FLOYD - ANDREW	2.03688	13.607084	2.721417	-3.57985	7.65361	.748	24	.461

Figure 14: t-test result output

The value of t obtained was 0.748 and the critical value of T at the 5% level of significance is 2.064. Thus, the null hypothesis cannot be rejected suggesting that no statistical difference between the two variables can be observed.

4.4.1.3 Relative Aggregate Transfer Error (RATE)

The relative aggregate transfer error is the ratio between the locally estimated model RMSE and the transferred model RMSE (Elmi et al., 1999). In the present case the transferred model was the Floyd model applied to the Andrew data. In this case the friction factors that were obtained from the Floyd model were given as an input to the

Andrew model. The locally estimated model was the Andrew model applied to the Andrew data. In this case the Andrew model was calibrated and applied on the Andrew data.

$$\text{RATE} = \frac{RMSE_i(\beta_i)}{RMSE_i(\beta_j)}$$

$RMSE_i(\beta_j)$ = RMSE of the transferred model from j and applied in i.

$RMSE_i(\beta_i)$ = RMSE of the locally estimated model

The transfer is considered good if the RATE value tends to 1 and it is considered bad if the RATE value tends to zero.

The RMSE of the transferred model and the locally estimated model were calculated using the trip interchanges. The RMSE of the locally estimated model obtained was 0.1404 and the RMSE of the transferred model obtained was 0.2103. The RATE that is the ratio of the RMSE of the locally estimated model and the transferred model obtained was 0.66. From the RATE value obtained it can be inferred that it was a relatively good transfer. Since the value of RATE is tending towards 1 the transferability test proves positive i.e. the Floyd model transferred on to the Andrew data had reproduced the distribution of the Andrew data.

5. Summary and Conclusions

5.1. Summary

Trip distribution in a hurricane evacuation is an important step for emergency preparedness. Not much study has been done that addresses the issue of modeling the trip distribution of the traffic during a hurricane evacuation. The present study has been conducted to test whether a gravity model can effectively reproduce the trip distribution patterns observed during evacuation from a hurricane. Also the transferability of a model estimated in one area and applied in another was tested. The home of friends and relatives, and hotels and motels were the two major types of destinations for which the models were developed for the present study.

In this study, the data from Hurricane Floyd and Hurricane Andrew were used to calibrate and apply the gravity model. Data from Hurricane Andrew was used to test the transferability. About 700 evacuee responses were observed for Hurricane Floyd data and about 100 responses were observed for Andrew data.

The gravity model was applied on the Floyd data and the observed TLD and the estimated OD matrix were computed. To check how well the model reproduced the observed destinations, Chi-squared test statistic was used to compare the observed and the estimated OD matrices. Based on the chi-square test statistic we were unable to reject the null hypothesis that the values in the observed and the estimated OD matrices are the same at the 5% level of significance for both the destination types.

Transferability tests were conducted to see if the model performs well in a context other than the one for which it was estimated. The Floyd model was transferred and applied to the Andrew data. Since the Andrew data was limited compared to the Floyd data, only the friends and relatives destination type data from Andrew data was used to run the transferability tests.

The Kolmogorov-Smirnov (KS) two-sample test, paired samples t-test and Relative Aggregate Transfer Error (RATE) test were conducted to test the transferability of the model. The KS test was run on the trip length frequencies of the local model (Andrew) and the transferred model (Floyd) to determine whether the two distributions belong to the same distribution or not. At the 5% level of significance we were unable to reject the null hypothesis suggesting that no statistical difference between the two trip length frequency distributions can be observed. The paired samples t-test was run on the friction factors of the Floyd and Andrew model to test if there is any significant difference between the two variables. At the 5% level of significance we were unable to reject the null hypothesis suggesting that no statistical difference between the two variables can be observed. The RATE test was conducted using the trip interchanges of the transferred and the local model. This test was conducted by calculating the Root Mean Square Error. A value of 0.66 was obtained, since the value tends to 1 the transfer is considered good.

5.2. Conclusions

Based on the results and analyses reported above, the conclusions drawn from the present study are as follows:

- Based on the statistical comparison of the observed O-D matrix and the estimated O-D matrix, the gravity model successfully reproduced the observed trip destinations at the 5% level of significance. Therefore it is concluded that the gravity model developed in this study has demonstrated that it can successfully reproduce the observed trip destinations during a hurricane evacuation

- Three tests of transferability were conducted using the Floyd model on Hurricane Andrew data. Based on statistical tests, all of the three tests conducted showed that the model can be successfully transferred to a different context than the one in which it was estimated. It is concluded that the gravity model developed on the Floyd data can be transferred and used on the Andrew data.
- The gravity model is the popular model used in urban planning. This study was used to study if the gravity model would function satisfactorily in an evacuation context. The finding suggest that with a few modifications (i.e. altering from trip purpose stratification to destination type stratification) the model will function satisfactorily in the hurricane evacuation modeling
- The analysis is based on very limited tests. One model is tested in one other situation. It is possible that it will not prove the same in another situation. Therefore more investigation is required
- Intuitively one would expect that other factors than impedance influence the destination choice in evacuation modeling. The other factors that might influence are the direction of storm, intensity of storm, and the distance of the destination from the eye of the storm. It is possible that these factors could impact the model.

