A structural equation analysis of Florida journey to work characteristics using aggregate Census 2000 data

Srikalyan Challa
University of South Florida

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A Structural Equation Analysis of Florida Journey to Work Characteristics

Using Aggregate Census 2000 Data

by

Srikalyan Challa

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Civil Engineering
Department of Civil and Environmental Engineering
College of Engineering
University of South Florida

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Keywords: census tracts, work commute travel time, place of work, mode to work, peak period departure

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A STRUCTURAL EQUATION ANALYSIS OF FLORIDA JOURNEY TO WORK CHARACTERISTICS USING AGGREGATE CENSUS 2000 DATA

Srikalyan Challa

ABSTRACT

The need for a better understanding of journey to work behavior has never before been so important. Many transportation corridors are functioning at unacceptable levels of service and many a times to their capacity. This phenomenon is more pronounced during peak period when majority of the population is making their work trip. This research builds on the recent developments in structural equations modeling technique for identifying the socio-demographic influences on the commute behavior of the population in Florida.

Towards this purpose a series of five structural equations models are estimated using aggregate level data from census 2000. Each of these models has a set of journey to work characteristics that are observed for their behavior against prevalent socio-demographic characteristics. The journey to work characteristics identified are exhaustively studied for various relationships to the socio-demographic characteristics.

The model estimation led to the identification of relations between various journey to work characteristics and the socio-demographic characteristics at the Census Tract level. Some of the results obtained supported other studies performed earlier. It is hoped that the findings of this research would broaden the horizon in understanding journey to work behavior of the population of Florida.
CHAPTER 1
INTRODUCTION

1.1 Background

In this era of changing travel behavior and trip making characteristics, journey to work constitutes a significant activity in the routine of an individual. Work trips contribute substantially to congestion in urban areas. For majority of the population, journey to work is the most predictable in terms of various trip features like trip length, mode used, and time of departure, origin and destination, and transfer locations. The observable work trip characteristics include travel time, travel mode, time of departure, work place location.

The understanding of journey to work characteristics is of utmost importance to the transportation policy makers at various levels in the government. These characteristics need to indicate the behavior across jurisdictions of various sizes than just observations at specific locations. One of the significant factors influencing the characteristics of a work trip is the social and economic variability in worker composition at any given location. These characteristics interact among themselves and also with work trip characteristics to various degrees resulting in the observed journey to work behavior. This thesis is an attempt to gain insights into the causal relations for work trip characteristics from the prevailing socio-demographic dispersion in the State of Florida.
1.2 Objectives

The overall objective of this research is to develop and estimate simultaneous equation models relating to socio-demographic characteristics and journey to work behavior to better address the following issues:

- Journey to work behavior relations at an aggregate level
- Identification of significant relationships among socio-demographics and journey to work behavior
- Understanding the direct, indirect, and total effects in the modeling system

Recent research in the travel behavior arena has focused on a variety of disaggregate analysis techniques to understand accurately, by clearly identifying any inter-relations among the units of analysis. To utilize the findings at the lowest unit level (say, person or household) in predicting the behavior of a larger geographic unit such as a census tract, county or a state, the quantified results (at person or household level) need to be aggregated to the higher level (county, state) of interest.

Disaggregate methods of analysis usually need data at person or household level. These data collection processes are labor intensive, which constraints such data collection at various geographic locations. Hence a perfect representation of the population can not be obtained for use to aggregate the estimates. In this context, aggregate models play a significant supporting role not only to check for discrepancies from the estimates at disaggregate level obtained by using localized data but also in giving a over all trend about a characteristic of interest.
1.3 Methodology

Structural equation models (SEM) were developed to understand the causal relationships between socio-demographic variables and journey to work characteristics like travel time, time of departure, and mode of departure. A set of five models was used to observe consistency in the behavior of the relationships. The models developed examine the interactions between socio-demographic characteristics and journey to work variables at the level of census tract. Data for this model development was obtained from the Census Summary File 3 (SF3).

1.4 Outline

The remainder of the thesis is organized as follows. Next chapter provides an literature review on the journey to work characteristics and usage of structural equation models to understand travel behavior. The third chapter constitutes description of the data that was used in this study. The fourth chapter describes the methodology. The fifth chapter specifies the models used to in this research and tabulates their estimation results. The sixth chapter interprets the model estimation results. The seventh chapter draws conclusions and gives directions for future research which is followed by the list of references.
CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Many significant research contributions were made in understanding journey to work characteristics of individuals. Transportation engineers, land planners, policy makers are all interested in understanding the significant, predictable trip making behavior of individuals. The transportation system is at its peak usage during the peak period caused by journey to work trips of individuals. Structural equation modeling is used in this thesis to analyze the commute behavior at an aggregate level. The unit of analysis is census tract and the socio economic information obtained is a cumulative for the census tract.

2.2 Travel time to work

Brownstone, et al. (2003) developed a logit model to identify the road user’s willingness to pay as much as $30 an hour on the I-15 in California. Road user’s perception of congestion and sensitivity to travel time might vary depending on the available alternatives. This study found that commuters, individuals from high income (income greater than 100K) households, women, and individuals between the ages of 35 and 45 are more likely to pay toll to avoid congestion. These observations give us an understanding on the sensitivity levels of these particular groups to travel time.
Schwanen, et al. (2001) used the data from Dutch national survey and analyzed the relationship between travel time and work duration. They found that workers are willing to have travel time up to 10 percent of their work time. Though, this study is from Europe, the results give an understanding of the general commuter tolerance to travel time compared against working time.

Bhat and Guo (2003) estimated a mixed logit model to identify the factors in residential choice location. It was found that commute travel time is a significant factor in the decision making along with socio-demographics, transportation system LOS.

Levinson (1998) analyzed the effect of accessibility to jobs and houses at both the home and work ends of trips on commuting duration for respondents to a household travel survey in metropolitan Washington, DC. He found that residences in job-rich areas and workplaces in housing-rich areas are associated with shorter commutes. An implication of this study is that, by balancing accessibility, the suburbanization of jobs maintains stability in commuting durations despite rising congestion, increasing trip lengths, and increased work and non-work trip making.

2.3 SOV mode to work

Collia, et al. (2003) studied the travel behavior of older population (with age greater than 65 years of age) as depicted in 2001 NHTS and found that use of alternative transportation is relatively low. Excluding personal vehicle and walking, all other means of transportation account for about 2% of daily travel. Further, of the older population with medical conditions that affect their travel, only about 12% use special transportation
services such as dial-a-ride. This shows a greater dependence of elderly population on SOV mode.

Bhat, et al. (1997) formulated an econometric methodology to estimate the component of the analysis framework involving the joint modeling of evening commute mode choice, number of evening commute stops, and number of stops after arriving home from work. The results of this study indicate strong effects of socio-economic variables, residential/workplace location characteristics, work schedule characteristics and level of service measures on evening commute mode choice.

Cervero (2002) studied the effect of built environment on mode choice. His analysis reveals intensities and mixtures of land use significantly influence decisions to drive-alone, share a ride, or patronize transit, while the influences of urban design tend to be more modest.

Sermons and Koppelman (2001) developed multinomial logit models (MNL) of residential location choice for two-worker households in the San Francisco Bay Metropolitan Area to identify household characteristics that account for the relative differences in household sensitivity to female and male commutes when making residential choices. The results reveal that presence of children, occupation of the male worker, and the relative order of the last residential change and the last change in the female worker's workplace are important determinants of female and male commuting time parameters in household residential location utility functions.
2.4 Location of employment

Analysis by Clark, et al. (2000) utilized descriptive measures of distance and time to work for pre- and post-residential relocations and develops estimates from a probability model of work-place attraction. The findings indicate that both one- and two-worker households with greater separation between workplace and residence make decreases in distance and time. Overall, as other studies have shown, women commute shorter distances and are more likely to minimize commuting after a move than are men.

Randall Crane (1994) found that more likely, the individual value of a given home and the choice of commute length are based not only on the current job site, but also on the expectation of where future jobs will be and the likelihood of both job separations and residential moves.

2.5 Peak period departure to work

Conquest, et al. (2002) classified users as (a) route changers, willing to change route both on Interstate 5 and before leaving; (b) non-changers, unwilling to change departure time, route, or mode of transportation; (c) route and time changers, willing to change route and departure time; and (d) pre-trip changers, willing to change departure time, route, or mode before departure but unwilling to change en route. Knowledge of such groups and their behavioral characteristics is useful in designing advanced traveler information systems that seek to affect commuter behavior and increase the efficiency of current transportation facilities.

Hendrickson, et al. (1984) examined the flexibility of departure times for the journey to work making use of data gathered in Pittsburgh, Pennsylvania. Measured
travel time peaking is pronounced for trips into the Pittsburgh Central Business District, although the variation in travel time is low for a particular route, mode and departure time. Estimation of a logit model of simultaneous mode and departure time interval choice is reported. Departure time decisions are found to be much more flexible (elastic) than are mode choices.

2.6 Structural equations modeling

Structural Equations Modeling (SEM) is a statistical methodology that takes a confirmatory hypothesis-testing approach to the analysis of a structural theory regarding phenomenon. Typically, this theory represents “causal” processes that generate observations on multiple variables. The term structural equation modeling conveys two important aspects of the procedure: (1) that the causal processes under study are represented by a series of structural equations, and (2) that these structural relations can be modeled pictorially to enable a clearer conceptualization of the theory under study.

Golob and Zondag (1984) is another early application of SEM. Golob and Van Wissen (1989) attempt an explanation of car ownership and travel distances by mode, but the SEM has just household income as a household characteristic.

Applied to data on attitudes, perceptions, stated behavioral intentions, and actual behavior, SEM can be used to specify and test alternative hypotheses of causality. Tardiff (1976) used path analysis (a simplified application of SEM) to demonstrate empirical evidence that the causal link from choice behavior to attitudes is stronger than the link from attitudes to choice behavior. Subsequent studies using different forms of simultaneous equation modeling showed consistently that attitudes, especially
perceptions, are conditioned by choices, while at the same time, attitudes affect choices (e.g., Dobson, et al., 1978).

Golob and Brownstone (1992) is another early application of SEM in which it is shown that behavior conditions attitudes, while, simultaneously, attitudes have some affect of behavior. Golob, et al. (1997) presented an SEM in which changes in travel times, attitudes toward carpooling, mode choice, and use of an exclusive freeway lane for carpools are modeled over time using a U.S. panel dataset.

