ABSTRACT

Title of Document:	EXPLORING THE INFLUENCE OF URBAN FORM ON TRAVEL AND ENERGY CONSUMPTION, USING STRUCTURAL EQUATION MODELING
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This dissertation has contributed to the current knowledge by gaining additional insights into the linkages of different aspects of the built environments, travel behavior, and energy consumption using Structural Equation Modeling (SEM) that provides a powerful analytic framework for a better understanding of the complex relationships of urban form, travel and energy consumption. Several urban form measurements (density, mixed land use index, street network connectivity, regional accessibility, and distance to transit) were gathered from multiple external sources and utilized for both trip/tour origins and destinations. This dissertation also contributed to the analysis framework by aggregating trips into tours to test whether the tour-based analysis generates better results than the trip-based analysis in terms of model fit, significance, and coefficient estimations. In addition to that, tour-based samples were also stratified into three different classification schemes to investigate

the variations of relationship of urban form and travel among auto and transit modes and among various travel types.: (1) by modes (i.e. auto and transit); (2) by travel purposes (i.e. work, mixed, and non-work tours); and (3) by modes and purposes (first by modes, then by purpose). Stratification by purposes and modes provided an in-depth investigation of the linkages of urban form and travel behavior.

The research findings are many: (1) urban form does have direct effects on travel distance for all tour types modeled; (2) urban form at the destination ends has more influence than on the origin ends; (3) Urban form has indirect effects on travel distance and energy consumption through affecting driving patterns, mode choice, vehicle type and tour complexity; (4) People tend to drive when they have complicated travel patterns; (5) The effects of intermediate variables (driving patterns, tour complexity, mode choice, and vehicle type) are stronger than the direct effects generated from urban form; (6) Tour-based analyses have better model fit than trip-based analysis; (7) Different types and modes of travel have various working mechanisms for travel behavior. No single transportation technology or land use policy action can offer a complete checklist of achieving deep reductions of travel and energy consumption while preserving mobility of driving.

EXPLORING THE INFLUENCE OF URBAN FORM ON TRAVEL AND ENERGY CONSUMPTION, USING STRUCTURAL EQUATION MODELING

By

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Dedication

To my parents and my sister for their love.

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Chapter 1: Introduction

1.1 Research Background

With the growth in automobile use and increase in daily vehicle miles traveled (VMT), the transportation sector's shares of energy consumption and air pollution are significant and increasing. Between 1970 and 2005 average annual VMT per household increased by 50 percent (Bureau of Transportation Statistics, 2007). The transportation sector accounts for approximately 33 percent of total CO_2 emissions from fossil fuel combustion, the largest share of any end-use economic sector (EIA, 2007). In addition to the environmental damages, extensive automobile usage also causes problems in areas of public health and social equity. Understanding transportation energy consumption is vital for the planning of the evaluation of incentives aimed at travel and energy use reduction. The spatial location of the residence and destinations is a pivotal factor for driving patterns, vehicle choice, the use of public transportation and non-motorized modes, complexity of travel, and travel distance and energy consumption. In addition to the role of the built environment, the travel distance and corresponding energy usage of households are clearly the outcome of complex decisions that combine vehicle ownership and travel activities. Travel makers play major roles in all of the decisions, as do many socio-demographic characteristics.

There is a substantial body of literature that examines the connection between urban form and travel behavior (Crane 2000, Ewing and Cervero 2001, Ewing and Cervero 2010). Yet surprisingly little consensus has been reached to date about how the built environment affects travel behavior. In contrast to the focus on the effect of the built environment on travel, there has been relatively less attention on the influence of built environment on transportation energy consumption and emissions. Based on the current literature, with more compact land use patterns, the reduction of vehicle energy consumption and emissions should be expected to generally follow the same trend of the reduction in VMT. However, compact land development may cause lower speeds and more stop-and-go driving, which might offset some of the air quality benefits resulting from lower VMT. Also, urban form may have a significant impact on mode choice, vehicle ownership and type, and driving patterns, which further influence energy use.

Most of the existing studies investigate the connection of urban form and travel in a separated way, which did not reflect the reality that built environment affects different travel outcome components simultaneously and that the travel components interact with each other. These travel outcomes intertwine with each other in the way that the isolated approaches are not suitable to handle the complexity of the relationship. This dissertation contributes to the current literature by establishing a new framework and applying a new approach: Structural Equation Modeling (SEM), for better understanding the extent to which change in the built environment can affect travel distance and energy consumption through influencing mode choice, driving patterns, vehicle holdings, and tour complexity.

1.2 Research Objectives

The existing studies that investigate how built environment affects people's travel behavior do not account for the relationships of built environment and travel outcomes. Separate single regressions are not suitable to handle the complexity of the relationship. SEM is a very powerful statistical modeling technique to handle a large number of endogenous and exogenous variables and to estimate the relationships among variables by calculating direct effects, indirect effects, and total effects. In this study, urban form directly affects travel distance due to the separation of residential and activity sites. Urban form also indirectly affects travel distance through influencing intermediate factors: mode choice, vehicle type choice, tour complexity, and driving patterns. The intermediate factors also have impacts on travel distance and energy consumption.

In addition to test the interrelationships among built environment, travel behavior and energy consumption, multiple urban form measurements for both trip/tour origins and destinations are utilized to test the sensitivity of the representations of urban form. We started our analysis using trip as the analysis unit. However, tours that link individual trips together match closely to people's travel behavior. The goal of this study is to test whether tour-based analysis can generate better results in terms of model fit, significance, and coefficients. To investigate the accurate travel behavior, tours were further stratified by mode and purposes to reveal the underlying mechanism of travel behavior.

We are trying to answer the following seven research questions and test seven major hypothetical paths:

Research questions:

(1) To what extent do urban form variables directly affect travel and subsequent energy consumption, when controlling for socio-demographic factors?

(2) Do urban form variables indirectly affect travel and energy consumption through different paths by influencing driving patterns, vehicle type choice, mode choice, and tour complexity, individually?

(3) What are the relationships among the intermediate variables including vehicle type, mode, driving patterns, and tour complexity?

(4) Are there significant differences of magnitudes of direct and indirect effects through different paths?

(5) What are the differences among different types of travel and what would be the underlying mechanism?

(6) To what extent does tour-based analysis differ from trip-based analysis in terms of model fit and explanatory powers?

(7) What are the differences between auto and transit travel since the two modes have different working mechanism?

Research hypotheses:

Hypothesis 1: urban form variables directly affect travel distance (subsequently affecting energy consumption) due to the separation of residence and activity sites.

Hypothesis 2: urban form variables affect travel distance and corresponding energy indirectly.

Hypothesis 2a: urban form variables affect household vehicle type choice. Specifically, households living in denser areas will choose smaller vehicles consume less energy.

Hypothesis 2b: less dense areas involve more motorized and highway travel, which causes increases in travel distance, and energy consumption.

Hypothesis 2c: denser areas are associated with more congestion (measured by speed), which consumes more energy.

Hypothesis 2d: people living in denser areas have more complex tours and consume more energy.

Hypothesis 3: among the intermediate variables, mode choice and tour complexity influence travel speed. The tour complexity also has direct effects on mode choice.

Hypothesis 4: urban form variables have stronger direct effects on travel and energy consumption than the indirect impacts through affecting intermediate variables: mode choice, speed, vehicle types, and tour complexity.

Hypothesis 5: commuting tours have more stable travel patterns and show more significant results than non-work and mixed-work-non-work tours.

Hypothesis 6: Tour-based analysis generates better results than trip-based analysis.

Hypothesis 7: Separating auto and transit samples from the whole sample generates better model results.

1.3 Research Contribution

This dissertation contributes to the current literature by gaining additional insights into both research implications and policy implications. From research implication perspectives, this study provides valuable information on improvement of current modeling approaches (i.e. tour-based analysis and model stratifications) that are more suitable for the research on built environment and travel behavior connections. From policy implication perspectives, this dissertation contributes to the current literature by gaining additional insights into the linkages of different aspects of the built environments, travel behavior, and energy consumption using SEM, which provides a powerful analysis framework that makes it possible to analyze the complex relationships of urban form, travel and energy consumption. More specifically,

The research findings related to policy implications are:

- Urban form does have direct effects on travel distance for all tour types modeled;
- Urban form at the destination ends has more influence than on the origin ends;
- Urban form has indirect effects on travel distance and energy consumption through affecting driving patterns, mode choice, vehicle type and tour complexity.
- People tend to drive when they have complicated travel patterns (e.g. combining work and non-work activates);
- The effects of intermediate variables (driving patterns, tour complexity, mode choice, and vehicle type) are stronger than the direct effects generated from urban form; and

- Different types of travel have various working mechanisms for travel behavior: among tour-based models, both work tour models and non-work tour models generate better model fit than mixed tour models.

The findings related to research implications are:

- Tour-based analyses have better model fit than trip-based analysis;
- Disaggregating tours into different travel purposes reveals more accurate and detailed travel patterns; and
- Transit and auto tours should be modeled separately.

The policy and research implications of this dissertation are multiple and extensive. From a research perspective, tour-based analysis and stratification (by modes and travel purposes) improve travel model accuracy. From a policy perspective, no single transportation technology or land use policy action can offer a complete checklist of achieving deep reductions of travel and energy consumption while preserving mobility of driving.

1.4 Research Organization

Chapter 2 provides an extensive literature review on the existing studies on the relationships of built environment and travel behavior and introduces the new approach: SEM. Chapter 3 discusses the comprehensive data set that combines the NHTS data with built environment data that gathered from multiple external sources. Chapter 4 illustrates the conceptual framework and lays out the research questions, hypotheses, and methodological details. Chapter 5 analyzes and compares the trip-based and tour-based samples. Chapter 6 focuses on tour-based models and conducts more detailed analyses by stratifying tours into auto and transit sub-samples, and work, non-work, and mixed sub-samples. Major findings, research implications, policy implementations, and future research are presented in Chapter 7.

Chapter 2: Literature Review

2.1 Introduction

Many researchers have studied the connection between aspects of built environments (density, diversity, and design) and travel behavior. Yet, surprisingly little consensus has been reached to date about how the built environment affects travel behavior. In contrast to the focus on the effect of the built environment on travel, there has been relatively less attention on the influence of built environment on transportation energy consumption and emissions. Most of the existing studies investigated the connection of urban form and travel in an isolated way, which did not reflect the reality that the built environment and different travel outcome components, including travel choice, vehicle choice, driving behavior, travel distance, and energy consumption. These travel outcomes intertwine with each other in a way that makes the isolated approaches unsuitable for handling the complexity of the relationship. This dissertation contributes to the current literature by establishing a new framework and applying a new approach (SEM) for understanding the relationships of urban form and different travel outcomes, simultaneously.

The purpose of this chapter is to review the current literature on the connection among the built environments and travel behavior, and further, on energy consumption/emissions. Then, the new approach and conceptual framework will also be introduced and discussed.

2.2 Current Literature

Figure 2.1 demonstrates the current four groups of literature on the connection among built environments and travel behavior, and further, on energy consumption. The four groups of literature can be summarized as: (1) the links between urban form, travel, energy consumption and CO_2 emissions, (2) the impact of urban form on vehicle type choice, (3) the connection between urban form and mode choice, and (4) the relationship between the built environment and driving patterns. Each group will be discussed individually below.

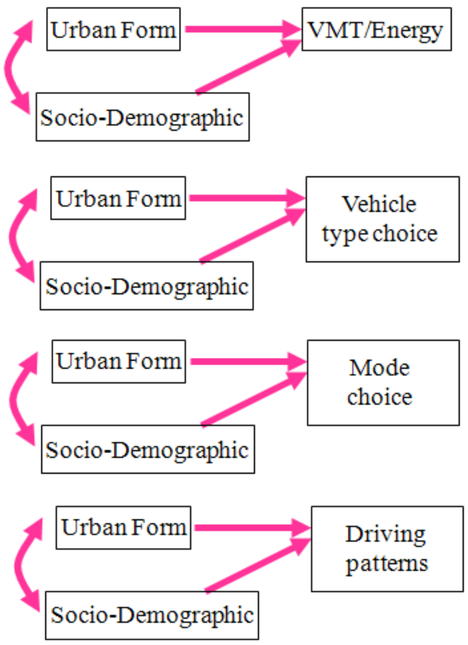


Figure 2.1 Structure of current literature

2.2.1 Urban Form, Travel, Energy Consumption, and CO_2

There is a substantial body of literature that examines the connection between the built environment and travel behavior (see Crane, 2000, Ewing and Cervero, 2001 & 2010, and TRB, 2009 for reviews of this literature). However, the empirical results have provided rather mixed evidence of the influence of the built environment on travel. Some researchers, such as Boarnet and Sarmiento (1998) and Giuliano and Small (1993), showed that land use variables provided little explanatory power for observed travel. Others, including Krizek (2003) and Shen (2000), found that households change travel behavior when locating in differing built environments.

Even less conclusive is the extent to which the urban form impacts on household energy consumption and emissions. So far, relatively few researchers have empirically investigated the linkage between the built environment and transportation energy use. It may be due to the lack of reliable energy and emission data. Or, people just assume that when longer distances are driven, more energy is consumed and more emissions are generated, due to the separation of the travel models and energy/emission models.

There is certainly little consensus within the body of research as to the relationship between land use and energy consumption and emissions (Anderson, Kanaroglou, and Miller, 1996 provided a good literature synthesis). Some believe that higher density is expected to lead to a decrease in transportation energy consumption and consequently enables a reduction in vehicle emissions. Some are more cautious and suggest that urban form factors are, at most, playing a partial role. Other factors, such as income, are more important in influencing travel, energy consumption and emissions. The underlying discrepancy between the two groups might stem from the difference of assumptions, data and methodologies. Literature could be organized in different ways, for example, by travel purpose (journey-to-work versus non-work), analytical method (descriptive versus regression, etc.), or the measurements of urban form (density versus accessibility, etc.). Each approach provides different insights into how and why different approaches yield different results. The current studies were divided into approximately three categories based on methodology: simulation analysis, descriptive analysis, and regression analysis.

2.2.1.1 Simulation analysis

The general idea of simulation analysis is to strategically and simply control land use patterns and clearly link the hypothetical urban form variables to travel, energy consumption and emissions. Due to the first petroleum crisis during the 1970s, a number of studies started focusing on the estimation of the effectiveness of land use planning for energy conservation. The studies in the 1970s applied a similar analysis method, by which each proposed a different hypothetical urban form, or different hypothetical land use development scenario for existing cities. The earlier studies (The Council of Environmental Quality, 1975) proposed that the most compact centralized form was the most energy-efficient. Later research (Carrol's, 1977 and

Edward, 1977) favored a compact multinucleated form. Although the results of these studies provided some valuable insights, they shared many important limitations: (1) the anticipated scenarios were too simplistic; (2) Most of them merely emphasized journey-to-work travel in estimating transport energy demand and lacked the consideration of non-work trips that made up around 75% of total trips; (3) they were weak on modeling the behavioral responses of individual households compared to some other factors, such as price changes (Anderson, Kanaroglou, and Miller, 1996).

Improved data and statistical procedures in recent years make the simulation studies more sophisticatedly constructed, which provides more evidence. The most noticeable studies are those presented in Rickaby (1987; 1991), Wegener (1995), Stone, Mednick, et al., (2007), and Behan et al. (2008), which are discussed below:

Rickaby (1987, 1991) applied an urban simulation model called TRANUS to 20 British cities to simulate six different growth patterns for a 25-year period. He found that while the compact land use development was the most energy efficient urban form, it was also the most costly due to the increases in congestion. Therefore, the nodal developments that were strategically located around the existing city were considered as the most desirable urban form. However, the hypothetical land use patterns were created by redistributing the population to different locations and transportation networks of the city rather than measuring urban form configurations based on various aspects.

Wegener (1995) used his model for the city of Dortmund in Germany, to analyze the sensitivity of changing cost and speed of travel. In this model, the city was divided into thirty zones connected to each other by transportation networks containing major links of public transportation and road networks. Three types of scenarios were simulated: scenarios of travel cost changes, scenarios of travel speed changes, and scenarios of combination of travel cost and speed changes. The results had been shown that travel outcomes, like mode choices and trip lengths, were both sensitive to these types of changes. He believed that the changes of urban form could have influence on reducing the auto usage. However, these results might not be applicable to more dispersed cities that lacked the sufficient public transportation. This research did not consider the factors in the analysis: such as car sharing, trip-chaining, and socio-demographic.

Stone, Mednick, et al. (2007) developed a vehicle emission estimation approach to analyze emissions, including CO_2, under different land development scenarios for eleven U.S. metropolitan areas. They estimated that the median reduction in CO_2 emissions under a compact growth scenario to be 5.1%. However, this estimation was based upon future vehicle activity projected using the "NPTS transferability framework," in which household VMT was assumed to change correspondingly as the characteristics of urban form variables changes over time. This assumption is pre-determined, rather than modeled within the context of the different built environments. Another limitation of this research is that it focused on the built environment determinants at census tract level, which is an aggregated geographic unit for the analysis of travel behavior.

Behan et al. (2008) used the IMULATE, a large-scale integrated urban land use and transportation simulation model, and conducted simulation analysis of several growth scenarios, ranging from "business-as-usual" to different levels of anticipated growth by hypothetically reallocating the households in the urban center. The IMULATE improved the aforementioned previous simulation models in two aspects: first, it captured the bidirectional relationship between land use and transportation by considering the impacts of changes of the level of congestion on residential and employment choices. Second, emissions estimation was collectively decided by many factors including vehicle-fleet characteristics, average speed, and temperature and vehicle operation modes. The results had been shown that the most sprawled growth pattern consumed more than 36% of energy than the "business-as-usual" pattern. However, this research only considered the level of household changes per census tract over time, which might mask the variation within census tracts.

A most recent report published by the National Academy in the year of 2009, entitled "Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO_2 Emissions" provided a comprehensive literature review and a scenario analysis on the impact of land use development on VMT, energy consumption and CO_2 emissions. The committee developed the estimates of potential reductions in travel and energy consumption and emissions from more compact and mixed-use development. Two hypothetical scenarios relative to the base case were developed based on the literature and paper that the committee studied. The base case assumes that land use development will continue the urban sprawl pattern in the future, while the two alternative scenarios are based on more compact and mix-used development patterns. The results show that the reduction in VMT, energy consumption and emissions resulting from compact development (in an upper bound scenario) would range from 8% to 11% in 2050. A moderate scenario would result in reductions in energy use and CO_2 emissions of about 1% in 2050. However, the scenarios that the committee developed did not reflect the reality since the projected development is significantly higher than the existing growth rate (National Research Council Committee 2009). For example, doubling density could be achieved by eliminating half of the low-density development in some areas, which need more aggressive infill development.

The aforementioned research shares some common limitations: first, they investigated scenarios of what might happen, rather than the measurements of what actually has happened (Anderson, Kanaroglou, and Miller, 1996). As a result, the simulation results depended on the accuracy of assumptions. Different scenarios often generated extreme variations in the magnitude of the reductions of energy and emission. Second, as Handy (1996) pointed out, simulation studies were not intended to explain behavior. Although, the above research used the real-world data, they made certain assumptions with regard to behavior and then applied those assumptions to alternative situations to see what would happen. In general, the assumptions could not reflect the real responses of travelers to changes in their circumstances. Third, most simulation analyses were based on the assumption that the causal relationship between urban form and travel behavior exists. They did not model within the context of the study areas. Finally, simulation studies usually focus on a rather aggregated geographic scale, which might neglect the variation of the connection of the built environment and travel at micro levels.

2.2.1.2 Descriptive analysis

The most important part of descriptive analysis is that it can provide a clear picture of understanding what is going on. A good example is the work done by Ewing et al. (2008). Ewing's approach was based on a comprehensive review of existing research on the relationship between urban development, travel, and the CO_2 emitted by motor vehicles. It provided evidence on and insights into how much transportation-related CO_2 savings could be expected with compact development. In their analysis, there were six primary factors that affected CO_2 reduction: (1) market share of compact development; (2) reduction in VMT per capita with compact development; (3) increment of new development or redevelopment relative to the base; (4) percentage of weighted VMT within urban areas; (5) ratio of CO_2 to VMT reduction for urban travel; and (6) proportion of transport CO_2 due to motor vehicle travel. Given all the factors, compact development had the potential to reduce U.S.

transportation CO_2 emissions by 7% to 10%, when compared to continuing urban sprawl.

In terms of empirical studies, based on National Household Travel Survey (NHTS) for 2001, Glaeser and Kahn (2008) compared the effects of urban form on CO_2 emissions and social costs in 66 metropolitan areas. They found that metropolitan areas with low-density development, particularly those in the south, are associated with far more CO_2 emissions per household than metropolitan areas where density is relatively high.

Although descriptive studies have the advantages of providing the big picture, the work only provides summary statistics or literature of energy consumption and CO_2 emissions without making an effort to model the causal mechanisms. They can only describe what happens, but they cannot explain the relationships among different factors. The studies reviewed in the next section attempt to address the methodological challenges more directly.

2.2.1.3 Regression analysis

Unlike descriptive studies, regression analyses attempt to explain rather than just describe what is going on and are thus more methodologically sound. Regression analysis varies in different aspects. For example, different regression analyses use different data. Different data include various characteristics of the built environment, travelers, and levels of detail. Even using the same data, they might investigate different questions or use different methods and get various results. The complexity of relationships between land use and travel, as well as energy consumption and emissions, together with the difficulty of choosing appropriate variables and methods, results in the lack of consensus regarding the linkage of urban form, travel, energy use, and emissions. For example, different components of built environments (such as density, mix land use index, street connectivity, regional accessibility, distance to transit, etc.) complicate the concept of urban form, which makes it difficult to model the influence of urban form on travel. We will divide the literature roughly into two groups. The first group supports the argument that urban form variables have significant influence on travel, energy, and emissions. The second group of studies believes that other variables, such as income, are the most important variables that affect travel, energy consumption, and emissions.

A widely quoted study is that of Newman and Kenworthy (1989a; 1989b). This research is the first attempt of exploring the connections of density and energy usage. They used data from a sample of international cities to show a strong negative relationship between population density and transportation energy consumption per capita. However, the criticism of Newman and Kenworthy's analysis could be divided into two aspects. (1) Limitation one: inconsistency of data among different cities and the method of analysis. Therefore, some researchers question the applicability of their conclusion. For example, Mindali et al. (2004) used the same data set but applied refined urban form measurements and more sophisticated regression models. They found that there was no direct impact of total urban density on VMT. The results suggested that it was not accurate to consider all urban areas as one entity. Instead, by dividing the urban areas into more sub-entities (e.g., CBD, inner and outer areas), other relationships between energy consumption and refined density attributes can be identified. (2) Limitation two: no statistical control for socio-economic variables. Other research results showed that Newman and Kenworthy did not control for socio-economic variations among the cities. Some critics argued that by masking these differences, Newman and Kenworthy's studies did not reveal the true relationship between urban form and household energy consumption (Gomez-Ibanez, 1991).

Banister et al. (1997) conducted another widely cited research that supported the arguments of Newman and Kenworthy that investigated the relationship among urban form, transportation and energy by providing empirical evidence, from five case-study cities in Britain and one in The Netherlands. The cases selected in the study provided a variation of cities in terms of urban size, urban type, and urban configuration. Each city also represented an interesting variation of planning and transportation policies. The results showed that there were significant relationships between energy consumption and physical characteristics of the city, such as density, size, and amount of open space. However, they only applied density, a rather crude measurement of urban form. In addition, the lack of data comparability makes the research difficult to establish confirmative relationships between the built environment and energy consumption in transportation.

Grazi, Bergh et al. (2008) used disaggregated data to examine the impact of urban density on commuting behavior by individuals and consequences for CO_2 emissions in The Netherlands. This study involved a range of techniques, including Ordinary Least Square (OLS), Probit, Tobit and Instrumental Variable (IV). The results suggested that in the densest urban locations, CO_2 emissions by auto were considerably reduced. In this study, however, urban form was measured through density, which did not capture all aspects of land use patterns.

Based on a 10-page self-completion questionnaire, Musti, Kortum, and Kockelman (2010) examined personal travel decisions and residents' opinions on energy policy options in the Austin metropolitan area using weighted least square regression. The results suggested that better transit access, higher population density, and higher job density were associated with shorter annual driving distances and less fuel consumption. However, density and distance-to-CBD variables exhibited multi-collinearity, which makes it difficult to determine the degree to which fuel consumption is affected by density or distance-to-CBD.

The aforementioned studies support the argument that the built environment plays a more important role than other factors in decreasing energy consumption, enabling a reduction in emissions. However, other research reached the opposite conclusions. For example, Hickman and Banister (2007) used a case study of a county in the United Kingdom to test the relationships between land use and socio-economic variables, and their effects individually and in combination on transportation energy consumption. The linear regression analysis showed that land-use and socio-economic variables, when considered together, explained 60% of the variation in energy consumption. Breaking down the regression analysis showed that land use variables only explained a limited amount of the variation in energy consumption, whereas socio-economic variables explained more of the variation in energy consumption.

Susilo and Stead (2007) used more detailed travel data (Dutch National Travel Survey) to estimate transport energy consumption and emissions in the Netherlands. Their regression results showed that commuters who reside in denser urban areas consume less energy compared to commuters who reside in less urbanized areas, but socio-economic variables were more important than the built environment factors in influencing household travel and CO_2 emissions. Drawing on more comprehensive travel data, this study traced the trend of commuters' daily travel behavior between 1990 and 2005. However, commuting travel patterns are the main focus of the study. It would be better to extend the research to broader travel purposes (i.e., non-work travel). Moreover, the study only analyzed land-use variables at just one end of the journey (i.e., the origin- the home location), the physical characteristics of the destination also play an important role in influencing transportation-related energy consumption and should be incorporated in the research.

Brownstone and Golob (2009) carefully controlled the self-selection through using a rich set of socioeconomic variables. They modeled the relationship among residential density, vehicle use, and fuel consumption for California households (data were drawn on 2001 NHTS data subsample). They found that, after controlling for socioeconomic differences, a 40% increase in the residential density is associated with about 5% less annual VMT. However, the most important exogenous variables are the number of household drivers, the number of workers, education and income. In addition, due to the data limitation, only residential density was employed to describe built environment.

Most existing studies focused on the effects of urban form on household travel, energy consumption and CO_2 emissions, aiming to test the hypothesis that households located in less dense areas tend to drive more and consume more energy due to the increased separation of residential and activity sites. Only a few have explored how urban form may affect travel, fuel consumption, and related emissions by influencing household vehicle choice, travel mode and driving patterns, simultaneously.

2.2.2 Built Environment and Vehicle Type Choice

The increasing diversity of motorized vehicle type holdings and the growing share of less fuel-efficient vehicles owned by households will have significant influence on transportation energy consumption of households. The 2001 NHTS data showed that only about 57% of the personal-use vehicles are cars or station wagons, while 21% are vans or Sports Utility Vehicles (SUV) and 19% are pickup trucks (Pucher and Renne, 2003). The increased holdings of vans, SUVs and pickup trucks that have lower fuel economy in passenger vehicle fleets has contributed to higher levels of emissions and oil dependence. A few recent studies have found that land use development is associated with different vehicle preferences. For example, by examining data from the 2000 San Francisco Bay Area Travel Survey (BATS), Bhat and Sen (2006) analyzed the holdings and use of multiple vehicle types by households. The results indicated that households living in denser areas are less inclined to drive SUVs and pickup trucks.

By using the same data set, Bhat, Sen and Eluru (2009) improved the regression analysis by incorporating a comprehensive set of vehicle holding characteristics and more detailed urban form measurements and also controlled for household demographics, vehicle attributes, and fuel cost. Similar results were obtained, showing that households located in urban areas or in high residential or commercial/industrial neighborhoods are less likely to own/use large vehicle types such as pickup trucks and vans.

Using the 2001 National Household Travel Survey data, Fang (2008) developed a Bayesian Multivariate Ordered Probit & Tobit (BMOPT) model to measure the influence of residential density on households' vehicle fuel efficiency and usage choices. The author also found that increasing residential density reduced households' truck holdings and usage. However, some of the studies found that urban form only had limited influence on household vehicle choice. For example, Cao et al. (2006) examined the relationship between neighborhood characteristics and two behaviors that affected emissions: driving and choice of vehicle type. Through using a quasi-experimental method by investigating the changes of neighborhood characteristics and preferences, changes of attitudes, changes of socio-demographic and travel behaviors of “movers” and “non-movers,” they found that changes in the built environment were significantly related to driving, controlling for current attitudes and changes in socio-demographics. Land use development changes that were designed to put residents closer to destinations and to provide transportation modes other than drive-alone would result in less driving. As regards to vehicle type choice, they found that the built environment played a rather modest role in vehicle choice. Similar results have been shown in the research of Musti, Kortum, and Kockelman (2010). They found that closer distance to CBD was associated with more fuel efficient vehicle and lower vehicle ownership. However, the socio-demographic variables (e.g., income and education attainment) indicated stronger explanation power in the model.

Many studies that have examined the relationships of the built environment and vehicle type choice focused on the models of vehicle type specification, vehicle ownership of the households, or a combination of the two. However, these studies limited built environment characteristics to density measurements, which neglect other aspects of the built environment. Since the built environment is such a complicated construct, it is not possible to isolate the individual effects or interaction effects of specific sets of built environment variables.

2.2.3 Built Environment and Mode Choice

Many studies found that the built environment variables to be associated with the levels of usage for transit and non-motorized modes (Cervero 1994; Handy 1996; Ewing and Cervero 2001; Frank and Pivo 1994; Badoe and Miller, 2000; Zhang 2004). For example, Parsons Brinkerhoff, Quade and Douglas Inc. (1996a) used the American Housing Survey, transit and land use for Chicago, and a mail survey of residents and field observation of urban design in 12 East Bay census tract in San Francisco area to examine how mixed land-uses and urban design in residential neighborhoods affected travel choices after controlling for densities, household income, and transit service characteristics. They found that density was a better explanatory variable to explain the transit use than land-use mix or design variable. Using the 1996 Bay Area household travel survey, Reilly and Landis (2002) used a two-day travel survey that was obtained from the Metropolitan Transportation Commission's 1996 Bay Area Travel Survey to investigate the effects of land use form on home-based non-work travel behavior. They found that higher population density is associated with higher probability of walking and transit use. This study employed detailed urban form variables based on grid level data, which provided various scales of urban form measurements. However, this research only showed the relationships of the built environment and travel, but it did not establish that the relationships are causal. Addressing the issue of causality requires collecting extensive travel data and developing more complicated behavior models.

However, other studies found that the effect of density is modest. Crane and Crepeau (2001) argued that density was associated with the level of transit service and merely mediated travel behavior through cost related variables, such as travel time. The study that was conducted by Frank et al. (2008) investigated how relative associations between travel time, costs, and land use patterns impact modal choice and trip chaining patterns in the Central Puget Sound (Seattle) region. The results showed that travel time is the most important variable. Similarly, using the data collected from the New York Metropolitan Region, Chen et al. (2008) found that the built environment variables play important roles in shaping people's model choice in home-based work tours. Employment density at work was found to be more important than density at home. However, travel time is more important than the built environment variables. Two features in the study showed the improvement as compared with previous studies: (1) tour as the analysis unit has been applied in the study; and (2) built environment measurements at the destination locations have been incorporated. However, the study only investigated the commuting travel and can be extended to a broader travel behavior of various travel purposes.

More and more research now focuses on the mode choice and energy consumption and emissions. For example, Naaelle, Morton, Jerrett, and Crawford-Brown (2010) examined how conversion of short auto trips (less than 3 miles) to other modes reduced VMT and emissions by using 1995 Nationwide Personal Transportation Survey data. The results suggested that reducing short auto trips would only have a modest effect on emissions. However, due to the data availability issue, this study did not incorporate sufficient built environment variables into model specifications.

2.2.4 Built Environment and Driving Patterns

In addition to household vehicle choice and mode choice, driving patterns also influence vehicle emissions and fuel consumption, and driving patterns are connected to land use. For example, Brundell-Freij and Ericsson's study (2001; Freij and Ericsson, 2005) used a Sweden travel survey data set to investigate the determinants of driving patterns, including street characteristics and driver-car categories. Factor analysis was utilized in this study. The results indicated that built environment variables were one of the most important variables that had impacts on driving patterns. However, only micro-level variables (such as street function, speed limit, number of lanes and junction density) were used to describe the built environment in this study.

2.3 Extension of Current Studies

A good portion of the aforementioned literature is based on the utility-based theories of urban travel demand, which has played a dominant role in the research of the built environments and travel behavior for three decades (Boarnet and Sarmiento 1998; Crane 1996; Crane 2000; Boarnet and Crane 2001). One of the limitations of the utility maximization theory is that it ignores the complex process when travelers make decisions on travel choice due to the strict assumptions. However, people decide how to travel, which vehicle to drive, and where to travel, in a very complicated way. Therefore, utility maximization theory has been extended by travel behavior researchers in ways to relax the assumptions and to fully understand travel behavior.

One extension is the tour-based analysis. Tour-based analysis is a relatively new way to look at the series trips made by people every day. There is no formal consensus definition of tour. For an operational purpose, NHTS defined tour as "travel between two anchor destinations, such as home and work, including both direct trips and chained trips with intervening stops." (McGuckin and Nakamoto 2004). Recent studies show that modeling spatial relationships between built environment and travel behavior is significantly improved through using a tour-based rather than a trip-based approach (Ben-Akiva et al. 1998; Shifan et al. 2003; Miller et al. 2005).

Traditional trip-based analysis does not consider the relationships of each trip and fails to work with the basic forces that generate and influence travel (Krizek, 2003). Tour-based modeling, however, links each individual trip together along the way, which captures the complexity of trip interaction and more closely matches people's travel behavior than trip-based analysis. Tour-based analysis has been applied increasingly in the travel demand modeling. As people's travel activities become more and more complex, people tend to chain multiple stops together in a single tour. The trip chaining behavior might provide more efficiency and convenience than several separate trips. For example, complex tours might increase the auto usage since complex trip chaining might be constrained by the limited access, schedule and route of transit. The results of some studies suggested that complex trip chains may tend to be more auto-oriented (Strathman and Dueker, 1995; Hensher and Reyes, 2000).