5.3. Further Research

- The model developed in the present study did not include the factors like direction of storm, intensity of storm and the distance of the destination from the eye of the storm. These factors are expected to influence the choice of destination, and if included, may enhance the explanation of the model in a more detailed manner and make the model more accurate and more applicable to different situations.

- A comparison should be made among models based on more data sets reflecting diverse storms so that the results obtained can be generalized.
- The study area in this present study was divided based on the county in which the destination is located. Dividing the study area using the evacuation zones in which the destinations are located may enhance the application of the model.

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Appendix: OD Matrices, TLD Matrices and Travel Time Matrices for Floyd and Andrew Data

Observed TLD Matrix on Floyd Data for Friends/Relatives

Matrix4 - Observed TLD for Friends/Relatives (TLD)

	Count	Percent	Cumulative Count	Cumulative Percent
2.00 - 3.00	26.00	6.30	26.00	6.30
3.00 - 4.00	21.00	5.08	47.00	11.38
4.00 - 5.00	55.00	13.32	102.00	24.70
5.00 - 6.00	56.00	13.56	158.00	38.26
6.00 - 7.00	28.00	6.78	186.00	45.04
7.00 - 8.00	20.00	4.84	206.00	49.88
8.00 - 9.00	58.00	14.04	264.00	63.92
9.00 - 10.00	28.00	6.78	292.00	70.70
10.00 - 11.00	55.00	13.32	347.00	84.02
11.00 - 12.00	33.00	7.99	380.00	92.01
12.00 - 13.00	7.00	1.69	387.00	93.70
13.00 - 14.00	7.00	1.69	394.00	95.40
14.00 - 15.00	10.00	2.42	404.00	97.82
15.00 - 16.00	1.00	0.24	405.00	98.06
16.00 - 17.00	5.00	1.21	410.00	99.27
17.00 - 18.00	1.00	0.24	411.00	99.52
18.00 - 19.00	0.00	0.00	411.00	99.52
19.00 - 20.00	0.00	0.00	411.00	99.52
20.00 - 21.00	0.00	0.00	411.00	99.52
21.00 - 22.00	1.00	0.24	412.00	99.76
22.00 - 23.00	1.00	0.24	413.00	100.00
23.00 - 24.00	0.00	0.00	413.00	100.00

Figure 15: Observed TLD for Friends/Relatives destination type

Estimated TLD Matrix on Floyd Data for Friends/Relatives

Matrix12 - Calibrated TLD for Friends/Relatives (TLD)

	Count	Percent	Cumulative Count	Cumulative Percent
2.00 - 3.00	23.53	5.66	23.53	5.66
3.00 - 4.00	18.33	4.41	41.86	10.07
4.00 - 5.00	53.97	12.98	95.84	23.05
5.00 - 6.00	54.51	13.11	150.35	36.16
6.00 - 7.00	27.43	6.60	177.78	42.76
7.00 - 8.00	20.68	4.97	198.46	47.73
8.00 - 9.00	59.99	14.43	258.45	62.16
9.00 - 10.00	29.62	7.12	288.07	69.28
10.00 - 11.00	57.25	13.77	345.31	83.05
11.00 - 12.00	35.26	8.48	380.58	91.54
12.00 - 13.00	7.60	1.83	388.17	93.36
13.00 - 14.00	7.76	1.87	395.93	95.23
14.00 - 15.00	10.62	2.56	406.56	97.78
15.00 - 16.00	1.17	0.28	407.72	98.07
16.00 - 17.00	5.85	1.41	413.58	99.47
17.00 - 18.00	1.20	0.29	414.77	99.76
18.00 - 19.00	0.00	0.00	414.77	99.76
19.00 - 20.00	0.00	0.00	414.77	99.76
20.00 - 21.00	0.00	0.00	414.77	99.76
21.00 - 22.00	0.50	0.12	415.27	99.88
22.00 - 23.00	0.50	0.12	415.77	100.00
23.00 - 24.00	0.00	0.00	415.77	100.00

Figure 16: Estimated TLD for Friends/Relatives destination type

Observed OD on Floyd Data for Friends/Relatives

	Aiken SC	Alamance NC	Anderson SC	Baldwin GA	Barnwell SC	Beaufort SC	Berkeley SC	Bibb GA	Bulloch GA	Buncombe NC	Burke GA
Beaufort SC	6.00	0.00	3.00	1.00	4.00	0.00	0.00	0.00	2.00	0.00	2.00
Charleston SC	3.00	1.00	3.00	1.00	0.00	0.00	3.00	1.00	0.00	3.00	0.00
Horry SC	1.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00

	Cabarrus NC	Charleston SC	Chatham GA	Chester SC	Clarendon SC	Clarke GA	Cleveland NC	Cobb GA	Cocke TN	Colleton SC	Craven NC
Beaufort SC	0.00	1.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	1.00	0.00
Charleston SC	1.00	2.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00
Horry SC	0.00	0.00	0.00	2.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00

	Cumberland NC	Darlington SC	Davidson NC	Davidson TN	Dillon SC	Dorchester SC	Dougherty GA	Early GA	Fannin GA	Fayette GA	Florence SC
Beaufort SC	1.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	3.00
Charleston SC	0.00	3.00	0.00	1.00	0.00	3.00	0.00	0.00	0.00	0.00	2.00
Horry SC	2.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	14.00