Lu and Pas (1999) have analyzed a set of relationships with travel behavior variables as endogenous and socio-demographics and activity participation variables as exogenous variables. This study performs the analysis at a disaggregate level.

In summary, many studies as examined in this literature review tried to explore the relationship between a particular journey to work characteristic like travel time, travel mode, peak hour departure, place of work and various other land use and socio-demographic characteristics. Each of these variables was analyzed in isolation from the other journey to work characteristic. Also, most of the studies used disaggregate data for their analysis. Hence, based on the available literature in using structural equations model and the journey to work characteristics, a set of five models were developed to explain commute characteristics at an aggregate level of census tracts.

The evolution of census tracts with respect to socio-economic and demographic characteristics and its implications for journey to work characteristics is an important issue that warrants study. Policy makers and planners would be able to assess the potential shifts in journey to work characteristics as census tract evolves.
CHAPTER 3

DESCRIPTION OF DATA

The amount of information desired from respondents by transportation planners has increased tremendously over recent years (Kalfs and Saris, 1997). Census survey still continues to be the most utilized information source regarding the prevalent demographic and economic conditions. It is planned to use census data in the proposed structural equation modeling framework of relationships between the journey to work variables and the demographic and economic variables.

This chapter aims at presenting an overview of the data set used in this study. This chapter elaborates on the depth of information that is available for usage in such an analysis. The next section gives a brief description of the 2000 Census survey that is used to collect the data that is analyzed in this research.

3.1 Census survey description

Census 2000 was the largest peacetime effort in the history of United States. Information about 115.9 million housing units and 281.4 million people across the United States was collected. A limited number of questions were asked of every person and housing unit in the United States. This is called the census short form. The questions asked include Household relationship, age, sex, Hispanic or Latino origin, race tenure (home is owned or rented). More detailed information was asked of a sample (1 in every
6) persons or housing units. This is called the long form survey. The long form survey included sections in population and housing. The journey-to-work items were provided in the population section.

The identification and location of an estimated 118 million housing units in the nation was performed by census bureau by developing and maintaining the Master Address File (MAF). The United States Postal Service (USPS) played a vital role in contributing to the MAF. The census questionnaire and related materials delivered to individual addresses carried the same themes and messages as the overall campaign. The Census Bureau used public meetings and the news media to inform the public about the value of the census and to encourage response.

In 2000, in addition to mailing the census questionnaires, the Census Bureau made the forms available in stores and malls, in schools, and in other public locations. A toll-free telephone number was available for those who wished to respond to the census by telephone. People also had the option to respond to the short form through Internet. In Census 2000, the questionnaire mailout/mailback system was the primary means of census-taking, as it has been since 1970. The short form was delivered to approximately 83 percent of all housing units. The short form asked only the basic population and housing questions, while the long form included additional questions on the characteristic of each person and of the housing unit. The long form was delivered to a sample of approximately 17 percent of all housing units. The Census Bureau adopted a ten part, integrated data enumeration strategy to ensure that completed questionnaires were obtained for every household possible. Special populations (American Indians, Alaskan Natives etc) were identified.
3.2 Census tract level data

Census tracts are sub-county geographic entities that are viewed as reasonably permanent and are typically identified by state and local participants in the Census Bureau’s Participant programs. The definition of census tracts is to generate and maintain long-term statistical units. The census tracts are intended to be maintained over many decades so that longitudinal comparisons can be made over various long form questions. The target population of a census tract is around 4000. Census tracts might be changed with local developments such as new subdivisions, highway construction, etc. In addition, census tracts occasionally are split due to population growth or combined as a result of substantial population decline. Census 2000 is the first census for which the entire United States was covered by census tracts.

Census Tracts are numbered by a four system of numbers ranging from 0001 to 9999. Some of the numbers are reserved for certain categories of population. The four digit number is followed by a two digit suffix which indicates the year in which the census tract was identified. The definitional criteria advertised by the Census Bureau contribute to a reasonable amount of uniformity, especially for tracts. Major geographic features, transportation routes, and boundaries of political entities constitute relatively stable universal standards for establishing tracts. The suggested population parameters for tracts and block groups are another source of uniformity. Local and state personnel involved in block group decisions may change them over time to suit changing local conditions. In contrast, the emphasis on preserving longitudinal comparability of tracts contributes to uniformity across time. Especially in the cores of longstanding metropolitan areas, census tracts provide a sound basis for longitudinal analysis.
Due to substantial and systematic variation in the characteristics of counties, they cannot be used as spatial units of analysis. Of the 3142 counties in United States, 25 percent occupy less than 450 square miles and another 25 percent cover at least 900 square miles. Those in the western United States tend to encompass much more territory than do counties in the east. In terms of population variability, 25 percent of U.S. counties have fewer than 11,000 residents while another 25 percent have populations in excess of 60,000. Also, there are statewide idiosyncrasies such as Louisiana’s Parishes and Virginia’s treatment of independent cities as county equivalents. Due to these reasons the census tract forms a much more consistent spatial unit of analysis, and hence is used in the thesis.

3.3 Florida census tracts

At the geographic level census tracts add up to form counties. The hierarchical chart depicts the various geographic levels identified in the Census enumeration. Florida constitutes 3154 census tracts. These census tracts vary in land area, population, socio-economic and journey to work characteristics. Census tract is the unit of modeling adopted in this research work.

3.3.1 Population

The average land area for the census tracts was found to be 17.1 square miles with a population average of 5067.
Figure 3.1 Standard hierarchy of census geographic entities

Source: Census 2000 summary file 3 technical documentation
The population density average of 3320 is far greater number than the density obtained from the average of total population to total land area. This indicates that large areas exist with much lesser population than the average and that population concentrations exist. This non-uniform population distribution can be seen in Figure 3.3 and in Figure 3.2 the distribution of population density across census tracts.

Table 3.1 Land area and population

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<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
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<td>3154</td>
<td>.03</td>
<td>1154.74</td>
<td>17.1</td>
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<td>3154</td>
<td>.00</td>
<td>24506.00</td>
<td>5067</td>
</tr>
<tr>
<td>Total Population Density</td>
<td>3154</td>
<td>0</td>
<td>38851</td>
<td>3320</td>
</tr>
</tbody>
</table>

### 3.3.2 Urban and rural classification

The Census Bureau classifies as urban all territory, population housing units located with in urbanized areas (UAs) and urban clusters (UCs). UAs and UCs boundaries constitute densely settled territory which consists of:

- A cluster of one or more block groups or census blocks each of which has a population density of at least 1000 people per square mile at the time
- Surrounding block groups and census tracts each of which has a population density of at least 500 people per square mile at a time
- Less densely settled blocks that form enclaves or indentations, or are used to connect discontiguous areas with qualifying densities

All areas that are not urban are classified as rural. Table 3.2 depicts the distribution of urban population in terms of percentage of total population for the entire state.
3.4 Person characteristics across census tracts

In order to better understand the overall behavior, the census tract composition in terms of persons living in a single census tract is to be clearly identified. These person characteristics are detailed in the next few sections.

![Figure 3.2 Total population density](image)

![Table 3.2 Percent urban population distribution in census tracts](data)

<table>
<thead>
<tr>
<th>Percent urban population in census tract</th>
<th>Frequency</th>
<th>Percent of census tracts</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 20</td>
<td>195</td>
<td>6.2</td>
</tr>
<tr>
<td>20.01 – 40</td>
<td>81</td>
<td>2.6</td>
</tr>
<tr>
<td>40.01 – 60</td>
<td>94</td>
<td>3.0</td>
</tr>
<tr>
<td>60.01 – 80</td>
<td>136</td>
<td>4.3</td>
</tr>
<tr>
<td>80.01 – 100</td>
<td>2648</td>
<td>84.0</td>
</tr>
<tr>
<td>Total</td>
<td>3154</td>
<td>100.0</td>
</tr>
</tbody>
</table>
It is observed that 84% of the census tracts have 80% or more of their population as urban population. Less than 10% of the Census tracts have predominantly rural population.

Table 3.3 Person characteristics - mean percent across census tracts

<table>
<thead>
<tr>
<th>Total number of census tracts</th>
<th>3154</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male age (&lt; 15) years</td>
<td>19.5%</td>
</tr>
<tr>
<td>Male age (15-25) years</td>
<td>12.4%</td>
</tr>
<tr>
<td>Male age (25-50) years</td>
<td>35.7%</td>
</tr>
<tr>
<td>Male age (50-70) years</td>
<td>20.3%</td>
</tr>
<tr>
<td>Male age (≥ 70) years</td>
<td>12.1%</td>
</tr>
<tr>
<td>Female age (&lt; 15) years</td>
<td>17.7%</td>
</tr>
<tr>
<td>Female age (15-25) years</td>
<td>11.4%</td>
</tr>
<tr>
<td>Female age (25-50) years</td>
<td>34.4%</td>
</tr>
<tr>
<td>Female age (50-70) years</td>
<td>21.3%</td>
</tr>
<tr>
<td>Female age (≥ 70) years</td>
<td>15.2%</td>
</tr>
<tr>
<td>Workers</td>
<td>42%</td>
</tr>
</tbody>
</table>

Table 3.3 details the mean values of the percent male and female population by age group. The mean value of percent workers among the population in a census tract is found to be 42 percent. Figure 3.3 gives the distribution of percent of males in the 25 to 50 age group across the census tracts.
Figure 3.3 Percent male population between twenty five and fifty years of age across census tracts

3.4.1 Gender distribution

The distribution of male population across the census tracts is described in Figure 3.4
Figure 3.4 Percent males in census tracts
Figure 3.5 Population distribution in Florida by census tract
It can be observed that mean male population in a census tract is around 50 percent. Similarly it was observed that the female average close to 51 %. Figure 3.6 depicts the distribution of population above 70 years of age across census tracts.