Another extension is the stratification of travel by purposes. Different types of travel possess different nature that generates various travel patterns and relationships to the built environment features. Several classification schemes have been developed in the literature to analyze travel behavior. Reichman (1976) explained the travel variation among households by categorizing trips into three classes: subsistence activities, maintenance activities, and leisure/discretionary activities. Subsistence activities are most commonly commuting travel; maintenance activities are the purchase and consumption of convenience goods or personal services needed by individuals or households; leisure/discretionary activities are multiple voluntary activities performed on free time, not allocated to work or maintenance activities. This typology of activities was employed by Pas (1982, 1984) to classify daily travel activity behavior. It has also been used more recently for daily activity modeling

(Gould & Golob 1997; Ma & Goulias 1997; Krizek 2003). Activity classification schemes can vary depending on research purposes.

By introducing tour-based analysis and the typologies of travel in the research will strengthen the research framework and better answer the research questions.

2.4 SEM Approach

As we discussed in the 2.1 introduction section, the existing studies investigate how built environment affects people's travel behavior in an isolated way. In reality, the built environment, travel choice, vehicle choice, driving behavior, travel distance, and energy consumption intertwine with each other in the way that separate single regressions are not suitable for handling the complexity of the relationship (Figure 2.2). In addition, most of the studies used density as urban form measurements, which cannot capture all the aspects of built environment (Kockelman 1997; Ewing and Cervero 2001). Kockelman's research suggested that incorporating more built environment measurements that can capture different scales of urban form features is better than only using density (Kockelman 1997).

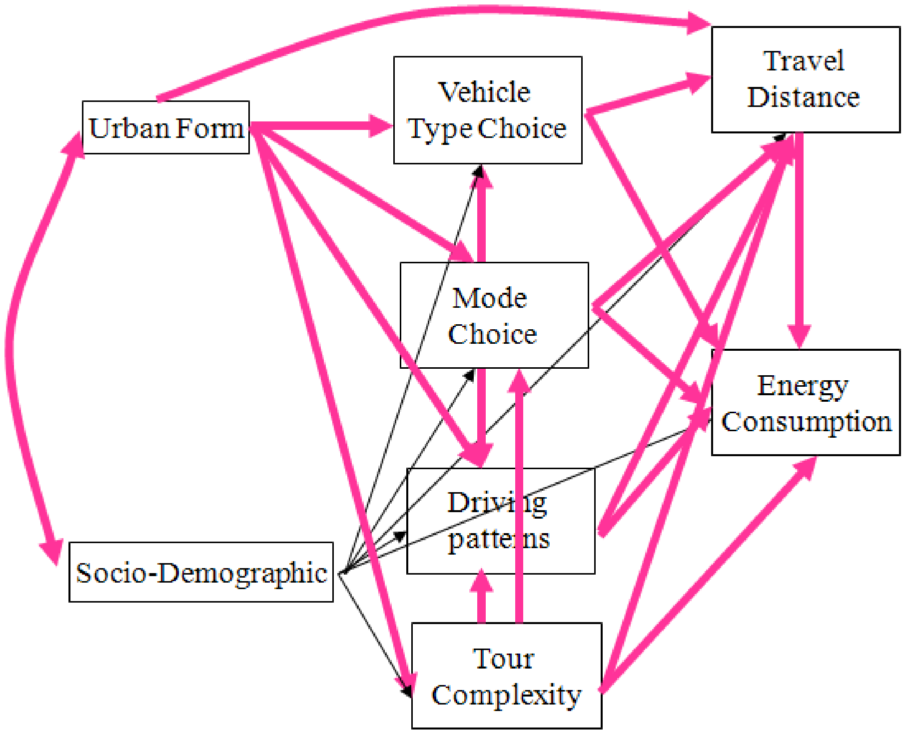


Figure 2.2 SEM approach

SEM is a very powerful statistical modeling technique used to handle a large number of endogenous and exogenous variables and to estimate the relationships among variables by calculating direct effects, indirect effects, and total effects. Direct effects are the links between exogenous variables and endogenous variables. Total effects are the sum of direct effects and indirect effects, where the indirect effects represent the sum of all of the effects of the intervening variables. Figure 2.3 illustrates a simple example showing the concept of direct effects, indirect effects and total effects.

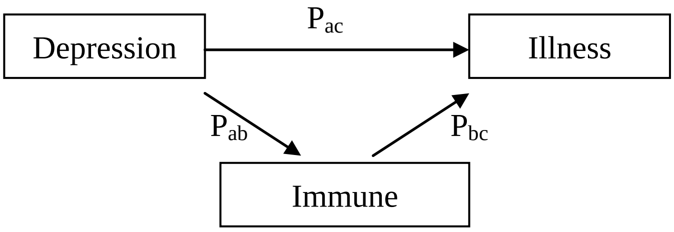


Figure 2.3 Illustration of direct, indirect, and total effects

Depression might impair people's immune systems, and further cause illness. Depression might also directly lead to illness. In SEM, the fact can be translated into the following: Depression has causal bearing on the Immune System (the coefficient is P_{ab}) and the Immune System has further causal bearing on the illness (P_{bc}). At the same time, Depression has a direct causal bearing on Illness (P_{ac}). In this example, the direct effect of Depression on Illness is the coefficient P_{ac} and the indirect effect from Depression to Illness through Immune System is measured by $P_{ab} * P_{bc}$. Then, the total effect of Depression on Illness is the sum of $P_{ac} + P_{ab} * P_{bc}$.

The analysis procedure involves six basic steps: model specification, model identification, model estimation, model fit evaluation and parameter interpretation, and model re-specification when necessary (Kline, 2005). Estimation of SEM is based on the WLSMV (weighted least square mean and variance). Goodness-of-fit tests are used to determine if the estimated model parameters are consistent with the patterns of variance-covariance (this will be discussed later). If the model fits are not desirable, alternative model specifications are needed to test against other model to get the final optimal model results.

SEM has been widely used in different fields, such as education, psychology, business and sociology. A comprehensive literature review from Golob (2003) provided an extensive summary of the studies that involve transportation from the perspectives of travel demand modeling, attitudes, perceptions and hypothetical choices, and driver behavior. However, to the best of our knowledge, SEM has rarely been utilized in the research on the connection between the built environment, travel and energy consumption. My research contributes to the current literature by gaining additional insights about how different urban form representations influence travel, vehicle usage and energy consumption through various paths concurrently. This dissertation employed SEM for a better understanding the extent to which change in the built environment can affect travel distance and energy consumption through influencing mode choice, driving patterns and vehicle holdings. This more sophisticated model will help to better understand the complex relationships of urban form, travel behavior and energy consumption, comparative to traditional regression models.

Chapter 3: Data

3.1 Introduction

In order to disentangle the complex relationship between urban form, travel and transportation energy consumption and emissions, an integrated data set that includes urban form variables, travel information, as well as energy/emissions is crucial for this study. The study area is the Baltimore metropolitan area, which includes the following one city and five counties: Baltimore City, Baltimore County, Howard County, Harford County, Carroll County, and Anne Arundel County. The whole region covers roughly 467 mi^2 of land and accommodates over 2.5 million people (Baltimore Metropolitan Council, 2006) (Figure 3.1).

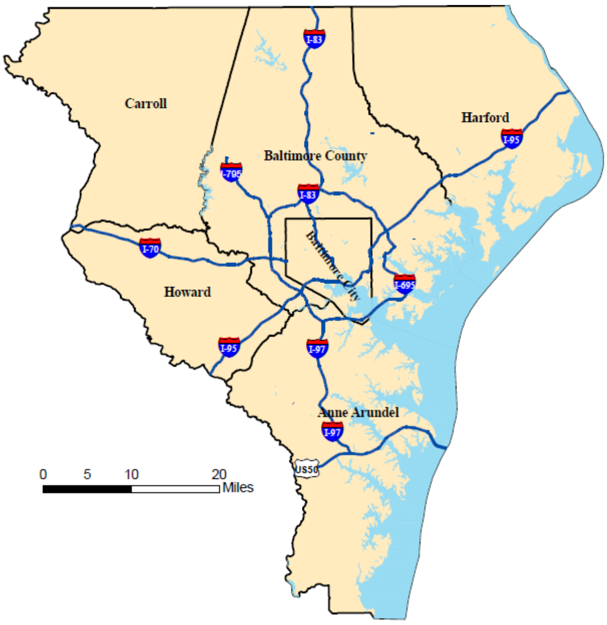


Figure 3.1 Study area

The data required involve various dimensions that capture the trip information, travelers' characteristics, vehicle information, land use measurements, as well as energy and emission data. Therefore, several primary key fields (Person ID, Vehicle ID, and Geographic ID) were utilized in this research to link all the variables together (Figure 3.2). The data were collected from multiple sources. The primary data source is the National Household Travel Survey (NHTS) 2001 Baltimore add-on data that contains traveler characteristics, trip information, as well as vehicle characteristics. The urban form variables capture five aspects of land use patterns including density, connectivity, accessibility, land use mix index, as well as distance to transit. To calculate urban form variables at different geographic levels, data were collected from five major data sets: Maryland Department of Planning (MDP), Baltimore Metropolitan Council (BMC), Claritas 2007, U.S. Census, and Maryland Transitview. The energy and emission data were derived from travel data since they are not available in NHTS. The master data set includes the following components: primary key fields, geocode ID, travelers' socio-demographic characteristics, vehicle information, urban form variables, and travel-related variables (distance, time, mode, and purpose). After merging all the components, the specific variables of the master data set are listed below:

- Trip ID
- Vehicle ID
- Income
- Race
- Gender
- Children present in family
- Age
- Education attainment
- Employment status
- Vehicle ownership
- Vehicle age
- Vehicle type
- Fuel economy (MPG)
- Density (population and employment)
- Street network Connectivity
- Mix land use index
- Regional Accessibility (auto and transit)
- Distance to the nearest bus stop and/or metro station
- Trip Geocodes of origins and destinations
- Average Speed
- Trip mode (auto, transit, non-motorized)

- Trip Energy consumption
- Trip distance

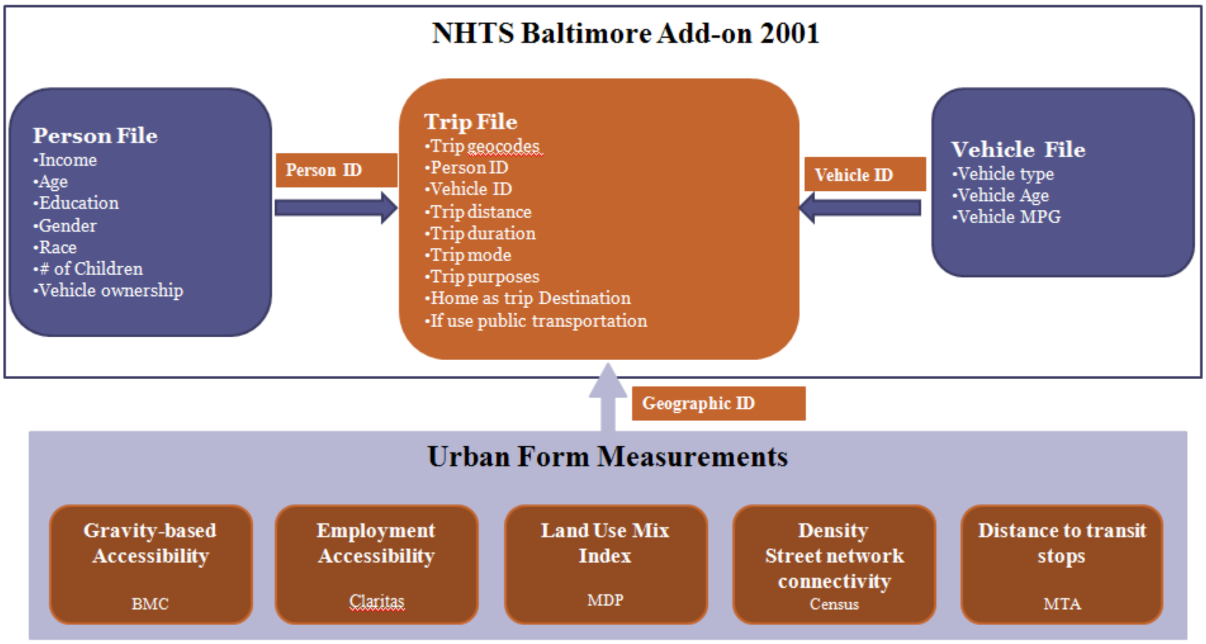


Figure 3.2 Data construction

3.2 Data Sources

A. NHTS 2001 data is a household-based travel survey conducted periodically by the U.S. Department of Transportation.[1] The NHTS data are organized into four different data files: household file, person file, vehicle file, and travel day trip file. The person file contains person information, such as income, vehicle ownership, life cycle, age, education, gender, and race of the respondents. The vehicle file includes vehicle make, model and year. The travel day trip file provides the information on

[1] Prior to 2001, the portion of the NHTS focusing on local trips was known as the National Personal Transportation Survey (NPTS) and the long-distance travel portion of the survey was called the American Travel Survey.

time trip begins and ends, trip purpose, locations of trip origins and destinations, trip distance, main mode of transportation, if public transit has been used (including access and egress mode used), if household vehicle used, and if someone else is on the trip (household member or non-household member). The 2001 NHTS data also provides several measures of land use related to trip location. Five major urban form measurements were incorporated into the data set. In addition to national data, the NHTS also provides nine add-on data that have similar data structure as national data but offer statewide or smaller areas of specific estimates. The Baltimore Metropolitan Council (BMC) through direction from the Baltimore Regional Transportation Board (BRTB) participated in the NHTS Add-on Program. Overall, travel information was collected from 3,519 households and 7,825 people in the Baltimore area. This data set also included 27,366 trips in the travel day trip file and 5,640 vehicles in the vehicle file.

B. Baltimore Metropolitan Council (BMC) charged by Baltimore Regional Transportation Board (BRTB) has been developing travel demand modeling (also called the four-step process), which can simulate and predict person travel demand and vehicle flows on the regional highway and transit system. The travel demand modeling is working on a simplified geographic unit called traffic analysis zone (TAZ) that is used to create trip generation rates for the region. TAZ is constructed by block information, such as vehicle ownership, household income, and employment within those zones. The study area has 1,151 TAZs, each with its own travel characteristics. The by-product of the travel demand modeling, travel time matrix of each TAZ zone pair is one of the major data sources for accessibility calculation.

C. Claritas Inc. is a private vendor that collects data from a variety of sources, including the U.S. Department of Labor, telephone books, county agencies, the U.S. Postal Service, and private utility companies. Claritas 2007 is the data source that contains the number of jobs at a location in 2007 and the spatial geocodes for those jobs, which are the other two components for accessibility calculation. The data were collected from the joint Environmental Protection Agency (EPA) STAR project of University of Michigan and University of Maryland: "Metropolitan Accessibility and Transportation Sustainability: Comparative Indicators for Policy Reform." This research focuses on an accessibility comparison between multiple metropolitan areas of the United States. The results of the research provide key information which can help decision-makers gauge the process of policy on transportation infrastructure and the built environment toward sustainability.

D. *MdProperty View* includes individual parcel records that are maintained by the State Department of Assessments and Taxation (SDAT). More than two million parcels in the state of Maryland make up the *MdProperty View* Parcel data set. This data set was first developed by the Maryland Department of Planning (MDP) in 1996 and has been updated annually. The data set is a comprehensive set of information about each of the property that incorporates parcel ownership, address, parcel valuation information and basic information about land and structures related with the parcel for Maryland’s 23 counties and Baltimore City. Property information of five counties and the Baltimore City was gathered and utilized. The parcel-based data is the data source for land use mix index calculation.

E. Census data is the most comprehensive data on population and housing at different geographic levels. Also, census data were summarized into four subsets based on geographic levels and data elements. Population, housing, and employment at block level were collected from the Census Summary File (SF1). The geographic boundary was obtained from the Census Topologically Integrated Geographic Encoding and Referencing system (Tiger/line) files. TIGER/Line Shapefiles contains features such as roads, rivers, and legal and statistical geographic areas. However, Tiger/line shapefiles do not include demographic data, but they contain the geographic IDs that can be linked to SF1 data. The data collected from the Census were gathered and utilized for density and street connectivity calculation.

F. Maryland Mass Transit Administration (MTA), a modal agency of the Maryland Department of Transportation, developed a comprehensive set of geographic data sets (*Transitview*) of public transit systems and used for service planning analysis and mapping applications. The data of *Transitview* were used for the distance to transit calculation.

3.3 Data Structure

Trip is the primary analysis unit for trip-based analysis and is the primary component unit for merging trips into tours. There are 27,366 trips in the NHTS Baltimore add-on travel day trip file. This file provided trip origin and destination geocodes that were used to link to urban form variables. Distance, speed, travel mode, energy variables were derived from the travel day trip file. The socio-demographic information of respondents including income, race, age, education, vehicle ownership, work status, and life cycle were obtained from the NHTS person file. Vehicle information including vehicle age and types were provided by the vehicle file. Then trips were linked into tours for further tour-based analysis. The process of data merging is displayed in Figure 3.3. Each step will be discussed in detail below. The finalized data set was showed in Table 3.1.

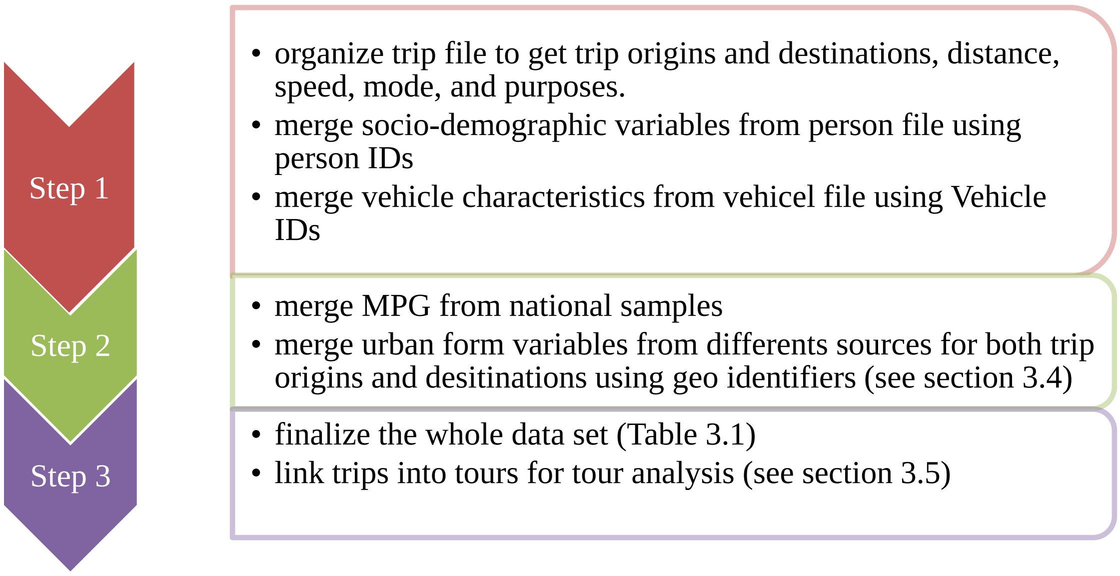


Figure 3.3 Data merging process

Urban form variables include density, street network connectivity, gravity-based accessibility, land use mix index, and the distance to transit. Different urban form variables are at various geographic levels and were collected from different sources. To calculate density data, population, housing and employment data were collected from the Census SF1 file and further incorporated into block level spatial data to compute density values. Street connectivity data were obtained from the Census Tiger street line files and were calculated using Visual Basic (VB) programming. In order to get the gravity-based accessibility, the component data for calculation were collected from BMC and Claritas 2007. A VB script was developed to compute the accessibility scores (the details of the measurement will be discussed later) at the TAZ level. The land use mix index is at parcel level data that were collected from the MDP (2001 MD property view dataset). Distance to Transit includes the distance to nearest bus stop and metro station and was computed using the Transitview data. To merge all the urban form measurements to each trip, each trip origin and destination locations were first identified. Then, spatial data at different geographic levels (block boundary, street network, TAZ boundary, and property parcel points) were overlapped on each trip origin and destination or trip origin and destination buffer zones to aggregate the value for each trip or buffer zone.

The NHTS Add-on 2001 data is the primary source for travel related variables. In addition to the trip identification number, travel day trip file offers the person identification number (personID) and the vehicle identification number (vehicleID) that were used to link to the person file and the vehicle file to merge trip makers socio-demographic characteristics and vehicle information.

The energy variable is not available in the NHTS add-on data. Energy of each trip was derived from the travel day trip file and vehicle file. Energy consumption for each trip was estimated by dividing the trip distance by vehicle fuel economy (MPG). However, the NHTS Add-on data did not require fuel economy data in the survey, and we estimated the MPG values from the NHTS national sample. The estimation procedure was developed based on the National Highway and Traffic Safety Administration (NHTSA) cold-deck imputation procedure.

NHTSA provides very detailed vehicle information including make, model, model year, EPA composite MPG, engine type, sales proportion, and so on. When matching the NHTS sample vehicles to the eligible NHTSA file record vehicles, the process involved many-to-many relationships (Figure 3.4). Because matching used a combination of four common variables, namely, make, model, model year, and type, there will be more than one eligible candidate from the NHTSA file. A cold-deck imputation procedure was adapted from the NHTS to match the NHTSA file record to the NHTS sample vehicle. A matching record was selected from many candidates that were weighted by possibility of proportional to sales, using the sale figures in the NHTSA file. However, since the national sample did not have vehicle sale proportion data, when selecting from multiple candidates, average value of the potential records in national sample were assigned to the matching record.

Energy consumption for transit mode is not available in the NHTS. We assumed that energy consumption from transit equals to zero. The assumption is made in this way because the energy consumption generated from individual transit rider is marginal and it is not the major concern of this study. Whether additional auto mode was used for travel is the major contribution to the energy consumption along the trip/tour.

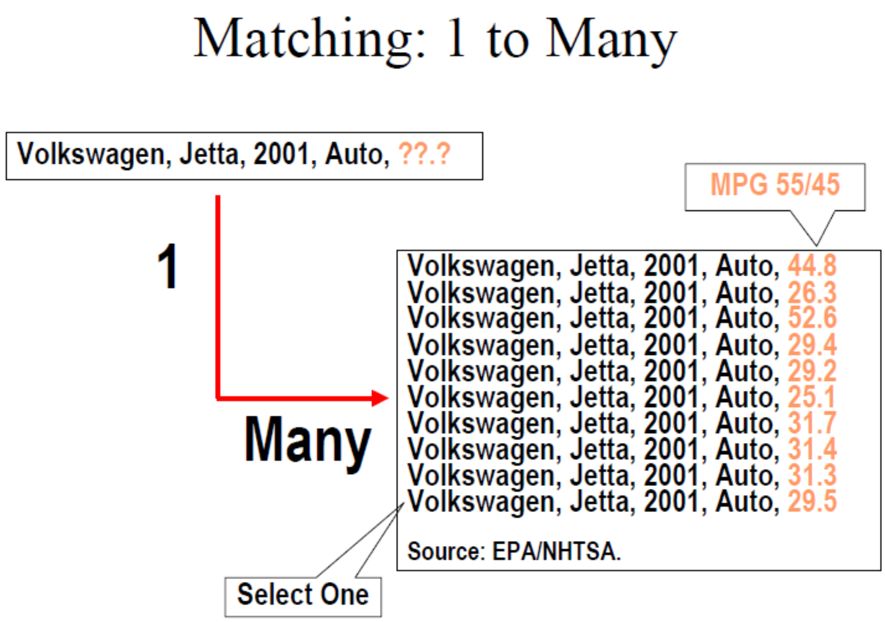


Figure 3.4 Example of linking or matching a NHTS sample vehicle to eligible NHTS national sample vehicles

Table 3.1 Variables name and descriptions (per trip)

	Variable Name	Variable Description
Person file	Person ID *	Identification number of respondent
	Income	Median Household Income
	Race	1, if respondent is White; 0, otherwise
	Gender	1, if respondent is male; 0, otherwise
	Children	Number of household members younger than 16
	Age	Age (years) of respondent
	Edu	1, if respondents completed college degree; 1, otherwise
	Worker	1, if respondent employed; 0, otherwise
	Vehicle	Number of Vehicles of households
Vehicle File	Vehicle ID *	Identification number of vehicle used for this trip
	Vehicle Age	Years for which vehicles have been used
	Vehicle Type	1, motorcycle; 2, passenger car; 3, VAN; 4, SUV; 5, pick-up truck; 6, larger truck
Urban form	Accessibility	Accessibility to employment at TAZ level (auto and transit)
	Connectivity	Street network connectivity within ¼ mile buffer of each trip origin
	Land Use Mix	A measure of the composition of residential, commercial, and office land uses within one-mile buffer of each trip origin
	Densities	Population and employment densities at block level
	Distance to Transit	Distance to nearest transit stops
Trip file	Trip Origin geocodes	X,Y coordinates of each trip origin
	Trip distance	Trip distance in miles traveled by respondent
	Speed	Average speed of each trip (trip length/trip time)
	Mode Choice	1, walking/bicycling; 2, transit; 3, shared ride; 4, drive alone
	Trip+Person ID *	Identification number of trip and person
	Trip+Vehicle ID *	Identification number of vehicle used for this trip
Derived variables	Energy Consumption	Vehicle energy consumption per trip by respondent

3.4 Constructed Variables

Five dimensions of land use are widely used to examine the influence of the built environment on travel: density, design, diversity, accessibility, and distance to transit. All of them were incorporated in this research to capture various aspects of urban form for both trip origins and destinations. The results of many studies have shown that the built environment of trip origins might play a different role from the built environment of trip destinations. For example, Shiftan and Barlach (2002) found that urban form variables at destinations have significant explanation power in mode choice. Chatman (2003) and Zhang (2004) found that higher population density at origin generates more use of non-motorized travel for work trips but not for non-work trips, while population density at destination has influence on both work and non-work travel. The NHTS Baltimore add-on travel day trip data has x, y coordinates of each trip origin and destination, which can be incorporated in GIS for further spatial analysis. Other maps that are related to the urban form measurements can be found in Appendix I 1-5.

(i) Density

Population density and employment density at the block level were applied in this research.

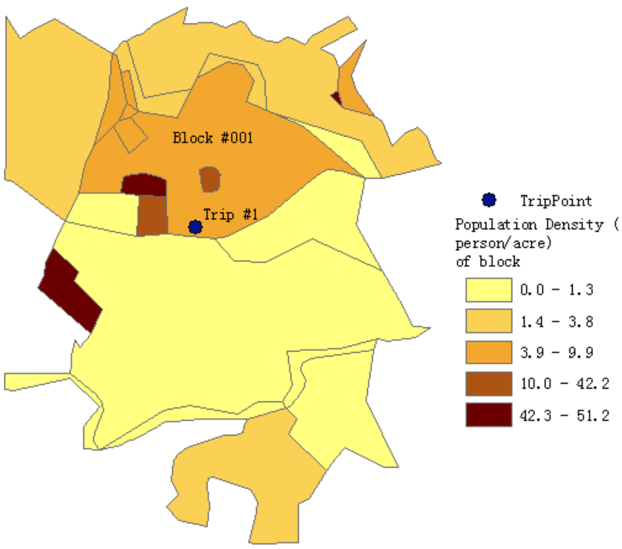


Figure 3.5 Population density for each trip origin

Block-based population and employment data collected from the U.S. Census Summary File 1 (SF1) were joined to spatial data. By using GIS X-Tools Pro, density values were calculated by dividing population, housing, and employment data by area (acre) of block. Geocodes of each trip origin were used to identify the locations and to further spatially join origin point to block data. Figure 3.5 shows an example of the population density value for a trip origin. The graduated color map shows population density of each block. Trip origin #1 falls within the boundary of Block #001, of which the density is 8 persons/acre.

(ii) Street Network Connectivity

Street network connectivity is measured by the number of intersections (except cul-de-sacs) within a ¼ mile buffer zone of each trip origin and destination (Figure 3.6). Connectivity measurement is a continuous variable indicating the connectivity of streets. To calculate connectivity of each trip origin and destination, each trip origin and destination were first located by using GIS. Then, a ¼- mile buffer zone around each trip origin and destination was created. Then, a street network layer was overlaid on the buffer layer to calculate the number of intersections within the buffer zones. Street network data were obtained from the U.S. Census Tiger 2000 files. Figure 3.6 shows how street network connectivity of a trip origin/destination is calculated. If the number of intersections within a one trip origin/destination buffer zone is higher, this trip origin/destination has greater connectivity than its counterparts.

Since there are 27,366 trip origins of the whole study area, VBA programming calculated the number of intersections at the county level and then the final results of five counties and one city were merged together.

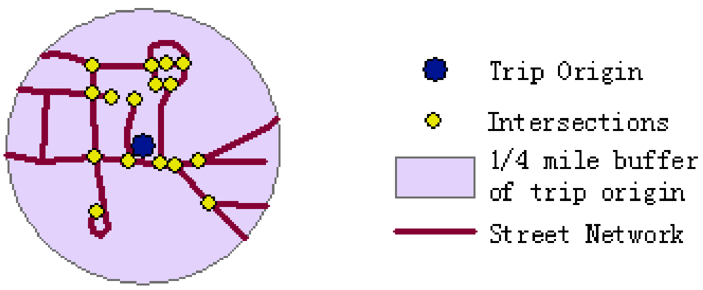


Figure 3.6 Street network connectivity within a ¼ mile buffer of trip origin

(iii) Land use mix

$$\text{Land use mix} = ((-1)/\ln n) * \sum_{i=1}^{n} p_i \ln p_i$$

Where

p_i is the percentage of land use type *i* of the total land area;

n is the number of different land use types

The land use mix ranges from 0 to 1 and captures how evenly the square footage of commercial, residential, and office floor area is distributed within each trip origin's 1-mile buffer. 0 represents a single land use environment, such as purely residential neighborhood. 1 represents the perfect even distribution of square footage of across all three land uses. In other words, the higher the value of land use mix index indicates the more balanced land use (Frank et al. 2004).

Land use data were originally acquired from the 2001 Maryland Property View data set, which are point-based data that include X,Y coordinates of properties, land acres, and land use types including residential, commercial, and office of each property. First, a 1-mile buffer zone for each trip origin was created; then, the percentage of each land use type within each buffer zone was calculated. Finally, the land use mix index was spatially joined to each trip buffer zone. Figure 3.7 illustrates how land use mix index is calculated for each trip origin buffer zone. For example, different types of properties fall within 1-mile buffer zone of each trip origin. Then the percentage of each type of land use area of the total land area was calculated. Each circle represents a 1-mile buffer zone from trip origin. The darker circles show the trip origins with more balanced land use patterns. The lighter circles show the trip origins with more homogenous land use patterns.

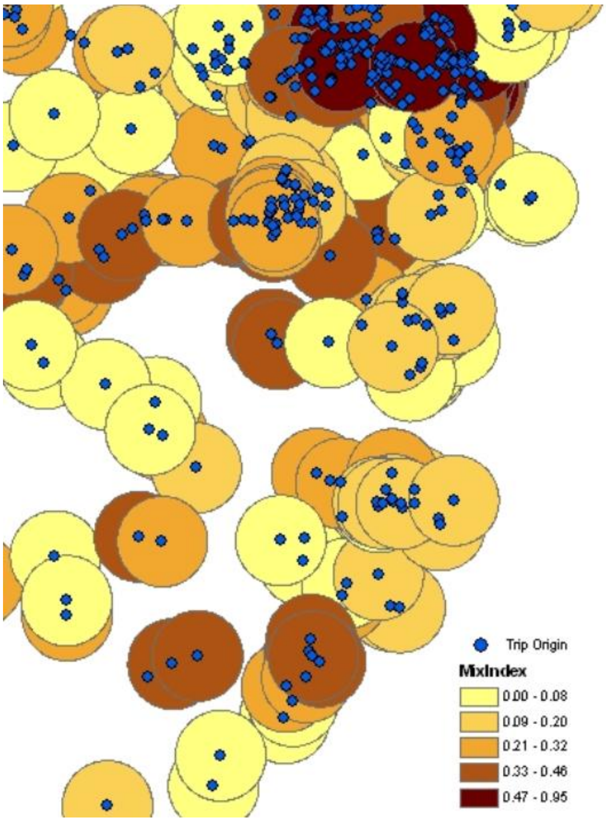


Figure 3.7 Land use mix index of each trip origin 1-mile buffer zone

(iv) Accessibility

$A_i = \Sigma_j O_j f(C_{ij})$

where

A_i is accessibility for TAZ i;

O_j is number of relevant opportunities in TAZ j;

C_{ij} is travel time or monetary cost for a trip from TAZi to TAZj;

$f(C_{ij})$ is the impedance function measuring the spatial separation between TAZ i and TAZ j;

For a region with n TAZs, $i = 1, 2, ..., n$, and $j = 1, 2, ..., n$.

The impedance function, $f(C_{ij})$, is an indicator of the difficulty of travel between TAZ i and TAZ j. A commonly used mathematical formula of the impedance function $f(Cij)$ is based on the theoretical work of Wilson (1971), and is expressed as $f(C_{ij}) = \exp(-\beta C_{ij})$, where β is an empirically calibrated parameter. The gravity-based accessibility provides accurate estimates of the accessibility of zone i to opportunities in all other zones in the region, where fewer and/or more distant opportunities provide diminishing influences (Geurs and Eck, 2001).

To calculate accessibility scores at the TAZ level, the number of jobs at the TAZ level, zone-to-zone travel time (including both transit and auto travel time), travel flow matrixes (including both transit and auto travel flow data), and calibrated β were needed. Job data were collected from Claritas 2007 and travel time and the travel flow matrix were obtained from BMC. As regards to β calibration, travel time and the travel flow matrixes were applied to calibrate β using an exponential function. TransCAD "Gravity Calibration" function compares the mean impedance of the forecast to the observed mean cost after each iteration. If the convergence has been reached, the iteration stops. A Visual Basic program has been developed to calculate accessibility scores at the TAZ level (Appendix II). GIS has been applied to check if the spatial patterns of final results were consistent with expected patterns. After getting the results of accessibility, each trip origin and destination were spatially joined to each TAZ. Figure 3.8 illustrates that trip origins fall within the TAZs and the spatial patterns of higher and lower accessibility scores.