	Franklin NC	Fulton GA	Georgetown SC	Glynn GA	Gordon GA	Greene GA	Greenville SC	Guilford NC	Gwinnett GA	Hamilton TN	Hampton SC
Beaufort SC	0.00	37.00	0.00	0.00	1.00	0.00	6.00	0.00	1.00	1.00	7.00
Charleston SC	0.00	23.00	0.00	0.00	0.00	0.00	21.00	0.00	0.00	2.00	1.00
Horry SC	1.00	7.00	3.00	1.00	0.00	1.00	8.00	4.00	0.00	1.00	0.00

	Hart GA	Haywood NC	Henderson NC	Horry SC	Jefferson GA	Kershaw SC	Lancaster SC	Laurens GA	Laurens SC	Lee GA	Lee SC
Beaufort SC	0.00	1.00	0.00	0.00	1.00	2.00	0.00	1.00	1.00	0.00	0.00
Charleston SC	1.00	0.00	1.00	1.00	0.00	1.00	2.00	0.00	3.00	1.00	1.00
Horry SC	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00

	Lexington SC	Liberty GA	Marion SC	McDowell NC	McMinn TN	Mecklenburg NC	Muscogee GA	New Hanover NC	Newberry SC	Oconee SC	Onslow NC
Beaufort SC	0.00	1.00	0.00	0.00	0.00	9.00	4.00	0.00	0.00	0.00	0.00
Charleston SC	3.00	0.00	0.00	1.00	2.00	12.00	3.00	0.00	1.00	1.00	0.00
Horry SC	1.00	0.00	1.00	0.00	0.00	12.00	1.00	1.00	0.00	0.00	1.00

	Orangeburg SC	Peach GA	Pickens SC	Richland SC	Richmond GA	Rockdale GA	Rowan NC	Rutherford NC	Screven GA	Sevier TN	Shelby TN
Beaufort SC	2.00	0.00	0.00	24.00	8.00	1.00	0.00	1.00	1.00	1.00	0.00
Charleston SC	5.00	1.00	5.00	31.00	3.00	0.00	1.00	0.00	0.00	1.00	1.00
Horry SC	0.00	0.00	0.00	13.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00

	Spartanburg SC	Sullivan TN	Sumter SC	Swain NC	Toombs GA	Transylvania NC	Turner GA	Union GA	Union NC	Wake NC
Beaufort SC	4.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00	1.00	0.00
Charleston SC	5.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00	5.00
Horry SC	2.00	0.00	3.00	1.00	0.00	0.00	0.00	0.00	0.00	3.00

	Ware GA	Washington GA	Watauga NC	Wilkes GA	Williamsburg SC
Beaufort SC	1.00	1.00	1.00	1.00	0.00
Charleston SC	0.00	0.00	0.00	1.00	1.00
Horry SC	0.00	0.00	0.00	0.00	0.00

Figure 17: Observed OD for Friends/Relatives destination type

Estimated OD on Floyd Data for Friends/Relatives

	Aiken SC	Alamance NC	Anderson SC	Baldwin GA	Barnwell SC	Beaufort SC	Berkeley SC	Bibb GA	Bulloch GA	Buncombe NC	Burke GA
Beaufort SC	3.64	0.23	2.95	0.76	1.93	0.00	0.51	0.29	1.26	0.65	0.84
Charleston SC	4.40	0.57	3.56	0.85	1.23	0.00	2.14	0.56	1.26	1.51	0.84
Horry SC	1.94	0.21	1.48	0.39	0.83	0.00	0.34	0.15	0.48	0.82	0.32

	Cabarrus NC	Charleston SC	Chatham GA	Chester SC	Clarendon SC	Clarke GA	Cleveland NC	Cobb GA	Cocke TN	Colleton SC	Craven NC
Beaufort SC	0.25	2.23	0.52	0.52	0.22	0.40	0.29	1.19	0.35	0.49	0.18
Charleston SC	0.40	0.46	0.34	0.96	0.50	0.37	0.46	1.33	0.42	0.44	0.52
Horry SC	0.35	0.30	0.14	0.52	0.27	0.22	0.25	0.47	0.23	0.06	0.29

	Cumberland NC	Darlington SC	Davidson NC	Davidson TN	Dillon SC	Dorchester SC	Dougherty GA	Early GA	Fannin GA	Fayette GA	Florence SC
Beaufort SC	0.78	0.69	0.68	0.00	0.16	0.73	0.52	0.56	0.40	0.40	4.18
Charleston SC	1.32	0.56	0.75	0.50	0.20	3.05	0.30	0.44	0.43	0.44	4.08
Horry SC	0.89	1.75	0.57	0.50	0.63	0.21	0.17	0.00	0.17	0.16	10.69

	Franklin NC	Fulton GA	Georgetown SC	Glynn GA	Gordon GA	Greene GA	Greenville SC	Guilford NC	Gwinnett GA	Hamilton TN	Hampton SC
Beaufort SC	0.28	36.42	0.25	0.37	0.47	0.32	10.79	0.96	0.40	0.66	5.04
Charleston SC	0.42	22.89	1.77	0.44	0.42	0.36	17.04	2.22	0.48	2.53	2.38
Horry SC	0.29	7.53	0.97	0.19	0.11	0.31	7.08	0.81	0.12	0.80	0.56