Figure 3.6 Percent population greater than seventy years of age in census tract
3.4.2 Worker distribution

The data on weeks worked in 1999 were derived from answers to long-form questionnaire Item 30b, which was asked of people 15 years old and over who indicated in long-form questionnaire Item 30a that they worked in 1999. The data were tabulated for people 16 years old and over and pertain to the number of weeks during 1999 in which a person did any work for pay or profit (or took paid vacation or paid sick leave) or worked without pay on a family farm or in a family business. Total workers per census tract are seen to be close to 42 percent.
3.4.3 Worker age distribution

The table 3.5 below describes variation in percent workers by varying percent of population less than 25 years of age. Large number of census tracts fall in the category having 20 to 40 percent of the population being less than 25 years of age. Among the census tracts with 20 to 40 percent of population less than 25 years of age, majority of the census tracts seem to have 40 to 60 percent workers in them. As expected, greater number of census tracts with less than 20 percent of population as workers seem to have less than 20 percent of their populations with age less than 25 years of age. The reason
for this might be due to a greater old age population in the census tracts which results in both lesser workers as well as lesser percent of population less than 25 years of age.

Table 3.4 Worker distribution across population less than twenty five years of age

<table>
<thead>
<tr>
<th>Census tracts with Percent population as Workers</th>
<th>Percent population less than 25 years of age</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>57 9 5 0 3</td>
<td>74</td>
</tr>
<tr>
<td>20-40</td>
<td>280 524 199 5 7</td>
<td>1015</td>
</tr>
<tr>
<td>40-60</td>
<td>132 1690 184 8 1</td>
<td>2015</td>
</tr>
<tr>
<td>60-80</td>
<td>10 34 3 2 0</td>
<td>49</td>
</tr>
<tr>
<td>80-100</td>
<td>1 0 0 0 0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>480 2257 391 15 11</td>
<td>3154</td>
</tr>
</tbody>
</table>

3.5 Household characteristics across census tracts

Household characteristics like the person characteristics influence the journey to work characteristics of the residents of a census tract. The following sections describe some of the household characteristics and their relationships. Table 3.6 gives the description on household size, household income and household auto ownership based on as mean values across census tracts.

Table 3.5 Household characteristics – mean percent across census tracts

<table>
<thead>
<tr>
<th>Total Number of Census tracts</th>
<th>3154</th>
</tr>
</thead>
<tbody>
<tr>
<td>One person household</td>
<td>26.2%</td>
</tr>
<tr>
<td>Two person household</td>
<td>36.2%</td>
</tr>
<tr>
<td>Three person household</td>
<td>15.6%</td>
</tr>
<tr>
<td>Four or more person household</td>
<td>22.0%</td>
</tr>
<tr>
<td>Low Income (&lt; 30,000$)</td>
<td>38.6%</td>
</tr>
<tr>
<td>Medium Income (30,000$-60,000$)</td>
<td>32.8%</td>
</tr>
<tr>
<td>High Income (≥ 60,000$)</td>
<td>28.6%</td>
</tr>
<tr>
<td>Zero car household</td>
<td>8.6%</td>
</tr>
<tr>
<td>One car household</td>
<td>40.6%</td>
</tr>
<tr>
<td>Two car household</td>
<td>38.2%</td>
</tr>
<tr>
<td>Three or more car household</td>
<td>12.6%</td>
</tr>
</tbody>
</table>
It could be observed from Table 3.6 on an average in all the census tracts two person households seem to form the highest percent of all households at 36.2% which is a little over one third of all households in a typical census tract. Single person households are also as common as two person households, by taking almost one third of all households. Four and more person households are about 20 percent of all the households.

Car ownership numbers from table 3.6 show that the largest share is taken by one and two car households, together forming 80 percent of all households. Zero car households form close to 10% of all households in the census tract. Interestingly, contrary to the income figures, we can see that percent of three or more car households are greater than percent of zero car households in a typical census tract.

### 3.5.1 Number of households

The number of households in a census tract averages at 2000 as shown in Figure 3.9. The size of the household varies from single person household to households with more than 7 persons. Census defines households as including all the people who occupy a housing unit. (People not living in households are classified as living in group quarters.) A housing unit is a house, an apartment, a mobile home, a group of rooms, or a single room occupied (or if vacant, intended for occupancy) as separate living quarters.

Separate living quarters are those in which the occupants live separately from any other people in the building and that have direct access from the outside of the building or through a common hall. The occupants may be a single family, one person living alone, two or more families living together, or any other group of related or unrelated people who share living quarters.
3.5.2 Annual household income

The mean distribution of income of income across census tracts shows that the low income households defined as households with income less than 30,000$ per annum, form the largest share of households in a typical census tract. On average 32.8% of all households in a census tract are middle income households, with income in the range 30K-60K per annum. An income variable used in this study is percent households with income greater than 60,000$ per annum, which averages at about a third of the household in a typical census tract.
3.5.3 Household size

It can be observed that on an average 40 percent of the population lives in one or two person households. Another 45 percent of a typical census tract lives in 3, 4 or 5 person households. Only about 15 percent of the population constitutes those living in large households averaging sizes above 6 persons and also those living in group quarters. Figures 3.11 and 3.12 depict the distribution of two and three person households across the census tracts.
Figure 3.11 Percent two person households in census tracts
3.5.4 Vehicle ownership

The table 3.7 explains the household vehicle ownership distribution by percent of total households in a census tract. From the table below it can be observed that for 91 percent of census tracts, the proportion of zero car households is less than 20 percent. Majority of the census tracts have one or two car households forming 20 to 60 percent of the total households. The distribution between the two levels (20 percent to 40 percent and 40 percent to 80 percent) seems to be equally distributed in almost half of the census Tracts.
Table 3.6 Vehicle distribution by percent of census tracts

<table>
<thead>
<tr>
<th>% Census tracts with</th>
<th>Household car ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of Total households</td>
<td>0</td>
</tr>
<tr>
<td>0 – 20</td>
<td>91.0</td>
</tr>
<tr>
<td>20.01 – 40</td>
<td>7.2</td>
</tr>
<tr>
<td>40.01 - 60</td>
<td>1.5</td>
</tr>
<tr>
<td>60.01 - 80</td>
<td>0.3</td>
</tr>
<tr>
<td>80.01 - 100</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Three car households have a similar distribution among the census tracts as the zero car households. 86 percent of the census tracts have three or more car households forming less than 20 percent of the entire households. Unlike the zero car households, a significant percent of census tracts (14 percent) seem to fall in the category of having 20 to 40 percent of their households with three or more cars.
3.6 Journey to work characteristics

3.6.1 Travel time to work

Travel time is the time required to traverse between two points in space. Travel time is commonly perceived measure of understanding the ease of navigating through a roadway network. For a greater population travel time to work is of greatest consideration. Job and residential location choice are impacted by a large variety of...
factors, many of which are related with a worker's orientation towards his/her household and leisure. Some workers show inflexibility in their travel times. Women especially seem to use commuting as a buffer between the different roles of being an employee and taking care of household members.

Figure 3.7 depicts the distribution of short work trip across various census tracts in Florida. Short work trips are defined as the trip which has less than 10 minutes of travel time. It is interesting to note that the percentage of short trips is in the lowest bracket (less than 10 percent) in the census tracts surrounding urbanized areas. These might be the suburban areas from where people commute to the urbanized areas to work.

Figure 3.8 shows the spatial distribution of long trips, defined as work trips with travel time more than 60 minutes, across the census tracts. It can be seen that low percent (less than 5%) of long trips exists in the census tracts very adjacent to an urbanized area. Census tracts with high percent (greater than 20%) of these trips lies in census tracts which are farthest from any urbanized area or in the farther suburban areas.

Many earlier studies have shown that income effects sensitivity to travel time for work trips. The high income population has high opportunity cost of time and hence high commuting cost per mile. The sensitivity of high income population to travel time tends to be high. Shown below is the histogram for percent of workers having travel time lesser than 10 minutes and also for percent of census tracts having travel time greater than 60 minutes.
Figure 3.14 Percent workers whose work travel time to work is less than ten minutes

Table 3.7 Short travel time in three person households

<table>
<thead>
<tr>
<th>Census tracts with</th>
<th>Percent three person households</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent workers with travel time less than 10 minutes</td>
<td>0-20 20-40 40-60 60-80 80-100 Total</td>
</tr>
<tr>
<td>0-20</td>
<td>90 49 14 4 2 159</td>
</tr>
<tr>
<td>20-40</td>
<td>390 209 24 3 0 626</td>
</tr>
<tr>
<td>40-60</td>
<td>1501 348 20 2 0 1871</td>
</tr>
<tr>
<td>60-80</td>
<td>482 10 4 1 0 497</td>
</tr>
<tr>
<td>80-100</td>
<td>0 1 0 0 0 1</td>
</tr>
<tr>
<td>Total</td>
<td>2463 617 62 10 2 3154</td>
</tr>
</tbody>
</table>

The Table 3.9 shows that greater number of census tracts fall in the category with less than 20 percent three person households and 40 to 60 percent workers with travel...
time less than 10 minutes. Higher the three person households lesser the population with travel time less than 10 minutes.

Figure 3.15 Percent workers whose work travel time to work is greater than sixty minutes

3.6.2 Place of work

Place of work is one of the important characteristic of the journey to work at both individual level as well as at the level of census tracts. Places, for the reporting of decennial census data, include census designated places, consolidated cities, and incorporated places.
Each place is assigned a five-digit Federal Information Processing Standards (FIPS) code, based on the alphabetical order of the place name within each state. If place names are duplicated within a state and they represent distinctly different areas, a separate code is assigned to each place name alphabetically by primary county in which each place is located, or if both places are in the same county, alphabetically by their legal description (for example, “city” before “village”).

Percent workers working in their place of work is of prime interest in this chapter. The geographic distribution can be seen in figure 3.10. The percent averages at about 25% of the workers in a census tract.

When comparing the old age population and percent workers working in place of residence, it can be observed from table 3.10 that the greater number of census tracts with higher percent of old age population have lesser percent of workers working in place.