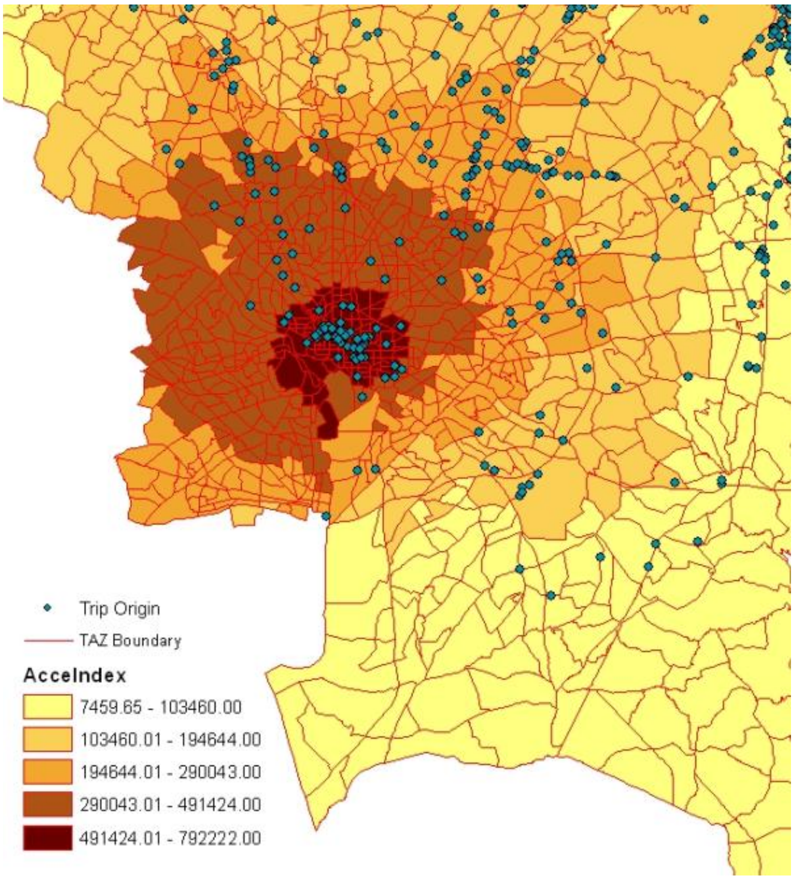


Figure 3.8 Accessibility index for each trip origin

(v) Distance to transit

Distance to transit is measured as the distance from each trip origin and destination to the nearest bus stop and metro stop.

3.5 Linking Trips to Tours

As we mentioned in the Chapter 2: Literature Review, due to the complexity of the relationship of the built environment and travel behavior, tour-based analysis matches more closely to people's travel behavior than traditional trip-based analysis. Tours (also known as trip chaining) link individual trips together and include the outbound and return trips along the way. In order to create the tour as the analysis unit, individual trips were aggregated into tours. The number of stops per tour is used to measure tour complexity. However, tour complexity only has been considered as one dimension of the travel; travel purpose is another important dimension in travel research. Different types of tours have significantly different characteristics. By grouping them together, we can understand the mechanism of travel behavior behind each type of travel and its relationship to the built environment.

Using tour as the analysis unit leads to a couple of challenges: (1) how to assign a single purpose to a multi-trip/multi-purpose tour, (2) how to decide the mode for each tour that individual trips that have their own modes, and (3) if travelers choose to drive, how to determine what type of vehicle that they choose as the primary vehicle for the entire tour.

Tour segments (stops) along the way might have more than one purpose and mode. However, we assumed that not all the purposes and modes are the main ones for the tour. If a worker makes a work trip or a student makes an education trip along the tour, then that is always the primary tour purpose. After the primary tour purpose is decided, the mode and vehicle type of the primary trip segment are considered as the primary mode and vehicle type for the entire tour. The underlying logic is that people typically decide which mode to use and which vehicle to choose for the entire tour before they leave home. For example, people might not take transit (they might take personal vehicles instead) to go to work if they know that they might stop by at the grocery stores on the way back from work. Also, people will decide not to take transit back home from work if they drive to work during the morning. If there are no work or education trips, the primary tour is the trip with the longest travel distance. Then, the mode and vehicle type of the primary trip become the primary mode and primary vehicle used for the entire tour.

In order to decide the primary tour purpose, the first step is to categorize the purposes for each individual trip segment. Previous studies provided different approaches of classifications of trip purpose. Some used a dichotomy coding method to divide tours into work and non-work tours (Ewing 1993 and Hanson 1980). Some used three types of classifications: work trip, discretionary trip, and maintenance trip (Pas and Bradley, 1984). Others used more detailed classification schemes (Golob 1994): work trip, shopping trip, school trip, personal trip, discretionary trip, and other trip.

A given classification scheme has to be considered subject to the purpose of studies. Also, a classification should be simple and clear. However, travel is so complicated that any classification scheme should take the complexity into account.

In order to better capture how different are the purposes of travel, the work-discretionary-maintenance typology scheme was applied. We first identified the individual trip purpose by considering the relationships of linked trips through identifying the purposes of the outbound and returning trip purposes. For example, if the trip chaining involves only commuting purpose, each trip segment is considered a work trip. If the trip chaining involves a maintenance and work trip, each trip segment is considered a mix-work-maintenance trip. The same approach is applied to other categories. As a result, the trips can be grouped into seven categories: work trip, maintenance trip, discretionary trip, mix-work-maintenance trip, mix-work-discretionary trip, mix-maintenance-discretionary trip, and mix-work-maintenance-discretionary trip. Table 3.2 shows the descriptive statistics by different trip purposes.

Table 3.2 Descriptive statistics by different trip purposes

Type #	Trip type	Coding	# of trips	% of trips	Mean distance (mile)
1	work trip	H-W-H	2581	13.1	12.69
2	maintenance trip	H-M-H	2855	14.5	6.62
3	discretionary trip	H-D-H	979	5.0	9.83
4	mix-work-maintenance trip	H-W-M-H	3489	17.7	9.16
5	mix-work- discretionary	H-W-D-H	2311	11.8	8.26
6	mix-maintenance-discretionary trip	H-M-D-H	4689	23.9	6.76
7	mix-work-maintenance-discretionary	H-W-M-D-H	2755	14.0	7.45

Based on the simple descriptive analysis of trips, we found that some of the categories share similar characteristics in terms of travel outcomes. For example, the average travel distance of discretionary trip and mix-work-maintenance trip are quite similar (9.83 miles). To be useful and practical, a taxonomy has to be simple and representative. We decided to reduce the categories of trip purposes by aggregating the aforementioned seven purposes into three main tour types: home-based work tour, mixed home-based work and non-work tour, and home-based non-work tour. Work tour is obligatory activity that occurs more or less with time regularity. Work tour includes trips for work, school or college trips. Non-work tours involve discretionary activities that have less time constraints. Non-work tours include personal, appointment, shopping, and visiting and free-time activities. Aggregating trips in this manner offers a parsimonious way to code and analyze tour complexity than using more complicated types but more detailed than the simple work/non-work dichotomy approach.

Table 3.3 indicates that about 26% of the tours away from home are work. Around 33% of the tours are mixed-work and non-work tours and 39% of the tours are non-work tours. The basic statistics show that among work-alone tour, 20% are transit tours and 9% are non-motorized tours. Among non-work tours, 5% are transit tours and 13% are non-motorized tours. In the context of mixed tours, the transit tours and non-motorized tours account for 5% and 14%, respectively. The statistics also indicate that the tours become more complicated when people combine work tours with non-work tours.

Table 3.3 Descriptive statistics of tours by purposes

Tour type	# of tours	# of walking tour	# of transit tour	# of trips/ tour (mean)	Tour distance (mile)	Energy consumption (gallon)
Work	1879	173	379	2.1	23.03	1.21
Mixed Work Non-work	2359	331	115	2.83	22.03	0.83
Non-work	2838	355	123	2.75	18.32	0.70

Chapter 4: Conceptual Framework, Research Questions, Hypotheses and Methodology

4.1 Conceptual Framework

The intention of this dissertation is to explore the relationships among various attributes of the built environment, travel behavior and the corresponding transportation energy consumption. Current literature has shown that with more compact land use patterns, the reduction of vehicle energy consumption and emissions should be positively associated with the decreases in VMT. However, compact development may mean lower speeds and more stop-and-go driving, which may offset some of the air quality benefits resulting from lower VMT. Also, urban form impacts mode choice and vehicle ownership and type, which further influences energy use. Due to the complexity of built environment and travel, SEM were built to develop a quantitative understanding of the extent to which change in the built environment can affect energy consumption by influencing travel mode, tour complexity, driving patterns and vehicle types. The interrelationships among various variables were illustrated by paths (arrows) in the conceptual framework below in Figure 4.1.

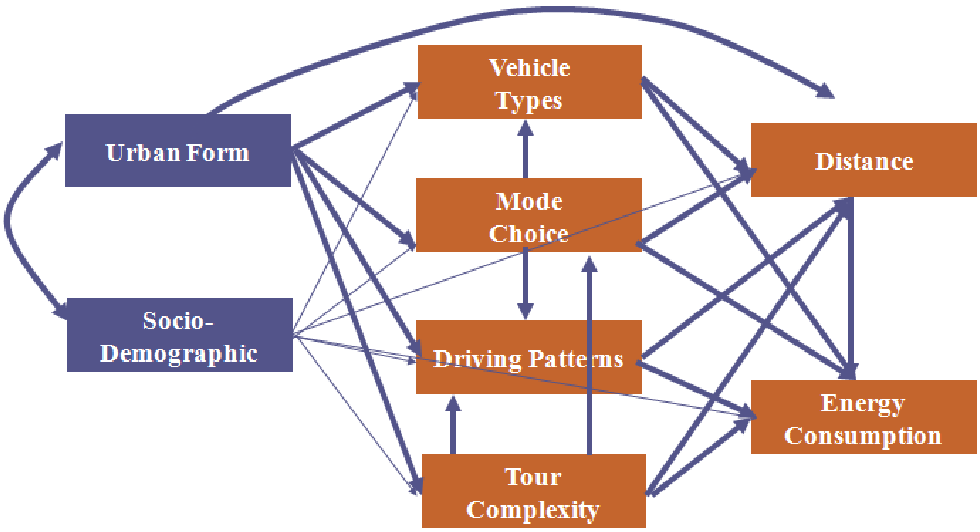


Figure 4.1 Conceptual framework

SEM is a statistical technique for testing and estimating causality among variables by separating the direct effects and indirect effects from the total effects. In this research, urban form variables may directly affect travel distance and subsequent energy consumption. The single-equation regression coefficients can only capture the direct effects of urban form on travel, or the direct effects of locally exogenous variables[2] on the endogenous variables. For example, vehicle type, mode choice, and driving pattern are the locally exogenous variables that influence travel distance and energy consumption. However, single-equation regression models cannot capture the intertwined nature of the effects of urban form on travel. Also, the indirect effects of the locally exogenous variables would not be made explicit, and either or both of their total effects on travel distance, energy/emissions might be misrepresented by the coefficients. SEM explicitly allows multiple directions of causality through

[2] A locally exogenous variable is defined as an element behaving as exogenous within the context of a pathway.

simultaneously estimating the parameters of multiple interconnected equations. It is then possible to distinguish the direct effect of urban form variables to energy consumption from its total effect on travel related variables.

Our initial analysis was based each individual trip. Then, the trips were aggregated into tours for further analysis. A trip is defined as travel directly between two anchor destinations, such as a trip from home to work. Tour (also called "trip chaining") is a relatively new way to examine the sequential trips made by people every day. However, there is no consensus on the definition of tour. For an operational purpose, NHTS defined tour as "travel between two anchor destinations, such as home and work, including both direct trips and chained trips with intervening stops." (McGuckin and Nakamoto 2004). Using tour as the primary analysis unit has several advantages: first, tour-based analysis more closely matches people's travel behavior by linking all the trips along the way. By using tour as the analysis unit, detailed built environment measurements for both tour origins and destinations can be incorporated into the models. Second, different urban form measurements might have various influences on different types of tours. Urban form near workplace locations may have more influence on commuting travel whereas urban form near a residence place may have more influence on non-work travel originating and ending at home. Grouping all the trip segments that have similar travel purposes along the tours will be more likely to reveal the inter-relationships between the built environment and travel behavior among different travel purposes.

In order to illustrate the difference between trip and tour, an example of one person's activity is shown below:

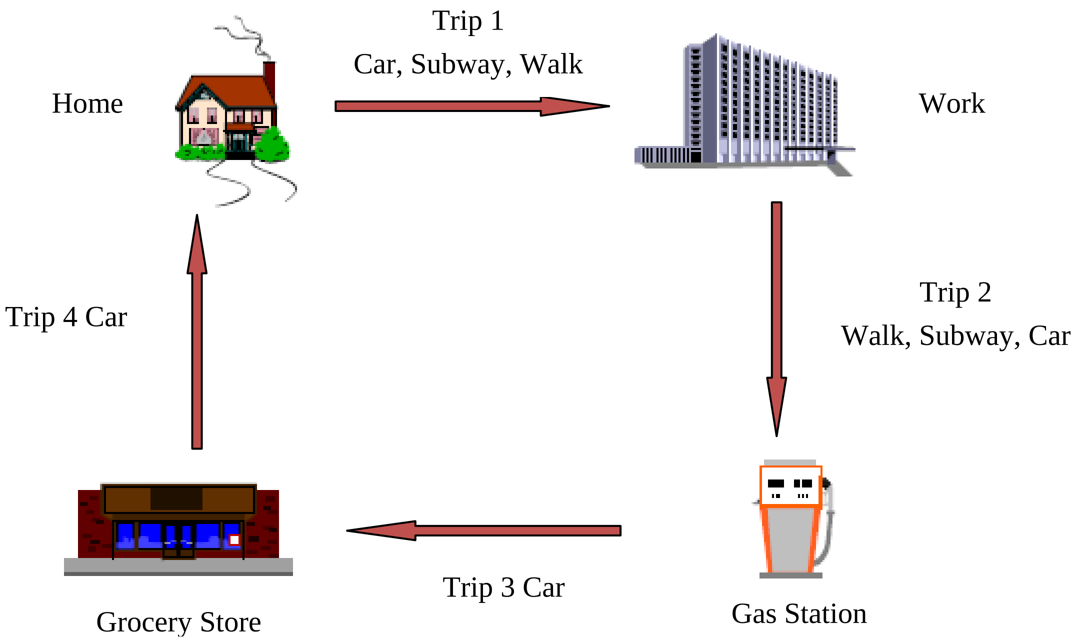


Figure 4.2 Example of a tour

The example above shows that this tour is composed of a sequence of four trips. Trip #1 is a commuting trip, but the trips #2, #3, and #4 from work to home are non-work trips. The non-work stops along the tour complicate the commuting trip. Trip analysis only considers each segment along the tour, which does not capture the travel behavior that people tend to combine various purposes along the way. By using tour analysis, we classify this type of tour as mixed-work-non-work tour. In this way, we can capture the nature of mixed commuting and non-work activities along the tour.

Both trip-based and tour-based analyses were conducted in this dissertation to compare the results based on model fits, significance tests, and coefficients. Trip and tour samples were also classified into sub-samples based on travel purposes and mode choice to test the variation of travel behavior among different purposes and modes.

Figure 4.3 is a flow chart that shows how the analyses are processed in the dissertation.

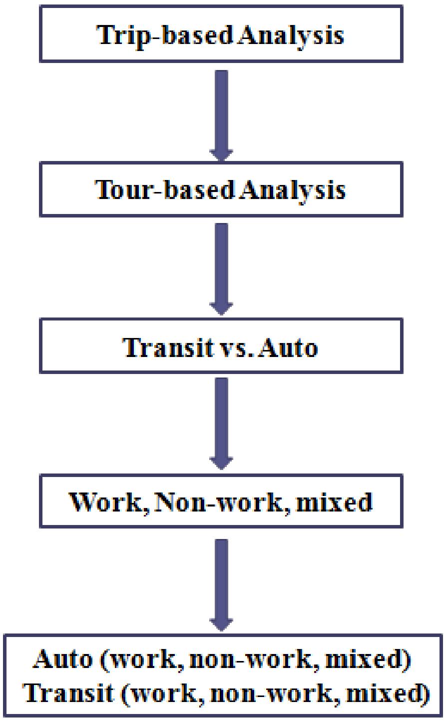


Figure 4.3 Flow chart of analysis

4.2 Research Questions and Hypotheses

4.2.1 Research Questions

Based upon the aforementioned conceptual framework, we are trying to answer the following seven research questions and test seven major hypothetical paths:

(1) To what extent do urban form variables directly affect travel and subsequent energy consumption, when controlling for socio-demographic factors?

(2) Do urban form variables indirectly affect travel and energy consumption through different paths by influencing driving patterns, vehicle type choice, mode choice, and tour complexity, individually?

(3) What are the relationships among the intermediate variables including vehicle type, mode, driving patterns, and tour complexity?

(4) Are there significant differences of magnitudes of direct and indirect effects through different paths?

(5) What are the differences among different types of travel and what would be the underlying mechanism?

(6) To what extent does tour-based analysis differ from trip-based analysis in terms of model fit and explanatory powers?

(7) What are the differences between auto and transit travel since the two modes have different working mechanisms?

4.2.2 Hypotheses

Seven corresponding hypotheses are tested in this study, with the first five focusing on the inter-relationships between urban form, travel and energy usage and the last two regarding the methodological issues:

Hypothesis 1: Urban form variables directly affect travel distance (subsequently affecting energy consumption) due to the separation of residence and activity sites. Urban form at the destinations has stronger effects than at the origins.

Hypothesis 2: Urban form variables affect travel distance and corresponding energy indirectly.

Hypothesis 2a: Urban form variables affect household vehicle type choice. Specifically, households living in denser areas will choose smaller vehicles and consume less energy.

Hypothesis 2b: Less dense areas involve more motorized and highway travel, which causes increases in travel distance, and energy consumption.

Hypothesis 2c: Denser areas are associated with more congestion (measured by speed), which consumes more energy.

Hypothesis 2d: People living in denser areas have more complex tours and consume more energy.

Hypothesis 3: Among the intermediate variables, mode choice and tour complexity have influence on travel speed. The tour complexity also has direct effects on mode choice.

Hypothesis 4: Urban form variables have stronger direct effects on travel and energy consumption than the indirect impacts through affecting intermediate variables: mode choice, speed, vehicle types, and tour complexity.

Hypothesis 5: Commuting tours have more stable travel patterns and show more significant results than non-work and mixed-work-non-work tours.

Hypothesis 6: Tour-based analysis generates better estimated results than trip-based analysis.

Hypothesis 7: Separating auto and transit samples from the whole sample generates better model results.

Hypothesized directions of relationships among the built environments and travel are shown in Table 4.1.

Table 4.1 Hypothesized directions of relationships among built environments and travel

↓ →	Urban Form	Vehicle Type	Mode Choice	Driving Patterns	Tour Complexity	Travel Distance	Energy Consumption
Urban Form		-	-	-	-	-	-
Vehicle Type					+		+
Mode Choice				+	+	+	+
Driving Patterns					-	+	+
Tour Complexity						+	+
Travel Distance							+

4.3 Methodology: SEM and Model Decomposition

This section discusses several core techniques of SEM: (1) graphic portrayal technique for analyzing SEM: path analysis; (2) model assumptions and estimation approach; (3) model identifications; (4) model fit index; and (5) two data issues.

4.3.1 Introduction of Path Analysis

Path analysis was used to decompose the aforementioned paths into more detailed links of the model. Path analysis is a method that is applied as a graphic demonstration of an SEM to analyze the magnitudes and significances of direct, indirect, and total effects among variables.

4.3.2 Model Estimation and Assumptions

The general approach to estimate the coefficients of SEM is covariance structure analysis. The concept is that the true population covariance structure is represented by covariance matrix ∑, for which the observed sample covariance matrix S is an unbiased estimator. The goal is to find the set of parameters that minimizes the discrepancy between the population covariance matrix (measured by S), and the covariance matrix implied by the model $\hat{\Sigma}$.

$$\begin{pmatrix} s_1^2 & s_{12} \\ s_{21} & s_2^2 \end{pmatrix} - \begin{pmatrix} \hat{\sigma}_1^2 & \hat{\sigma}_{12} \\ \hat{\sigma}_{21} & \hat{\sigma}_2^2 \end{pmatrix} = \begin{pmatrix} s_1^2 - \hat{\sigma}_1^2 & s_{12} - \hat{\sigma}_{12} \\ s_{21} - \hat{\sigma}_{21} & s_2^2 - \hat{\sigma}_2^2 \end{pmatrix}$$

S - $\hat{\Sigma}$ (S-$\hat{\Sigma}$)

Observed Covariance Matrix	Model-implied Covariance	Residual Covariance Matrix

There are two common approaches to estimating SEM: Maximum Likelihood (ML), and generalized least square (GLS). These two approaches assume the observed variables to be continuous and multivariate normally distributed. However, since the data gathered in this research involves non-normal ordered categorical data, different estimators are employed. The non-normality issue will be discussed in a later section (section 4.3.5).

4.3.3 Model Identifications

Model identification is applied to test whether it is theoretically possible to estimate the unknown parameters of an SEM. Because SEM involves the analysis of the covariance decomposition of exogenous and endogenous variables, the covariances/variances constitute the observations in the data set. The requirement for SEM identification is that there must be at least as many observations (n) as free model parameters (t): $t \leq n$.

4.3.4 Model Fit

In SEM, model fit refers to how close the model-implied covariance matrix $\hat{\Sigma}$ is to the true population covariance matrix Σ, as estimated by the observed sample covariance matrix **S**. The model fits tell us if the structured models fit the driving theories and which model specifications are relatively better than others. There are generally three broad classes of fit indices that are discussed below:

Absolute indices evaluate the overall discrepancy between observed and implied covariance matrices; fit improves as more parameters are added to the model: Root Mean Square Residual (RMSR) measures the standardized difference between the observed covariance and predicted covariance. A value of zero indicates perfect fit. A value less than 0.08 is considered a good fit.

Parsimonious indices evaluate the overall discrepancy between observed and implied covariance matrix when considering a model's complexity; Root Mean Square Error of Approximation (RMSEA) is a parsimony-adjusted index, in which its formula includes a built-in correction for model complexity. This means that given two models with similar overall explanatory power for the same data, the simpler model with fewer parameters will be favored. RMSEA and its associated 90% confidence interval should fall below 0.05. These cutoffs apply to models with continuous outcomes, however Yu and Muthen (2001) report that they are reasonable for models with categorical outcomes as well.

The formula is

$$\text{RMSEA}=\sqrt{\max\left[\frac{(\chi^2/df)-1}{n-1},0\right]}$$

Incremental indices assess absolute or parsimonious fit relative to a baseline model. The CFI is incremental fit index. The index assesses the relative improvement in fit of the researcher's model compared with a baseline model. The baseline model is also called an independent model, which assumes zero population covariance among the observed variables. Because the independent model assumes unrelated variables, the value of the Chi-square model is often quite large compared with the proposed model. Otherwise, there is no improvement and thus no reason to prefer the proposed model. A target value should be above 0.96 (Mueller and Hancock, 2009).

$$CFI=1-\frac{\max\left[(\chi^2_{\text{mod}el}-df_{\text{mod}el}),0\right]}{\max\left[(\chi^2_{\text{mod}el}-df_{null}),(\chi^2_{\text{mod}el}-df_{\text{mod}el}),0\right]}$$

Weighted Root Mean Square Residual (WRMR) is defined as the following formula:

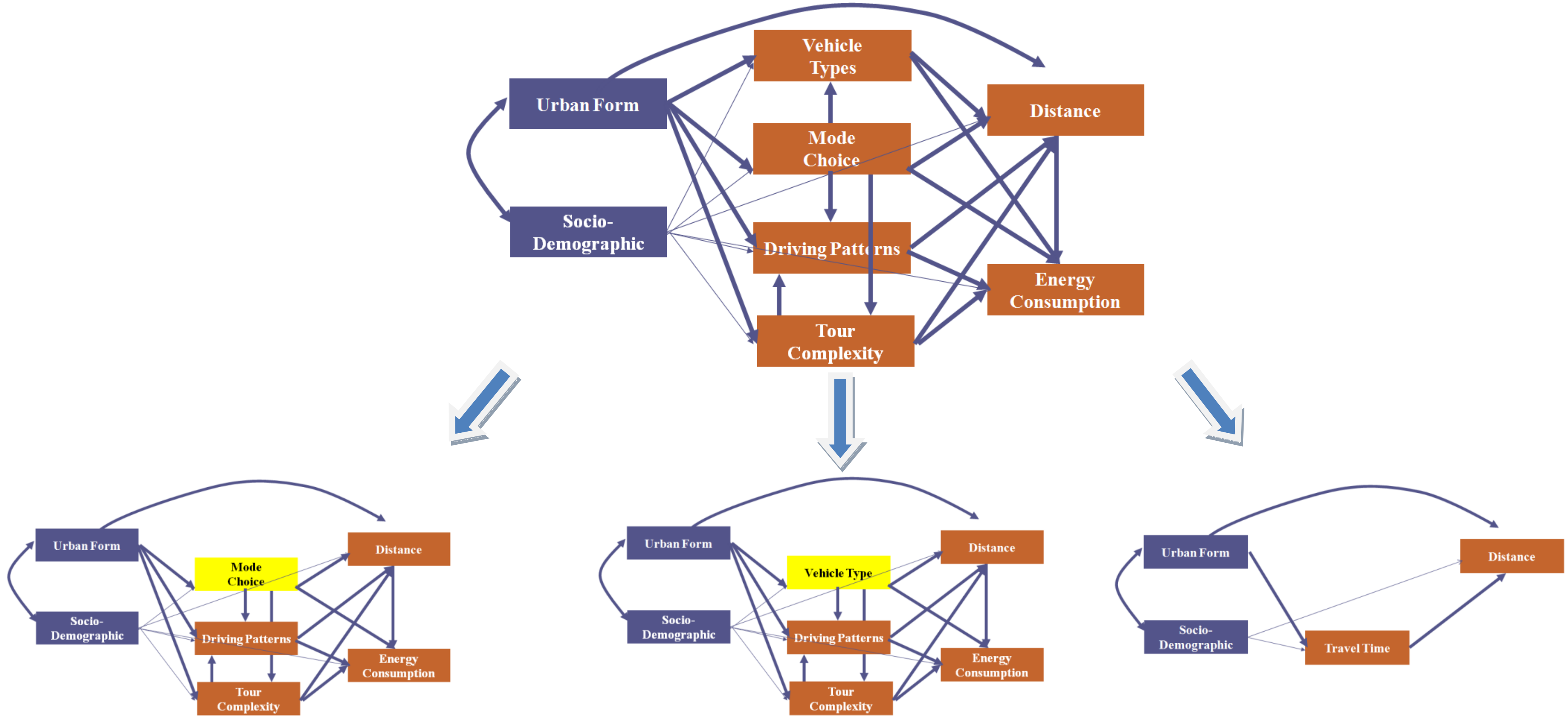
$$WRMR = \sqrt{\sum_{r}^{e} \frac{(s_r - \hat{\sigma}_r)^2 / \nu_r}{e}}$$

Where e is the number of sample statistics, s_r and $\hat{\sigma}_r$ are the elements of sample statistics and model-estimated vectors, respectively. ν_r is an estimate of the asymptotic variance of s_r. WRMR is suitable with non-normal statistics. A value less than 0.9 is considered a good fit (Muthen and Muthen , 2010).

4.3.5 Two Data Issues: Non-normality and Missing Data

As we mentioned in the previous section, the non-normality issue violates the assumption of ML estimation. The violation can produce biased results in terms of model fit as well as parameter estimates and their associated significance tests. In this dissertation, two dependent variables (vehicle type and mode choice) are ordinal rather than continuous and are thus not multivariate normally distributed. The recommended estimation procedure in models with categorical endogenous variables in Mplus is WLSMV (refers to estimating the weighted least square parameter estimates using a diagonal weight matrix with robust standard errors and mean- and variance-adjusted χ^2 test statistic; Muthen & Muthen, 2001). This technique assumes that categorical variable y represents an approximation of an underlying latent variable, y*, which is normally distributed (Muthen and Muthen, 2004). M-plus 6.0 software package was utilized in this research. Model fit was thus evaluated with the mean- and variance-adjusted χ^2 provided by WLSMV estimation, the Comparative Fit Index (CFI), the Root Mean Square Error of Approximation (RMSEA), the SRMR, and the WRMR.

Another data issue is the missing data problem. Vehicle type information is not available for transit tours and non-motorized tours, which is the missing data for the whole data set. The traditional techniques dealing with missing data are: listwise, pairwise, mean imputation and maximum likelihood methods. Listwise and pairwise approaches remove data with missing values, which might reduce the sample size and generate biased results. Mean imputation replaces the missing values with the mean of available observations. This technique might provide biased parameter estimates. Maximum likelihood methods use the full information matrix that requires random missing data, which is not suitable for this research. As a result, we decided to decompose the whole model into two parts to make sure that each part has complete data set. As shown in Figure 4.5, in Part I, the vehicle type variable has been removed and Part I is based on the sample of all the tours; in Part II, a mode choice construct has been deleted and Part II is based on the sub-sample of auto tours with available vehicle type information. Part III is based on transit sub-sample where only driving pattern is relevant in the model.



(a) All tours (b) auto tours (c) Transit tours

Figure 4.4 Decomposed conceptual framework

The primary goal of Model part I is to test the interrelationships among urban form, mode choice, driving patterns, tour complexity, travel distance, and energy consumption. Using only the auto tour samples, Model part II focuses more on the relationships of urban form, vehicle types, tour complexity, driving patterns, and energy consumption. Model part III focuses on transit samples, which has a different model specification due to the data availability.

Chapter 5: Trip-based and Tour-based Analysis

5.1 Introduction

The goal of this chapter is to examine the connection of the built environment and travel behavior by using SEM. Both trip-based and tour-based analyses were conducted to test whether the tour-based analysis generates more statistically more significant results than trip-based analyses. Trip-based and tour-based samples were also stratified into three subsamples by travel purposes (e.g., work, mixed, and non-work tours) to investigate the variations of relationship of urban form and travel among various travel types. Since not all the variables are available in both trip and tour samples, the conceptual framework was revised to make sure that the models are consistent between trip-based and tour-based analysis to make the comparison meaningful. For example, tour complexity (measured by the number of stops per tour) is not available for trip-based analysis. In addition, as mentioned in Chapter 4, vehicle type variable causes a missing data issue for the whole data set. As a result, these two variables were not included in the model. The revised model is shown in Figure 5.1.

We initially have 16 urban form variables that include density, accessibility, mixed-land use, street network connectivity, and distance to transit, at both trip and tour origin and destination ends. Some of these variables have high correlation coefficients, which generate multi-collinearity problems that typically arise when trying to include several urban form measurements in the model. We decided to select the variables that have strongest coefficients for the final models. Therefore, population and employment density at origin ends, distance to transit both for origin and destination ends, as well as accessibility index and street network connectivity at destination ends were incorporated into the models.

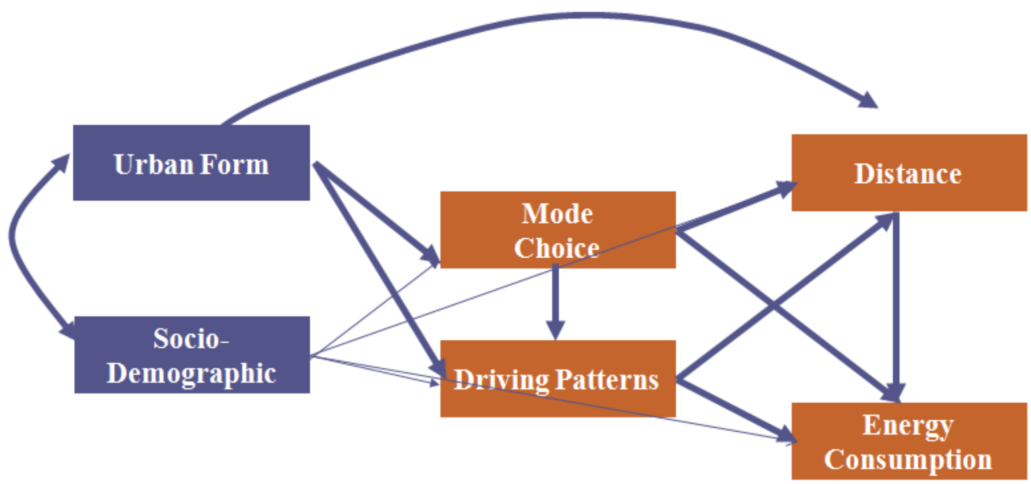


Figure 5.1 Trip-based and tour-based analysis comparison

In this study, trips are defined as travel directly between two anchor destinations, such as a trip from home to work. Trips were first utilized as the analysis unit in the study, and further aggregated into tours for model comparisons among different analysis units. Table 5.1 displays the descriptive statistics of trip data. The dataset includes a total of 19,299 trips, 3,519 households, and 5,189 persons. There are slightly more males than females in the sample. A very significant percent of travelers in the sample are White (80%) and 39% of all the travelers have attained college or higher education. Additionally, more than half of the travelers are employed.

A significant share of non-work trips has lower travel distance (6.67 miles) and energy consumption (0.29 gallons). Mixed trips have the longest average travel distance (12.57 miles) and work trips contribute the most energy consumption among all travel purposes (0.61 gallons). Table 5.2 summarizes the descriptive statistics of tours data, which includes a total of 7,115 tours. All the trips and tours were further divided by tour purposes, which were shown in Table 5.3. Non-work trips have the highest percentage of all trips (57.28%), followed by work trips (21.32%), and mixed work and non-work trips (21.41%). Non-work tours contribute the highest percentage (40.31%), followed by mixed tours (33.17%) and commuting tours (26.52%). Non-work tours have the shortest travel distance and energy usage and lowest average speed among all three sub-samples**.** In terms of mode choice, non-work and mixed tours have the lowest mode choice, which suggests that they are more flexible than commuting tours that have relatively fixed locations and travel patterns.