	Hart GA	Haywood NC	Henderson NC	Horry SC	Jefferson GA	Kershaw SC	Lancaster SC	Laurens GA	Laurens SC	Lee GA	Lee SC
Beaufort SC	0.34	0.33	0.45	0.63	0.27	1.70	0.57	0.48	1.42	0.59	0.25
Charleston SC	0.31	0.43	0.26	0.94	0.48	1.38	1.05	0.35	1.71	0.34	0.37
Horry SC	0.35	0.24	0.29	0.42	0.25	0.90	0.38	0.16	0.87	0.06	0.38

	Lexington SC	Liberty GA	Marion SC	McDowell NC	McMinn TN	ecklenburg NC	Muscogee GA	w Hanover NC	Newberry SC	Oconee SC	Onslow NC
Beaufort SC	1.16	0.58	0.13	0.25	0.33	10.03	3.07	0.35	0.40	0.34	0.32
Charleston SC	1.69	0.31	0.19	0.59	1.27	12.10	3.03	0.29	0.33	0.41	0.38
Horry SC	1.14	0.12	0.68	0.15	0.40	10.79	1.89	0.36	0.27	0.24	0.30

	Orangeburg SC	Peach GA	Pickens SC	Richland SC	Richmond GA	Rockdale GA	Rowan NC	Rutherford NC	Screven GA	Sevier TN	Shelby TN
Beaufort SC	2.80	0.24	1.39	21.84	3.92	0.24	0.89	0.50	0.52	0.61	0.35
Charleston SC	3.37	0.61	1.68	31.67	4.73	0.60	0.51	0.29	0.34	0.99	0.42
Horry SC	0.81	0.14	1.92	14.33	2.33	0.16	0.60	0.21	0.14	0.40	0.23

	Spartanburg SC	Sullivan TN	Sumter SC	Swain NC	Toombs GA	Transylvania NC	Turner GA	Union GA	Union NC	Wake NC
Beaufort SC	3.72	0.27	0.66	0.36	0.37	0.39	0.36	0.72	0.33	1.73
Charleston SC	4.81	0.45	1.51	0.43	0.44	0.47	0.48	0.86	0.43	4.01
Horry SC	2.44	0.28	0.82	0.21	0.19	0.13	0.16	0.42	0.24	2.24

	Ware GA	Washington GA	Watauga NC	Wilkes GA	Williamsburg SC
Beaufort SC	0.39	0.41	0.27	0.75	0.19
Charleston SC	0.44	0.32	0.36	0.90	0.52
Horry SC	0.16	0.26	0.37	0.35	0.28

Figure 18: Estimated OD for Friends/Relatives destination type

Travel Time (Shortest Path Matrix) on Floyd Data for Friends/Relatives

(Travel Times are reported in Hours)

	Aiken SC	Alamance NC	Anderson SC	Baldwin GA	Barnwell SC	Beaufort SC	Berkeley SC	Bibb GA	Bulloch GA	Buncombe NC	Burke GA
Beaufort SC	4.68	12.25	8.45	7.78	3.43	0.00	3.99	8.93	4.39	11.24	4.53
Charleston SC	4.91	10.48	8.62	8.97	4.17	3.00	1.37	10.12	5.95	10.52	5.71
Horry SC	7.37	7.20	9.84	11.59	6.95	7.33	3.90	12.96	9.33	10.67	9.10

	Cabarrus NC	Charleston SC	Chatham GA	Chester SC	Clarendon SC	Clarke GA	Cleveland NC	Cobb GA	Cocke TN	Colleton SC	Craven NC
Beaufort SC	9.56	3.00	3.05	7.30	4.54	8.59	9.69	11.45	13.74	1.89	13.56
Charleston SC	8.47	0.00	4.70	6.59	3.23	9.40	8.98	12.26	13.03	2.13	10.70
Horry SC	6.41	4.47	8.88	6.34	3.58	11.33	8.07	14.40	13.22	6.09	6.78

	Cumberland NC	Darlington SC	Davidson NC	Davidson TN	Dillon SC	Dorchester SC	Dougherty GA	Early GA	Fannin GA	Fayette GA	Florence SC
Beaufort SC	9.69	6.78	11.11	20.21	7.41	3.15	10.99	12.93	12.80	11.19	6.23
Charleston SC	7.74	5.01	9.78	21.02	5.50	1.53	12.64	14.58	13.45	12.00	4.19
Horry SC	4.11	2.83	7.10	22.08	2.15	5.50	16.40	18.33	14.65	14.35	2.77

	Franklin NC	Fulton GA	Georgetown SC	Glynn GA	Gordon GA	Greene GA	Greenville SC	Guilford NC	Gwinnett GA	Hamilton TN	Hampton SC
Beaufort SC	13.20	10.98	5.79	5.46	13.20	7.67	9.08	11.81	10.13	15.56	2.20
Charleston SC	11.25	11.79	2.94	7.11	14.01	8.48	8.37	10.04	10.94	16.37	3.41
Horry SC	7.33	14.14	2.24	11.29	15.94	10.83	9.27	7.28	12.87	17.69	7.37