Table 3.8 Percent population greater than seventy years of age and place of work

<table>
<thead>
<tr>
<th>Census tracts with Percent workers working in place</th>
<th>Percent population greater than 70 years of age</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>20-40</td>
</tr>
<tr>
<td>0-20</td>
<td>1439</td>
</tr>
<tr>
<td>20-40</td>
<td>496</td>
</tr>
<tr>
<td>40-60</td>
<td>311</td>
</tr>
<tr>
<td>60-80</td>
<td>122</td>
</tr>
<tr>
<td>80-100</td>
<td>176</td>
</tr>
<tr>
<td>Total</td>
<td>2544</td>
</tr>
</tbody>
</table>

It can also be observed from the table 3.11 that greater share of the census tracts with higher percent of two vehicle households have lesser percent of workers working in place of residence.
Figure 3.16 Percent workers working in their place of residence

Table 3.9 Percent two vehicle households and place of work

<table>
<thead>
<tr>
<th>Census tracts with Percent workers working in place</th>
<th>Percent two vehicle households</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent workers working in place</td>
<td>0-20</td>
<td>20-40</td>
<td>40-60</td>
<td>60-80</td>
<td>80-100</td>
<td>Total</td>
</tr>
<tr>
<td>0-20</td>
<td>50</td>
<td>758</td>
<td>920</td>
<td>55</td>
<td>0</td>
<td>1783</td>
</tr>
<tr>
<td>20-40</td>
<td>47</td>
<td>349</td>
<td>254</td>
<td>11</td>
<td>0</td>
<td>661</td>
</tr>
<tr>
<td>40-60</td>
<td>65</td>
<td>237</td>
<td>89</td>
<td>2</td>
<td>0</td>
<td>393</td>
</tr>
<tr>
<td>60-80</td>
<td>25</td>
<td>79</td>
<td>31</td>
<td>1</td>
<td>2</td>
<td>138</td>
</tr>
<tr>
<td>80-100</td>
<td>21</td>
<td>85</td>
<td>70</td>
<td>3</td>
<td>0</td>
<td>179</td>
</tr>
<tr>
<td>Total</td>
<td>208</td>
<td>1508</td>
<td>1364</td>
<td>72</td>
<td>2</td>
<td>3154</td>
</tr>
</tbody>
</table>
Figure 3.17 Workers with work travel time less than ten minutes across Florida
Figure 3.18 Workers with work travel time greater than sixty minutes across Florida
3.6.3 SOV mode to work

Single Occupancy Vehicles (SOV) continues to be the single largest mode choice for a work trip. The changes that took place in the last few decades led to a greater increase in the SOV usage. Expanding role of women in the paid labor force, reduction in family size, greater proportion of old age population are accustomed drivers. Many such factors contributed to greater auto usage in general and also SOV usage to work. It can be observed from the histogram below that greater number of census tracts have more than 60 percent of their workers using SOV mode to work. The percent averages at about 80.

As it can be seen from the spatial distribution of percent workers in a census tract using SOV mode to work, the census tracts in the urban areas have a greater percent of their workers using SOV mode to work. The percent falls down a little bit in the census tracts which form the suburban areas, as people might have longer work trips and other household activities like dropping kids at school can be performed in the process. Though this proportion might be lesser than what one can find in the urban areas but still it is a very sizable proportion of the workers in the census tract (65 – 75 percent).
Figure 3.19 Percent workers working in place of residence across Florida
It is interesting to observe in table 3.12 that greater number of census tracts with higher percent of aged population has greater percent of SOV usage to work.
Figure 3.21 Percent workers using SOV mode to work across Florida

Percent SOV Mode to Work
- 0 - 50
- 50.01 - 65
- 65.01 - 75
- 75.01 - 80
- 80.01 - 100
Table 3.10 SOV mode to work and population greater than seventy years of age

<table>
<thead>
<tr>
<th>Census tracts with</th>
<th>Percent population greater than 70 years of age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent workers using SOV mode to work</td>
<td>0-20</td>
</tr>
<tr>
<td>0-20</td>
<td>13</td>
</tr>
<tr>
<td>20-40</td>
<td>21</td>
</tr>
<tr>
<td>40-60</td>
<td>122</td>
</tr>
<tr>
<td>60-80</td>
<td>985</td>
</tr>
<tr>
<td>80-100</td>
<td>1009</td>
</tr>
<tr>
<td>Total</td>
<td>2148</td>
</tr>
</tbody>
</table>

Table 3.10 shows a higher SOV mode usage in census tracts with greater percent of two or more vehicle households.

Table 3.11 Auto ownership and SOV usage to work

<table>
<thead>
<tr>
<th>Census tracts with</th>
<th>Percent households with two or more vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent workers using SOV mode to work</td>
<td>0-20</td>
</tr>
<tr>
<td>0-20</td>
<td>12</td>
</tr>
<tr>
<td>20-40</td>
<td>15</td>
</tr>
<tr>
<td>40-60</td>
<td>78</td>
</tr>
<tr>
<td>60-80</td>
<td>78</td>
</tr>
<tr>
<td>80-100</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>208</td>
</tr>
</tbody>
</table>

Table 3.12 shows that higher is the percent of females in a census tract greater is the chance for it to have a higher SOV usage to work.

Table 3.12 Percent female population and SOV usage to work

<table>
<thead>
<tr>
<th>Census tracts with</th>
<th>Percent females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent workers using SOV mode to work</td>
<td>0-20</td>
</tr>
<tr>
<td>0-20</td>
<td>7</td>
</tr>
<tr>
<td>20-40</td>
<td>2</td>
</tr>
<tr>
<td>40-60</td>
<td>0</td>
</tr>
<tr>
<td>60-80</td>
<td>0</td>
</tr>
<tr>
<td>80-100</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
</tr>
</tbody>
</table>
3.6.4 Peak period departure to work

Peak period travel constitutes the most demand on the capacity of the regional transportation system. Though the percent of daily traffic traveling during peak hours decreased over the past few decades, the actual volume using the roadway network during peak period increased tremendously and in many corridors the system operates at its peak capacity. It can be seen from the table 3.15 that as percent households with high income increases the number of census tracts with higher percentage of workers departing during peak period increases.

Table 3.13 High income households and peak period departure

<table>
<thead>
<tr>
<th>Census tract with Percent workers departing during peak period</th>
<th>Percent households with income greater than $60,000</th>
<th>0-20</th>
<th>20-40</th>
<th>40-60</th>
<th>60-80</th>
<th>80-100</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>15</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>20-40</td>
<td>87</td>
<td>20</td>
<td>11</td>
<td>8</td>
<td>1</td>
<td>127</td>
<td></td>
</tr>
<tr>
<td>40-60</td>
<td>1015</td>
<td>1134</td>
<td>409</td>
<td>119</td>
<td>5</td>
<td>2682</td>
<td></td>
</tr>
<tr>
<td>60-80</td>
<td>41</td>
<td>127</td>
<td>103</td>
<td>51</td>
<td>1</td>
<td>323</td>
<td></td>
</tr>
<tr>
<td>80-100</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1161</td>
<td>1283</td>
<td>523</td>
<td>179</td>
<td>8</td>
<td>3154</td>
<td></td>
</tr>
</tbody>
</table>
For the purpose of this thesis, peak period is identified as the two hours having the highest departures to work. In this case it is between 6 AM to 8 AM. The distribution of percent workers departing during peak hour is shown in the histogram above. The average percent of workers departing during peak period is 50 percent. Also the spatial distribution of the percentage departures is shown in the figure 3.14.
Figure 3.14 Percent workers departing during peak period across Florida
CHAPTER 4
MODELING METHODOLOGY

4.1 Background

Many a researchers used structural equations model to analyze individuals travel behavior. These models were useful for the analysis of structural relations among the variables in a model. In a structural analysis approach, also know as causal analysis, path analysis, or simply simultaneous equations, the phenomenon under study is specified in terms of cause-and-effect relationships (Golob and Meurs, 1987).

The relationships are either unidirectional, that is, they each postulate that one variable influences another, or reciprocal where relationships are specified in both directions. In this way, many structural equation models incorporate both direct and feedback influences.

This chapter attempts a review of the best current practice in specifying and estimating such sophisticated models. The journey to work variables are the endogenous variables and the socio-economic variables form the exogenous variables. This chapter estimates the state of the art methods in specifying and estimating such sophisticated models. AMOS 4.01 was used to estimate the models.
4.2 Model structure

A structural equations model structure was proposed to take into consideration the effects of socio-economic variables on the journey to work characteristics at the level of census tracts for the state of Florida. The structure is shown in figure 4.1

Figure 4.1 Structural equations modeling framework

The model system can be specified in the structural equations framework as shown:

\[
Y_1 = Y_1 \alpha_{11} + Y_2 \alpha_{21} + \ldots + Y_J \alpha_{J1} + X_1 \beta_{11} + \ldots + X_K \beta_{K1} + \varepsilon_1
\]

\[
Y_2 = Y_1 \alpha_{12} + Y_2 \alpha_{22} + \ldots + Y_J \alpha_{J2} + X_1 \beta_{12} + \ldots + X_K \beta_{K2} + \varepsilon_2
\]

\[
\vdots
\]

\[
Y_G = Y_1 \alpha_{1J} + Y_2 \alpha_{2J} + \ldots + Y_J \alpha_{JJ} + X_1 \beta_{1J} + \ldots + X_K \beta_{KJ} + \varepsilon_G
\]

Where,

\[Y = \{ Y_1, Y_2, \ldots, Y_J \}\] = Limited dependent variables like travel time to work, mode used in the journey to work, peak time travel to work and place of work
\[ X = \{X_1, X_2, X_3, \ldots, X_K\} = \text{Socio-economic factors such as household size,} \]

\[ \text{household income, vehicle ownership, age distribution, gender etc.} \]

\[ A = \{\alpha_{11}, \ldots, \alpha_{JJ}\} = \text{Matrix of parameters associated with endogenous variables} \]

\[ B = \{\beta_{11}, \ldots, \beta_{KJ}\} = \text{Matrix of parameters associated with exogenous variables} \]

\[ \varepsilon = \{\varepsilon_1, \ldots, \varepsilon_J\} = \text{Matrix of unobservable values of the random error components} \]

A typical structural equations model (with ‘J’ endogenous variables) is defined by

\[ A \text{ a matrix equation system as shown in Equation 4.1.} \]

\[ \begin{bmatrix}
Y_1 \\
\vdots \\
Y_J
\end{bmatrix} = \begin{bmatrix}
Y \\
\vdots \\
Y_J
\end{bmatrix} A + \begin{bmatrix}
\varepsilon_1 \\
\vdots \\
\varepsilon_J
\end{bmatrix} \]

This equation can be rewritten as

\[ Y = AY + BX + \varepsilon \]

(or) \[ Y = (I - A)^{-1}(BX + \varepsilon) \]

Where \( Y \) is a column vector of endogenous variables,

\( A \) is a matrix of parameters associated with endogenous variables,

\( X \) is a column vector of exogenous variables,

\( B \) is a matrix of parameters associated with exogenous variables, and

\( \varepsilon \) is a column vector of error terms associated with the endogenous variables.