Table 5.1 Trip-based sample descriptive statistics (N=19,299)

	Variable Names	Minimum	Maximum	Mean	Std. Deviation
Socio-demographics	Income (Dollars)	5000.00	100000.00	56618.80	29887.75
	Age	0.00	94.00	41.72	20.48
	Children	0.00	8.00	1.01	1.20
	Gender (1, male; 0, female)	0.00	1.00	----	----
	Race (1, White; 0, others)	0.00	1.00	----	----
	Edu (1, college or higher; 0, others)	0.00	1.00	----	----
	Worker (1, employed; 0, others)	0.00	1.00	----	----
	Number of vehicles	0.00	9.00	1.73	1.24
Urban Form	Population Density at Origin (Block Group)	50.00	30000.00	8139.13	9042.56
	Employment Density at Origin (Tract)	11.04	16985.66	3318.13	3802.77
	Job Accessibility Auto Index at Origin	0.00	792222.00	173252.41	88850.89
	Job Accessibility Transit Index at Origin	0.00	334251.00	15179.55	19225.77
	# of Intersections at Origin	0.00	119.00	26.22	27.89
	Mixed Land Use Index at Origin	0.00	0.99	0.36	0.21
	Distance to Bus at Origin (Miles)	0.00	25.55	1.74	3.22
	Distance to Metro at Origin (Miles)	0.01	36.53	8.77	6.52
	Population Density at Destination (Block Group)	50.00	52845.72	6284.43	8404.19
	Employment Density at Destination (Tract)	10.00	20001.56	3518.13	4012.32
	Mixed Land Use Index at Destination	0.00	0.95	0.36	0.23
	Job Accessibility Auto Index at Destination	0.00	792222.00	183309.21	106478.3
	Job Accessibility Transit Index at Destination	0.00	334251.00	18450.74	26340.29
	# of Intersections at Destination	0.00	121.00	28.22	27.35
	Distance to Bus at Destination (Miles)	0.00	25.00	9.92	6.14
	Distance to Metro at Destination (Miles)	0.01	54.00	16.61	9.44
Travel Characteristics	Speed (Mph)	0.00	100.00	19.16	17.77
	Vehicle Type *	1.00	6.00	----	----
	Mode Choice *	1.00	4.00	----	----
	Trip Distance (Miles)	0.50	327.00	8.30	11.52
	Energy Consumption (Gallons)	0.00	50.00	0.38	0.75

* Vehicle type and mode choice variables were ranked in order of energy efficiency of the vehicle and how energy was consumed by each mode. They were ranked in this way to meet the requirements of the weighted least square approach.

Table 5.2 Tour-based sample descriptive statistics (N=7,115)

	Variable Names	Minimum	Maximum	Mean	Std. Deviation
Socio-demographics	Income (Dollars)	5000.00	100000.00	61353	29866.71
	Age	0.00	94.00	44.92	21.61
	Children	0.00	8.00	0.93	1.22
	Gender (1, male; 0, female)	0.00	1.00	----	----
	Race (1, white; 0, others)	0.00	1.00	----	----
	Edu (1, college or higher; 0, others)	0.00	1.00	----	----
	Worker (1, employed; 0, others)	0.00	1.00	----	----
	Vehicle	0.00	9.00	1.73	1.26
Urban Form	Population Density at Origin (Block Group)	50.00	30000.00	8190.00	8573.37
	Employment Density at Origin (Tract)	11.04	16900.00	3320.00	3583.44
	Job Accessibility Auto Index at Origin	0.00	792222.00	163900.90	109000.01
	Job Accessibility Transit Index at Origin	0.00	334251.00	15004.04	18031.94
	Mixed Land Use Index at Origin	0.00	0.97	0.39	18.02
	# of Intersections at Origin	0.00	120.00	26.80	27.00
	Distance to Bus at Origin (Miles)	0.00	25.05	1.70	18.32
	Distance to Metro at Origin (Miles)	0.00	36.53	9.54	19.39
	Population Density at Destination (Block Group)	0.00	52850.00	5240.00	6579.05
	Employment Density at Destination (Tract)	10.00	24000.00	4500.00	3683.22
	Job Accessibility Auto Index at Destination	0.00	792222.00	188640.00	120000.00
	Job Accessibility Transit Index at Destination	0.00	334251.00	20070.00	23427.07
	Mixed Land Use Index at Destination	0.00	0.99	0.40	0.26
	# of Intersections at Destination	0.00	121.00	26.86	27.89
	Distance to Bus at Destination (Miles)	0.00	25.00	1.62	5.13
	Distance to Metro at Destination (Miles)	0.01	56.00	8.18	8.55
Travel Characteristics	Speed (Mph)	0.00	96.00	20.94	13.73
	Vehicle Type *	1.00	6.00	----	----
	Mode Choice *	1.00	4.00	----	----
	Tour Distance (Miles)	0.50	327.00	20.80	24.81
	Energy Consumption (Gallons)	0.00	50.00	1.20	2.66

Table 5.3 Tour-based and trip-based sample summaries by tour purposes

	N		Percent		Average speed per tour (mph)		Average mode choice		Mean distance (miles)		Mean energy consumption (gallons)	
	tour	trip	tour	trip	tour	trip	tour	trip	tour	trip	tour	trip
Work	1887	4114	26.52	21.32	22.4	22.59	3.16	3.16	23.0	11.46	1.20	0.61
Mixed	2360	4131	33.17	21.41	20.70	22.57	3.08	3.26	22.03	12.57	0.83	0.40
Non-work	2868	11054	40.31	57.28	20.24	16.67	3.09	3.03	18.32	6.67	0.70	0.29
Total	7115	19299	100	100	20.94	19.16	3.12	3.11	20.80	8.30	1.20	0.38

5.2 Primary Findings of Trips Vs. Tours

The SEM provides both direct effect and total effect estimations. Direct effect of a variable is its structural coefficient and is interpreted as the initial response of the "effect" variables to the change of a "cause" variable (Hayduk, 1987). The indirect effect is the effect that a variable exerts on another variable through one or more endogenous variables. The total effect of one variable is the sum of direct effect and indirect effect(s). We started looking at the model results based on the whole samples of trips and tours. The direct effects of two models are displayed in Figure 5.2 and Figure 5.3. Then the whole samples of trips and tours were classified into three sub-samples by travel purposes (i.e., work, non-work, and mixed work and non-work), we will discuss them individually. Direct effects are presented in Figure 5.4 through Figure 5.6, total effects and indirect effects are documented through Table 5.4 to Table 5.6. Although total effects are our focus, direct and indirect effects help to show the paths of important variables that influence travel outcomes. The general conclusions of the comparison between trips and tours are also discussed at the end of this section.

5.2.1 All Trips and Tours

For both trip-based and tour-based analyses, if we compare the WRMR[3], tour-based model has better model fit than trip-based model, which suggests that model has been improved by aggregating trips into tours. However, WRMR for both trip-based and tour-based models are larger than the recommended values, which indicates that more detailed analysis is needed to improve the models. In the next section, we will discuss about the model disaggregation.

When comparing the magnitudes of the direct effects of urban form on travel distance and speed, tour-based model shows higher coefficients. Transit accessibility at the destinations and street network connectivity at destinations are the most significant variables. In model where urban form affects mode choice, some of the urban form variables are stronger in trip-based analysis: auto accessibility at the origins and street network connectivity at the destinations significantly influence people's mode choice. Further analysis is needed to understand the stronger impacts of urban form of trip-based analysis.

In the next section, both tour and trip samples were stratified into different travel purposes to conduct detailed analysis.

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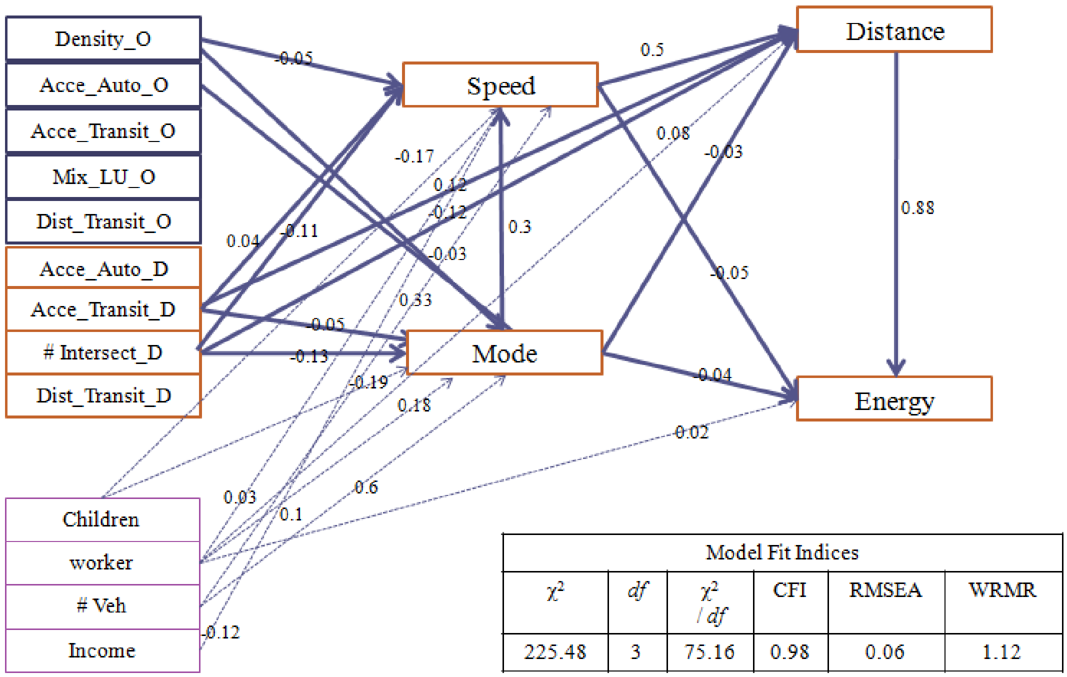
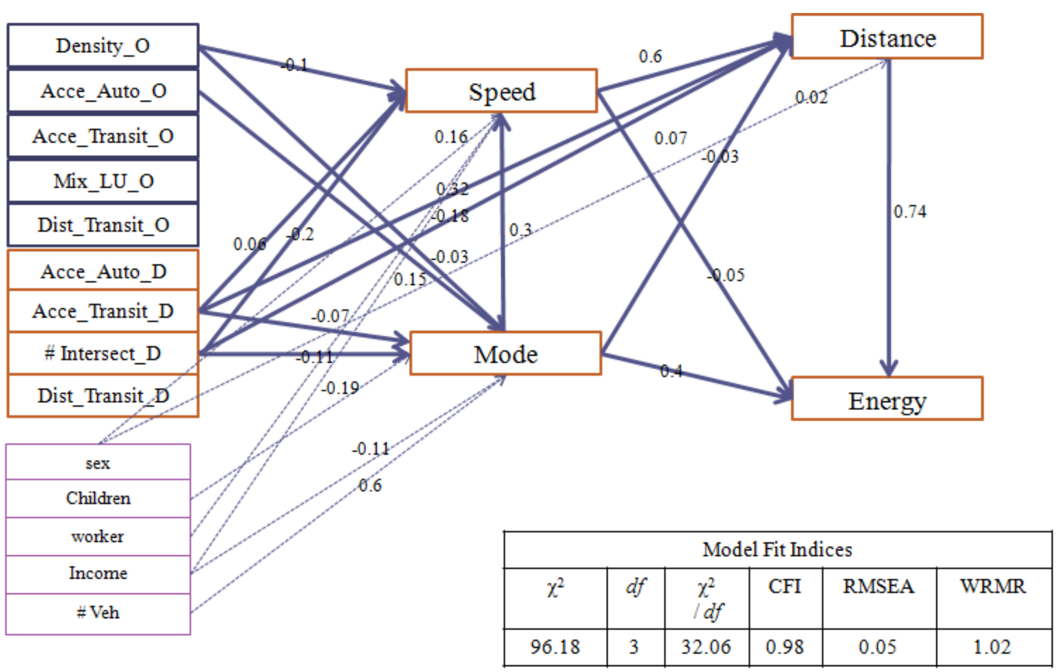
[3] Weighted Root Mean Square Residual (WRMR) is suitable with models with non-normal data. It gauges the model fit among models with different sample sizes. The recommended value is 0.9.



Model Fit Indices					
χ^2	*df*	χ^2 / df	CFI	RMSEA	WRMR
225.48	3	75.16	0.98	0.06	1.12

Figure 5.2 Standardized direct effects of all trips[4]

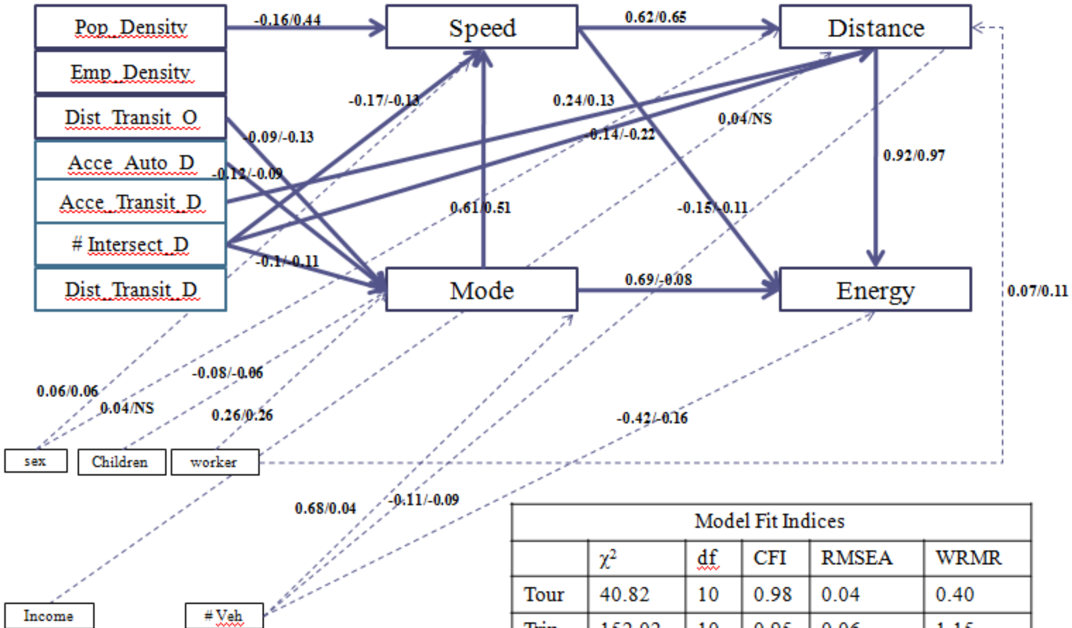


Model Fit Indices					
χ^2	*df*	χ^2 / df	CFI	RMSEA	WRMR
96.18	3	32.06	0.98	0.05	1.02

Figure 5.3 Standardized direct effects of all tours

[4] All the built in correlation matrixes were included in the Appendix III.

5.2.2 Disaggregating by Travel Purposes



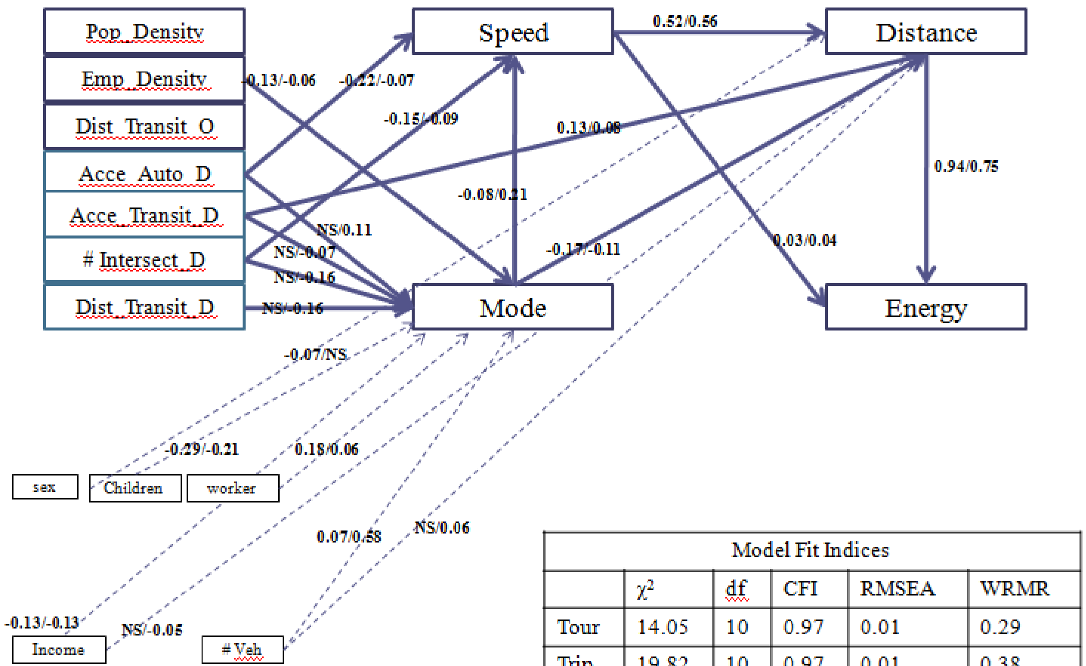
Model Fit Indices					
	χ^2	df	CFI	RMSEA	WRMR
Tour	40.82	10	0.98	0.04	0.40
Trip	152.02	10	0.95	0.06	1.15

Figure 5.4 Standardized direct effects of work tours and trips

Table 5.4 Standardized indirect and total effects of work tours and trips

	Work (Indirect Effects)								Work (Total Effects)							
	Mode		Speed		Distance		Energy		Mode		Speed		Distance		Energy	
	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip
PopDensityOrig				-0.49	-0.10					-0.07	-0.16	-0.05	-0.12	-0.11		
EmpDensityOrig				-0.42		0.08				-0.06		0.07				
AcceAutoOrig																
MixUseOrig																
DistTransitOrig			-0.06	-0.05	-0.03[a]				-0.09	-0.01	-0.04[a]		-0.05	0.08		
AcceAutoDest			-0.08		0.09[a]				-0.12		0.15[a]	-0.43	0.18	0.19		
AcceTransitDest										0.09			0.22	0.16		
ConnDest	-0.01		-0.06	-0.04	-0.15	-0.12			-0.10	-0.01	-0.23	-0.15	-0.29	-0.34		
DistTransitDest						0.03[c]					0.06[b]	0.04[b]	0.09	0.12		
Age																
Income						0.02[b]		0.04		0.00				0.06		0.06
Children			-0.05	-0.03					-0.08	0.00						
Race																
Sex					0.04	0.04	0.06[b]	0.03			0.06	0.05	0.08	0.06	0.09	0.03
Edu																
Worker			0.16	0.11	0.13	0.11	0.33	0.1	0.25	0.02	0.18	0.14	0.20	0.22	0.23	0.07
#Veh					0.21	0.16	0.52		0.67	0.04			0.09	0.62	0.10	-0.11
Mode					0.38		0.32	0.11			0.62	0.50	0.44	0.40	0.90	0.07
Speed							0.57	0.47					0.62	0.65	0.42	0.39
Distance															0.92	0.98

Notes: all the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1). Decomposed indirect effects are showed in Appendix IV.



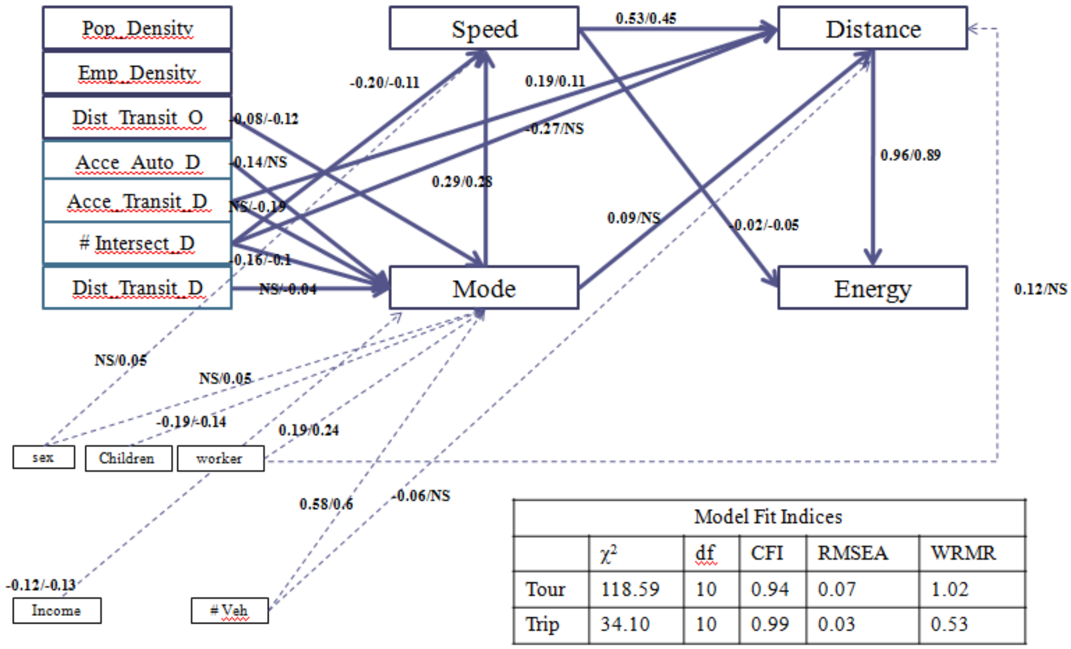
Model Fit Indices					
	χ^2	df	CFI	RMSEA	WRMR
Tour	14.05	10	0.97	0.01	0.29
Trip	19.82	10	0.97	0.01	0.38

Figure 5.5 Standardized direct effects of non-work tours and trips

Table 5.5 Standardized indirect and total effects of non-work tours and trips

	Non-work (Indirect Effects)								Non-work (Total Effects)							
	Mode		Speed		Distance		Energy		Mode		Speed		Distance		Energy	
	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip
PopDensityOrig					-0.05[a]	-0.02[a]					-0.09[a]	-0.03[b]				
EmpDensityOrig			0.01[a]	-0.01					-0.13	-0.06	0.06[b]					
AcceAutoOrig																
MixUseOrig																
DistTransitOrig			-0.01[a]						0.07[a]				-0.07[a]			
AcceAutoDest				0.02	-0.13	-0.04				0.11	-0.23	-0.05[b]	-0.18	-0.08		
AcceTransitDest				-0.01						-0.07			0.16	0.10		
ConnDest				-0.03	-0.09	-0.05			0.06[a]	-0.16	-0.15	-0.12	-0.17	-0.10		
DistTransitDest				-0.01	-0.09[a]					-0.04	-0.10	-0.02[b]	-0.09[a]	0.10		
Age																
Income					0.06	0.02[a]		-0.02[b]	-0.13	-0.13				-0.04	0.05[a]	-0.04[b]
Children			0.02[a]	-0.04	0.05	0.03			-0.29	-0.21						0.02[b]
Race																
Sex																
Edu																
Worker			-0.01[a]	0.01	-0.02[b]				0.18	0.06		0.03[a]				
#Veh					0.02	0.06	0.06	0.09	0.07	0.58			0.06	0.11	0.06	0.05
Mode					-0.04	0.12	-0.20	0.02[b]			0.23	0.21	-0.21		-0.20	
Speed							0.49	0.42					0.52	0.56	0.52	0.47
Distance															0.94	0.75

Notes: all the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1). Decomposed indirect effects are showed in Appendix IV.



Model Fit Indices					
	χ^2	df	CFI	RMSEA	WRMR
Tour	118.59	10	0.94	0.07	1.02
Trip	34.10	10	0.99	0.03	0.53

Figure 5.6 Standardized direct effects of mixed-work-non-work tours and trips

Table 5.6 Standardized indirect and total effects of mixed tours and trips

	Mixed (Indirect Effects)								Mixed (Total Effects)							
	Mode		Speed		Distance		Energy		Mode		Speed		Distance		Energy	
	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip
PopDensityOrig																
EmpDensityOrig																
AcceAutoOrig																
MixUseOrig																
DistTransitOrig			-0.02	-0.03	-0.03[a]	0.02[a]			-0.08		-0.04[b]		-0.05[a]	0.04[b]		
AcceAutoDest			-0.04						-0.14				0.11[a]			
AcceTransitDest				-0.05		-0.04			0.01	-0.19		-0.10	0.21	0.08[b]		
ConnDest			-0.05	-0.03	-0.14	-0.06			-0.16	-0.10	-0.25	-0.14	-0.42	-0.07[a]		
DistTransitDest				-0.01						-0.04			0.13			
Age																
Income						0.02			-0.12	-0.13						
Children			-0.06	-0.01					-0.19	-0.14						
Race																
Sex				0.01		0.02				0.05		0.06		0.05 [b]	0.04 [a]	0.04[b]
Edu																
Worker			0.06	0.07	0.07	0.04	0.17	0.07	0.19	0.24	0.09	0.11	0.19	0.09	0.14	
#Veh					0.24	0.07	0.15		0.58	0.60			0.18	0.07[b]	0.15	0.06[b]
Mode					0.15	0.13	0.23	0.06			0.29	0.28	0.24	0.08	0.20	0.04
Speed							0.51	0.40					0.53	0.45	0.49	0.35
Distance															0.96	0.89

Notes: all the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1). Decomposed indirect effects are showed in Appendix IV.

First, among all six models, four models have significant χ^2 and show good model fit indices, particularly for non-work tour and trip models. Work trip model and mixed-work-non-work tour models have larger χ^2 value, which suggests that the data do not fit the models very well. In general, when comparing between tour-based and trip-based analysis, tour-based analysis generates better model fit. The WRMR values are 0.4 and 1.15 for work tour-based analysis and trip-based analysis, respectively. The WRMR values are 0.29 and 0.38 for non-work tour-based and trip-based analysis, respectively. Mixed-work-non-work results show higher WRMR, which suggests that mixing commuting and non-work tours leads to worse model fit. In this case, trip-based analysis is better in terms of model fit indices. However, the coefficient estimates are similar for tour and trip analysis. These findings indicate the tour-based analysis is preferred but doesn't have significant differences relative to trip-based analysis.

Second, when controlling for other variables, urban form variables do have direct effects on travel distance. Relative to urban form measurements at origin ends, more measurements at destination ends were shown significant. Among all the urban form variables, regional accessibility of transit and street network connectivity have been shown to have significant direct effects on travel distance for work and mixed samples. For example, the direct effects of street connectivity at destinations for work tours and trips are -0.14 and -0.22, respectively, which suggest that, in highly connected areas, people tend to reduce their travel distance. Regional accessibility of transit has positive direct effects on travel distance. The coefficients for work tours and trips are 0.24 and 0.13, respectively. The results suggest that areas with higher transit accessibility are more likely to attract people from further areas to find jobs. In terms of total effects, more variables (population density and distance to transit at origins, accessibility of auto and transit, street network connectivity, and distance to transit at destinations) are shown to have significant impacts on travel, particularly for commuting travel. The indirect effects are also significant, which suggest that urban form influences travel through other channels. For example, indirect effects probably channeled through its effect on travel speed. This is indicated by urban form's (connectivity, for example) negative direct and total effects on travel speed and by travel speed's positive direct and total effects on travel distance.

Third, urban form also has negative direct and total effects on travel speed. For example, the direct effects of street network connectivity are -0.17 and -0.13 for work tours and trips, respectively. The coefficients are -0.15 and -0.09, respectively. Urban form generally has negative direct and total effects on mode choice, which suggests that people are more likely to walk in denser, more accessible, and connected areas. An interesting finding is that the impacts of the built environment on mode choice are more significant in non-work trip-based analysis. For example, four variables have negative direct effects urban form on mode choice in the trip-based sample whereas only one variable (employment density at origin ends) is shown significant in tour-based sample.

Fourth, among the dependent variables, mode choice generally has positive direct and total effects on speed, distance, and energy consumption. The patterns are consistent among all the models. In terms of total effects, tour-based analysis shows higher coefficients than trip-based analysis. Particularly, in the model of mode choice on energy consumption, results of tour-based analysis show much higher coefficients than trip-based analysis, which suggests that trip-based analysis provides a more complicated frame when dealing with the relationship between mode choice and energy consumption. For mode choice, people typically decide which mode to use for the entire tour before leaving home. For example, transit might be the dominant mode along the tour if people decided to take transit to work. In other words, a person will not decide to take transit if they have driven their car to work during the morning. Tours link all the individual trips (also including individual mode choices for each trip) together, which allow us to see that tour-based analysis shows a stronger explanation power. The effects of mode on travel distance and energy consumption are shown the strongest in commuting tour-based and trip-based results. Speed significantly and positively affects travel distance and consumption. The impacts of speed are shown the highest in commuting travel.

Fifth, some of the travelers' socio-demographics are significant determinants of travel distance and energy consumption. Number of vehicles is the most important variable that generally positively affects distance and energy usage. With respect to total effect estimates, one vehicle increases in the household, one member will travel 700 more miles per year. Gender has significant and positive direct and total effects on speed, distance and energy consumption. The results show that males tend to drive at higher speeds, longer distances and consume more energy than females. The magnitudes of direct and total effects of gender are quite similar between tour-based and trip-based analysis.

Sixth, income has a weak but positive effect on walking and public transit modes. The model estimates are quite similar between trips and tours for the non-work sample, and the mixed sample. Households with more children are more likely to use transit and walk, particularly for the non-work sample.

Chapter 6: Tour-based Analysis

6.1 Introduction

This section investigates the relationship between the built environments and travel using tour as the analysis unit. Initially, the models were based on all tour samples. Then, auto tours and transit tours were extracted from the data sets since the two modes have different working mechanisms on travel behavior. In addition, all tours were further disaggregated by travel purpose (work, mixed of work and non-work, and non-work). Finally, auto and transit tours were further classified into three travel types to improve the accuracy of model specification. Individual estimated models (all, auto and transit tour) and the differences among them are discussed in the later section.

The following sections present estimation results for the model developed in this study. The all tour models were discussed first, followed by results generated from auto and transit samples. For all, auto and transit samples, tours were further stratified into three subsamples based on travel purposes (work, mixed of work and non-work, and non-work) to investigate the detailed travel behavior. The organization of the model analysis is illustrated in Figure 6.1. The descriptive summaries of samples by travel purpose and mode are showed in Table 6.1.

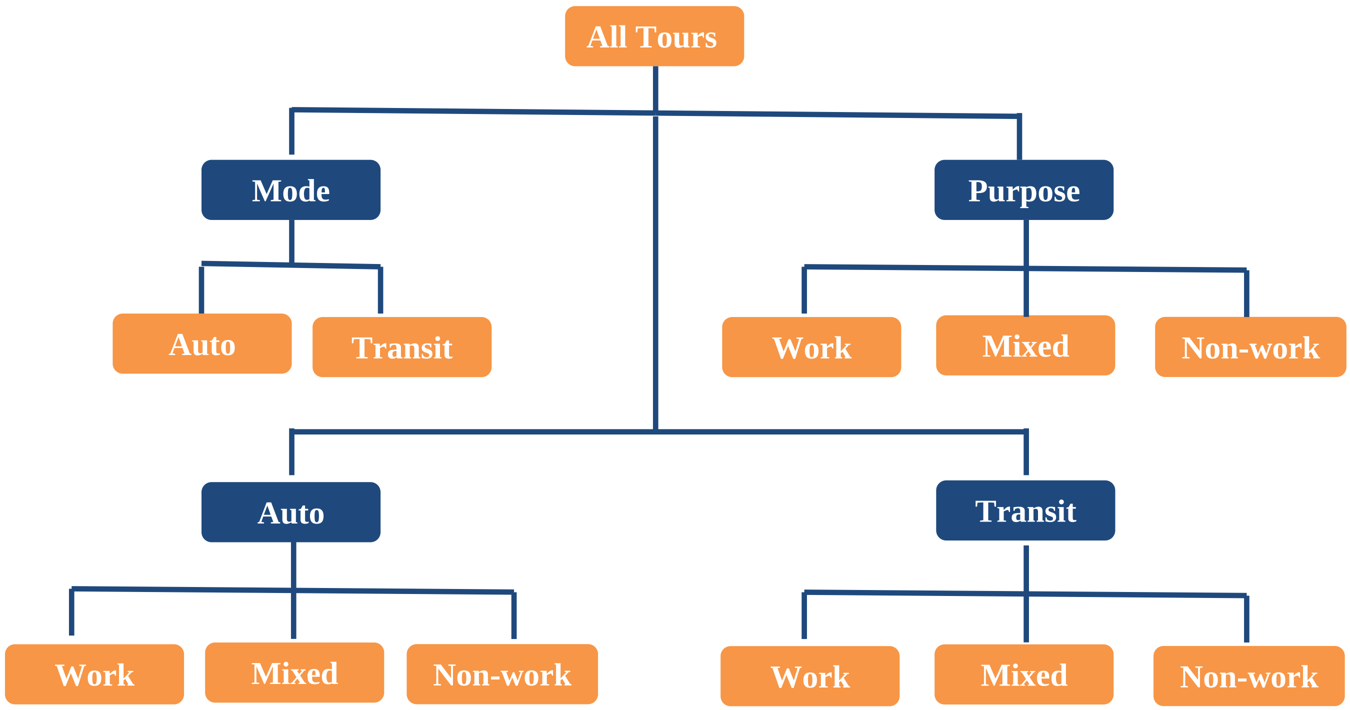


Figure 6.1 Analysis road map

Table 6.1 Sample summaries by tour modes and purposes

	Auto					Transit		
	N	Percent	Average speed per tour (mph)	Average tour complexity	Average Distance (miles)	N	Percent	Average Distance (miles)
Work	1301	26.19	26.86	2.11	27.17	366	60.7	19.74
Mixed	1591	32.02	23.82	2.71	23.34	112	18.57	19.68
Non-work	2076	41.79	22.98	2.63	18.77	125	20.73	23.82

6.2 All Tours

6.2.1 All Tours

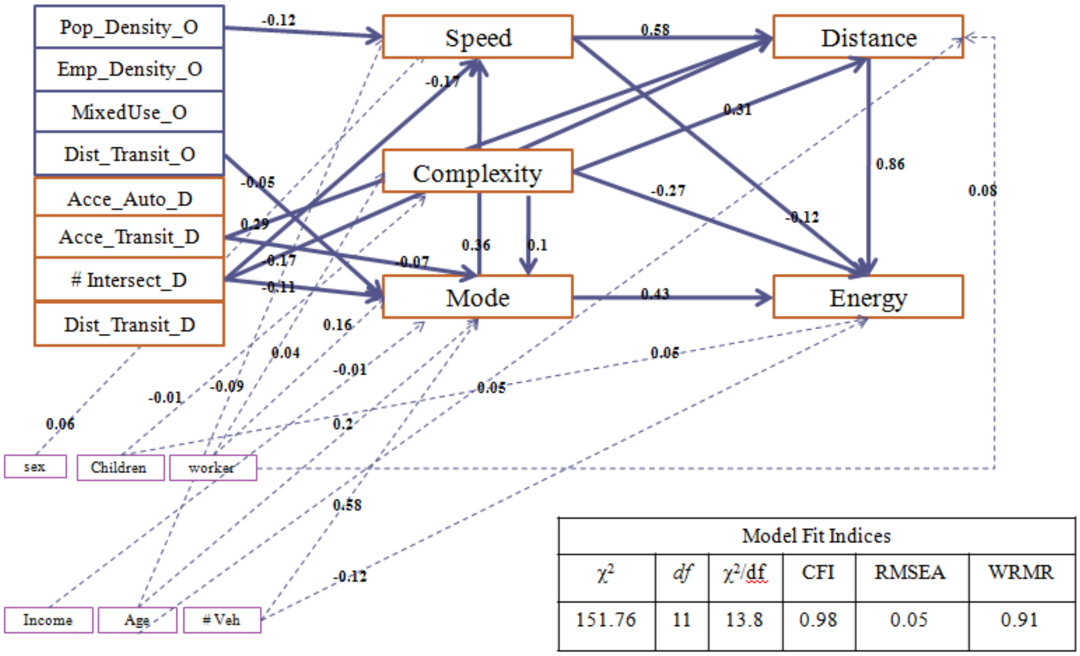
Of all four model fit indices, the WRMR[5] statistics become lower when the data were separated into subsamples by purposes, which suggest that modeling the relationships between land use and travel of various purposes is more rigorous and the comparison among models will potentially reveal detailed information (to be discussed later in the section 6.2.3).