	Hart GA	Haywood NC	Henderson NC	Horry SC	Jefferson GA	Kershaw SC	Lancaster SC	Laurens GA	Laurens SC	Lee GA	Lee SC
Beaufort SC	8.66	12.03	10.47	7.33	5.70	6.36	7.57	6.98	7.83	10.51	5.88
Charleston SC	9.42	11.31	9.76	4.47	6.88	5.35	6.56	8.55	7.12	12.17	4.76
Horry SC	10.77	11.60	10.05	0.00	10.05	4.50	5.17	11.93	8.02	15.92	3.44

	Lexington SC	Liberty GA	Marion SC	McDowell NC	McMinn TN	Mecklenburg NC	Muscogee GA	New Hanover NC	Newberry SC	Oconee SC	Onslow NC
Beaufort SC	5.59	3.98	7.38	11.21	15.58	8.84	11.83	10.25	6.60	9.77	12.23
Charleston SC	4.88	5.63	4.72	10.50	16.23	8.13	13.28	7.39	5.89	9.93	9.37
Horry SC	6.01	9.81	1.27	9.99	17.20	6.25	16.16	3.47	6.79	11.01	5.45

	Orangeburg SC	Peach GA	Pickens SC	Richland SC	Richmond GA	Rockdale GA	Rowan NC	Rutherford NC	Screven GA	Sevier TN	Shelby TN
Beaufort SC	3.64	9.48	9.52	5.55	5.10	9.68	10.44	10.24	3.81	14.56	27.14
Charleston SC	3.08	10.91	9.17	4.83	5.91	10.49	9.34	9.53	5.00	13.97	27.95
Horry SC	5.48	13.75	10.08	5.11	8.50	12.83	6.95	8.98	8.38	14.26	29.83

	Spartanburg SC	Sullivan TN	Sumter SC	Swain NC	Toombs GA	Transylvania NC	Turner GA	Union GA	Union NC	Wake NC
Beaufort SC	8.62	14.11	4.99	12.86	5.85	10.84	9.36	12.08	8.47	11.99
Charleston SC	7.91	13.40	3.86	12.96	7.51	10.32	11.01	12.73	7.38	10.05
Horry SC	8.34	12.19	3.64	13.25	11.37	11.01	14.84	13.93	5.32	6.33

	Ware GA	Washington GA	Watauga NC	Wilkes GA	Williamsburg SC
Beaufort SC	7.30	6.56	12.23	7.05	5.69
Charleston SC	8.95	7.75	11.52	7.86	3.07
Horry SC	13.13	10.63	10.07	9.79	3.25

Figure 19: Travel Time Matrix for Friends/Relatives destination type

Friction Factors on Floyd Data for Friends/Relatives

Dataview6 - FF

Bins	[OD matrix-FR]
0	4.383
1	34.702
2	25.775
3	10.074
4	5.356
5	4.455
6	6.619
7	4.334
8	4.039
9	3.086
10	6.465
11	3.368
12	3.111
13	2.756
14	2.036
15	1.000
16	3.160
17	1.829
18	0.000
19	5.091
20	0.000
21	6.191
22	11.306
23	5.091
24	5.091

Figure 20: Friction Factors for Friends/Relatives destination type

Observed TLD Matrix on Floyd Data for Hotels/Motels

Matrix17 - Observed TLD for Hotels/Motels (TLD)

	Count	Percent	Cumulative Count	Cumulative Percent
2.00 - 3.00	5.00	1.81	5.00	1.81
3.00 - 4.00	11.00	3.99	16.00	5.80
4.00 - 5.00	23.00	8.33	39.00	14.13
5.00 - 6.00	41.00	14.86	80.00	28.99
6.00 - 7.00	14.00	5.07	94.00	34.06
7.00 - 8.00	11.00	3.99	105.00	38.04
8.00 - 9.00	59.00	21.38	164.00	59.42
9.00 - 10.00	14.00	5.07	178.00	64.49
10.00 - 11.00	45.00	16.30	223.00	80.80
11.00 - 12.00	19.00	6.88	242.00	87.68
12.00 - 13.00	5.00	1.81	247.00	89.49
13.00 - 14.00	8.00	2.90	255.00	92.39
14.00 - 15.00	12.00	4.35	267.00	96.74
15.00 - 16.00	5.00	1.81	272.00	98.55
16.00 - 17.00	4.00	1.45	276.00	100.00
17.00 - 18.00	0.00	0.00	276.00	100.00
18.00 - 19.00	0.00	0.00	276.00	100.00
19.00 - 20.00	0.00	0.00	276.00	100.00
20.00 - 21.00	0.00	0.00	276.00	100.00
21.00 - 22.00	0.00	0.00	276.00	100.00
22.00 - 23.00	0.00	0.00	276.00	100.00
23.00 - 24.00	0.00	0.00	276.00	100.00

Figure 21: Observed TLD Matrix for Hotels/Motels destination type

Estimated TLD Matrix on Floyd Data for Hotels/Motels

Matrix22 - Calibrated TLD for Hotels/Motels (TLD)