Estimation procedures for a set of structural equations could be performed one equation at a time or the entire equation set together. The estimation where the equations are estimated one at a time when the equations are identified is called limited information estimation. One of the most common estimation is the ordinary least squares (OLS)
estimation. If the estimation is performed for all the structural equations together, it is called full information maximum likelihood estimation. Since the full information maximum likelihood methods consider the entire set of equations at a time for estimation, the resulting estimates are more precise. However, the estimation of full information maximum likelihood methods are computationally burdensome to estimate.

4.3 Covariance-based structural analysis

In the covariance based structural analysis approach, the estimation procedure minimizes the difference between the sample covariance and covariance predicted by the model. The fundamental hypothesis for the covariance-based estimation procedures is that the covariance matrix of the observed variables is a function of a set of parameters as shown:

\[ \Sigma = \Sigma(\theta) \]

where, \( \Sigma \) is the population covariance matrix of observed variables,

\( \theta \) is a vector that contains the model parameters, and

\( \Sigma(\theta) \) is the covariance matrix written as a function of \( \theta \).

The relation of \( \Sigma \) to \( \Sigma(\theta) \) is basic to an understanding of identification, estimation, and assessments of model fit. The matrix \( \Sigma(\theta) \) has three components, namely, the covariance matrix of \( Y \), the covariance matrix of \( X \) with \( Y \), and the covariance matrix of \( X \).

The implied covariance matrix of \( Y \) can be derived as:

\[ \Sigma_{YY}(\theta) = E(YY') \]

\[ = E[(I - A)^{-1} (BX + \varepsilon)((I - A)^{-1} (BX + \varepsilon))'] \]
\[
= (I - A)^{-1} \left( E(BXX'B') + E(BX\varepsilon') + E(\varepsilon X'B') + E(\varepsilon'\varepsilon') \right) (I - A)^{-1}
\]

\[
= (I - A)^{-1} \left( B\Phi B' + \Psi \right) (I - A)^{-1}
\]

Let \( \Phi \) = covariance matrix of \( X \) and \( \Psi \) = covariance matrix of \( \varepsilon \).

The implied covariance matrix of \( X \),
\[
\Sigma_{XX}(\theta) = E(XX') = \Phi
\]

and \( \Sigma_{XY}(\theta) = E(XY') \)
\[
= E[X(I - A)^{-1}(BX + \varepsilon)']
\]

\[
= \Phi B'(I - A)^{-1}
\]

Then, it can be shown that (Bollen 1989):
\[
\Sigma(\theta) = \begin{bmatrix}
(I - A)^{-1}(B\Phi B'\Phi B'\Psi)(I - A)^{-1} & (I - A)^{-1}B\Phi \\
\Phi B'(I - A)^{-1} & \Phi
\end{bmatrix}
\]

### 4.4 Model identification

Model identification in simultaneous structural equations systems is a mathematical problem concerned with the ability to obtain unique estimates of the structural parameters. It is associated with the question of the possibility or impossibility of obtaining meaningful estimates of the structural parameters. If an estimate of a structural parameter is in fact an estimate of that parameter and not an estimate of something else, then the parameter is said to be identified. The identification problem is typically resolved by applying restrictions on model parameters. The restrictions usually employed are zero restrictions where certain endogenous variables and certain exogenous variables do not appear in certain equations.
Various rules such as t-Rule, Null B Rule, and Recursive Rule are used for verifying identification of the whole structural model. A model is over identified when each parameter is identified and at least one parameter is over-identified. A model is exactly identified if each parameter is identified but none is over-identified.

The model estimation is based on the relation of covariance matrix of observed variables and to that one with structural parameters. In case of perfect specification $\Sigma = \Sigma(\theta)$. If we consider a simple structural equation where the parameter associated with exogenous variable is set to one:

$$y_1 = x_1 + \varepsilon_1$$

where $y_1$ = an endogenous variable in the first structural equation of the model

$x_1$ = an exogenous variable in the first structural equation of the model and

$\varepsilon_1$ = random disturbance associated with the first equation of the model.

The covariance matrix of $y_1$ and $x_1$ is

$$\Sigma = \begin{bmatrix} \text{VAR}(y_1) & \text{COV}(y_1, x_1) \\ \text{COV}(x_1, y_1) & \text{VAR}(x_1) \end{bmatrix}$$

The $\Sigma$ matrix in terms of the structural parameters is

$$\Sigma(\theta) = \begin{bmatrix} \Phi_{11} + \Psi_{11} & \Phi_{11} \\ \Phi_{11} & \Phi_{11} \end{bmatrix}$$

At this stage of estimation we do not know either the covariances and variances or the parameters. Hence we need to arrive at the sample estimates of unknown parameters based on sample estimates of the covariance matrix. The sample covariance matrix is given by

$$S = \begin{bmatrix} \text{VAR}(y_1) & \text{COV}(y_1, x_1) \\ \text{COV}(x_1, y_1) & \text{VAR}(x_1) \end{bmatrix}$$
This is made equal to the implied covariance matrix, \( \hat{\Sigma} = \begin{bmatrix} \hat{\Phi}_{11} + \hat{\Psi}_{11} & \hat{\Phi}_{11} \\ \hat{\Phi}_{11} & \hat{\Phi}_{11} \end{bmatrix} \).

\( \hat{\Phi}_{11} \) and \( \hat{\Psi}_{11} \) are chosen such that \( \hat{\Sigma} \) is closest to \( S \).

When equations with more complexities exist, similar process adopted for estimating unknown parameters in A, B, \( \Phi \), and \( \Psi \). In order to achieve this objective a fitting function \( F(S, \Sigma(\theta)) \) is defined which is minimized.

The fitting function has following properties:

- \( F(S, \Sigma(\theta)) \) is a scalar
- \( F(S, \Sigma(\theta)) \geq 0 \)
- \( F(S, \Sigma(\theta)) = 0 \) \( \iff \Sigma(\theta) = S \)
- \( F(S, \Sigma(\theta)) \) is continuous in \( S \) and \( \Sigma(\theta) \)

### 4.5 Maximum likelihood (ML)

The fitting function that is minimized in the maximum likelihood method of estimation of structural parameters is (Bollen, 1989):

\[
F_{\text{ML}} = \log |\Sigma(\theta)| + \text{tr} (S \Sigma^{-1}(\theta)) - \log |S| - (G + K)
\]

Where, \( G = \) Number of excluded endogenous variables on RHS of the model, and

\( K = \) Number of included exogenous variables on RHS of the model.

The asymptotic covariance matrix for the ML estimator \( \theta \) is given by,

\[
\left( \frac{2}{N - 1} \right) \left( \mathbb{E} \left[ \frac{\partial^2 F_{\text{ML}}}{\partial \theta \partial \theta'} \right] \right)^{-1}
\]
When \( \hat{\theta} \) is substituted for \( \theta \), an estimated asymptotic covariance matrix that allows tests of statistical significance on parameters of \( \hat{\theta} \) is obtained.

### 4.6 Model evaluation

The \( \text{F}_{\text{ML}} \) estimators provide test for overall model fit for over-identified models. Researchers used several ways to calibrate the match of \( S \) and \( \hat{\Sigma} \). Joreskog and Sorbom (1986) proposed a goodness of fit Index (GFI) and adjusted goodness of fit Index for models fitted with \( \text{F}_{\text{ML}} \).

\[
\text{GFI}_{\text{ML}} = 1 - \frac{\text{tr}[(\hat{\Sigma}^{-1} S - I)^2]}{\text{tr}[(\hat{\Sigma}^{-1} S)^2]}
\]

\[
\text{AGFI}_{\text{ML}} = 1 - \frac{K(K+1)}{2df} [1 - \text{GFI}_{\text{ML}}]
\]

Brown and Cudeck (1993) proposed root mean square error of approximation (RMSEA) which is a measure of compensation for the effect of model complexity. A value of the RMSEA of about 0.05 or less would indicate a close fit of the model in relation to the degrees of freedom.

### 4.7 Types of relationships

Three different types of relationships were studied from the structural equations modeling procedures utilized in this study. They are direct effects, indirect effects and total effects. A direct effect is one in which a variable has a direct relationship or link to
another variable where as an indirect effect is one in which a variable effects another variable through an intermediate variable. The total effect of one variable on another is the sum of its direct and indirect effects.
CHAPTER 5
MODEL SPECIFICATION AND RESULTS

5.1 Background

The objective of this study is to explore relationships among work travel and socio-economic characteristics for a given fixed geographic scale and utilize the observed relations in better understanding journey to work patterns in Florida. Towards this goal, and to appreciate the complicated interrelations that exist among the variables of interest, a single model specification would not suffice. Hence, a set of five models were developed to better comprehend and compare the interactions among the endogenous and exogenous variables. The level of geography used to implement these models suits the data requirements for structural equation model estimation.

As mentioned previously, endogenous variables used were travel time to work (for travel time less than ten minutes and greater than sixty minutes), work location, travel mode used to reach work, and peak hour proportion. Socio-economic variables include household size, car ownership, age, gender, income, and population density taken per unit land area.

This chapter describes the structural relations among the journey to work variables and socio economic variables through a series of structural equations models. All five models developed in this study are explained in this section.
5.2 Path diagrams

A path diagram is a pictorial representation of a system of simultaneous equations. Path Diagram pictures the relationships among the variable of interest. The symbols to understand path diagrams are as follows. The observed variables are enclosed in boxes.

\[ \text{Observed Variable} \]

The error terms are enclosed in a circle

\[ \varepsilon_n \]

A straight arrow signifies assumption that variable at base of the arrow causes variable at the head of the arrow. A double headed arrow represents an unanalyzed association between the two variables. The ‘n’ which forms subscript to the error term represents its relation to a particular endogenous variable.
5.3 Travel time – Place of work model

Travel Time – Place of Work Model is specified to identify the relationships among the two journey to work characteristics, travel time (percent workers whose travel time is less than ten minutes, percent workers whose travel time is greater than sixty minutes) and percent workers working in same place as residence. This model also explores the relation between socio-economic characteristics of the geographic unit, which in this case is the census tract, and two journey to work variables.