In all tour models, the direct effect of urban form on tour distance is statistically significant. Among all the urban form variables, transit accessibility at destinations is positive whereas street network connectivity is negatively associated with travel distance. Population density at the origins was shown negatively related with travel distance, which is through affect speed. Population density and street network connectivity have negative effects on speed, suggesting that speed is slower in denser and more grid-like street network neighborhoods. Distance to transit station

[5] Weighted Root Mean Square Residual (WRMR) is suitable with models with non-normal data. It gauges the model fit among models with different sample sizes. The recommended value is 0.9.

at origin ends was shown to have a negative relationship with mode choice, which suggests that better transit accessibility encourages transit usage. The tour complexity is positively related with mode choice and travel distance, which suggests that complex tours tend to increase dependency on auto mode and generate longer travel distance. The results also show that auto driving increases energy usage and highway travel is likely to increase tour distance.

In addition, it was found that socio-demographic characteristics significantly influence mode choice, driving patterns, tour complexity, tour distance and energy consumption. For example, vehicle ownership (measured by the number of vehicles in households) has a significant and positive direct and total effect on the use of auto mode. More vehicles in households generate longer travel and more energy consumption. The influence of vehicle ownership on energy consumption is through the indirect effects of vehicle ownership on auto mode choice (the coefficient of the indirect effect is 0.31). Employed persons are more likely to be auto-oriented, make more complex tours, and tend to travel longer.



Model Fit Indices					
χ^2	*df*	χ^2/df	CFI	RMSEA	WRMR
151.76	11	13.8	0.98	0.05	0.91

Figure 6.2 Standardized direct effects of all tours

Table 6.2 Standardized total effects and indirect effects of all tours

	Mode Choice	Speed	Tour Complexity	Distance	Energy
PopDensityOrigin	0.03^{b}	-0.12		(-0.06)	
EmploymentDensityOrigin	-0.04^{b}	(-0.01^{a})			
MixedLandUseOrigin					
DistanceToTransitOrigin	(-0.003^{b})	-0.03^{a} (-0.02)	-0.04^{a}	(-0.02^{a})	
AccessibilityAutoDestination		(0.02^{b})			
AccessibilityTransitDestination	(-0.004^{a})	0.05^{b} (-0.03)	-0.06^{a}	0.31	
ConnectivityDestination	-0.11	-0.25 (-0.04)		-0.30 (-0.13)	
DistanceToTransitDestination				0.03^{a}	
Age	0.20	(0.07)		(-0.04)	0.06 (0.1)
Income	-0.06 (0.002^{a})		0.03^{a}		
Children	-0.10 (-0.01)	(-0.03)		(-0.02^{b})	0.03^{b} (-0.02^{b})
Race	0.05				
Sex	(-0.002^{a})	0.03^{a}	-0.03^{a}		0.08 (0.04)
Edu					
Worker	0.16			0.14 (0.05)	0.19 (0.16)
#Vehicle	0.56	0.2 (0.2)		0.12 (0.06)	0.07 (0.31)
Tour Complexity		(0.03)		0.31	0.03^{a} (0.3)
Mode Choice		0.36		0.09 (0.21)	0.42 (0.04^{a})
Speed				0.58	0.37 (0.5)
Distance					0.86

Notes: Indirect effects are showed in parentheses. All the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1). Decomposed indirect effects are showed in Appendix V.

6.2.2 Auto Compared to Transit

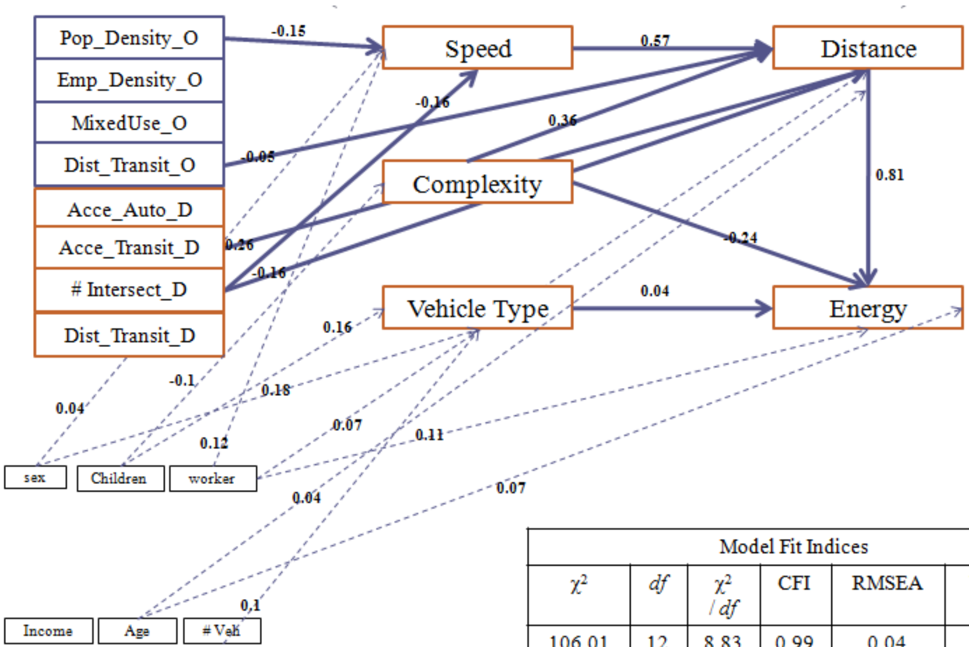
Auto and transit modes have different working mechanisms that affect travel behavior. Thus, the two modes were modeled separately. The transit mode is constrained by fixed routes and schedules, and difficulty of waiting and transferring. Especially for complex tours, auto mode has greater flexibility than transit mode. Mode choice largely depends on vehicle availability. In the data set, most of transit riders do not have the access to auto and highly rely on transit (90% of the transit riders do not own vehicles in households. This result is consistent with the 2007 On-

Board Transit Survey by the Baltimore Metropolitan Council). The lack of vehicles limits their destination choices only at or near the transit stations. Therefore, it is reasonable to examine the relationships of urban form and travel behavior for auto tours and transit tours separately.

6.2.2.1 Auto tours

In the auto tour model, urban form variables do not have any direct or total effects on vehicle type choice. However, some of the socio-demographic variables were found to have significant effects on vehicle type. For example, households with more children and vehicles tend to have larger vehicles. Males are more likely to drive larger vehicles than females.

There are some significant differences between all tour models and auto tour models: it was found that the impact of the number of vehicles on travel distance is not significant in auto tours. This is possibly because tour makers tend to drive, regardless how many cars are available in the households. Population density at tour origins and street network connectivity at tour destinations have higher coefficients for travel distance for auto tours model. Tours made by persons living in less dense areas are likely to be more auto-oriented, while higher road density might reduce people's driving tendency. There is no direct effect of speed on energy consumption, whereas the indirect effect of speed on energy is strong (the coefficient is 0.46), which is consistent with the intuition that more highway driving is related with higher energy usage.



Model Fit Indices					
χ^2	*df*	χ^2 / df	CFI	RMSEA	WRMR
106.01	12	8.83	0.99	0.04	0.83

Figure 6.3 Standardized direct effects of all auto tours

Table 6.3 Standardized total effects and indirect effects of all auto tours

	Vehicle Type	Speed	Tour Complexity	Distance	Energy
PopDensityOrigin		-0.15		-0.09 (-0.08)	
EmploymentDensityOrigin	-0.07^{a}	0.06^{a}		(0.03^{a})	
MixedLandUseOrigin					
DistanceToTransitOrigin	0.04^{b}			-0.06	
AccessibilityAutoDestination				(-0.07^{b})	
AccessibilityTransitDestination				0.26	
ConnectivityDestination		-0.21		-0.28 (-0.12)	
DistanceToTransitDestination			0.06^{a}		
Age	-0.05^{a}	-0.07		(-0.05)	0.07
Income		-0.002^{b} (-0.002^{b})			
Children	0.16	(0.002^{b})			
Race					
Sex	0.18	0.04	-0.03^{a}	0.04 (0.02^{a})	0.08 (0.05)
Edu					
Worker	0.04^{a}	0.12	0.03^{a}	0.15 (0.08)	0.22 (0.11)
#Vehicle	0.09	0.03^{a}			0.05 (0.03)
Tour Complexity		-0.03^{a}		0.36 (-0.02^{b})	0.03^{a} (0.27)
Vehicle Type					0.07 (0.03^{a})
Speed				0.57	0.43 (0.46)
Distance					0.81

Notes: Indirect effects are showed in parentheses. All the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1). Decomposed indirect effects are showed in Appendix V.

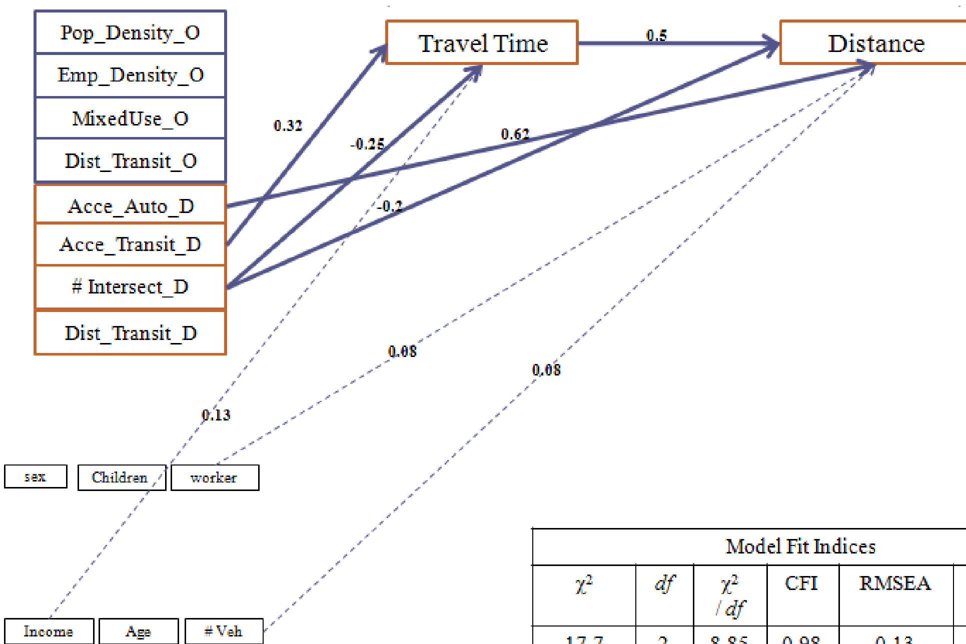
6.2.2.2 Transit tours

Table 6.4 displays the descriptive summary of transit samples. Commuting tours have the largest transit mode share, suggesting that more people rely on transit for work purposes than for other purposes. When analyzing transit data, vehicle type and mode choice were not relevant to the model specification and were removed from the model. Due to the lack of variation of tour complexity, tour complexity was also deleted. Figure 6.4 shows the direct effects of transit tour model. Transit tours are further classified into three subsamples by travel purposes and the results are discussed in section 6.4.

Table 6.4 Descriptive summary of transit tours

	Number of transit tours	Total number tours	Percent transit tours
All	603	7115	8.5%
Work	366	1887	20%
Mixed	112	2360	4.7%
Non-work	125	2868	4.4%

In the transit model, only auto accessibility and street network connectivity significantly influence travel distance (the coefficients are 0.62 and -0.2, respectively). Accessibility has a stronger direct effect on travel distance than the indirect effects (through speed). Higher transit accessibility is associated with higher speed while more connected street network lowers the speed. In regard to socio demographic variables, only employment status and vehicle ownership are significant and positively related with travel distance, which indicates that more vehicle in the households generate longer travel distance.



Model Fit Indices					
χ^2	*df*	χ^2 / df	CFI	RMSEA	SRMR
17.7	2	8.85	0.98	0.13	0.01

Figure 6.4 Standardized direct effects of all transit tours

6.2.2.3 Summary

After splitting auto tours and transit tours, WRMR of auto tour model (0.83) is lower than all tour model (0.91). The result suggests that separating auto from the whole sample improves the model. At the same time, transit tour model has poor model fit, which indicates that the transit tours behave differently and should be separated from the whole sample to conduct further analysis. The detailed analyses of auto tours and transit tours that were disaggregated by travel purposes are discussed in section 6.3 and section 6.4.

6.2.3 Disaggregating by Travel Purposes

Travel purpose is another dimension of travel behavior. Tours were classified into three types: work tours, mixed-work and non-work tours, and non-work tours. Work tours include tours for work, school or college. Non-work tours involve personal errands, appointments, shopping, visiting and free-time activities. Mixed tours refer to the trip chaining that involves both work and non-work activities along the tours. The underlying rationale of tour classification is that the causal relationships for work tours differ from non-work tours and mixed tours. Since work tours have more spatial constrains than non-work tours, the work and work-related activities may lead to different model results among various travel purposes.

In addition to testing the variation of travel behavior among different travel purposes, the whole tour data sets were separated by groups to make sure the records are independent. In the data set, some persons might make multiple tours per day. Therefore, the tours made by the same persons share the same socio-demographic characteristics. This makes some of the records share identical information, which violates the assumptions of SEM.

Individual estimations for work tours, mixed tours, and non-work tours are discussed in this section. Figure 6.5 through Figure 6.7 illustrate the direct effects. Table 6.5 through Table 6.7 present the total and indirect effects.

6.2.3.1 Commuting Tours

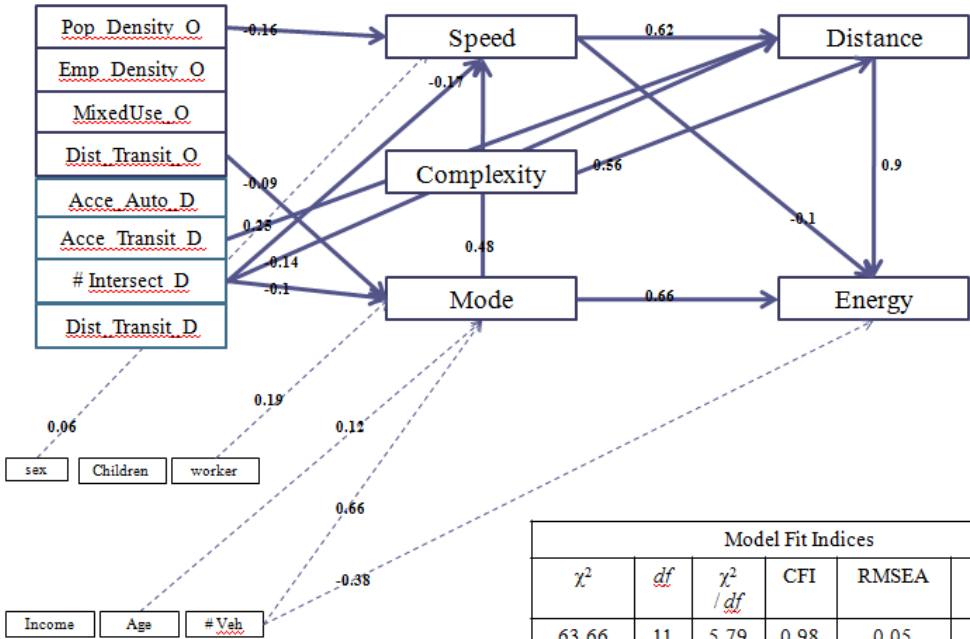
Model fit has been improved when the commuting tours were extracted from all tour samples and modeled individually. CFI, RMSEA, and WRMR show the model has a better fit than all tour models.

Urban form variables do have direct effects on tour distance. The standardized coefficients of accessibility of transit at destinations and street connectivity are 0.25 and -0.14, respectively. The positive direct effect of transit accessibility and total effect of auto accessibility at destinations measure the accessibility effect at a regional scale, which suggests that areas with higher transit accessibility tend to pull the labor force from farther areas to the employment sites. In terms of total effect, population density at origins is statistically significant and negative, which suggests that people living in denser areas are less auto-oriented. Population density also has indirect effect (-0.08) on distance, which shows that denser areas involve less highway driving, and consequently shorter tour distance. Street network connectivity also has negative indirect effects through the effects on speed.

Urban form variables also have direct effects on speed and mode choice. As expected, street network connectivity has negative impacts on speed and mode choice, suggesting that denser street network is associated with slower speed and more walking and bicycling. However, it was found that people tend to drive to work if their home is closer to transit stops. The counter-intuitive result needs further analysis to fully understand this issue.

Model results of the impacts of intermediate variables on distance and energy show that more highway driving and more complex tours lead to longer commuting distance and more energy usage. However, speed has a negative direct effect on energy consumption. This can be translated into the result that higher speed is associated with less energy, which needs further analysis to explain. The total effects of all the intermediate factors have expected signs: tour complexity, speed, and mode choice have significant and positive effects on travel distance and energy usage. The signs are intuitive and consistent with the hypotheses. The intermediate effects of tour complexity, speed, and mode are stronger than the direct effects of urban form, which suggests that urban form variables are significant but the effects are small.

Among all the socio-demographic variables, age, gender, employment status, as well as vehicle ownership, are shown significant. The number of vehicles is the strongest determinant that positively affects mode choice and has strong indirect effect (0.32) on speed. The results suggest that higher auto ownership is the dominant factor that causes more auto-oriented travel behavior. Employment status has the strongest total effect on tour distance and energy usage.



Model Fit Indices					
χ^2	*df*	χ^2 / *df*	CFI	RMSEA	WRMR
63.66	11	5.79	0.98	0.05	0.54

Figure 6.5 Standardized direct effects of all work tours

Table 6.5 Standardized total and indirect effects of all work tours

	Mode Choice	Speed	Tour Complexity	Distance	Energy
PopDensityOrigin		-0.15	0.04[b]	-0.12 (-0.08)	
EmploymentDensityOrigin					
MixedLandUseOrigin		(0.02[a])	(-0.02[b])		
DistanceToTransitOrigin	-0.09	(-0.05)			
AccessibilityAutoDestination		0.15[a]		0.18 (-0.04)	
AccessibilityTransitDestination		-0.05[a]		0.24	
ConnectivityDestination	-0.10	-0.22 (-0.05)		-0.29 (-0.14)	
DistanceToTransitDestination		(-0.02[b])		0.09 (0.06[a])	
Age	0.12	0.06[a](0.06[a])		0.07[a] (0.04[a])	0.07[a] (0.13)
Income					
Children		(-0.02[b])	-0.06[b]		
Race					
Sex		0.05		0.07 (0.04)	0.08 (0.06[a])
Edu					
Worker	0.19		0.03[a]	0.19 (0.14)	0.21
#Vehicle	0.66	0.32 (0.32)		0.09 (0.25)	0.10 (0.48)
Tour Complexity		(0.04 [b])		0.58	0.61 (0.57)
Mode Choice		0.48		0.37 (0.3)	0.94 (0.29)
Speed				0.62	0.46 (0.56)
Distance					0.90

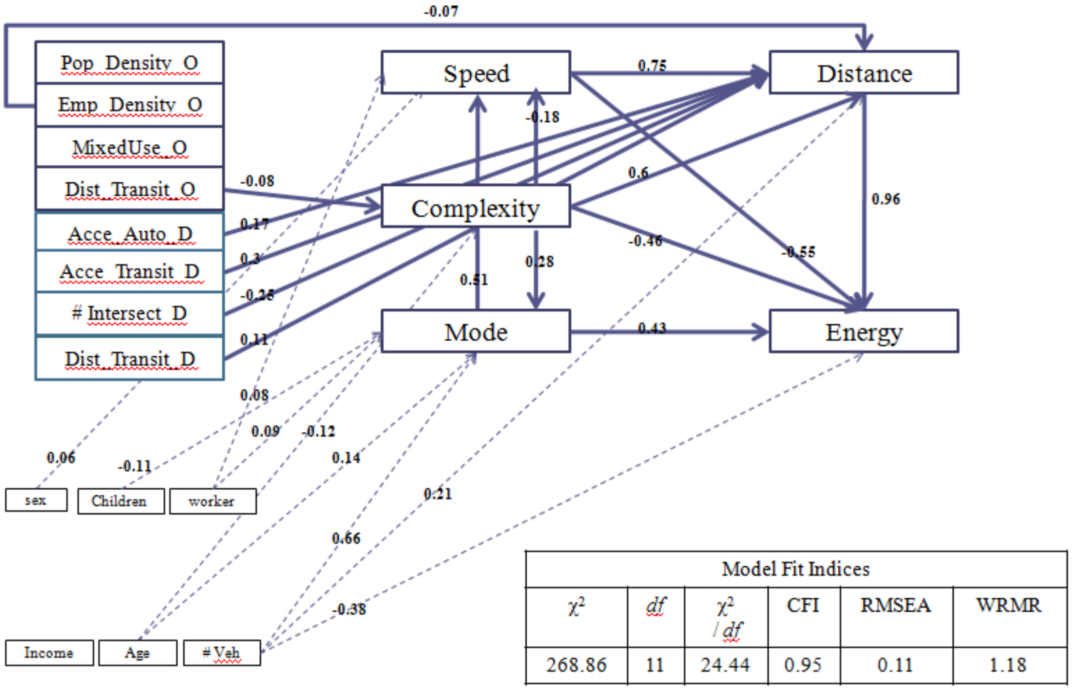
Notes: Indirect effects are showed in parentheses. All the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1). Decomposed indirect effects are showed in Appendix V.

6.2.3.2 Mixed tours

In the mixed work and non-work tour models, model fit indices indicate the model does not have a good fit. RMSEA and WRMR, are higher than the recommended values. It is interesting to see that both work tour models and non-work tour models generate a good model fit. However, mixed tours combine and complicate the travel patterns of commuting and non-work tours, which lead to the non-significant model results.

The results show that more urban form variables significantly and directly affect tour distance. The coefficients of auto and transit accessibility and distance to transit at destinations are significant and positive, whereas employment density at origins and street network connectivity are negatively associated with tour distance, which indicates that denser areas with more connected street network is related to shorter travel distance. One of the built environment variables, distance to transit at origins, has a negative impact on tour complexity, which suggests that easier access to transit might complicate people's travel behavior by increasing the number of stops along the tours. As expected, the direct effects also suggest that more highway driving leads to longer travel distance. Complicated tours and auto usage cause higher energy usage. It is interesting to find that tour complexity has a positive impact on the choice of auto and has negative impact on speed. Another interesting finding is that the number of vehicles in households plays an important role in mode choice and travel distance. The coefficients of the direct effects on mode and distance are 0.66 and 0.21, respectively, which are quite high. The impacts of socio-demographic variables indicate that males and employed travelers have the tendency to drive at higher speeds. More children in the family generate more non-motorized travel. Elderly people are more likely to reduce tour complexity and be more auto-oriented. The signs and magnitudes of total effects are not consistent with these direct effects, which indicate that the indirect effects are significant: distance to transit does not have a direct effect mode choice. However, the distance to transit does have a significant and negative indirect effect on mode choice, which is through the effect on tour complexity. The possible explanation could be that transit riders tend to reduce the tour complexity along the tours. Or, transit riders might also use a park-and-ride mode along the tours. However, the relationship between transit access and mode choice needs further research efforts. Tour complexity has a negative direct effect on energy usage, but the total effect has an opposite sign. This is possibly because tour complexity affects energy usage through other channels of model choice, speed, and travel distance.

The direct effects of tour complexity indicate that more complex tours generate longer travel distance but less energy usage. However, the indirect effect of tour complexity has a stronger effect and exceeds the direct effect. The total effect indicates that higher tour complexity leads to more energy consumption when taking all the effects into account.



Model Fit Indices					
χ^2	*df*	χ^2 / df	CFI	RMSEA	WRMR
268.86	11	24.44	0.95	0.11	1.18

Figure 6.6 Standardized direct effects of mixed work and non-work tours

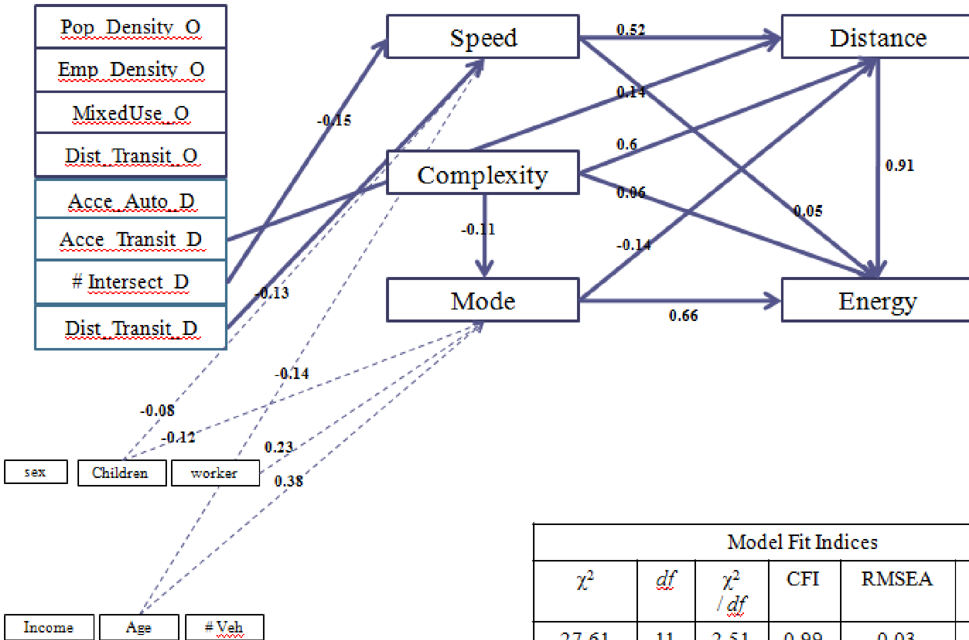
Table 6.6 Standardized total and indirect effects of mixed work and non-work tours

	Mode	Speed	Tour complexity	Distance	Energy
PopDensityOrigin				-0.08[b] (-0.08[b])	
EmploymentDensityOrigin					
MixedLandUseOrigin				-0.04[a]	
DistanceToTransitOrigin	-0.08 (-0.02)	-0.04[a](-0.03)		-0.05[a](-0.04[a])	
AccessibilityAutoDestination	0.14	(0.06[a])		0.13[a]	
AccessibilityTransitDestination		(-0.03[a])		0.32	
ConnectivityDestination	-0.19	-0.21(-0.09)		-0.35 (-0.1)	
DistanceToTransitDestination				0.12	
Age	0.10	(0.07)	-0.07	-0.05[b](-0.17)	-0.05[b] (0.07[b])
Income	-0.10				
Children	-0.14 (-0.02)	(-0.06)			(-0.06[b])
Race					
Sex					0.04[a] (0.04[b])
Edu					
Worker	0.17 (0.08)			0.20	0.14 (0.15)
#Vehicle	0.61	0.30 (0.30)		0.19 (0.19)	0.14 (0.34)
Tour Complexity		-0.04[b](0.14)		0.45 (-0.15)	0.32 (0.78)
Mode Choice		0.51		(0.38)	0.07[a]
Speed				0.75	0.52 (0.52)
Distance					0.96

Notes: Indirect effects are showed in parentheses. All the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1). Decomposed indirect effects are showed in Appendix V.

6.2.3.3 Non-work tours

In the context of all non-work tours, model fit (WRMR) indicates a better fit than the work tour model and the mixed tour model. In the model where urban form affects travel distance, transit accessibility at tour destinations has both direct and total effects on tour distance. Auto accessibility and street network at destinations are negatively associated travel distance indicated by the negative total effects. The indirect effects that contribute to negative total effects are through intermediate effects of speed. Street connectivity is negatively related to speed, which is consistent across different subsamples. Among the intermediate effects of speed, tour complexity, and mode choice, the direct effect of mode choice on energy consumption is quite high: 0.66. However, the corresponding total effect is -0.15, which means that the direct effects were offset by indirect effects of other variables. Due to the non-significance of indirect effects of mode choice, more analysis is needed to solve the puzzle. Similarly, tour complexity has a positive direct effect and a non-significant total effect on tour distance. The indirect effect of tour complexity generated from mode choice exceeds the positive direct effect, yielding the insignificance of total effect. Socio-demographic variables including age, the number of children, employment status, and the number of vehicles all have expected signs.



Model Fit Indices					
χ^2	*df*	χ^2 / *df*	CFI	RMSEA	WRMR
27.61	11	2.51	0.99	0.03	0.38

Figure 6.7 Standardized direct effects of non-work tours

Table 6.7 Standardized total and indirect effects of non-work tours

	Mode Choice	Speed	Tour Complexity	Distance	Energy
PopDensityOrigin	(-0.01[a])	-0.1[a]	0.09[a]		
EmploymentDensityOrigin					
MixedLandUseOrigin				0.04[b]	
DistanceToTransitOrigin				-0.06[a]	
AccessibilityAutoDestination		-0.18		-0.20 (-0.07[b])	
AccessibilityTransitDestination				0.15	
ConnectivityDestination	0.07[b]	-0.16		-0.16 (-0.11)	
DistanceToTransitDestination		-0.13		-0.09[a](-0.06[a])	
Age	0.37	-0.15		-0.06[a]	(-0.06[a])
Income				(0.02[b])	
Children	-0.11	-0.08			
Race					
Sex					
Edu					
Worker	0.24 (0.01[a])		-0.06[a]		
#Vehicle	0.08			(-0.03[a])	
Tour Complexity				(0.02[a])	0.37 (0.32)
Mode Choice				-0.17	-0.15 (-0.15)
Speed					0.52 (0.47)
Distance					0.91

Notes: Indirect effects are showed in parentheses. All the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1). Decomposed indirect effects are showed in Appendix V.

6.3 Auto Tours

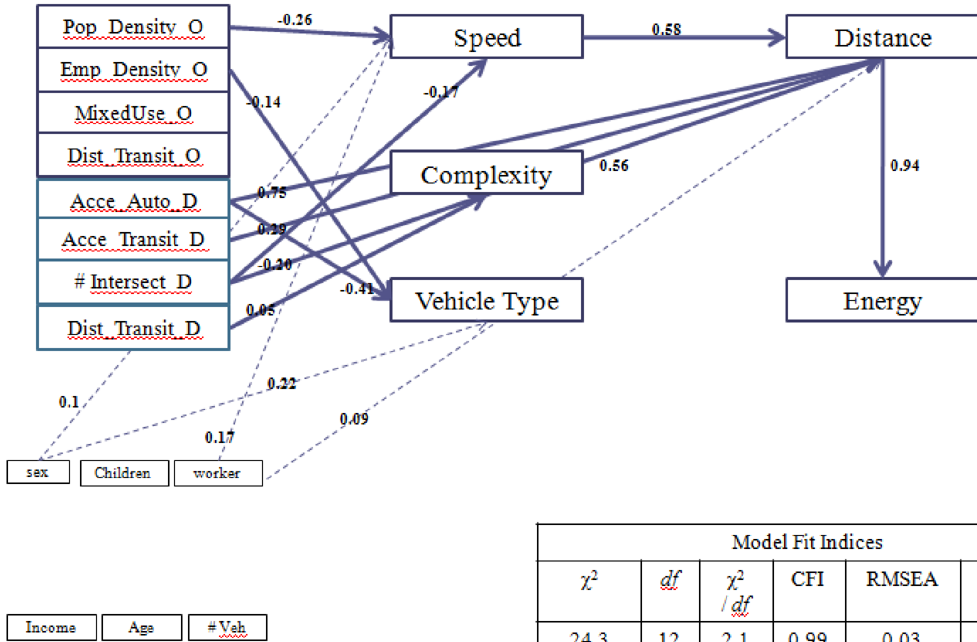
As we stated in the previous section, auto tours and transit tours are split for the further analysis. In addition to that, both auto tours and transit tours are further stratified by travel purposes to conduct detailed analysis. In this section, we focus on auto tours and discuss the results of stratified samples: commuting tours, mixed tours, and non-work tours. Direct effects were shown in Figure 6.8 through Figure 6.10 and total and indirect effects were revealed in Table 6.8 through Table 6.10.

6.3.1 Commuting Tours

Model fit indices indicate that the model is a good fit to the data: CFI is 0.99, RMSEA is 0.03, and WRMR is 0.35. Auto accessibility at destination has a very strong direct effect on travel distance, but the total and indirect effects are not significant. Transit accessibility at destination has both significant and positive direct and total effects on travel distance. Population density at origins and connectivity at destinations both have indirect effects on tour distance through affect speed. However, the indirect effect is not as strong as the direct effects.

Urban form does have impacts on vehicle type choice. Both employment density at origins and auto accessibility at destinations indicate that travelers in denser areas with greater auto accessibility are more likely to drive more compact vehicles. Population density at origins and connectivity at destinations have negative direct and total effects on driving patterns. Driving pattern has positive direct and total effects on travel distance and energy consumption, which is intuitive and consistent with the hypotheses. Tour complexity does not have a direct effect on travel distance whereas the indirect effects on distance and energy consumption are significant. Vehicle type does not have significant effects on distance and energy consumption, which needs further research to solve the puzzle.

Among socio-demographic characteristics, results indicate that males are more likely to drive larger-size vehicles and employed household members tend to travel longer.