	Count	Percent	Cumulative Count	Cumulative Percent
2.00 - 3.00	5.23	1.89	5.23	1.89
3.00 - 4.00	9.73	3.51	14.96	5.40
4.00 - 5.00	21.52	7.77	36.48	13.16
5.00 - 6.00	38.28	13.81	74.75	26.98
6.00 - 7.00	13.77	4.97	88.52	31.95
7.00 - 8.00	10.84	3.91	99.36	35.86
8.00 - 9.00	58.89	21.25	158.25	57.11
9.00 - 10.00	14.22	5.13	172.47	62.24
10.00 - 11.00	47.29	17.07	219.76	79.31
11.00 - 12.00	20.08	7.25	239.84	86.56
12.00 - 13.00	5.37	1.94	245.21	88.49
13.00 - 14.00	8.82	3.18	254.03	91.68
14.00 - 15.00	13.12	4.73	267.14	96.41
15.00 - 16.00	5.50	1.99	272.65	98.40
16.00 - 17.00	4.44	1.60	277.09	100.00
17.00 - 18.00	0.00	0.00	277.09	100.00
18.00 - 19.00	0.00	0.00	277.09	100.00
19.00 - 20.00	0.00	0.00	277.09	100.00
20.00 - 21.00	0.00	0.00	277.09	100.00
21.00 - 22.00	0.00	0.00	277.09	100.00
22.00 - 23.00	0.00	0.00	277.09	100.00
23.00 - 24.00	0.00	0.00	277.09	100.00

Figure 22: Estimated TLD Matrix for Hotels/Motels destination type

Observed OD on Floyd Data for Hotels/Motels

	Abbeville SC	Aiken SC	Anderson SC	Baldwin GA	Beaufort SC	Bibb GA	Bulloch GA	Buncombe NC	Candler GA	Charleston SC
Beaufort SC	0.00	5.00	2.00	1.00	0.00	10.00	3.00	4.00	1.00	0.00
Charleston SC	1.00	0.00	1.00	0.00	0.00	0.00	0.00	10.00	0.00	1.00
Horry SC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	0.00	1.00

	Chatham GA	Clarke GA	Cleveland NC	Cocke TN	DeKalb GA	Florence SC	Fulton GA	Gordon GA	Greenville SC	Guilford NC
Beaufort SC	1.00	3.00	0.00	1.00	1.00	1.00	24.00	1.00	4.00	1.00
Charleston SC	0.00	0.00	1.00	2.00	0.00	3.00	9.00	0.00	12.00	0.00
Horry SC	0.00	0.00	0.00	1.00	0.00	5.00	1.00	0.00	2.00	2.00

	Habersham GA	Hamilton TN	Haywood NC	Horry SC	Houston GA	Jackson GA	Jasper SC	Jefferson GA	Kershaw SC	Knox TN
Beaufort SC	1.00	3.00	2.00	0.00	2.00	1.00	2.00	2.00	0.00	2.00
Charleston SC	0.00	2.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00
Horry SC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00

	Lancaster SC	Laurens GA	Laurens SC	Mecklenburg NC	Morgan GA	Muscogee GA	Newberry SC	Newton GA	Orangeburg SC	Pickens SC
Beaufort SC	1.00	1.00	0.00	13.00	1.00	2.00	0.00	1.00	6.00	1.00
Charleston SC	0.00	0.00	0.00	11.00	1.00	0.00	0.00	0.00	4.00	1.00
Horry SC	1.00	1.00	0.00	12.00	0.00	2.00	1.00	0.00	0.00	1.00

	Richland SC	Richmond GA	Rockdale GA	Rutherford NC	Sevier TN	Spalding GA	Spartanburg SC	Swain NC	Wake NC	Wilkes GA
Beaufort SC	10.00	15.00	1.00	1.00	3.00	1.00	3.00	3.00	0.00	0.00
Charleston SC	9.00	6.00	0.00	0.00	3.00	0.00	4.00	0.00	2.00	1.00
Horry SC	7.00	1.00	0.00	0.00	0.00	0.00	1.00	3.00	0.00	0.00

Figure 23: Observed OD for Hotels/Motels destination type

Estimated OD on Floyd Data for Hotels/Motels

	Abbeville SC	Aiken SC	Anderson SC	Baldwin GA	Beaufort SC	Bibb GA	Bulloch GA	Buncombe NC	Candler GA	Charleston SC
Beaufort SC	0.62	2.75	1.77	0.72	0.00	6.34	2.18	6.54	0.71	1.51
Charleston SC	0.34	1.52	0.98	0.21	0.00	3.30	0.70	6.98	0.20	0.24
Horry SC	0.04	0.73	0.24	0.07	0.00	0.36	0.12	4.47	0.09	0.25

	Chatham GA	Clarke GA	Cleveland NC	Cocke TN	DeKalb GA	Florence SC	Fulton GA	Gordon GA	Greenville SC	Guilford NC
Beaufort SC	0.61	2.16	0.30	2.10	0.67	2.50	23.78	0.62	6.44	0.87
Charleston SC	0.31	0.46	0.43	1.16	0.19	2.77	6.84	0.24	9.27	0.93
Horry SC	0.08	0.37	0.27	0.74	0.14	3.73	3.38	0.14	2.29	1.21