This structural equation system has three equations. The socio-economic variables included are population density in the census tract, percent female population, percent male population between the ages twenty to fifty, population with age greater than seventy, percent households with two and three persons, percent households with annual income greater than sixty thousands and vehicle ownership variable used is percent households with two or more vehicles. ‘ε₁’, ‘ε₂’, and ‘ε₄’ are the error terms associated with percent workers with travel time less than ten minutes, percent workers with travel time greater than sixty minutes and percent workers working in the place of residence.

A causal structure was pre-specified based on the observed descriptive analysis of the data from the census tracts in Florida. This basic model structure was adjusted depending on 95 percent statistical significance of the causal relations previously assumed. New relations were tried till a perfect fit was obtained. This model is depicted in figure 5.1.
Figure 5.1 Travel time – Place of work model

- Percent workers working in place
- Percent workers with travel time less than 10 min
- Percent workers with travel time greater than 60 min

- Total Population Density
- Percent Females
- Percent Males between ages 25 and 50 years
- Percent Population with age greater than 70 years
- Percent two person households
- Percent three person households
- Percent Households with Income greater than 60 K
- Percent two or more vehicles in households
5.4 Trip mode – Place of work model

The journey to work characteristics whose relationships were explored with socio-economic variables are percent workers using single occupancy vehicles (SOV) to work and percent workers working in the same place as their residence. This model is graphically depicted in the Figure 5.2

This two structural equation system has as its exogenous variables, average population density by area of census tract (sq. mile), gender distribution of females, and percent population with age less than twenty five years, percent households with size two, percent households with annual income greater than hundred thousands and percent households with two or more vehicles.

‘ε₁’ and ‘ε₂’ are the error terms corresponding to percent workers using SOV to go to work and percent people working in place of their residence respectively.
Figure 5.2 Trip mode – Place of work model

- Total Population Density
- Percent Females
- Percent population with less than 25 years of age
- Percent two person households
- Percent three person households
- Percent Households with Income greater than 100 K
- Percent two or more vehicles in households
- Percent Workers using SOV mode to work
- Percent workers working in place

$\varepsilon_1$

$\varepsilon_2$
5.5 Travel time - Trip mode model

This model specifies statistically significant relations between two journey to work variables representing travel time and mode of travel for work trips. Travel time is represented in the model framework by percent workers having travel time less than ten minutes. Travel mode is represented by the percent workers using SOV for work trip in the census tract.

The exogenous variables used in this two equation structural equation model include all the variables that are used in Travel Time – Place of Work Model (i.e.) population density, female population percentage, percent of male population between ages twenty five and fifty, percent population above the age of seventy, percent two person and three person households, percent households with income greater than sixty thousand, percent households with two or more vehicles.

The error terms for endogenous variables, percent workers whose travel time to work is less than ten minutes and percent workers who use SOV to work are ‘ε₁’, and ‘ε₂’ respectively. This model is depicted in figure 5.3.
Figure 5.3 Travel time – Trip mode model

- Total Population Density
- Percent Females
- Percent Males between ages 25 and 50 years
- Percent Population with age greater than 70 years
- Percent two person households
- Percent three person households
- Percent Households with Income greater than 60 K
- Percent two or more vehicles in households

- Percent Workers with Travel time less than 10 min
- Percent Workers using SOV mode to work
5.6 Trip mode - Peak period model

This model was estimated with its endogenous variables as percent workers using SOV to work and percent workers traveling during peak period to work. This model is like previous models A, Trip Mode – Place of Work Model, Travel Time – Trip Mode Model is a two equation structural model. All the socio-economic variables used in Travel Time – Trip Mode Model are used as the exogenous variables in this model. This is the last of the two equation structural model in the set.

Work travel mode is depicted by the one of the endogenous variables, percent of workers using SOV mode to work. Peak period travel is highest percent of travel in a two hour period. This period is identified as between 7:00 AM and 9:00 AM. So the percent of workers starting their work trip between 7:00 AM and 9:00 AM constitute the peak hour travel.

Same set of socio-economic variables that are used in Trip Mode – Place of Work Model and Travel Time – Trip Mode Model were used as exogenous variables. This model is depicted in Figure 5.4
Figure 5.4 Trip mode and Peak period model

- Total Population Density
- Percent Females
- Percent Males between ages 25 and 50 years
- Percent Population with age greater than 70 years
- Percent two person households
- Percent three person households
- Percent Households with Income greater than 60 K
- Percent two or more vehicles in households

Percent Workers using SOV mode to work

Percent workers departing during peak period

$\varepsilon_1$

$\varepsilon_2$
5.7 Travel time – Trip mode - Peak period - Work location model

In order to explain the relation between work location and peak period travel and work trip travel time and peak period travel, two models were used. Travel Time – Trip Mode - Work Location - Peak Period Model has percent workers whose work trip travel time is less than ten minutes, percent workers whose work trip travel time is greater than sixty minutes, percent workers using SOV to work, percent working in location of their residence and percent with peak period travel.

The exogenous variables used in this model are same as the ones used in Travel Time – Trip Mode Model and Trip Mode and Peak Period Model. Travel Time – Trip Mode - Work Location - Peak Period Model is a five structural equation system. Travel Time – Trip Mode - Work Location - Peak Period Model is depicted in Figure 5.5.
Figure 5.5 Travel time – Trip mode - Work location - Peak period model

- Percent Females
- Percent Males between ages 25 and 50 years
- Percent Population with age greater than 70 years
- Percent two person households
- Percent three person households
- Percent Households with Income greater than 60 K
- Percent two or more vehicles in households

- Percent Workers with Travel time less than 10 min
- Percent Workers with Travel time greater than 60 min
- Percent workers using SOV mode to work
- Percent workers working in place
- Percent workers departing during peak period
Table 5.1 Travel time – Place of work model results

<table>
<thead>
<tr>
<th>Endogenous Variable</th>
<th>Intercept</th>
<th>Effect</th>
<th>HH with two or more vehicles</th>
<th>Two person HH</th>
<th>Population with age &gt; 70 years</th>
<th>HH with income &gt; 60,000 per annum</th>
<th>Three person HH</th>
<th>Females</th>
<th>Population density</th>
<th>Workers working in place</th>
<th>Workers working in Place</th>
<th>Workers working in Place</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workers working in Place</td>
<td>45.341</td>
<td>Total</td>
<td>-0.856</td>
<td>-0.148</td>
<td>-0.709</td>
<td>0.392</td>
<td>-0.310</td>
<td>0.638</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>-0.856</td>
<td>-0.148</td>
<td>-0.709</td>
<td>0.392</td>
<td>-0.310</td>
<td>0.638</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Travel time greater than 60 minutes</td>
<td>38.635</td>
<td>Total</td>
<td>0.033</td>
<td>-0.089</td>
<td>0.000</td>
<td>-0.053</td>
<td>0.012</td>
<td>-0.245</td>
<td>0.000</td>
<td>-0.038</td>
<td>-0.112</td>
<td>-0.112</td>
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<td>Direct</td>
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<td>-0.037</td>
<td>0.000</td>
<td>-0.221</td>
<td>0.000</td>
<td>-0.038</td>
<td>-0.112</td>
<td>-0.112</td>
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<tr>
<td></td>
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<td>Indirect</td>
<td>0.033</td>
<td>0.006</td>
<td>0.027</td>
<td>-0.015</td>
<td>0.012</td>
<td>-0.025</td>
<td>0.000</td>
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</tr>
<tr>
<td>Travel time less than 10 minutes</td>
<td>29.196</td>
<td>Total</td>
<td>-0.099</td>
<td>-0.017</td>
<td>-0.082</td>
<td>-0.003</td>
<td>-0.652</td>
<td>-0.204</td>
<td>-0.001</td>
<td>0.115</td>
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<tr>
<td></td>
<td></td>
<td>Direct</td>
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<td>0.000</td>
<td>0.000</td>
<td>-0.048</td>
<td>-0.616</td>
<td>-0.278</td>
<td>0.000</td>
<td>0.115</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>-0.099</td>
<td>-0.017</td>
<td>-0.082</td>
<td>0.045</td>
<td>-0.036</td>
<td>0.073</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
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</tr>
</tbody>
</table>

Note:  
N = 3154 Chi-Squared = 15.813 with df = 11; p-value = 0.148; CFI = 1; RMSEA = 0.012
All Variables Significant at 95% level
All Variables are in Percentage excluding population density
Table 5.2 Trip mode – Place of work model results

<table>
<thead>
<tr>
<th>Endogenous Variable</th>
<th>Intercept</th>
<th>Effect</th>
<th>Households with two or more vehicles</th>
<th>Households with income greater than 100 K per annum</th>
<th>Three person households</th>
<th>Two person households</th>
<th>Population density</th>
<th>Females</th>
<th>Workers working in place</th>
<th>Population with age less than 25 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workers working in Place</td>
<td>62.115</td>
<td>Total</td>
<td>-0.645</td>
<td>0.480</td>
<td>0.376</td>
<td>-0.405</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>-0.645</td>
<td>0.480</td>
<td>0.376</td>
<td>-0.405</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Workers using SOV mode to work</td>
<td>33.209</td>
<td>Total</td>
<td>0.434</td>
<td>-0.153</td>
<td>0.131</td>
<td>0.055</td>
<td>0.000</td>
<td>0.642</td>
<td>-0.030</td>
<td>-0.862</td>
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<td></td>
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<td>Direct</td>
<td>0.414</td>
<td>-0.139</td>
<td>0.143</td>
<td>0.043</td>
<td>0.000</td>
<td>0.642</td>
<td>-0.030</td>
<td>-0.862</td>
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<tr>
<td></td>
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<td>Indirect</td>
<td>0.020</td>
<td>-0.015</td>
<td>-0.011</td>
<td>0.012</td>
<td>0.000</td>
<td>0.000</td>
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<td>0.000</td>
</tr>
</tbody>
</table>

Note:  
N = 3154; Chi-Squared = 3.171 with df = 4; p-value = 0.530; CFI = 1; RMSEA = 0.000  
All Variables Significant at 95% level  
All Variables are in Percentage excluding population density
Table 5.3 Travel time – Trip mode model results