Model Fit Indices					
χ^2	*df*	χ^2 / *df*	CFI	RMSEA	WRMR
24.3	12	2.1	0.99	0.03	0.35

Figure 6.8 Standardized direct effects of auto work tours

Table 6.8 Standardized total and indirect effects of auto work tours

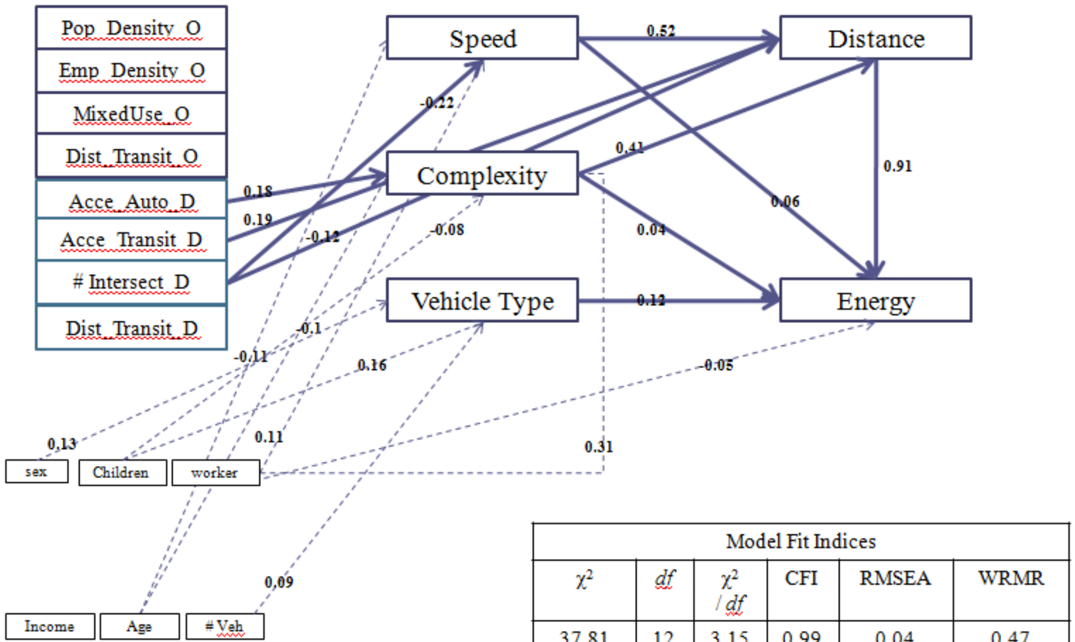
	Vehicle Type	Speed	Tour Complexity	Distance	Energy
PopDensityOrigin		-0.26		-0.16 (-0.13)	
EmploymentDensityOrigin		0.09[b]			
MixedLandUseOrigin	-0.05[b]				
DistanceToTransitOrigin				-0.09	
AccessibilityAutoDestination	-0.46	0.14[b]		(-0.68[a])	
AccessibilityTransitDestination				0.28	
ConnectivityDestination		-0.17		-0.30 (-0.11)	
DistanceToTransitDestination			0.05[a]	0.09 (0.08[a])	
Age					
Income				0.06[b]	(0.05[b])
Children	0.07[a]				
Race					
Sex	0.22	0.10		0.09 (0.07)	0.11 (0.1)
Edu					
Worker		0.17		0.21 (0.12)	0.24 (0.19)
#Vehicle	0.05[b]				
Tour Complexity				0.83	0.85 (0.78)
Vehicle Type					
Speed				0.58	0.53 (0.54)
Distance					0.94

Notes: Indirect effects are showed in parentheses. All the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1). Decomposed indirect effects are showed in Appendix V.

6.3.2 Mixed Tours

In the context of mixed tour models, mode fit indices are better than the fit of all tour models. However, relative to all tour models, fewer urban form variables significantly affect travel distance. Only transit accessibility and street network at destinations have both significant direct and total effects on tour distance. Direct effects and total effects of the built environment on vehicle type choice were shown to have no casual effects. This is consistent with the results of commuting auto tours. Travel speed and tour complexity have positive direct effects on travel distance and energy usage, which indicates that higher speed and more complicated tours are associated with longer travel and more energy consumption. Unlike the commuting auto tours model, vehicle type has a significant and positive direct effect on energy consumption.

Among socio-demographic variables, the number of vehicles is not the most important factor and the direct effect on travel distance is not significant. Employment status, the number of children in households, age, and gender showed more explanatory powers. The number of children, gender, and the number of vehicles have positive direct and total effects on vehicle type. The intuitive explanations is that large families need bigger vehicle to accommodate more children. A family that has more than one vehicle is likely to have a larger vehicle. Males tend to have larger vehicle than females.



Model Fit Indices					
χ^2	*df*	χ^2 / *df*	CFI	RMSEA	WRMR
37.81	12	3.15	0.99	0.04	0.47

Figure 6.9 Standardized direct effects of auto mixed work and non-work tours

Table 6.9 Standardized total and indirect effects of auto mixed work and non-work tours

	Vehicle Type	Speed	Tour Complexity	Distance	Energy
PopDensityOrigin		-0.11^{a}		-0.08^{a}	
EmploymentDensityOrigin				(0.05^{b})	
MixedLandUseOrigin				-0.05^{a}	
DistanceToTransitOrigin				-0.06^{a}	
AccessibilityAutoDestination					
AccessibilityTransitDestination				0.23	
ConnectivityDestination		-0.22	-0.06^{b}	-0.26 (-0.14)	
DistanceToTransitDestination			0.07^{b}	0.08^{a} (0.06^{a})	
Age		-0.11		-0.07^{a}(-0.07^{a})	-0.07^{a}(-0.08^{a})
Income			0.05^{b}	(0.02^{a})	
Children	0.16			(-0.04^{a})	
Race					
Sex	0.13				0.05^{b}(0.05^{b})
Edu					
Worker	0.06^{b}	0.11		0.22 (0.19)	0.18 (0.23)
#Vehicle	0.09				0.06^{a}
Tour Complexity				0.41	0.42 (0.38)
Vehicle Type					0.15
Speed				0.52	0.53 (0.48)
Distance					0.98

Notes: Indirect effects are showed in parentheses. All the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1). Decomposed indirect effects are showed in Appendix V.

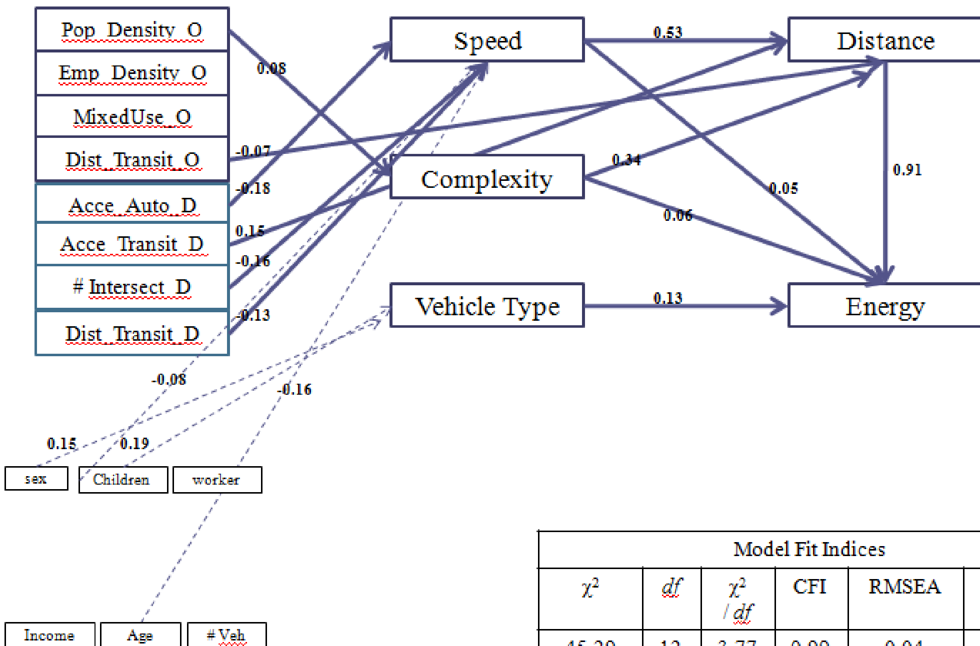
6.3.3 Non-work Tours

The model fit has been significantly improved from the all auto sample model. However, model fit indices show that the fit of non-work auto model is not as good as the work auto model and the mixed auto model. WRMR is 0.51, which is slightly higher than the work auto model and the mixed auto model. Model fit indicates that non-work tours have more a complicated travel behavior than work tours or mixed tours.

Distance to transit at origins and transit accessibility at destinations have significant direct effects on travel distance. The results are interesting: being closer to transit stations from home results in longer travel distance. As we discussed in the earlier section, transit mode is constrained by fixed routes and difficulties of transferring and waiting. Although transit stations are closer to tour origins, people still have to travel longer to get to destinations.

Urban form measurements do not have either direct or total effects on vehicle type choice. This might be explained as the complexity of non-work tours might lead to more diverse choice of the vehicle types. Population density at tour origins shows a positive direct effect on tour complexity, which suggests that people tend to make more stops from home in denser areas. Similarly to the indirect effects of auto accessibility and street network connectivity, they also have indirect impacts on travel distance through speed. Accessibility, street network connectivity and the distance to transit have negative impacts on speed. As expected, speed and tour complexity have both direct and total effects on tour distance and energy consumption. Vehicle type is also found to have a positive direct effect on energy consumption, which suggests that larger vehicles consume more energy than compact vehicles.

Among the effects of socio-demographic variables, relative to all non-work tour samples, age and employment status are not significant. The number of children, gender, and the number of vehicles have significant and positive total effects on vehicle type choice, which are consistent with the results of mixed auto tours.



Model Fit Indices					
χ^2	*df*	χ^2 / *df*	CFI	RMSEA	WRMR
45.29	12	3.77	0.99	0.04	0.51

Figure 6.10 Standardized direct effects of auto non-work tours

Table 6.10 Standardized total and indirect effects of auto non-work tours

	Vehicle Type	Speed	Tour Complexity	Distance	Energy
PopDensityOrigin		-0.1[a]	0.08[a]		
EmploymentDensityOrigin					
MixedLandUseOrigin				0.04[b]	
DistanceToTransitOrigin				-0.07[a]	
AccessibilityAutoDestination		-0.18		-0.20 (-0.07[b])	
AccessibilityTransitDestination	-0.12[a]			0.15	
ConnectivityDestination		-0.16		-0.15[b] (-0.06[b])	
DistanceToTransitDestination		-0.13			
Age	-0.08[a]	-0.15		-0.06[a]	(-0.07[a])
Income					
Children	0.19	-0.08		-0.05[b] (-0.04[b])	
Race					
Sex	0.15				
Edu					
Worker			-0.06[a]		
#Vehicle	0.12				0.05[b](0.05[b])
Tour Complexity				0.34	0.37
Vehicle Type					0.17 (0.03[b])
Speed					0.53
Distance					0.91

Notes: Indirect effects are showed in parentheses. All the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1). Decomposed indirect effects are showed in Appendix V.

6.4 Transit Tours

In this section, the results of the direct, indirect, and total effects of transit tours are discussed. We stratified transit tours into three different samples: commuting tours, mixed tours, and non-work tours. Direct effects were shown in Figure 6.11 through Figure 6.13. Total and indirect effects were shown in Table 6.11 through Table 6.13.

6.4.1 Commuting Tours

Model fit indices show that this model does not have good fit. RMSEA is 0.16, which is much higher than the recommended value. In the transit model, auto accessibility was shown to have a positive direct effect on travel distance, while street network connectivity has a negative direct effect on travel distance. Areas with higher auto accessibility is associated with longer travel whereas better street network connectivity reduces travel distance. Connectivity also has a negative indirect effect (through speed) on travel distance. Among all the urban form measurements, accessibility has the strongest explanation power. Among socio-demographic variables, only the number of vehicle is shown to be significant.

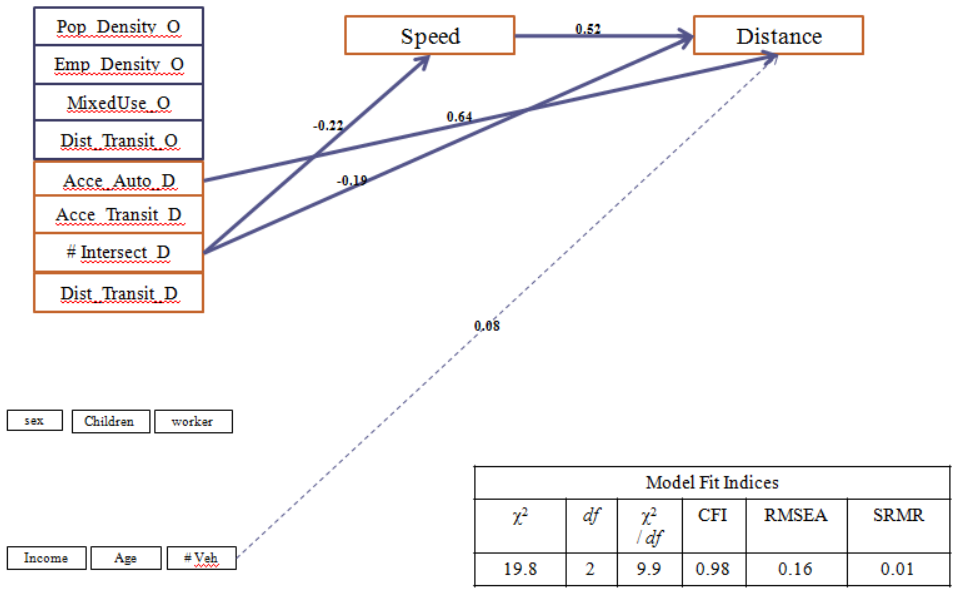


Figure 6.11 Standardized direct effects of transit work tours

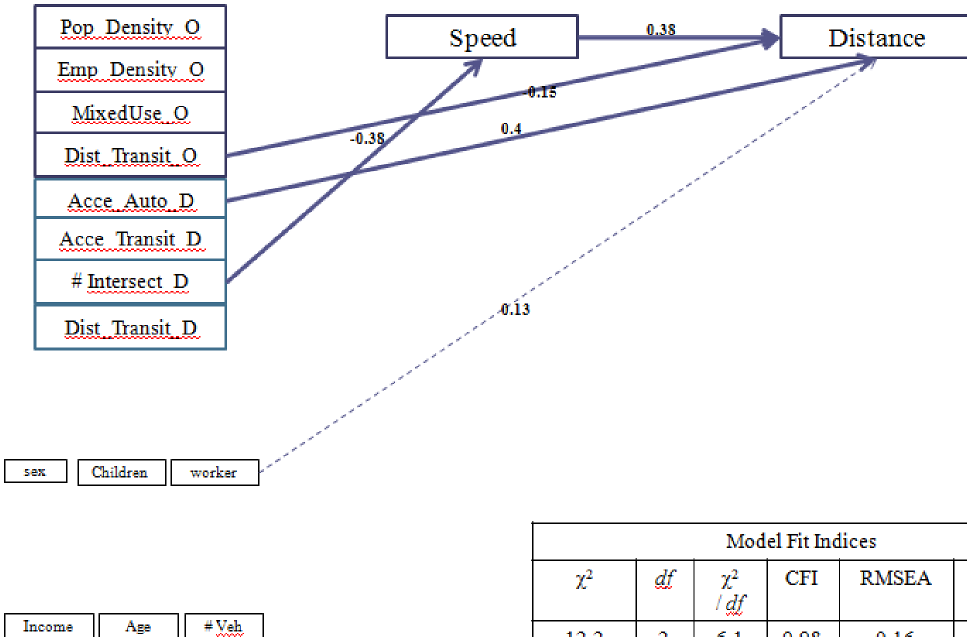
Table 6.11 Standardized total and indirect effects of transit work tours

	Speed	Distance
PopDensityOrigin		
EmploymentDensityOrigin		
MixedLandUseOrigin		
DistanceToTransitOrigin		
AccessibilityAutoDestination		0.69
AccessibilityTransitDestination		
ConnectivityDestination	-0.22	-0.3 (-0.11)
DistanceToTransitDestination		0.23
Age	0.16[b]	0.15[a](0.08[b])
Income		(0.06[a])
Children		
Race		
Sex		
Edu		
Worker		
#Vehicle		0.1
Speed		0.52
Distance		

Notes: Indirect effects are showed in parentheses. All the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1).

6.4.2 Mixed Tours

The model fit indices are slightly better than for the work tour model. In the model where urban form affects travel distance, only the distance to transit of tour origins and auto accessibility at destinations were significant (the coefficients are -0.15 and 0.4, respectively). The results suggest that a better access to transit stops from home is associated with shorter travel time. However, higher regional accessibility for auto leads to longer travel. Employment status positively and significantly affects travel distance.



Model Fit Indices					
χ^2	*df*	χ^2 / *df*	CFI	RMSEA	SRMR
12.2	2	6.1	0.98	0.16	0.01

Figure 6.12 Standardized direct effects of transit mixed tours

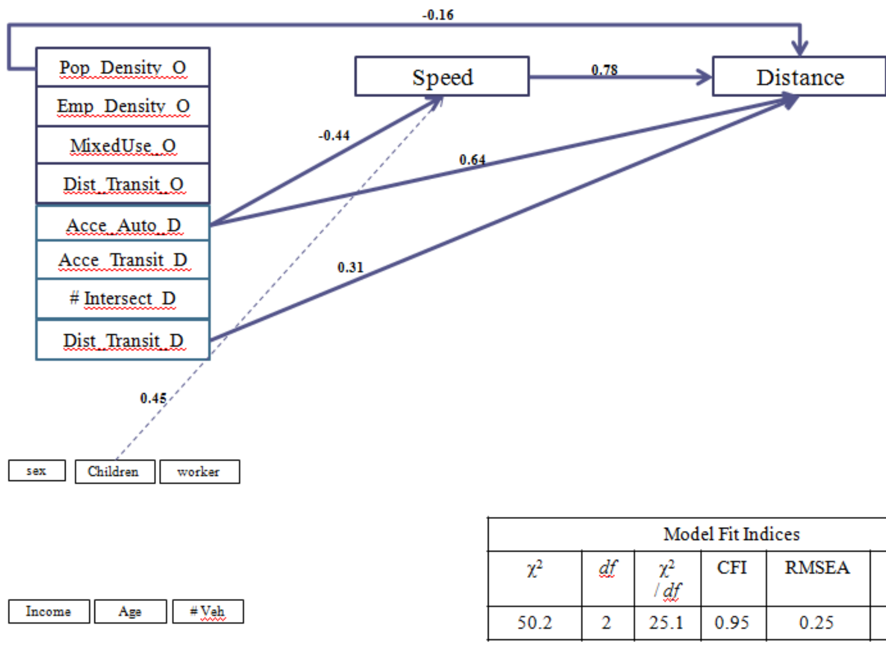
Table 6.12 Standardized total and indirect effects of transit mixed tours

	Speed	Distance
PopDensityOrigin		0.14[b]
EmploymentDensityOrigin		
MixedLandUseOrigin		
DistanceToTransitOrigin		-0.15[a]
AccessibilityAutoDestination	-0.56[b]	
AccessibilityTransitDestination	0.6[b]	-0.15[a](0.22[a])
ConnectivityDestination	-0.38	-0.42 (-0.14)
DistanceToTransitDestination		
Age		
Income		
Children		
Race		
Sex		0.11[a]
Edu		
Worker		0.12 (0.07[b])
#Vehicle		
Speed		0.38
Distance		

Notes: Indirect effects are shown in parentheses. All the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1).

6.4.3 Non-work Tours

The non-work transit model does not have a good model fit. In terms of coefficients, both auto accessibility and the distance to transit stops at the destinations have significant and positive effects on travel distance. The results suggest that people travel longer to the destinations with higher accessibility. The distance to transit stops at the destinations does not reduce the travel distance for non-work tours. In addition, street network connectivity is not significant. Further research is needed to explain the underlying causes. Relative to the socio-demographic characteristics in work tours mixed tours, only the number of children is significant. The indirect effect of the number of children is stronger and plays a more important role in affecting travel distance.



Model Fit Indices					
χ^2	*df*	χ^2 / df	CFI	RMSEA	SRMR
50.2	2	25.1	0.95	0.25	0.08

Figure 6.13 Standardized direct effects of transit non-work tours

Table 6.13 Standardized total and indirect effects of transit non-work tours

	Speed	Distance
PopDensityOrigin		-0.18[b]
EmploymentDensityOrigin		
MixedLandUseOrigin		
DistanceToTransitOrigin		
AccessibilityAutoDestination		(-0.34[a])
AccessibilityTransitDestination	0.41[a]	0.34[a] (0.31[a])
ConnectivityDestination		
DistanceToTransitDestination		-0.2[a]
Age		
Income		-0.19[a](-0.1[b])
Children		0.47 (0.35)
Race		
Sex		
Edu		
Worker		
#Vehicle		
Speed		
Distance		

Notes: all the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1).

6.5 Results Comparison

Model fit

As we stated in chapter 5, using tour-based approach improves the model fit (WRMR increases from 1.12 to 1.02). At the same time, the all tour model without tour complexity variable has higher WRMR (1.02). Incorporating tour complexity improves the model fit. Transit tour models do not have significant model fit indices across different purposes. Among all auto tour models, the work tour model has the best model fit, followed by the mixed tour model, and non-work tour model. The comparison of model fit indices shows that (1) stratifying tours by purposes improve model fit; and (2) transit and auto tours should be separated from the whole sets.

Table 6.14 Model fit indices comparison

	Model Comparison					
	χ2	*df*	χ2/*df*	CFI	RMSEA	WRMR (SRMR)
All trip	225.48	3	75.16	0.98	0.06	1.12
All tour without “tour complexity”	96.18	3	32.06	0.98	0.05	1.02
Disaggregation by mode						
All	151.76	11	13.80	0.98	0.05	0.91
All Auto	106.01	12	8.83	0.99	0.04	0.83
All Transit	17.7	2	8.85	0.98	0.13	0.01
Disaggregation by purpose						
Work	63.66	11	5.79	0.98	0.05	0.54
Mixed	268.86	11	24.44	0.95	0.11	1.18
Non-work	27.61	11	2.51	0.99	0.03	0.38
Disaggregation by mode and purpose						
Work Auto	24.3	12	2.03	0.99	0.03	0.35
Mixed Auto	37.81	12	3.15	0.99	0.04	0.47
Non-work Auto	45.29	12	3.77	0.99	0.04	0.51
Work Transit	19.8	2	9.90	0.98	0.16	0.01
Mixed Transit	12.2	2	6.10	0.98	0.16	0.01
Non-work Transit	50.2	2	25.10	0.95	0.25	0.08

Table 6.15 Model comparison (Standardized direct effects)

	mode Choice			Speed			Tour Complexity			Distance			Energy		
	Work	Mixed	Non-work	Work	Mixed	Non-work	Work	Mixed	Non-work	Work	Mixed	Non-work	Work	Mixed	Non-work
PopDensityOrigin				-0.16											
EmploymentDensityOrigin											-0.07				
MixedLandUseOrigin															
DistanceToTransitOrigin	-0.09	-0.06						-0.08							
AccessibilityAutoDestination											0.17				
AccessibilityTransitDestination										0.25	0.30	0.14			
ConnectivityDestination	-0.10	-0.18		-0.17	-0.13	-0.15				-0.14	-0.25				
DistanceToTransitDestination						-0.13					0.11				
Age	0.12	0.14	0.38		-0.14	-0.14		-0.12					-0.06	-0.12	
Income		-0.10													
Children		-0.11	-0.12			-0.08		-0.08							
Race															
Sex				0.06											
Edu															
Worker	0.19	0.09	0.23		0.08			0.30					-0.07		
#Vehicle	0.66	0.60								-0.17	0.21		-0.38	-0.20	
Tour Complexity		0.28	-0.11		-0.18					0.56	0.60	0.32		-0.46	0.06
Mode Choice				0.48	0.51						-0.44	-0.14	0.66	0.43	
Speed										0.62	0.75	0.52	-0.10	-0.55	0.05
Distance													0.90	0.96	0.91

Notes: all the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1).

Table 6.16 Model comparison (Standardized indirect effects)

	Mode Choice			Speed			Tour Complexity			Distance			Energy		
	Work	Mixed	Non-work	Work	Mixed	Non-work	Work	Mixed	Non-work	Work	Mixed	Non-work	Work	Mixed	Non-work
PopDensityOrigin										-0.08					
EmploymentDensityOrigin															
MixedLandUseOrigin															
DistanceToTransitOrigin		-0.02		-0.05	-0.03										
AccessibilityAutoDestination										-0.04					
AccessibilityTransitDestination															
ConnectivityDestination				-0.05	-0.09					-0.14	-0.10	-0.11			
DistanceToTransitDestination															
Age				0.06	0.07						-0.17		0.13		
Income															
Children		-0.02			-0.06										
Race															
Sex										0.04					
Edu															
Worker		0.08								0.14				0.15	
#Vehicle				0.32	0.30					0.25	0.19		0.48	0.34	
Tour Complexity					0.14						-0.15	0.34	0.57	0.78	0.32
Mode Choice										0.30	0.38		0.29		-0.15
Speed													0.56	0.52	0.47
Distance															

Notes: all the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1).

Table 6.17 Model comparison (Standardized total effects)

	Mode Choice			Speed			Tour Complexity			Distance			Energy		
	Work	Mixed	Non-work	Work	Mixed	Non-work	Work	Mixed	Non-work	Work	Mixed	Non-work	Work	Mixed	Non-work
PopDensityOrigin				-0.15						-0.12					
EmploymentDensityOrigin															
MixedLandUseOrigin															
DistanceToTransitOrigin		-0.08													
AccessibilityAutoDestination	-0.09	0.14				-0.18				0.18		-0.20			
AccessibilityTransitDestination										0.24	0.32	0.15			
ConnectivityDestination		-0.19		-0.22	-0.21	-0.16				-0.29	-0.35	-0.16			
DistanceToTransitDestination	-0.10					-0.13				0.09	0.12				
Age		0.10	0.37			-0.15		-0.07							
Income	0.12	-0.10													
Children		-0.14	-0.11			-0.08									
Race															
Sex				0.05						0.07			0.08		
Edu															
Worker	0.19	0.17	0.24							0.19	0.20		0.21	0.14	
#Vehicle	0.66	0.61	0.08	0.32	0.30					0.09	0.19		0.61	0.14	
Tour Complexity										0.58	0.45			0.32	0.37
Mode Choice				0.48	0.51					0.37			0.90		
Speed										0.62			0.46	0.52	0.52
Distance													0.90		0.91

Notes: all the coefficients in the table are significant at 0.001 level (variables are at different significant levels are indicated as a<0.05, and b<0.1).

Urban form and travel distance

In the context of the all tour models, urban form variables were hypothesized to have direct effects on travel distance. The model results show that urban form measurements do have direct effects on tour distance. Among all the urban form variables, transit accessibility at destinations has positive direct effects, which is consistent across three subsamples. Street network connectivity has significant and negative effects on tour distance. However, this effect is not significant for non-work tours. In mixed tour models, employment density at origins, auto accessibility at destinations, and the distance to transit also have significant direct effects on travel distance. More urban form variables were shown significant in total effects for commuting tours, which suggests that some of these variables affect tour distance indirectly. The indirect effects are primarily generated through affecting driving patterns. For example, population density at origins does not have a direct effect on travel distance. The indirect effect is significant and negative and is generated through affecting speed. Street network connectivity at destinations has negative direct effects on travel distance. The indirect effects generated through affect speed strengthening the direct effect.

When we compare the magnitudes of the built environments impacts on travel, transit accessibility and street network connectivity at destinations were found to have the strongest effects for mixed tours than for commuting tours and non-work tours. It appears that land use development has stronger impacts on mixed tours than on other types of travel since commuting tours have more stable travel distances whereas non-work tours have more flexibility in travel distance.

Urban form and mode choice, speed, tour complexity, and vehicle types

The built environment variables also directly affect mode choice, speed, and tour complexity. In the model where urban form affects mode choice, the mixed tour model was found to have the highest coefficients (both direct and total effects) than the commuting tour model. It is also interesting to find that the urban form variables do not have any impacts on mode choice for non-work tours. Similar patterns have been found in the model where urban form affects speed as evidenced by the negative coefficients of street network connectivity on speed. However, the commuting tour model is more sensitive in the model where urban form affects speed than in the mixed tour model and the non-work tour model. In the model of the relationship between urban form and tour complexity, for both direct and total effects, only distance to transit has a significant impact on tour complexity. The reason that other variables do not have either direct or total effects requires a further investigation.

Relationships of dependent variables

It is interesting to find that in the mixed tour model, tour complexity has a direct and positive impact on mode choice whereas it has opposite effect on mode choice for the non-work tour model, which suggests that people tend to drive when they decide to combine non-work stops on the way to/from the workplace and are less likely to use for non-work tours even though they might also make more complex tours.

The findings of the effects of intermediate effects on travel distance and energy consumption are consistent with expectations: auto driving is associated with higher speed, although the effect is slightly higher in the mixed tour model. More highway driving and more complicated tours lead to longer tour distance. Again, the coefficients of these paths show highest for the mixed tour model.

Some of the counter-intuitive signs are worth mentioning here: in mixed tour models, tour complexity has a negative indirect effect on travel distance. Mode choice has negative direct effects and positive indirect effects on travel distance. The direct and indirect effects cancel each other out. The total effect is significant but only in work tour models. Driving patterns have negative direct effects on energy consumption, but the positive indirect effects surpass the direct effects and make the total effect significant and positive. The indirect effects are primarily generated from affecting mode choice, but more detailed analysis is needed to explore the working mechanism of driving patterns.

Socio-demographics and travel outcomes

Among the socio-demographic variables, vehicle ownership is the dominant factor that affects travel distance, energy consumption, and mode choice directly and indirectly. The indirect effects are stronger than the direct effects. Older people have a higher propensity to use auto than younger people. The elderly people are less likely to pursue complex mixed tours, possibly because they have fewer household obligations. Families with more children tend to drive less and perform fewer multi-stop tours. In addition, age and the number of children have stronger impacts on non-work tours than work tours. Employment status and vehicle ownership have stronger explanatory powers for work tours. People who are employed and own more vehicles are more likely to drive and perform more complicated travel activities. These two variables also have significant negative direct effects and positive total effects on energy usage. The positive indirect effects through mode choice exceed the direct effects, which make the total effect positive. Gender does not significantly influence tour complexity.

Results of auto and transit tours

In auto tour models, transit accessibility and street network connectivity are the highest coefficient estimates. When comparing the magnitudes of effects of urban form on travel distance, the commuting auto tour was found to be more sensitive to the effects of urban form, relative to other types of tours. This is possibly because auto driver behaviors are more sensitive to land use development for commuting tours. In the model where urban form variables affect vehicle types, it is found that employment density at origins and auto accessibility at destinations have negative direct effects on vehicle type choice, suggesting that in denser areas and higher auto accessibility areas, people drive smaller cars. However, the coefficients are only significant in commuting tour model. Some of the socio-demographics characteristics play important roles in affecting vehicle type choice model: the number of children, gender, and the number of vehicles are found to be significant and positive, which indicate that families with more children and vehicles are prone to have larger vehicles. These relationships were shown the strongest in non-work tour model.

In the transit tour models, auto accessibility and street network connectivity are significant for all transit tour model and commuting tour model. The distance to transit and auto accessibility are significant for mixed and non-work transit models. Different socio-demographic characteristics play different roles in affecting driving patterns and travel distance. For example, vehicle ownership is more important in commuting tours, whereas employment status and the presence of children in the household are shown more significant in mixed and non-work tours, respectively.

6.6 Results Summary

The study adds to the understanding of how the built environments influence travel outcomes, including travel distance and energy consumption, by considering the intermediate effects of tour complexity, congestion (measured by speed), mode choice, and vehicle type choice through using SEM.

The findings suggest that: first, in terms of the overall model fit, the all -tour model does not have a good model fit. However, after separating only the auto tour model from the whole data set, the model fit was improved significantly. However, mixed tour models still show poor model fit. Transit models have insignificant results.

Second, in terms of model fit indices, significance, and magnitudes of coefficients, auto commuting tours have more stable travel patterns than other types of tours. In addition, non-work tour models generate stronger coefficients among all tour subsamples.

Third, urban form measurements do have direct effects on travel distance for all tour types modeled. Of all the urban form measurements, transit accessibility at destinations was found to be statistically significant and positive for all models whereas street network connectivity had a direct and negative effect for commuting and mixed tours. Some of the urban form measurements also have significant indirect effects on travel distance, which is through affecting travel speed. Mixed tours were found to be more sensitive to urban form variables than other types of tours.

Fourth, the built environment variables also directly and indirectly affect the intermediate variables, such as mode choice, speed, vehicle type, and tour complexity. In the model where urban form affects mode choice, street network connectivity is significant and positive. The mixed tour model was found to have higher coefficients (both direct and total effects) than the commuting tour model. It is also interesting to find that urban form variables do not have any impacts on mode choice for non-work tours. Similar patterns have been found in the model where urban form affects speed as evidenced by the negative coefficients of street network connectivity on speed. In the context of modeling the relationship between urban form and vehicle types, employment density at origins and auto accessibility at destinations have a negative direct effect on vehicle type choice. The coefficients are only significant in the commuting tour model. Finally, urban form variables do not have strong impacts on tour complexity. The findings indicate that the distance to transit is the only variable that has a significant and negative impact on tour complexity for mixed tours.

Fifth, in the model where intermediate variables interact with each other, auto driving is associated with higher speed, although the effect is slightly higher in the mixed tour model. It is interesting to find that in mixed tour model, tour complexity has a direct and positive impact on mode choice, whereas it has a negative effect on mode choice for the non-work tour model. As we stated in the previous section, people tend to drive to accomplish more complicated tours, especially for work and non-work chaining tours. However, if the tours are all non-work tours, people are more likely to use non-motorized modes. All the effects of intermediate variables on travel distance and energy consumptions are consistent with expectations.

Sixth, some of the household socio-demographics have significant impacts on tour distance and energy consumption. Vehicle ownership is the dominant factor that affects travel distance, energy consumption, and mode choice directly and indirectly. The indirect effects are stronger than the direct effects. Age and the number of children have stronger explanatory power for mixed and non-work tour models. Employment status and the number of vehicles are stronger determinants for commuting tours. The contradictory signs of direct and total effect on energy consumption indicated that these variables operate indirectly through other variables, for example, mode choice.

Seventh, some of the counter-intuitive signs are worth further exploration: in mixed tour models, tour complexity has a negative indirect effect on travel distance. Mode choice has negative direct effects on travel distance. Driving patterns have negative direct effects on energy consumption. More detailed analyses are needed to explore the working mechanism of driving patterns.

Chapter 7: Conclusions and Future Research

This dissertation has contributed to the current knowledge by gaining additional insights into the linkages of different aspects of the built environments, travel behavior, and energy consumption using SEM that provides a powerful analytic framework for a better understanding of the complex relationships of urban form, travel and energy consumption.