	Habersham GA	Hamilton TN	Haywood NC	Horry SC	Houston GA	Jackson GA	Jasper SC	Jefferson GA	Kershaw SC	Knox TN
Beaufort SC	0.62	1.85	1.07	0.00	0.70	0.40	1.67	1.18	0.42	3.51
Charleston SC	0.34	3.15	1.78	0.00	0.95	0.54	0.23	0.56	0.27	2.13
Horry SC	0.04	0.00	1.14	0.00	0.34	0.06	0.10	0.26	0.30	1.36

	Lancaster SC	Laurens GA	Laurens SC	Mecklenburg NC	Morgan GA	Muscogee GA	Newberry SC	Newton GA	Orangeburg SC	Pickens SC
Beaufort SC	1.21	1.45	0.00	17.92	1.44	1.69	0.50	0.40	5.72	1.24
Charleston SC	0.45	0.42	0.00	9.93	0.31	1.02	0.32	0.54	3.17	0.69
Horry SC	0.34	0.13	0.00	8.15	0.25	1.29	0.18	0.06	1.11	1.07

	Richland SC	Richmond GA	Rockdale GA	Rutherford NC	Sevier TN	Spalding GA	Spartanburg SC	Swain NC	Wake NC	Wilkes GA
Beaufort SC	11.28	12.27	0.40	0.62	3.14	0.67	3.32	2.21	0.29	0.62
Charleston SC	10.72	6.80	0.54	0.14	1.74	0.19	3.50	1.22	0.91	0.34
Horry SC	4.00	2.93	0.06	0.24	1.12	0.14	1.18	2.57	0.80	0.04

Figure 24: Estimated OD for Hotels/Motels destination type

Travel Time (Shortest Path Matrix) on Floyd Data for Hotels/Motels

Travel Times are reported in Hours

	Abbeville SC	Aiken SC	Anderson SC	Baldwin GA	Beaufort SC	Bibb GA	Bulloch GA	Buncombe NC	Candler GA	Charleston SC
Beaufort SC	7.47	4.68	8.45	7.78	0.00	8.93	4.39	11.24	4.88	3.00
Charleston SC	7.74	4.91	8.62	8.97	3.00	10.12	5.95	10.52	6.54	0.00
Horry SC	9.05	7.37	9.84	11.59	7.33	12.96	9.33	10.67	10.03	4.47

	Chatham GA	Clarke GA	Cleveland NC	Cocke TN	DeKalb GA	Florence SC	Fulton GA	Gordon GA	Greenville SC	Guilford NC
Beaufort SC	3.05	8.59	9.69	13.74	10.40	6.23	10.98	13.20	9.08	11.83
Charleston SC	4.70	9.40	8.98	13.03	11.21	4.19	11.79	14.01	8.37	10.07
Horry SC	8.88	11.33	8.07	13.22	13.56	2.77	14.14	15.94	9.27	7.30

	Habersham GA	Hamilton TN	Haywood NC	Horry SC	Houston GA	Jackson GA	Jasper SC	Jefferson GA	Kershaw SC	Knox TN
Beaufort SC	10.29	15.56	12.03	7.33	9.25	9.39	1.75	5.70	6.36	15.45
Charleston SC	10.94	16.37	11.31	4.47	10.69	10.19	3.40	6.88	5.35	14.74
Horry SC	12.14	17.69	11.60	0.00	13.94	12.13	7.58	10.05	4.50	14.92

	Lancaster SC	Laurens GA	Laurens SC	Mecklenburg NC	Morgan GA	Muscogee GA	Newberry SC	Newton GA	Orangeburg SC	Pickens SC
Beaufort SC	7.57	7.01	7.83	8.84	8.43	11.83	6.60	9.39	3.64	9.52
Charleston SC	6.56	8.55	7.12	8.13	9.24	13.28	5.89	10.20	3.08	9.17
Horry SC	5.17	11.93	8.02	6.25	11.59	16.16	6.79	12.54	5.48	10.08

	Richland SC	Richmond GA	Rockdale GA	Rutherford NC	Sevier TN	Spalding GA	Spartanburg SC	Swain NC	Wake NC	Wilkes GA
Beaufort SC	5.55	5.10	9.64	10.24	14.66	10.59	8.62	12.86	12.04	7.05
Charleston SC	4.83	5.91	10.45	9.53	14.07	11.52	7.91	12.96	10.09	7.86
Horry SC	5.11	8.50	12.80	8.98	14.36	13.87	8.34	13.25	6.37	9.79

Figure 25: Travel Time Matrix for Hotels/Motels destination type

Friction Factors on Floyd Data for Hotels/Motels

Dataview18 - FF:1

Bins	Ho_Mo
0	9.454
1	68.987
2	33.090
3	16.864
4	15.769
5	9.193
6	7.902
7	11.765
8	6.170
9	2.377
10	5.787
11	3.005
12	1.000
13	3.277
14	2.319
15	2.119
16	6.492
17	0.000
18	6.106
19	1.000
20	1.000
21	1.000
22	1.000
23	1.000
24	1.000

Figure 26: Friction Factors for Hotels/Motels destination type

Observed TLD Matrix on Andrew Data for Friends/Relatives

Matrix27 - Observed TLD for Friends/Relatives (TLD)