<table>
<thead>
<tr>
<th>Endogenous Variable</th>
<th>Intercept</th>
<th>Effect</th>
<th>HH with two or more vehicles</th>
<th>HH with income &gt; 60,000 per annum</th>
<th>Two person HH</th>
<th>Population with age greater than 70 years</th>
<th>Male population between ages 25 and 50 years</th>
<th>Three person HH</th>
<th>Females</th>
<th>Population density</th>
<th>Workers using SOV mode to work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workers using SOV mode to work</td>
<td>-18.040</td>
<td>Total</td>
<td>0.410</td>
<td>-0.063</td>
<td>0.278</td>
<td>0.405</td>
<td>0.494</td>
<td>0.201</td>
<td>0.790</td>
<td>0.000</td>
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<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.410</td>
<td>-0.063</td>
<td>0.278</td>
<td>0.405</td>
<td>0.494</td>
<td>0.201</td>
<td>0.790</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Travel time less than 10 minutes</td>
<td>49.988</td>
<td>Total</td>
<td>-0.099</td>
<td>0.015</td>
<td>-0.067</td>
<td>-0.098</td>
<td>-0.119</td>
<td>-0.658</td>
<td>-0.296</td>
<td>-0.001</td>
<td>-0.241</td>
</tr>
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<td></td>
<td></td>
<td>Direct</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>-0.609</td>
<td>-0.106</td>
<td>-0.001</td>
<td>-0.241</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>-0.099</td>
<td>0.015</td>
<td>-0.067</td>
<td>-0.098</td>
<td>-0.119</td>
<td>-0.048</td>
<td>-0.190</td>
<td>0.000</td>
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</tr>
</tbody>
</table>

Note:
N = 3154; Chi-Squared = 11.855 with df = 7; p-value = 0.105; CFI = 1; RMSEA = 0.015
All Variables Significant at 95% level
All Variables are in Percentage excluding population density
Table 5.4 Trip mode - Peak period model results

<table>
<thead>
<tr>
<th>Endogenous Variable</th>
<th>Intercept</th>
<th>Effect</th>
<th>Females</th>
<th>HH with two or more vehicles</th>
<th>HH with income &gt; 60000 per annum</th>
<th>Three person HH</th>
<th>Two person HH</th>
<th>Population age &gt; 70 years</th>
<th>Male population between ages 25 and 50 years</th>
<th>Population density</th>
<th>Workers using SOV mode to work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workers using SOV mode to work</td>
<td>-18.200</td>
<td>Total</td>
<td>0.788</td>
<td>0.408</td>
<td>-0.063</td>
<td>0.209</td>
<td>0.280</td>
<td>0.406</td>
<td>0.499</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.788</td>
<td>0.408</td>
<td>-0.063</td>
<td>0.209</td>
<td>0.280</td>
<td>0.406</td>
<td>0.499</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Workers departing in Peak period</td>
<td>18.780</td>
<td>Total</td>
<td>0.225</td>
<td>0.059</td>
<td>0.072</td>
<td>0.327</td>
<td>0.080</td>
<td>0.227</td>
<td>0.314</td>
<td>0.000</td>
<td>0.285</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.000</td>
<td>-0.057</td>
<td>0.090</td>
<td>0.268</td>
<td>0.000</td>
<td>0.111</td>
<td>0.171</td>
<td>0.000</td>
<td>0.285</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>0.225</td>
<td>0.116</td>
<td>-0.018</td>
<td>0.060</td>
<td>0.080</td>
<td>0.116</td>
<td>0.142</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Note:  
N = 3154; Chi-Squared = 7.045 with df = 5; p-value = 0.217; CFI = 1; RMSEA = 0.011  
All Variables Significant at 95% level  
All Variables are in Percentage excluding population density
Table 5.5 Travel time – Trip mode - Work location - Peak period model results

<table>
<thead>
<tr>
<th>Endogenous Variable</th>
<th>Intercept Effect</th>
<th>HH with 2 or more vehicles</th>
<th>Two person HH</th>
<th>Populati on age &gt; 70 years</th>
<th>HH with income &gt; 60 K</th>
<th>Three person HH</th>
<th>Female s</th>
<th>Population densit y</th>
<th>Worker s working in place</th>
<th>Worker s working in Direct Place</th>
<th>Worker s working in Indirect Place</th>
<th>Travel time &lt; 10 minutes</th>
<th>Travel time &lt; 60 minutes</th>
<th>SOV mode to work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workers working in Place</td>
<td>44.895</td>
<td>Total</td>
<td>-0.856</td>
<td>-0.147</td>
<td>-0.709</td>
<td>0.391</td>
<td>-0.316</td>
<td>0.645</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>-0.856</td>
<td>-0.147</td>
<td>-0.709</td>
<td>0.391</td>
<td>-0.316</td>
<td>0.645</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>-17.149</td>
<td>Total</td>
<td>0.406</td>
<td>0.281</td>
<td>0.381</td>
<td>-0.049</td>
<td>0.202</td>
<td>0.812</td>
<td>0.000</td>
<td>-0.031</td>
<td>0.498</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.379</td>
<td>0.281</td>
<td>0.381</td>
<td>-0.049</td>
<td>0.202</td>
<td>0.812</td>
<td>0.000</td>
<td>-0.031</td>
<td>0.498</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>0.026</td>
<td>0.005</td>
<td>0.022</td>
<td>-0.012</td>
<td>0.010</td>
<td>-0.02</td>
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<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Travel time &gt; 60 minutes</td>
<td>42.284</td>
<td>Total</td>
<td>0.033</td>
<td>-0.085</td>
<td>0.000</td>
<td>-0.055</td>
<td>0.012</td>
<td>-0.239</td>
<td>0.000</td>
<td>-0.039</td>
<td>0.108</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.000</td>
<td>-0.090</td>
<td>-0.027</td>
<td>-0.040</td>
<td>0.000</td>
<td>-0.214</td>
<td>0.000</td>
<td>-0.039</td>
<td>0.108</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>0.033</td>
<td>0.006</td>
<td>0.027</td>
<td>-0.015</td>
<td>0.012</td>
<td>-0.025</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Travel time less than 10 minutes</td>
<td>28.607</td>
<td>Total</td>
<td>-0.129</td>
<td>-0.042</td>
<td>-0.113</td>
<td>0.020</td>
<td>-0.653</td>
<td>0.224</td>
<td>0.001</td>
<td>-0.111</td>
<td>0.045</td>
<td>-0.091</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>-0.028</td>
<td>-0.600</td>
<td>-0.222</td>
<td>0.001</td>
<td>0.003</td>
<td>0.045</td>
<td>0.000</td>
<td>-0.028</td>
<td>-0.600</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>-0.129</td>
<td>-0.042</td>
<td>-0.113</td>
<td>0.048</td>
<td>-0.053</td>
<td>-0.002</td>
<td>0.000</td>
<td>0.000</td>
<td>0.045</td>
<td>0.000</td>
<td>-0.028</td>
<td>-0.600</td>
</tr>
<tr>
<td>Workers departing in Peak period</td>
<td>36.183</td>
<td>Total</td>
<td>0.066</td>
<td>0.110</td>
<td>0.214</td>
<td>0.063</td>
<td>0.326</td>
<td>0.291</td>
<td>0.000</td>
<td>-0.010</td>
<td>0.329</td>
<td>0.150</td>
<td>0.214</td>
<td>0.063</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.000</td>
<td>0.000</td>
<td>0.129</td>
<td>0.043</td>
<td>0.244</td>
<td>0.000</td>
<td>0.000</td>
<td>-0.026</td>
<td>0.174</td>
<td>0.143</td>
<td>0.129</td>
<td>0.043</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>0.066</td>
<td>0.110</td>
<td>0.085</td>
<td>0.02</td>
<td>0.082</td>
<td>0.291</td>
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<td>0.015</td>
<td>0.154</td>
<td>0.007</td>
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Note: 
N = 3154; Chi-Squared = 10.114 with df =13; p-value = 0.0685; CFI = 1; RMSEA = 0.000 
All Variables Significant at 95% level
All Variables are in Percentage except population density
Table 5.5 Continued

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<thead>
<tr>
<th>Endogenous Variable</th>
<th>Intercept</th>
<th>Effect</th>
<th>Travel time &gt; 60 minutes</th>
<th>Travel time &lt; 10 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workers working in Place</td>
<td>44.895</td>
<td>Total</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Workers using SOV mode to work</td>
<td>-17.149</td>
<td>Total</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Travel time greater than 60 minutes</td>
<td>42.284</td>
<td>Total</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Travel time less than 10 minutes</td>
<td>28.607</td>
<td>Total</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Workers departing in Peak period</td>
<td>36.183</td>
<td>Total</td>
<td>-0.737</td>
<td>-0.081</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>-0.737</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indirect</td>
<td>0.000</td>
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</tr>
</tbody>
</table>
CHAPTER 6
MODEL RESULTS INTERPRETATION

This Chapter explains the relations obtained by using structural equations analysis using journey to work characteristics as endogenous variables and socio-demographic characteristics as exogenous variables. All these relations are obtained at an aggregate level of census tracts. It should also be noted that the data used through the course of this thesis is primarily from the Census Summary File 3 which does not include information on other traditionally observed significant factors effecting journey to work characteristics.

6.1 Travel time to work and household income

In the models developed, variable used to represent high income population in a census tract is the percent households with income greater than sixty thousand per annum. Two variables were used to represent short and long trip travel times. They are percent workers with work trip travel time greater than sixty minutes and percent workers with work trip travel time less than ten minutes.

It has been observed from the estimation of models that percent households with annual income greater than sixty thousands has a negative influence on percent workers having sixty minutes or more travel time to work. This implies that high percent of households in a census tract with income greater than sixty thousands cause the census
tract to have lesser percent of workers having their work travel time greater than sixty minutes. As can be observed from the figure 3.15, distribution of percent workers whose travel time to work is less than 60 minutes, the percent of workers with travel time greater than 60 minutes is a small percentage averaging around 8 percent of the total number of workers, across all the census tracts. This consistently low value of the travel time variable itself might draw a negative relation towards percent households with high income.

6.2 Travel time to work and household size

Model estimates for household size indicate that percent households with three persons have a positive effect on percent workers who travel more than sixty minutes to work. This means that greater the percent of three person households in a census tract greater is the percent of workers having long commutes to work. It should be noted that it is an indirect positive effect between these two variables.

6.3 Travel time to work and old age population

The variable used for representing the old age population proportion in the model was percent population whose age was greater than seventy years of age. Usually, population of this age constitutes retirees, people with health conditions, people who do not have significant contribution in the work force.