Several urban form measurements (density, mixed land use index, street network connectivity, regional accessibility, and distance to transit) were gathered from multiple external sources (including MDP, BMC, Claritas, U.S. Census, and the MTA) and utilized for both trip origins and destinations.

We started our analysis using trip as the analysis unit. Then trips were aggregated into tours to test whether the tour-based analysis generates better results than the trip-based analysis in terms of model fit, significance, and coefficient estimations. In addition to the comparison between trip-based and tour-based analysis, tour-based samples were also stratified into three different classification schemes to investigate the variations of relationship of urban form and travel among auto and transit modes and among various travel types.: (1) by modes (i.e. auto and transit); (2) by travel purposes (i.e. work, mixed, and non-work tours); and (3) by modes and purposes (first by modes, then by purpose, see Figure 6-1 in Chapter 6). Since auto and transit travel have different choice mechanisms, transit samples and auto samples were separated and were modeled individually. Stratification by purposes and modes provided an in-depth investigation of the linkages of urban form and travel behavior.

Section 7.1 of this chapter discusses the findings that respond to the hypotheses (introduced in Chapter 4) and Section 7.2 provides the corresponding policy implementations. Limitations and directions for further research of this dissertation are discussed in Section 7.3.

7.1 Research Findings

Among all the seven hypotheses that were set out in chapter 4, the first five focus on the inter-relationships between urban form, travel and energy consumption. The last two hypotheses are more related to the methodological issues, the research implications in response to the findings are provided in this section.

Hypothesis 1: Urban form variables directly affect travel distance (subsequently affecting energy consumption) due to the separation of residence and activity sites. Urban form at the destinations has stronger effects than at the origins.

The findings suggest that urban form does have direct effects on travel distance for all tour types modeled. This finding is consistent with those of other researchers who claim that changing land use development patterns should be part of the solution in VMT and energy consumption reduction (Krizek 2003; Shen 2000; Ewing and Cervero, 2001 & 2010, and TRB, 2009). Higher street connectivity was found to reduce travel distance. This finding suggests that the largest travel distance and energy reduction would come from creating more compact communities with highly connected infrastructure supporting more non-motorized travel. Another finding is that higher transit accessibility is associated with longer travel distance. This finding suggests that areas with higher transit accessibility attract the labor force from further areas to travel to the workplaces.

It is also interesting to find that urban form at the destinations has more influence on travel than at the origins. Destination activities include employment, retail, services, entertainment, and other uses that attract significant numbers of person trips, as distinguished from residential ends that attract fewer people.

Hypothesis 2: Urban form variables affect travel distance and corresponding energy indirectly.

Hypothesis 2a: Urban form variables affect household vehicle type choice. Specifically, households living in denser areas will choose smaller vehicles and consume less energy.

Hypothesis 2b: Less dense areas involve more motorized and highway travel, which causes increases in travel distance, and energy consumption.

Hypothesis 2c: Denser areas are associated with more congestion (measured by speed), which consumes more energy.

Hypothesis 2d: People living in denser areas have more complex tours and consume more energy.

The results indicate that urban form affect travel distance and energy consumption indirectly. (a) People choose more compact vehicles in denser and more accessible areas. More compact vehicles consume less energy. However, the impacts of urban form on vehicle type choice are not very strong. (b) In less dense areas, people are more auto-oriented, travel longer and faster, and consume more energy. (c) The total effects of urban form on driving patterns are shown to have stronger impacts than its effects on mode choice. (d) Urban form does not have strong impacts on tour complexity.

Hypothesis 3: Among the intermediate variables, mode choice and tour complexity influence travel speed. The tour complexity also has direct effects on mode choice.

The findings suggest that people tend to drive when they have complicated travel patterns (e.g., combining work and non-work activities). Factors such as fixed schedules and routes, boarding fares, limited destination choices, difficulties of transferring, and access/egress issues, make it less attractive to use public transit for complex tours. Attention needs to be paid to land use development around transit stops/stations. For example, promoting mixed land use development around transit stations will allow travelers to fulfill a variety of activities at one location instead of taking additional trips.

Hypothesis 4: Urban form variables have stronger direct effects on travel and energy consumption than the indirect impacts through affecting intermediate variables: mode choice, speed, vehicle types, and tour complexity.

Findings suggest that the effects of intermediate variables (mode choice, speed, vehicle types, and tour complexity) are stronger than the direct effects generated from urban form. The results of all tour models have shown that more highway driving leads to the increases in travel distance and energy consumption. These findings suggest that providing alternative transportation modes (such as transit and non-motorized) and more advanced traffic control management can reduce travel and energy consumption and also play a pivotal role in lowering VMT, energy and emissions. However, these policies work as complements to rather than as substitutes for land use policies (Boarnet, 2010).

Hypothesis 5: Different types of travel have various working mechanisms: commuting tours have more stable travel patterns and show more significant results than non-work and mixed-work-non-work tours.

By stratifying tour samples into different travel purposes, we tested how transportation and land use can collectively and separately impact travel distance, mode choice, driving patterns and tour complexity for work, non-work and mixed tours. Different results were revealed: both work tour models and non-work tour models generate better model fit than mixed tour models. Urban form measurements (i.e. street network connectivity) have stronger impacts on mixed tours than on other types of travel. Vehicle ownership plays a more important role in affecting energy consumption for commuting tours than other socio-demographic factors. These results call for much needed attention regarding the different nature of work tours and other types of tours. The enormous complexity between urban form and travel behavior requests the disaggregation by tour types to reveal more accurate and detailed travel patterns.

Hypothesis 6: Tour-based analysis generates better estimated results than trip-based analysis.

The results show that the tour-based analysis has a better model fit than trip-based models. This result is consistent with the recent research trend suggesting that modeling spatial relationships between travel behavior and land use is improved through the use of a tour-based rather than a trip-based approach (Shiftan et al. 2003). Trip-chaining is often seen as a way to reduce the cost of travel, since accomplishing activities can be more efficient when they are linked in sequence, which has been evidenced in the results of the tour-based analysis. The results of this dissertation indicate that by linking trips into tours, model fit has been significantly improved, especially for work alone tours and non-work tours.

Hypothesis 7: Separating auto and transit samples from the whole sample generates better model results.

The findings indicate that transit riders and auto drivers have completely different travel behaviors and should be modeled separately. Transit mode is constrained by fixed routes, schedules, difficulty of waiting and transferring, as well as the access and egress issues. But transit also has the advantage of cheap cost which is more attractive to regular commuters. Although we do not have enough samples to draw strong conclusions to fully understand the behavior difference between transit riders and auto drivers, this research points out the need of separating auto and transit to get a better understanding of how transit should be incorporated differently in travel behavior research.

7.2 Implementations

Given the increasing debate concerning the capacity that alternative land use planning can change travel behavior, it is important for both planners and policy makers to recognize that land use can play a pivotal role in the reduction of travel and energy consumption by considering the following potential suggestions:

Urban form has direct effects on travel behavior and further on transportation energy consumption. At the same time, the urban land use-transportation system is such a complex entity that all the components in the system work collaboratively rather than separately. This is evidenced in the results that urban form affects travel through influencing driving patterns, mode choice, vehicle types, and tour complexity.

This information can help planners and policy makers develop a more thorough understanding on how urban form can influence travel behavior. Policy makers should be aware that no single transportation technology or land use policy action can offer a complete checklist of achieving deep reductions of travel and energy consumption. Instead, a mix of different technologies, policies, and strategies is necessary (Jonathan and Noland, 2010). The mixed policies likely will involve land development policies that reduce the demand for auto travel and the strategies that provide alternative travel modes and improve efficiency of transportation systems.

Urban form at the destinations plays a more critical role in affecting travel. Policies aiming at reducing travel by changing land use development could focus on destination ends of the travel. For example, locating destinations in walkable clusters linked with high quality public transit service is crucial for reducing the numbers and percentage of tours made by auto. This policy is also consistent with the finding that people tend to drive when they have more complicated travel patterns. Therefore, more Transit-oriented Development (TOD) that promotes compact, transit and pedestrian–friendly development provides more urban environment benefits including reduction of auto dependency, energy usage, and air pollution.

7.3 Limitations and Future Research

This empirical effort also revealed some major data and methodological challenges for modeling and analyzing the relationships between urban form and transportation energy consumption.

First, the current study is cross-sectional and the self-selection is problematic in this study. People who prefer to drive less may selectively live in more compact, mixed land use, and more connected neighborhoods and thus walk more and drive less. In this case, urban form does not have direct relationship with travel behavior. It is the residential choice which determines the travel behavior. To solve this problem, more attitude data or other techniques (e.g. panel data) are needed to control the self-selection bias.

Second, currently available data on household transportation energy consumption is estimated rather than directly measured. This raises the question about the reliability of the estimation. Yet, even more challenging is to extend the research to model CO_2 emissions. Even estimated data on household CO_2 emissions is not available in the NHTS. Therefore, a sophisticated and robust CO_2 emission estimation method, along with household energy consumption diary (that can track gas usage of the travelers), are urgently needed.

Third, the relationships that were examined were based on statistical estimations on revealed outcome data. Such data provides insights into what people have done, it does not provide the decision mechanisms and behavioral processes. The enormous complexity between attitudes, household behavior (e.g. combined decision making between couples in the households), preferences, and socio and economic constraints make the analysis extremely difficult. Therefore, more detailed travel data related to the decision making process are urgently needed.

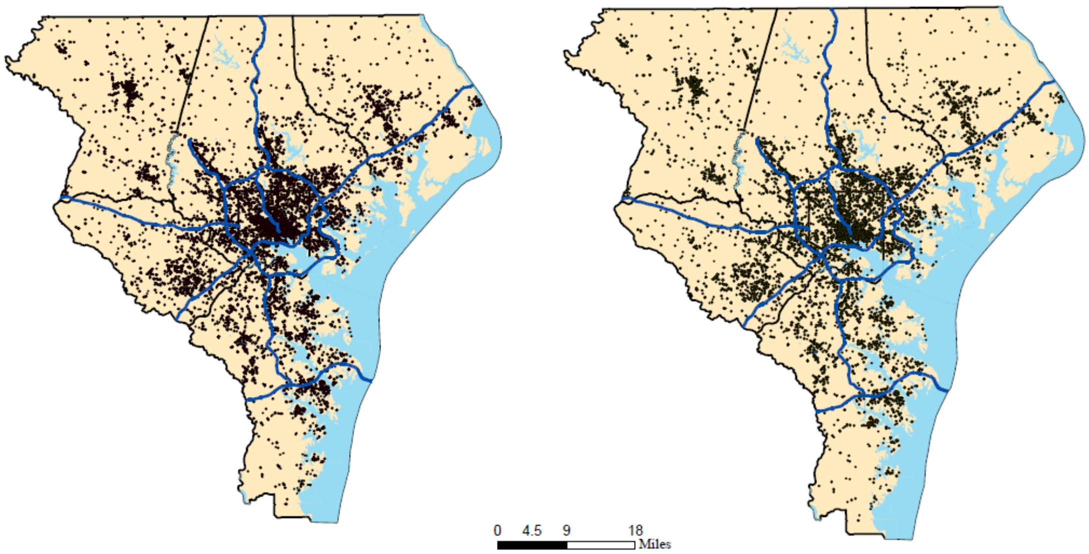
Fourth, future research should also explore the magnitude of the role that public transportation can play to reduce transportation energy and emissions. Some research has found that transit only constitutes a small share of the total trips. Others suggest that public transportation could have a significant share of commuting trips where land-use patterns could appropriately support the transit system (Anderson et al. 1996). It is also important to be aware that auto ownership plays a very critical role in the decision to use transit. However, in this study, due to the limited transit sample, we cannot draw strong conclusion on how people make decision to use transit. In addition, in this research, when modeling the transit data, vehicle type and mode choice were not relevant to the model specification. We had to restructure the model to cope with this problem. The issues of insufficient data and methodologies should be addressed in the future framework that integrates transportation and land use.

Fifth, the lack of more detailed travel data presents another major challenge. To examine the multiple ways in which urban form influences vehicle energy consumption and emissions, it requires much more information on each journey, including travel mode, distance, vehicle fuel type, vehicle occupancy, and speed. For example, the current study only used average speed of the entire tours as the proxy for driving patterns. However, in order to operationalize detailed driving patterns (such as cruising, frequent stops due to traffic lights or bumps, and sharp turns), more detailed network conditions (including congestion by time of the day, transit schedule and frequency, etc.) are needed to reflect the driving variations in the study area.

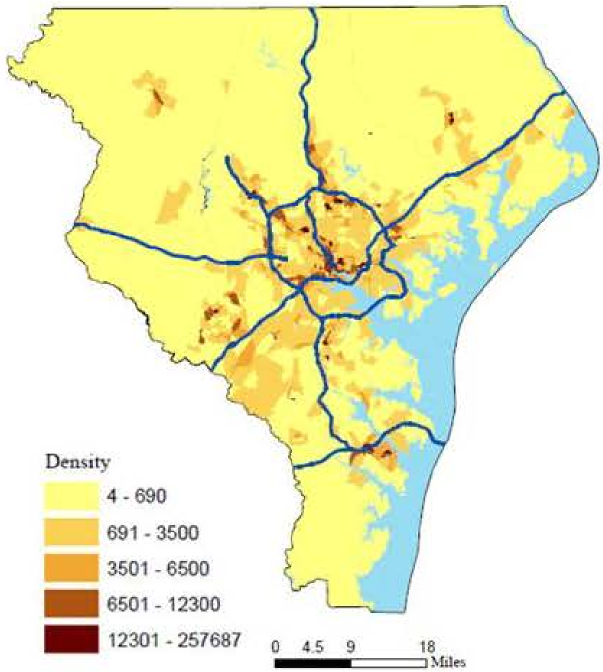
Sixth, using trip as the analysis unit generates the dependency of the observations since same travelers make serial trips along the way. Simply stratifying the trips into different purposes is not sufficient for solving the dependency problems. More sophisticated approaches are needed for further research.

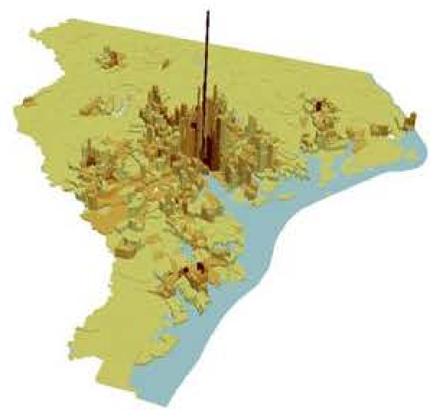
Appendices

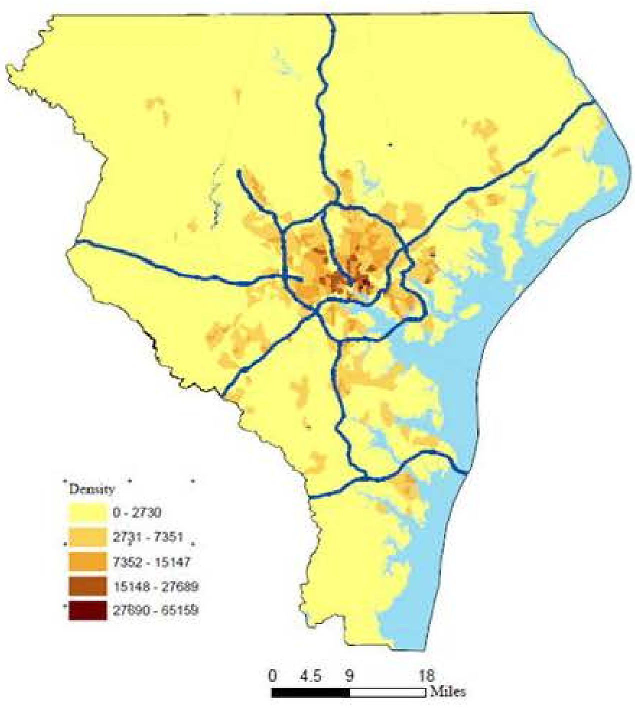
Appendix I-1: Trip origins and trip destinations

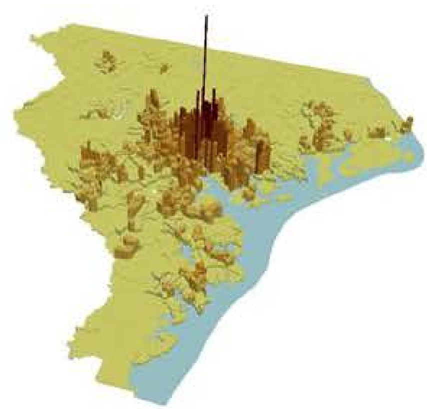


Appendix I-2: Employment Density and Population Density

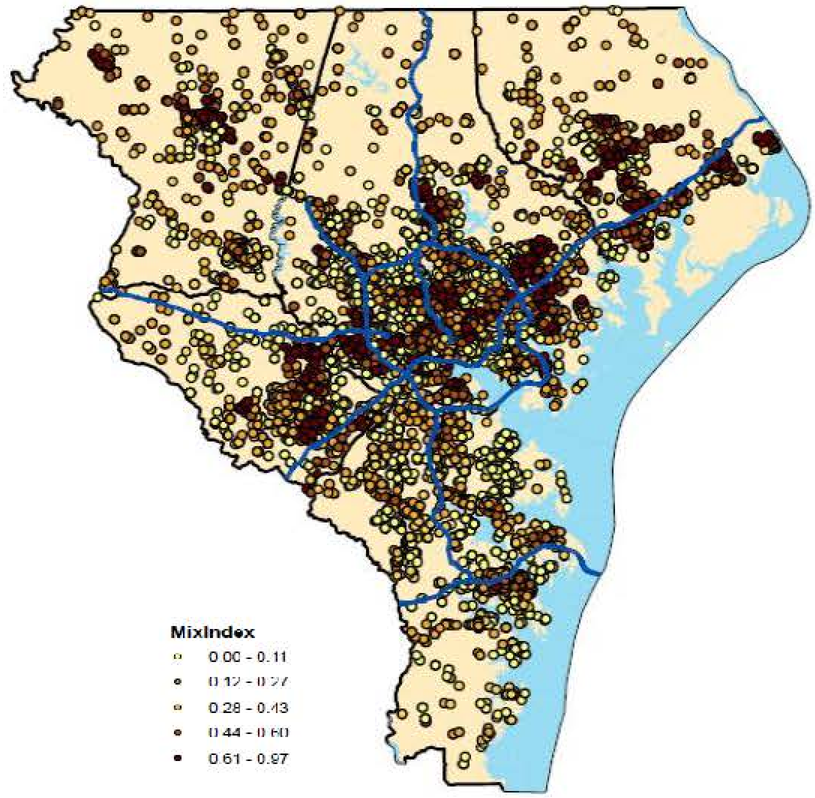




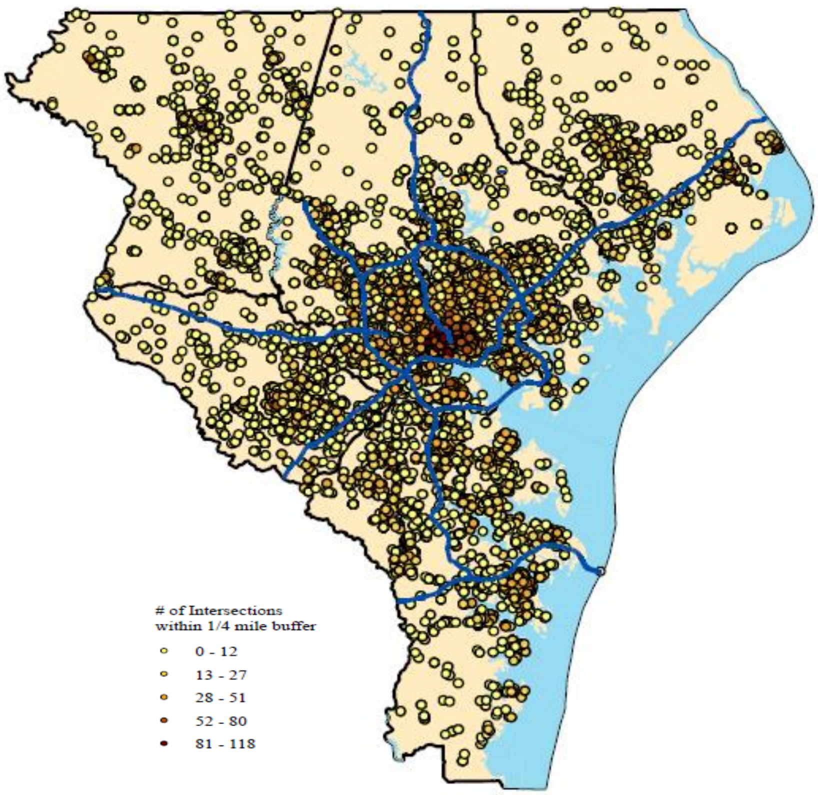




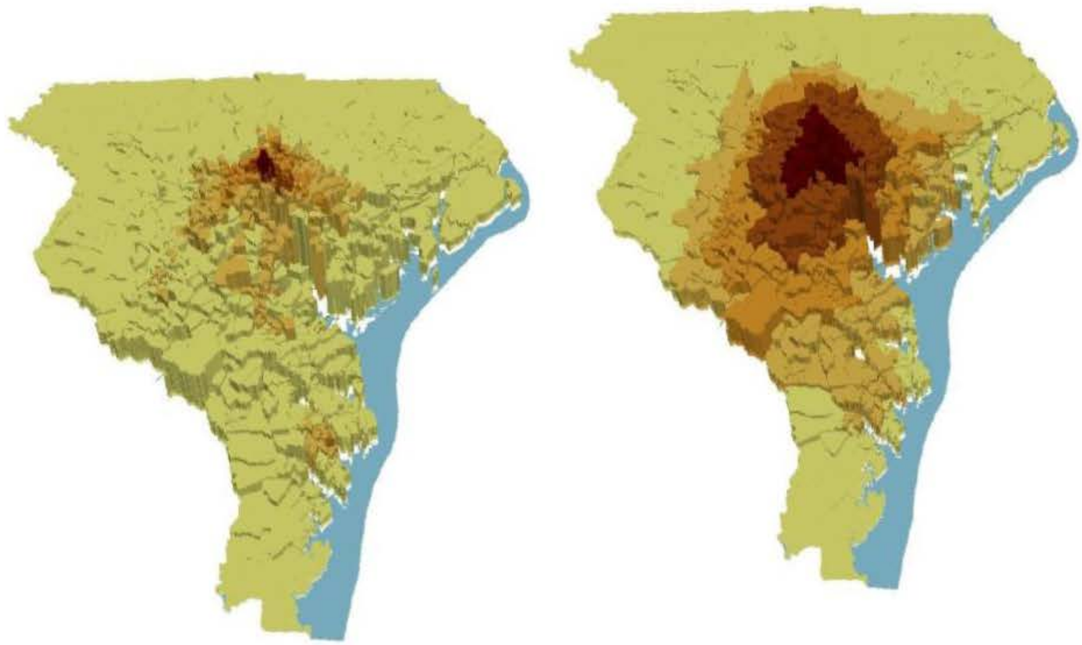
Appendix I-3: Mix land use index



Appendix I-4: Street network connectivity



Appendix I-5: Regional auto and transit accessibility



Appendix II: Visual Basic calculation of regional accessibility

```
Dim SOVTime(1 To 2024, 1 To 2024) As Single
Dim BusTime(1 To 2024, 1 To 2024) As Single
Dim Job(1 To 2024) As Long
Dim Worker(1 To 2024) As Long
Private Sub Command1_Click()
Dim SovDb As Database, SovRs As Recordset
Dim I As Integer, J As Integer

  Set SovDb = OpenDatabase("L:\EPAProject\April2009\Atlanta", False, _
  False, "TEXT;Database=L:\EPAProject\April2009\Atlanta;table=AtlNPTimeAuto.txt")
  Set SovRs = SovDb.OpenRecordset("AtlNPTimeAuto.txt")

Form2.Show
Form2.ProgressBar1.Max = 2024
Form2.ProgressBar1.Value = 1

SovRs.MoveFirst
 Do Until SovRs.EOF = True

    I = SovRs.Fields(0).Value
    J = SovRs.Fields(1).Value
    SOVTime(I, J) = SovRs.Fields(2).Value

    Form2.ProgressBar1.Value = I

  SovRs.MoveNext
Loop
Form2.Hide
SovRs.Close
MsgBox "done!Sov time matrix in memory!"

End Sub

Private Sub Command2_Click()
Dim BusDb As Database, BusRs As Recordset
Dim I As Integer, J As Integer

  Set BusDb = OpenDatabase("L:\EPAProject\April2009\Atlanta", False, _
  False, "TEXT;Database=L:\EPAProject\April2009\Atlanta;table=AtlNPTimeTransit.txt")
  Set BusRs = BusDb.OpenRecordset("AtlNPTimeTransit.txt")
Form2.Show

Form2.ProgressBar1.Max = 2024
Form2.ProgressBar1.Value = 1

BusRs.MoveFirst
 Do Until BusRs.EOF = True
```

```
    I = BusRs.Fields(0).Value
    J = BusRs.Fields(1).Value
    BusTime(I, J) = BusRs.Fields(2).Value
    Form2.ProgressBar1.Value = I
'     DoEvents
  BusRs.MoveNext

Loop

BusRs.Close
Form2.Hide
MsgBox "done!Bus time matrix in memory!"
End Sub


Private Sub Command3_Click()
Dim JobDb As Database, JobRs As Recordset
   Set JobDb = OpenDatabase("L:\EPAProject\April2009\Atlanta", False, _
   False, "TEXT;Database=L:\EPAProject\April2009\Atlanta;table=AtlNonwork.txt")
   Set JobRs = JobDb.OpenRecordset("AtlNonwork.txt")


Dim TAZ As Integer

JobRs.MoveFirst

While Not JobRs.EOF

   TAZ = JobRs.Fields(0).Value

   Job(TAZ) = JobRs.Fields(1).Value
   'JobLow(TAZ) = JobRs.Fields(2).Value
   'JobMid(TAZ) = JobRs.Fields(3).Value
   'JobHig(TAZ) = JobRs.Fields(4).Value


   JobRs.MoveNext

Wend


JobRs.Close

MsgBox "done! Job Parameters in memory!"

End Sub
'Private Sub Command5_Click()
```

```
'Dim WorkerDb As Database, WorkerRs As Recordset
  ' Set WorkerDb = OpenDatabase("H:\EPAproject\ConferenceApril\Baltimore", False, _
  ' False, "TEXT;Database=H:\EPAproject\ConferenceApril\Baltimore;table=BaltWorkers.txt")
 '  Set WorkerRs = WorkerDb.OpenRecordset("BaltWorkers.txt")


'Dim TAZ As Integer

'WorkerRs.MoveFirst

'While Not WorkerRs.EOF

 '  TAZ = WorkerRs.Fields(0).Value

  ' Worker(TAZ) = WorkerRs.Fields(1).Value
   'WorkerLow(TAZ) = WorkerRs.Fields(2).Value
   'WorkerMid(TAZ) = WorkerRs.Fields(3).Value
   'WorkerHig(TAZ) = WorkerRs.Fields(4).Value


  ' WorkerRs.MoveNext

'Wend


'WorkerRs.Close

'MsgBox "done! Worker Parameters in memory!"

'End Sub


Private Sub Command6_Click()
If IsNumeric(Text2.Text) And IsNumeric(Text3.Text) And _
Val(Text2.Text) <= 2024 And Val(Text3.Text) <= 2024 Then

If Option1.Value = True Then

   MsgBox SOVTime(Val(Text2.Text), Val(Text3.Text))

Else
    MsgBox BusTime(Val(Text2.Text), Val(Text3.Text))
End If

Else
 MsgBox "Input right OD!"
End If
```

```
End Sub


Private Sub Command4_Click()

Dim Unadjusted_Auto As Single, Unadjusted_Bus As Single
'Dim Demand(1 To 4874) As Single
Dim Acc_Auto As Single, Acc_Bus As Single
Dim I As Integer, J As Integer, K As Integer
Dim a As Integer
Open "L:\EPAProject\April2009\Atlanta\AtlResultNonWorkcheck.txt" For Output As #1 '
Print #1, "TAZ, NonWorkJob, Unadjusted_Auto, Unadjusted_Bus"
beta = Val(Text1.Text)
Form2.Show
'For J = 1 To 4874
'Demand(J) = 0

'If J = 701 Then
'   MsgBox "701"
'End If
'For K = 1 To 4874
'If SOVTime(K, J) > 1440 Then SOVTime(K, J) = 1440
'If BusTime(K, J) > 1440 Then BusTime(K, J) = 1440

' Demand(J) = Demand(J) + (Auto(K) * Worker(K)) / (Exp(beta * SOVTime(K, J))) + _
     ((1 - Auto(K)) * Worker(K)) / (Exp(beta * BusTime(K, J)))

' Next K
'Next J


For I = 1 To 2024

  'Form2.ProgressBar1.Value = I

  Acc_Auto = 0
  Acc_Bus = 0
  Unadjusted_Auto = 0
  Unadjusted_Bus = 0


    For J = 1 To 2024


Unadjusted_Auto = Unadjusted_Auto + Job(J) / (Exp(beta * SOVTime(I, J)))
Unadjusted_Bus = Unadjusted_Bus + Job(J) / (Exp(beta * BusTime(I, J)))
'Acc_Auto = Acc_Auto + (Job(J) / (Exp(beta * SOVTime(I, J)))) / Demand(J)
'Acc_Bus = Acc_Bus + (Job(J) / (Exp(beta * BusTime(I, J)))) / Demand(J)
```

```
   Next
 Print #1, Str(I) + "," + Str(Job(I)) + "," + Str(Worker(I)) + "," _
 + Str(Unadjusted_Auto) + "," + Str(Unadjusted_Bus)
Next
Close #1
Form2.Hide
MsgBox "done! accessbility scores in file"
End Sub

Private Sub Command8_Click()

 Open "H:\EPAproject\October\SanFrancisco\SFNPTimeAuto.txt" For Output As #1 '
 Open "H:\EPAproject\October\SanFrancisco\SFPKTimeTransit.txt" For Output As #2 '

Dim I As Integer, J As Integer
For I = 1 To 1454
  For J = 1 To 1454
Print #1, Str(I) + "," + Str(J) + "," + Str(SOVTime(I, J))
Print #2, Str(I) + "," + Str(J) + "," + Str(BusTime(I, J))
  Next J
Next I

Close #1
Close #2


'Dim OBJFUN As String
'Dim CONS_Worker(1 To 1151) As String, CONS_Job(1 To 1151) As String

'Dim I As Integer, J As Integer



'  Open "C:\ITS\Chao\test2.txt" For Output As #1 ' ´ò¿ªÊä³öÎÄ¼þ

'    Form2.Show

'  OBJFUN = "MIN "
'  For I = 1 To 100
'    Form2.ProgressBar1.Value = I

'     For J = 1 To 100
'        OBJFUN = OBJFUN & SOVTime(I, I) & " " & "X" & I & "_" & J & " +"
'        CONS_Worker(I) = CONS_Worker(I) & " X" & I & "_" & J & " +"


'     Next
```

```
'  Next


'  Close #1


End Sub

Private Sub Command9_Click()
Dim Unadjusted_Auto As Single, Unadjusted_Bus As Single
Dim Demand(1 To 2024) As Single


  Dim Acc_Auto As Single, Acc_Bus As Single

  Dim I As Integer, J As Integer, K As Integer
  Dim a As Integer

  Open "L:\EPAProject\April\Atlanta\AtlantaworkT23.txt" For Output As #1 ‘
 Print #1, "TAZ, NonWorkJob,  Unadjusted_Auto, Unadjusted_Bus"
  beta = Val(Text1.Text)
  Form2.Show


'For J = 1 To 4874

'Demand(J) = 0

'If J = 701 Then
'   MsgBox "701"
'End If
'For K = 1 To 4874
'If SOVTime(K, J) > 1440 Then SOVTime(K, J) = 1440
'If BusTime(K, J) > 1440 Then BusTime(K, J) = 1440
'   If SOVTime(K, J) <= 15 Then
'     Demand(J) = Demand(J) + Auto(K) * Worker(K)
'   End If
'   If BusTime(K, J) <= 15 Then
'     Demand(J) = Demand(J) + (1 - Auto(K)) * Worker(K)
'   End If

' Next K
'Next J


For I = 1 To 2024

  Form2.ProgressBar1.Value = I
```

```
'  Acc_Auto = 0
'  Acc_Bus = 0
  Unadjusted_Auto = 0
  Unadjusted_Bus = 0


    For J = 1 To 2024

If SOVTime(I, J) <= 23 Then

   Unadjusted_Auto = Unadjusted_Auto + Job(J)
'   Acc_Auto = Acc_Auto + Job(J) / Demand(J)

End If

If BusTime(I, J) <= 23 Then

  Unadjusted_Bus = Unadjusted_Bus + Job(J)
'  Acc_Bus = Acc_Bus + Job(J) / Demand(J)

End If

    Next



 Print #1, Str(I) + "," + Str(Job(I)) + "," + Str(Worker(I)) + "," _
 + Str(Unadjusted_Auto) + "," + Str(Unadjusted_Bus)


Next



 Close #1

  Form2.Hide

 MsgBox "done! accessbility scores in file"

End Sub
```

Appendix III Built in correlation matrix

Appendix III-1 Built in correlation matrix of all trips

	Density_O	Acce_Auto_O	Mix_LU_O	Dist_Transit_O	Acce_Auto_D	Acce_Transit_D	#Intersect_D	Dist_Transit_D	Income	Children	Worker	#Veh
Density_O	----											
Acce_Auto_O	0.50	----										
Mix_LU_O	0.05	0.09	----									
Dist_Transit_O	-0.29	-0.58	-0.10	----								
Acce_Auto_D	0.58	0.85	0.08	-0.49	----							
Acce_Transit_D	0.44	0.59	0.08	-0.25	0.81	----						
#Intersect_D	0.58	0.54	0.04	-0.25	0.68	0.65	----					
Dist_Transit_D	-0.02	-0.01	0.00	0.01	-0.10	-0.05	-0.06	----				
Income	-0.32	-0.18	-0.06	0.08	-0.25	-0.20	-0.26	0.01	----			
Children	-0.08	-0.12	-0.04	0.10	-0.13	-0.11	-0.10	0.00	0.09	----		
Worker	0.02	0.04	0.00	-0.03	0.06	0.09	0.04	-0.02	0.17	-0.21	----	
#Veh	-0.39	-0.30	-0.06	0.20	-0.38	-0.35	-0.37	-0.03	0.41	0.01	0.16	----