	Count	Percent	Cumulative Count	Cumulative Percent
2.00 - 3.00	3.00	8.33	3.00	8.33
3.00 - 4.00	4.00	11.11	7.00	19.44
4.00 - 5.00	5.00	13.89	12.00	33.33
5.00 - 6.00	3.00	8.33	15.00	41.67
6.00 - 7.00	2.00	5.56	17.00	47.22
7.00 - 8.00	9.00	25.00	26.00	72.22
8.00 - 9.00	2.00	5.56	28.00	77.78
9.00 - 10.00	3.00	8.33	31.00	86.11
10.00 - 11.00	1.00	2.78	32.00	88.89
11.00 - 12.00	2.00	5.56	34.00	94.44
12.00 - 13.00	1.00	2.78	35.00	97.22
13.00 - 14.00	0.00	0.00	35.00	97.22
14.00 - 15.00	0.00	0.00	35.00	97.22
15.00 - 16.00	1.00	2.78	36.00	100.00
16.00 - 17.00	0.00	0.00	36.00	100.00
17.00 - 18.00	0.00	0.00	36.00	100.00
18.00 - 19.00	0.00	0.00	36.00	100.00
19.00 - 20.00	0.00	0.00	36.00	100.00
20.00 - 21.00	0.00	0.00	36.00	100.00
21.00 - 22.00	0.00	0.00	36.00	100.00
22.00 - 23.00	0.00	0.00	36.00	100.00
23.00 - 24.00	0.00	0.00	36.00	100.00

Figure 27: Observed TLD Matrix on Andrew Data for Friends/Relatives destination type

Estimated TLD Matrix on Andrew Data for Friends/Relatives

Matrix32 - Calibrated TLD for Friends/Relatives (TLD)

	Count	Percent	Cumulative Count	Cumulative Percent
2.00 - 3.00	3.26	8.74	3.26	8.74
3.00 - 4.00	4.29	11.49	7.56	20.22
4.00 - 5.00	5.61	15.02	13.17	35.24
5.00 - 6.00	3.28	8.77	16.45	44.01
6.00 - 7.00	2.02	5.40	18.47	49.41
7.00 - 8.00	9.08	24.30	27.55	73.71
8.00 - 9.00	2.13	5.71	29.68	79.42
9.00 - 10.00	3.05	8.16	32.73	87.58
10.00 - 11.00	0.95	2.55	33.69	90.13
11.00 - 12.00	1.90	5.09	35.59	95.22
12.00 - 13.00	0.95	2.53	36.53	97.75
13.00 - 14.00	0.00	0.00	36.53	97.75
14.00 - 15.00	0.00	0.00	36.53	97.75
15.00 - 16.00	0.84	2.25	37.37	100.00
16.00 - 17.00	0.00	0.00	37.37	100.00
17.00 - 18.00	0.00	0.00	37.37	100.00
18.00 - 19.00	0.00	0.00	37.37	100.00
19.00 - 20.00	0.00	0.00	37.37	100.00
20.00 - 21.00	0.00	0.00	37.37	100.00
21.00 - 22.00	0.00	0.00	37.37	100.00
22.00 - 23.00	0.00	0.00	37.37	100.00
23.00 - 24.00	0.00	0.00	37.37	100.00

Figure 28: Estimated TLD Matrix on Andrew Data for Friends/Relatives destination type

Estimated TLD Matrix on Andrew Data by Using the Floyd Model for Friends/Relatives

(The model is transferred by giving the friction factors of the Floyd Model as an input to the Andrew Model)

Matrix34 - Transferred TLD for Friends/Relatives (TLD)

	Count	Percent	Cumulative Count	Cumulative Percent
2.00 - 3.00	6.08	16.44	6.08	16.44
3.00 - 4.00	4.48	12.11	10.55	28.56
4.00 - 5.00	3.02	8.19	13.58	36.75
5.00 - 6.00	3.01	8.15	16.59	44.90
6.00 - 7.00	3.30	8.92	19.88	53.82
7.00 - 8.00	4.59	12.43	24.48	66.25
8.00 - 9.00	4.20	11.36	28.68	77.61
9.00 - 10.00	2.24	6.06	30.91	83.67
10.00 - 11.00	1.90	5.14	32.81	88.81
11.00 - 12.00	2.19	5.92	35.00	94.73
12.00 - 13.00	1.36	3.69	36.36	98.42
13.00 - 14.00	0.00	0.00	36.36	98.42
14.00 - 15.00	0.08	0.23	36.45	98.65
15.00 - 16.00	0.03	0.09	36.48	98.74
16.00 - 17.00	0.26	0.71	36.75	99.45
17.00 - 18.00	0.20	0.55	36.95	100.00
18.00 - 19.00	0.00	0.00	36.95	100.00
19.00 - 20.00	0.00	0.00	36.95	100.00
20.00 - 21.00	0.00	0.00	36.95	100.00
21.00 - 22.00	0.00	0.00	36.95	100.00
22.00 - 23.00	0.00	0.00	36.95	100.00
23.00 - 24.00	0.00	0.00	36.95	100.00

Figure 29: Estimated TLD Matrix for Transferred Model

Vita

Naveen Kumar Modali was born in India on July 21, 1981. He received his bachelor's degree in civil engineering from Andhra University, India, in June 2002. He came to the United States to pursue a master's degree in civil engineering in August 2002 at Louisiana State University, Baton Rouge, Louisiana. He is expected to fulfill the requirements for a master's degree in civil engineering in May 2005.