The results of the models showed that percent population with age greater than 70 had a negative effect on percent workers with travel time less than ten minutes. This implies that census tracts with higher percent of old aged population (age greater than seventy
years) has lesser percent of its worker population having less than ten minutes of travel time to work. The negative effect of percent population with age greater than 70 on percent workers having less than 10 minutes of travel time is an indirect effect.

6.4 Travel time to work and vehicles in household

The variable, percent household with two or more vehicles is taken to represent auto ownership. Model estimates show that percent household with two or more vehicles variable has a negative effect on percent workers whose travel time is less than ten minutes. At the same time, percent households with two or more vehicles have a positive effect on the percent workers whose travel time to work is greater than sixty minutes. Both the effects observed are indirect effects.

6.5 Travel time to work and population density

Population density is defined as number of people living per unit land area. In this case it has been defined as population per square mile averaged over the census tract. The estimates in the models show that population density has a negative effect on percent workers whose travel time is less than ten minutes. Due to very high values of density in the data set and low values of percent workers whose travel time to work is less than 10 minutes; such pronounced difference might show a negative effect on percent workers with less than 10 minutes travel time.
6.6 Travel time to work and percent female population

A number of studies have shown that women have significantly different travel patterns than men. Women tend to have shorter average trip lengths. Women account for roughly two-thirds of the new entrants into the labor force in the last twenty years, and rising female labor force participation rates account for a substantial portion of the overall growth in travel and automobile use. Women’s household-serving travel patterns appear to be a function of both socialization and the sexual division of household responsibilities.

The estimates in the model show that percentage female population in the census tract has a negative effect on percent workers whose work trip travel time is greater than sixty. Interestingly, the estimates also show that greater female proportion also has a negative effect on percent work trips with travel time less than 10 minutes. Again, due to a consistently high value of percent female population and consistently low values for percent workers whose travel time are less than 10 minutes the negative effect might have shown up.

6.7 Travel time to work and working male population

The model estimates indicate that the percent males in the age group 25 to 50 have a negative effect on percent long work trips. The magnitude of this effect perceived is very small compared to magnitudes of other relations. Especially, with percent workers having travel time greater than 60 minutes having very low magnitudes, this relation needs to be considered in comparison with other relations.
6.8 Place of work and household income

From the model results it can be understood that percent high income households (defined as households with annual income greater than 60 K) tend to have a positive direct effect on percent of workers working in same place as their residence. Higher the percent of households with income greater than 60 K, greater would be the percent of workers working in their place of residence.

6.9 Place of work and household size

The estimation results showed that percent two person households in a census tract has a negative effect on percent workers working in their place of residence. Similar results are shown by three person households. The low magnitude of the endogenous variables must be watched for before concluding the negative effect.

6.10 Place of work and aged population

Model estimates show a negative direct effect of percent aged population on the percent workers working in place. Higher percent of aged population means a lower percents of workers working in the place of their residence.

6.11 Place of work and percent female population

Higher percent of females in a census tract has a strong positive direct effect on the percent workers working in the place of their residence. Higher the percent females in census tracts, higher are the percent of workers working in the place of their residence.
6.12 Place of work and vehicles in household

Percent households with two vehicles have a negative effect on percent workers working in place. This relation is also a negative direct relation. Higher two vehicle households, lesser are the percent workers working in the place of residence.

6.13 Travel mode to work and household income

The estimates from the model indicate that percent households with annual income greater than sixty thousands and percent households with income greater than hundred thousands both have a negative effect on percent workers using SOV to work in a census tract. This relation is contradictory to general observation of finding greater percent of SOV users to work, with increased percent of high income households in a region. This relation needs further exploration.

6.14 Travel mode to work and household size

The estimation results show that percent two person households have a positive effect on percent workers using SOV mode to work. Though, estimation results for percent households with three person shows a positive effect on percent workers using SOV to work, it has a lesser magnitude than the effect for a two person household

6.15 Travel mode to work and aged population

It is observed from the model estimates that percent population above seventy years has a positive effect on the percent of workers using SOV mode to work. This relation has a complete direct effect.
6.16 Travel mode to work and vehicles in household

The model estimates show that percent households with two vehicles have positive effect on percent workers using SOV mode to work. This implies that greater the percent of two vehicle households in a census tract, higher are the percent of workers that use SOV mode to work.

6.17 Travel mode to work and percent female population

Many studies in the past have shown that women are more likely to travel to work in a SOV than men. It is found in this analysis that percent female population has a positive effect on percent workers using SOV mode to work. This implies that greater the percent of females, greater is the percent workers using SOV mode to work in the census tract.

6.18 Travel mode to work and working male population

Working male population is taken as the male population between ages 25 and 50. It was observed that percent male population between the ages 25 and 50 has a positive effect on percent workers using SOV mode to work.

6.19 Travel mode to work and percent population less than twenty five years of age

Percent population of age less than 25 years of age has a negative effect on percent workers using SOV mode to work.
6.20 **Peak period departure and household income**

It has been observed that households with income greater than 60 K annually has a positive effect on percent workers departing during peak period to work.

6.21 **Peak period departure and household size**

The estimation results show that as the percent of three person households increases the percent workers departing during the peak period increases.

6.22 **Peak period departure and male population between the ages twenty five and fifty**

It is observed from the model estimates that male population between the ages of 25 and 50 years have a positive effect on the percent worker departures during peak period.
CHAPTER 7

CONCLUSIONS

7.1 Background

This research builds on the recent developments in the utilization of structural equations modeling to identify effects of socio-economic variables on the journey to work characteristics at an aggregate level. The Census 2000 data was utilized at an aggregate level to perform the analysis. Estimation was performed using the 3154 census tracts in Florida as units of analysis. Equations were developed using journey to work characteristics as endogenous variables and socio-economic characteristics as exogenous variables. The journey to work variables include: travel period to work (less than 10 minutes and greater than 60 minutes) - percent values for less than 10 minutes and greater than 60 minutes are considered, SOV mode to work – percent value for mode chosen for work trip, place of work – person working in place of residence, peak period of departure – workers departed to work in peak period (two hour period). Causal relations between socio-economic and endogenous variables and between endogenous variables were studied.

This method of analysis of census data at an aggregate level has a significant advantage in terms of convenience of development when compared to other data intensive procedures for describing the same journey to work behavior. Another significant advantage of using aggregate census data is that, it is free from the
complexities of sampling a given region for observing travel behavioral characteristics. Since sampling for Census data is done on a national level, data obtained at various geographies can be compared to observe local trends or regional variation in any of the observable travel behavior characteristic.

7.2 Summary of findings

This research effort aims at a comprehensive understanding of the journey to work characteristics in the state of Florida. Structural equations modeling seems to be a very effective means for simultaneously representing multiple causal relationships among the endogenous variables in the presence of multiple error covariances. A set of five models were used to arrive at these results.

7.2.1 Relations between socio-economic and journey to work characteristics

The estimation results obtained show the relationships between the aggregate socio-economic variables and journey to work characteristics at an aggregate level. Though there are several effects that were identified through this analysis, some of the results need to be further explored or can not be generalized and conclusions drawn based on them. Percent workers having a short or long travel time are very small in magnitude compared to other variables in the analysis and some of the results obtained in this analysis are counter intuitive. Similarly, the high value of population density compared to all other values in the analysis also cause wrong effects to be found in the analysis.

Some of the relations obtained in the analysis between the journey to work variables and socio-economic characteristics of the census tracts include: percent females
in a census tract seem to have a negative effect on the percent workers whose travel time
to work is greater than sixty minutes. Percent high income households had a positive
direct effect on percent workers working in place of residence. Percentages of both two
and three person households had a negative effect on percent workers working in the
place of their residence. Vary low percentages of the endogenous variables should be
taken in to consideration before any conclusion can be drawn from the relationships.
Percent female population in a census tract had positive effect on the workers working in
the place of their residence. Percent households with income greater than 60 K per annum
seem to have a negative effect on percent workers using SOV mode to work. This
relation needs to be further examined. Such relationships were observed between other
endogenous and exogenous variables.

7.2.2 Relations among journey to work characteristics

The relationships obtained between various journey to work characteristics were
also obtained in the analysis. Percent workers working in place of residence has a
negative effect on percent workers with travel time greater than 60 minutes to work. The
low values of percent workers having travel time greater than 60 minutes need to be
noted. Percent workers working in place also had a negative effect on percent workers
using the SOV mode to work and percent workers departing during peak period.
Similarly percent workers who had travel time less than 10 minutes had a negative effect
on percent workers departing in peak period. It is also observed that percent workers who
have their travel time greater than 60 minutes had negative effect on percent workers
departing during peak period. It is also observed that percent workers departing using
SOV mode to work had negative effect on percent workers having their travel time less than 10 minutes and a positive effect on percent workers using SOV mode to work. Some of the relationships observed are to be further analyzed with a broader range of values and also in the presence of other traditionally observed significant factors relating to journey to work characteristics and to avoid pitfalls in drawing conclusive relationships.

7.3 Omitted variables

In the present analysis of the journey to work characteristics, the exogenous variables considered for the analysis are the prevailing socio-demographics in the census tracts. Just the socio-demographic variables do not encompass the complete list of factors that might significantly effect the journey to work characteristics. Incorporation of some other characteristics representative of the prevailing land use would better the estimates. Network mobility and area-wide congestion factors also need to be incorporated in the analysis.

Employment locations relative to the residential locations is a strong measure in determining journey to work characteristics of a census tract. These variables if suitable used along with the socio-demographic variables would provide better estimates of the relationships.

7.4 Conclusions and future research directions

Structural equations methodology (SEM) has been successfully applied to analyze the journey to work behavior using aggregate Census data. The results of these models are at census tract level which could be aggregated to Counties and States. Unlike
disaggregate level models; the models in this thesis do not need any additional investment in resources for conducting surveys etc.

For a general understanding of the journey to work behavior this research gives very usable and considerably accurate relations. These models if applied and tested against other disaggregate modeling techniques and various geographies, would form a very powerful and quick tool to understand overall relationships in journey to work data. Also, incorporation of other important aggregate factors like network density, area-wide network level of service characteristics, employment totals would definitely improve the estimates.

In conclusion, there still exists a great need for models that could serve the users with limited resources. There lies a tremendous scope in refining the models developed in this thesis and bringing out more readily usable models that could deliver solutions with lesser data input.
REFERENCES


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