Appendix III-2 Built in correlation matrix of all tours

	Density_O	Acce_Auto_O	Mix_LU_O	Dist_Transit_O	Acce_Auto_D	Acce_Transit_D	#Intersect_D	Dist_Transit_D	Income	Children	Sex	Worker	#Veh
Density_O	----												
Acce_Auto_O	0.23	----											
Mix_LU_O	0.00	0.06	----										
Dist_Transit_O	-0.28	-0.56	-0.10	----									
Acce_Auto_D	0.51	0.61	0.04	-0.47	----								
Acce_Transit_D	0.35	0.45	0.04	-0.22	0.81	----							
#Intersect_D	0.48	0.23	0.02	-0.20	0.61	0.58	----						
Dist_Transit_D	-0.41	-0.43	0.01	0.36	-0.72	-0.46	-0.44	----					
Income	-0.32	-0.03	-0.04	0.05	-0.21	-0.14	-0.24	0.16	----				
Children	-0.07	-0.10	-0.04	0.09	-0.13	-0.11	-0.08	0.09	0.07	----			
Sex	-0.02	-0.02	-0.01	0.02	-0.01	-0.01	-0.02	0.01	0.06	-0.01	----		
Worker	0.02	0.12	0.02	-0.06	0.09	0.12	0.02	-0.06	0.19	-0.22	0.02	----	
#Veh	-0.40	-0.06	-0.05	0.15	-0.36	-0.32	-0.34	0.33	0.42	-0.01	0.03	0.18	----

Appendix III-3 Built in correlation matrix of work trips

	PopDensity	EmpDensity	Dist_Transit_O	Acce_Auto_D	Acce_Transit_D	#Intersect_D	Dist_Transit_D	Income	Children	Sex	Worker	VEHNUM
PopDensity	----											
EmpDensity	0.80	----										
Dist_Transit_O	-0.26	-0.25	----									
Acce_Auto_D	0.55	0.53	-0.47	----								
Acce_Transit_D	0.39	0.40	-0.23	0.83	----							
#Intersect_D	0.58	0.56	-0.25	0.64	0.58	----						
Dist_Transit_D	-0.52	-0.50	0.47	-0.84	-0.56	-0.57	----					
Income	-0.34	-0.31	0.02	-0.23	-0.18	-0.27	0.20	----				
Children	-0.08	-0.12	0.12	-0.16	-0.13	-0.10	0.14	0.02	----			
Sex	-0.09	-0.07	0.04	-0.07	-0.08	-0.07	0.06	0.09	0.04	----		
Worker	0.05	0.08	-0.06	0.12	0.11	0.05	-0.11	0.07	-0.45	0.00	----	
VEHNUM	-0.34	-0.32	0.15	-0.32	-0.30	-0.30	0.26	0.40	-0.14	0.07	0.31	----

Appendix III-4 Built in correlation matrix of work tours

	PopDensity	EmpDensity	DistTransitO	Acce_Auto_D	Acce_Transit_D	#Intersection	DistTransitD	Income	Children	Sex	Worker	#Veh
PopDensity	----											
EmpDensit	0.81	----										
DistTransitO	-0.25	-0.25	----									
Acce_Auto_D	0.42	0.41	-0.44	----								
Acce_Transit_D	0.28	0.28	-0.23	0.86	----							
#Intersection	0.41	0.36	-0.19	0.54	0.51	----						
DistTransitD	-0.43	-0.40	0.45	-0.79	-0.53	-0.50	----					
Income	-0.36	-0.32	0.02	-0.16	-0.10	-0.23	0.15	----				
Children	-0.07	-0.12	0.12	-0.17	-0.14	-0.06	0.15	0.01	----			
Sex	-0.09	-0.07	0.04	-0.06	-0.07	-0.07	0.03	0.09	0.04	----		
Worker	0.03	0.08	-0.09	0.17	0.15	0.02	-0.16	0.08	-0.44	0.00	----	
#Veh	-0.34	-0.33	0.16	-0.28	-0.27	-0.25	0.21	0.39	-0.15	0.07	0.30	----

Appendix III-5 Built in correlation matrix of non-work trips

	PopDensity	EmpDensity	Dist_TransitO	Acce_Auto_D	Acce_Transit_D	#Interset_D	Dist_TransitD	Income	Children	Worker	#Veh
PopDensity	----										
EmpDensity	0.79	----									
Dist_TransitO	-0.31	-0.31	----								
Acce_Auto_D	0.63	0.60	-0.53	----							
Acce_Transit_D	0.57	0.55	-0.31	0.80	----						
#Interset_D	0.62	0.59	-0.27	0.73	0.80	----					
Dist_TransitD	-0.02	-0.01	0.00	-0.11	-0.06	-0.07	----				
Income	-0.30	-0.21	0.11	-0.29	-0.27	-0.25	0.00	----			
Children	-0.07	-0.10	0.08	-0.12	-0.10	-0.10	0.00	0.15	----		
Worker	0.03	0.06	0.01	-0.01	0.02	0.04	-0.01	0.22	-0.10	----	
#Veh	-0.41	-0.39	0.23	-0.41	-0.39	-0.40	-0.04	0.42	0.07	0.13	----

Appendix III-6 Built in correlation matrix of non-work tours

	PopDensity	EmpDensity	Dist_Transit_O	Acce_Auto_D	Acce_Transit_D	#Intersect_D	Dist_Transit_D	Income	Children	Worker	#Veh
PopDensity	----										
EmpDensity	0.80	----									
Dist_Transit_O	-0.32	-0.32	----								
Acce_Auto_D	0.62	0.59	-0.55	----							
Acce_Transit_D	0.53	0.50	-0.33	0.78	----						
#Intersect_D	0.57	0.55	-0.21	0.69	0.76	----					
Dist_Transit_D	-0.41	-0.39	0.31	-0.69	-0.47	-0.41	----				
Income	-0.33	-0.24	0.05	-0.30	-0.28	-0.25	0.18	----			
Children	-0.04	-0.06	0.07	-0.09	-0.08	-0.07	0.06	0.13	----		
Worker	0.00	0.04	-0.01	-0.03	0.00	0.02	0.02	0.25	-0.09	----	
#Veh	-0.48	-0.44	0.17	-0.46	-0.43	-0.44	0.44	0.48	0.06	0.15	----

Appendix III-7 Built in correlation matrix of mixed trips

	PopDensity	EmpDensity	Dist_TransitO	Acce_Auto_D	Acce_Transit_D	#IntersectD	Dist_TransitD	Income	Children	Sex	Worker	#Veh
PopDensity	----											
EmpDensity	0.83	----										
Dist_TransitO	-0.26	-0.25	----									
Acce_Auto_D	0.49	0.48	-0.44	----								
Acce_Transit_D	0.34	0.35	-0.19	0.83	----							
#IntersectD	0.49	0.47	-0.22	0.59	0.53	----						
Dist_TransitD	-0.01	-0.01	0.02	-0.10	-0.05	-0.06	----					
Income	-0.34	-0.26	0.06	-0.19	-0.12	-0.25	0.00	----				
Children	-0.10	-0.12	0.12	-0.15	-0.14	-0.11	0.01	-0.01	----			
Sex	-0.04	-0.01	0.04	-0.02	-0.01	-0.04	0.00	0.08	0.06	----		
Worker	-0.03	0.01	-0.10	0.09	0.08	0.00	-0.01	0.18	-0.38	-0.04	----	
#Veh	-0.37	-0.33	0.16	-0.39	-0.37	-0.35	-0.04	0.38	0.04	0.07	0.11	----

Appendix III-8 Built in correlation matrix of mixed tours

	PopDensity	EmpDensity	Dist_TransitO	Acce_Auto_D	Acce_Transit_D	#IntersectD	Dist_TransitD	Income	Children	Sex	Worker	#Veh
PopDensity	----											
EmpDensity	0.80	----										
Dist_TransitO	-0.25	-0.24	----									
Acce_Auto_D	0.46	0.45	-0.45	----								
Acce_Transit_D	0.32	0.33	-0.22	0.82	----							
#IntersectD	0.43	0.37	-0.20	0.60	0.56	----						
Dist_TransitD	-0.40	-0.38	0.38	-0.74	-0.48	-0.46	----					
Income	-0.27	-0.21	0.06	-0.17	-0.08	-0.23	0.15	----				
Children	-0.10	-0.13	0.10	-0.16	-0.15	-0.10	0.10	0.03	----			
Sex	-0.01	0.03	0.01	0.00	0.01	-0.02	0.01	0.08	-0.01	----		
Worker	0.04	0.06	-0.08	0.11	0.13	0.01	-0.06	0.21	-0.31	-0.01	----	
#Veh	-0.37	-0.33	0.14	-0.33	-0.31	-0.34	0.28	0.38	0.05	0.04	0.14	----

Appendix III-9 Built in correlation matrix of all tours

	PopDensity	EmpDensity	MixedLandUseO	Dist_TransitO	Acce_AutoD	Acce_TransitD	#IntersectD	Dist_TransitD	Income	Age	Children	Sex	Worker	#Veh
PopDensity	----													
EmpDensity	0.80	----												
MixedLandUseO	0.00	0.00	----											
Dist_TransitO	-0.28	-0.27	-0.10	----										
Acce_AutoD	0.51	0.48	0.04	-0.47	----									
Acce_TransitD	0.35	0.34	0.04	-0.22	0.81	----								
#IntersectD	0.48	0.44	0.02	-0.20	0.61	0.58	----							
Dist_TransitD	-0.41	-0.39	0.01	0.36	-0.72	-0.46	-0.44	----						
Income	-0.32	-0.25	-0.04	0.05	-0.21	-0.14	-0.24	0.16	----					
Age	-0.05	-0.04	0.03	-0.01	0.05	0.04	0.00	-0.03	-0.11	----				
Children	-0.07	-0.10	-0.04	0.09	-0.13	-0.11	-0.08	0.09	0.07	-0.55	----			
Sex	-0.02	-0.01	-0.01	0.02	-0.01	-0.01	-0.02	0.01	0.06	-0.02	-0.01	----		
Worker	0.02	0.05	0.02	-0.06	0.09	0.12	0.02	-0.06	0.19	0.23	-0.22	0.02	----	
#Veh	-0.40	-0.37	-0.05	0.15	-0.36	-0.32	-0.34	0.33	0.42	0.06	-0.01	0.03	0.18	----

Appendix III-10 Built in correlation matrix of all auto tours

	PopDensity	EmpDensity	MixedLandUse	Dist_Transit_O	Acce_Auto_D	Acce_Transit_D	#Intersect	Dist_Transit _D	Income	Age	Children	Sex	Worker	#Veh
PopDensity	----													
EmpDensity	0.82	----												
MixedLandUse	0.00	0.00	----											
Dist_Transit_O	-0.28	-0.28	-0.10	----										
Acce_Auto_D	0.48	0.45	0.04	-0.54	----									
Acce_Transit_D	0.35	0.32	0.06	-0.28	0.76	----								
#Intersect	0.39	0.35	0.01	-0.20	0.60	0.68	----							
Dist_Transit _D	-0.38	-0.36	0.02	0.42	-0.76	-0.50	-0.40	----						
Income	-0.24	-0.19	-0.03	0.03	-0.12	-0.06	-0.12	0.08	----					
Age	-0.04	-0.04	0.04	-0.02	0.06	0.06	0.04	-0.06	-0.18	----				
Children	-0.11	-0.12	-0.05	0.10	-0.14	-0.11	-0.09	0.10	0.12	-0.53	----			
Sex	-0.02	-0.01	-0.01	0.02	-0.01	-0.01	-0.03	0.00	0.06	0.00	0.00	----		
Worker	0.05	0.06	0.02	-0.06	0.10	0.13	0.05	-0.07	0.16	0.17	-0.17	0.03	----	
#Veh	-0.31	-0.29	-0.06	0.17	-0.24	-0.18	-0.17	0.21	0.40	-0.10	0.09	0.07	0.13	----

Appendix III-11 Built in correlation matrix of all work tours

	PopDensity	EmpDensity	MixedLandUseO	Dist_TransitO	Acce_AutoD	Acce_TransitD	#IntersectD	Dist_TransitD	Income	Age	Children	Sex	Worker	#Veh
PopDensity	---													
EmpDensity	0.81	---												
MixedLandUseO	0.04	0.05	---											
Dist_TransitO	-0.25	-0.25	-0.14	---										
Acce_AutoD	0.42	0.41	0.07	-0.44	---									
Acce_TransitD	0.28	0.28	0.04	-0.23	0.86	---								
#IntersectD	0.41	0.36	0.05	-0.19	0.54	0.51	---							
Dist_TransitD	-0.43	-0.40	-0.09	0.45	-0.79	-0.53	-0.50	---						
Income	-0.36	-0.32	-0.02	0.02	-0.16	-0.10	-0.23	0.15	---					
Age	-0.03	0.01	0.05	-0.04	0.12	0.10	0.01	-0.12	0.03	---				
Children	-0.07	-0.12	-0.03	0.12	-0.17	-0.14	-0.06	0.15	0.01	-0.50	---			
Sex	-0.09	-0.07	-0.01	0.04	-0.06	-0.07	-0.07	0.03	0.09	0.00	0.04	---		
Worker	0.03	0.08	0.04	-0.09	0.17	0.15	0.02	-0.16	0.08	0.64	-0.44	0.00	---	
#Veh	-0.34	-0.33	-0.06	0.16	-0.28	-0.27	-0.25	0.21	0.39	0.23	-0.15	0.07	0.30	---

Appendix III-12 Built in correlation matrix of all mixed tours

	PopDensity	EmpDensity	MixedLandUse	Dist_Transit_O	Acce_Auto_D	Acce_Transit_D	#Intersect	Dist_Transit _D	Income	Age	Children	Sex	Worker	#Veh
PopDensity	----													
EmpDensity	0.80	----												
MixedLandUse	0.04	0.04	----											
Dist_Transit_O	-0.25	-0.24	-0.15	----										
Acce_Auto_D	0.46	0.45	0.09	-0.45	----									
Acce_Transit_D	0.32	0.33	0.08	-0.22	0.82	----								
#Intersect	0.43	0.37	0.04	-0.20	0.60	0.56	----							
Dist_Transit _D	-0.40	-0.38	-0.02	0.38	-0.74	-0.48	-0.46	----						
Income	-0.27	-0.21	-0.04	0.06	-0.17	-0.08	-0.23	0.15	----					
Age	-0.08	-0.07	0.07	-0.03	0.03	0.02	0.00	-0.01	-0.07	----				
Children	-0.10	-0.13	-0.10	0.10	-0.16	-0.15	-0.10	0.10	0.03	-0.54	----			
Sex	-0.01	0.03	0.01	0.01	0.00	0.01	-0.02	0.01	0.08	-0.02	-0.01	----		
Worker	0.04	0.06	0.06	-0.08	0.11	0.13	0.01	-0.06	0.21	0.29	-0.31	-0.01	----	
#Veh	-0.37	-0.33	-0.06	0.14	-0.33	-0.31	-0.34	0.28	0.38	0.07	0.05	0.04	0.14	----

Appendix III-13 Built in correlation matrix of all non-work tours

	PopDensity	EmpDensity	MixedLandUse	Dist_Transit_O	Acce_Auto_D	Acce_Transit_D	#Intersect	Dist_Transit _D	Income	Age	Children	Sex	Worker	#Veh
PopDensity	----													
EmpDensity	0.80	----												
MixedLandUse	-0.06	-0.07	----											
Dist_Transit_O	-0.32	-0.32	-0.04	----										
Acce_Auto_D	0.62	0.59	-0.04	-0.55	----									
Acce_Transit_D	0.53	0.50	0.03	-0.33	0.78	----								
#Intersect	0.57	0.55	-0.04	-0.21	0.69	0.76	----							
Dist_Transit _D	-0.41	-0.39	0.07	0.31	-0.69	-0.47	-0.41	----						
Income	-0.33	-0.24	-0.05	0.05	-0.30	-0.28	-0.25	0.18	----					
Age	-0.05	-0.06	-0.01	0.02	0.01	0.01	-0.01	-0.01	-0.24	----				
Children	-0.04	-0.06	0.01	0.07	-0.09	-0.08	-0.07	0.06	0.13	-0.59	----			
Sex	0.02	0.01	-0.03	0.02	0.01	0.02	0.03	0.01	0.03	-0.03	-0.04	----		
Worker	0.00	0.04	-0.03	-0.01	-0.03	0.00	0.02	0.02	0.25	-0.05	-0.09	0.02	----	
#Veh	-0.48	-0.44	-0.05	0.17	-0.46	-0.43	-0.44	0.44	0.48	-0.08	0.06	0.00	0.15	----

Appendix III-14 Built in correlation matrix of work auto tours

	PopDensity	EmpDensity	MixedLandUse	Dist_Transit_O	Acce_Auto_D	Acce_Transit_D	#Intersect	Dist_Transit _D	Income	Age	Children	Sex	Worker	#Veh
PopDensity	----													
EmpDensity	0.82	----												
MixedLandUse	0.04	0.05	----											
Dist_Transit_O	-0.26	-0.25	-0.14	----										
Acce_Auto_D	0.43	0.38	0.11	-0.54	----									
Acce_Transit_D	0.33	0.28	0.07	-0.29	0.79	----								
#Intersect	0.33	0.27	0.05	-0.19	0.66	0.81	----							
Dist_Transit _D	-0.35	-0.33	-0.10	0.49	-0.84	-0.60	-0.46	----						
Income	-0.24	-0.20	-0.02	-0.03	-0.05	-0.03	-0.08	0.00	----					
Age	-0.06	-0.02	0.09	-0.05	0.06	0.05	0.03	-0.07	-0.05	----				
Children	-0.11	-0.16	-0.04	0.15	-0.13	-0.09	-0.06	0.12	0.07	-0.42	----			
Sex	-0.10	-0.08	-0.02	0.04	-0.05	-0.06	-0.08	0.01	0.09	0.02	0.06	----		
Worker	0.08	0.10	0.09	-0.13	0.14	0.13	0.07	-0.13	0.00	0.51	-0.33	-0.01	----	
#Veh	-0.31	-0.29	-0.05	0.17	-0.24	-0.18	-0.16	0.21	0.35	-0.06	0.01	0.08	0.00	----

Appendix III-15 Built in correlation matrix of mixed auto tours

	PopDensity	EmpDensity	MixedLandUse	Dist_Transit_O	Acce_Auto_D	Acce_Transit_D	#Intersect	Dist_Transit _D	Income	Age	Children	Sex	Worker	#Veh
PopDensity	----													
EmpDensity	0.82	----												
MixedLandUse	0.06	0.05	----											
Dist_Transit_O	-0.29	-0.28	-0.15	----										
Acce_Auto_D	0.42	0.40	0.11	-0.52	----									
Acce_Transit_D	0.28	0.26	0.10	-0.27	0.78	----								
#Intersect	0.34	0.26	0.06	-0.24	0.57	0.60	----							
Dist_Transit _D	-0.34	-0.32	-0.03	0.41	-0.72	-0.46	-0.39	----						
Income	-0.23	-0.19	-0.05	0.06	-0.11	-0.01	-0.12	0.08	----					
Age	-0.05	-0.04	0.07	-0.04	0.07	0.06	0.04	-0.04	-0.13	----				
Children	-0.14	-0.13	-0.11	0.11	-0.16	-0.13	-0.11	0.10	0.07	-0.55	----			
Sex	-0.01	0.02	0.01	0.01	0.01	0.01	-0.02	0.00	0.08	-0.01	-0.02	----		
Worker	0.07	0.08	0.08	-0.08	0.13	0.14	0.05	-0.08	0.19	0.26	-0.28	0.00	----	
#Veh	-0.31	-0.28	-0.07	0.18	-0.23	-0.18	-0.16	0.21	0.39	-0.04	0.09	0.06	0.08	----

Appendix III-16 Built in correlation matrix of non-work auto tours

	PopDensity	EmpDensity	MixedLandUse	Dist_Transit_O	Acce_Auto_D	Acce_Transit_D	#Intersect	Dist_Transit _D	Income	Age	Children	Sex	Worker	#Veh
PopDensity	----													
EmpDensity	0.83	----												
MixedLandUse	-0.05	-0.06	----											
Dist_Transit_O	-0.30	-0.30	-0.04	----										
Acce_Auto_D	0.57	0.56	-0.04	-0.55	----									
Acce_Transit_D	0.47	0.46	0.02	-0.30	0.74	----								
#Intersect	0.49	0.48	-0.04	-0.19	0.60	0.70	----							
Dist_Transit _D	-0.42	-0.41	0.11	0.40	-0.76	-0.50	-0.38	----						
Income	-0.26	-0.18	-0.04	0.05	-0.19	-0.16	-0.18	0.12	----					
Age	-0.02	-0.04	-0.01	0.02	0.04	0.04	0.02	-0.05	-0.29	----				
Children	-0.10	-0.10	0.01	0.07	-0.13	-0.11	-0.10	0.09	0.21	-0.59	----			
Sex	0.02	0.00	-0.03	0.02	-0.01	-0.01	0.00	0.00	0.03	-0.01	-0.03	----		
Worker	0.02	0.04	-0.03	-0.01	0.00	0.03	0.05	0.02	0.22	-0.05	-0.06	0.02	----	
#Veh	-0.31	-0.29	-0.05	0.16	-0.28	-0.23	-0.20	0.24	0.45	-0.18	0.13	0.04	0.18	----

Appendix IV-1 Decomposed indirect effects of work tours and trips

	Work (Indirect Effects)							
	Mode		Speed		Distance		Energy	
	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip
PopDensityOrig (O1)				-0.49	-0.1			
O1->Speed-> Distance					-0.1	-0.41		
O1->Mode->Speed->Distance						0.33		
O1->Mode->Speed				0.51				
EmpDensityOrig (O2)				-0.42		0.08		
O2->Speed-> Distance						-0.08		
O2->Mode->Speed->Distance						0.11		
O2->Mode->Speed				0.17				
AcceAutoOrig								
MixUseOrig								
DistTransitOrig (O7)			-0.06	-0.05	-0.03[a]			
O7->Mode -> Speed-> Distance					-0.03[a]	0.05		
O7->Mode->Speed->Distance			-0.06			-0.04		
O7->Mode->Speed				-0.07				
AcceAutoDest (D3)			-0.08		0.09[a]			
D3->Mode->Speed			-0.08					
D3->Speed->Distance					0.14			
D3->Mode->Speed->Distance					-0.05			
AcceTransitDest								
ConnDest (D6)			-0.06	-0.04	-0.15	-0.12		
D6->Mode->Speed			-0.06	-0.05				
D6->Speed->Distance					-0.1	-0.08		
D6->Mode->Speed->Distance					-0.04	-0.04		
DistTransitDest								
Age								
Income						0.02[b]		0.04
Income->Speed->Distance						0.03		
Income->Mode->Speed->Distance						-0.01		
Children			-0.05	-0.03				
Children->Mode->Speed			-0.05	-0.03				
Children ->Speed->Distance					0.04	0.03		
Children->Mode->Speed->Distance					-0.03	-0.02		
Children->Mode->Energy							-0.05	0.004
Children->Speed->Energy							-0.01	-0.004
Children->Speed->Mode->Energy							0.007	0.003
Children->Speed->Distance->Energy							0.04	0.02
Children->Mode->Speed->Distance->Energy								-0.02
Race								
Sex					0.04	0.04	0.06[b]	0.03

Sex->Speed->Distance					0.04	0.04		
Sex->Speed->Energy							-0.009	-0.005
Sex->Distance->Energy							0.04	
Sex->Speed->Distance->Energy							0.03	0.03
Worker			0.16	0.11	0.13	0.11	0.33	0.1
Worker->Mode->Speed			0.16	0.14				
Worker ->Mode->Speed->Distance					0.1	0.03		
Worker->Mode->Energy							0.2	-0.02
Worker->Mode->Speed->Energy							-0.02	-0.01
Worker->Mode->Speed->Distance->Energy							0.09	0.07
Worker ->Speed->Distance->Energy								0.02
#Veh					0.21	0.16	0.5	
#Veh->Speed->Distance					-0.1	-0.04		
#Veh->Mode->Speed->Distance					0.26	0.22		
#Veh->Mode->Energy							0.47	
#Veh->Speed->Energy							0.02	0.005
#Veh->Distance->Energy							-0.1	-0.07
#Veh->Mode->Speed->Energy							0.04	-0.03
#Veh->Speed->Distance->Energy							-0.08	
#Veh->Mode->Speed->Distance->Energy							0.24	
Mode					0.38		0.32	0.11
Mode->Speed->Distance					0.38			
Mode->Speed->Energy							-0.09	-0.45
Mode->Speed->Distance->Energy							0.36	
Speed							0.42	
Speed->Distance->Energy							0.57	0.47
Distance								

Appendix IV-2 Decomposed indirect effects of non-work tours and trips

	Non-work (Indirect Effects)							
	Mode		Speed		Distance		Energy	
	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip
PopDensityOrig					-0.05[a]	-0.02[a]		
O1->Speed-> Distance					-0.05[a]	-0.02[a]		
O1->Mode->Speed->Distance								
O1->Mode->Speed								
EmpDensityOrig			0.01[a]	-0.01				
O2->Speed-> Distance								
O2->Mode->Distance					0.02	-0.002		
O2->Mode->Speed->Distance						0.002		
O2->Mode->Speed				-0.01	0.01	-0.01		
AcceAutoOrig								
MixUseOrig								
DistTransitOrig			-0.01[a]					
O7->Mode -> Speed-> Distance								
O7->Mode->Distance					-0.01			
O7->Mode->Speed->Distance					-0.003			
O7->Mode->Speed					-0.005			
AcceAutoDest				0.02	-0.13	-0.04		
D3->Mode->Speed				0.02				
D3->Speed->Distance					-0.09	-0.004		
D3->Mode->Speed->Distance						0.01		
AcceTransitDest				-0.01				
ConnDest				-0.03	-0.09	-0.05		
D6->Mode->Speed				-0.03		-0.03		
D6->Speed->Distance					-0.08	-0.05		
D6->Mode->Speed->Distance						-0.02		
DistTransitDest (D8)				-0.01	-0.09[a]			
D8->Speed->Distance					-0.06			
Age								
Income					0.06	0.02[a]		-0.02[b]
Income->Speed->Distance					0.04			
Income->Mode->Speed->Distance					0.006	-0.02		
Income->Mode->Speed->Distant->Energy					0.006[a]			-0.001
Children			0.02[a]	-0.04	0.05	0.03		
Children->Mode->Speed				-0.04	0.02[a]			
Children ->Speed->Distance						0.03		
Children ->Mode->Distance					0.05	0.02		
Children->Mode->Speed->Distance					0.01	-0.02		
Children->Mode->Energy								
Children->Speed->Energy								0.002

Children->Speed->Mode->Energy								
Children->Speed->Distance->Energy								
Children->Mode->Speed->Distance->Energy					0.01			-0.02
Sex								
Sex->Speed->Distance								
Sex->Speed->Energy								
Sex->Distance->Energy								
Sex->Speed->Distance->Energy								
Edu								
Worker			-0.01[a]	0.01	-0.02[b]			
Worker->Mode->Speed				0.01	-0.01[a]			
Worker ->Mode->Speed->Distance					-0.007[a]			
Worker->Mode->Energy								-0.001
Worker->Mode->Speed->Energy								
Worker->Mode->Speed->Distance->Energy					0.015[a]			0.005
Worker ->Speed->Distance->Energy								
#Veh					0.02	0.06	0.06	0.09
#Veh->Speed->Distance						0.05		
#Veh->Mode->Distance					-0.01	-0.06		
#Veh->Mode->Speed->Distance					-0.003[b]	0.07		
#Veh->Mode->Energy								-0.01[a]
#Veh->Speed->Energy								0.004
#Veh->Distance->Energy								0.04
#Veh->Mode->Speed->Energy					0.0001[a]			0.01
#Veh->Speed->Distance->Energy					-0.013			
#Veh->Mode->Speed->Distance->Energy					-0.003[b]			0.05
Mode					-0.04	0.12	-0.20	0.02[b]
Mode->Speed->Distance					-0.04	0.12		
Mode->Speed->Energy					-0.003[a]			0.01
Mode->Speed->Distance->Energy								
Mode->Distance->Energy					-0.16			-0.08
Mode->Speed->Distance->Energy					-0.04			0.09
Speed							0.49	0.42
Speed->Distance->Energy					0.49			
Distance								

Appendix IV-3 Decomposed indirect effects of mixed tours and trips

	Mixed (Indirect Effects)							
	Mode		Speed		Distance		Energy	
	Tour	Trip	Tour	Trip	Tour	Trip	Tour	Trip
PopDensityOrig								
O1->Speed-> Distance								
O1->Mode->Speed->Distance								
O1->Mode->Speed								
EmpDensityOrig								
O2->Speed-> Distance								
O2->Mode->Distance								
O2->Mode->Speed->Distance								
O2->Mode->Speed								
AcceAutoOrig								
MixUseOrig								
DistTransitOrig			-0.02	-0.03	-0.03[a]	0.02[a]		
O7->Mode->Distance					-0.007			
O7->Mode->Speed->Distance					-0.013	-0.015		
O7->Mode->Speed			-0.02			-0.03		
AcceAutoDest			-0.04					
D3->Mode->Speed			-0.04					
D3->Speed->Distance								
D3->Mode->Speed->Distance					-0.02			
AcceTransitDest				-0.05		-0.04		
ConnDest			-0.05	-0.03	-0.14	-0.06		
D6->Mode->Speed			-0.05			-0.027		
D6->Speed->Distance					-0.11	-0.05		
D6->Mode->Speed->Distance					-0.02	-0.01		
DistTransitDest				-0.01				
D8->Speed->Distance						-0.005		
Age								
Income						0.02		
Income->Speed->Distance						0.03		
Income->Mode->Distance					-0.01	0.005[a]		
Income->Mode->Speed->Distance					-0.02	-0.016		
Income->Mode->Speed->Distant->Energy							-0.02	
Children			-0.06	-0.01				
Children->Mode->Speed			-0.05			-0.039		
Children ->Speed->Distance					0.04			
Children ->Mode->Distance					-0.02			
Children->Mode->Speed->Distance					-0.03	-0.018		
Children->Mode->Energy								0.003
Children->Speed->Energy								
Children->Speed->Mode->Energy								

Children->Speed->Distance->Energy							-0.02	
Children->Mode->Speed->Distance->Energy							-0.03	0.005[b]
Race								
Sex				0.01		0.02		
Sex->Speed->Distance						0.02[a]		
Sex->Speed->Energy								-0.002
Sex->Distance->Energy								
Sex->Speed->Distance->Energy								0.005
Edu								
Worker			0.06	0.07	0.07	0.04	0.17	0.07
Worker->Mode->Speed			0.06					
Worker->Mode->Distance					0.02	-0.01[b]		
Worker ->Mode->Speed->Distance					0.03	0.03		
Worker->Mode->Energy						-0.006[a]		
Worker->Mode->Speed->Energy								-0.009
Worker->Mode->Speed->Distance->Energy							0.02[b]	0.027
Worker ->Speed->Distance->Energy								
Worker->Distance-> Energy						0.046	0.11	
#Veh					0.24	0.07	0.15	
#Veh->Speed->Distance					0.1	0.02[a]		
#Veh->Mode->Distance					0.05	-0.025[a]		
#Veh->Mode->Speed->Distance					0.09	0.076		
#Veh->Mode->Energy								-0.015
#Veh->Speed->Energy								-0.002
#Veh->Distance->Energy							-0.06	
#Veh->Mode->Speed->Energy								-0.008
#Veh->Speed->Distance->Energy							0.1	
#Veh->Mode->Speed->Distance->Energy							0.1	0.07[a]
Mode					0.15	0.13	0.23	0.06
Mode->Speed->Distance					0.15	0.13		
Mode->Speed->Energy								
Mode->Speed->Distance->Energy								
Mode->Distance->Energy							0.09	
Mode->Speed->Distance->Energy							0.15	
Speed							0.51	0.40
Speed->Distance->Energy							0.51	
Distance								

Appendix V-1 Decomposed indirect effects of all tours

	Standard Coefficient	P-Value
O1->Speed->Distance	-0.068	0
O2->Mode->Distance	0.004	0.037
O2->Speed->Distance	0.026	0.032
O2->Mode->Speed->Distance	-0.008	0.029
O5->Mode->Distance	-0.005	0.002
O5->Mode->Speed->Distance	0.008	0.002
O7->Complexity->Distance	-0.011	0.03
O7->Mode->Distance	0.006	0.001
O7->Count->Mode->Distance	0	0.05
O7->Mode->Speed->Distance	-0.011	0
O7->Comp->Mode->Speed->Distance	-0.001	0.039
D3-> Mode-> Distance	-0.006	0.078
D3->Mode->Speed-> Distance	0.011	0.07
D4->Comp->Distance	-0.019	0.026
D4->Mode->Distance	0.008	0.004
D4->Speed->Distance	0.041	0.007
D4->Comp->Mode->Distance	0.001	0.043
D4->Mode->Speed->Distance	-0.015	0.001
D4->Comp->Mode->Speed->Distance	-0.001	0.035
D6->Mode->Distance	0.013	0
D6->Speed->Distance	-0.119	0
D6->Mode->Speed->Distance	-0.023	0
Age->Mode->Distance	-0.022	0
Age->Speed->Distance	-0.052	0
Age->Mode->Speed->Distance	0.041	0
Worker->Mode->Distance	-0.018	0.005
Worker->Speed->Distance	0.026	0.016
Worker->Count->Mode->Distance	0	0
Worker->Count->Mode->Speed->Distance	0.001	0.01
Children->Comp->Distance	-0.023	0
Children->Mode->Distance	0.01	0
Children->Speed->Distance	0.015	0.074
Children->Comp->Mode->Distance	0.001	0.001
Children->Mode->Speed->Distance	-0.019	0
Children->Comp->Mode->Speed->Distance	-0.001	0
SEX->Comp->Distance	-0.01	0.014
SEX->Speed->Distance	0.012	0.084
SEX->Comp->Mode->Distance	0	0.031
SEX->Comp->Mode->Speed->Distance	0	0.022

Income->Comp->Distance	0.01	0.035
Income->Mode->Distance	0.007	0
Income->Comp->Mode->Distance	0	0.053
Income->Mode->Speed->Distance	-0.013	0
Income->Comp->Mode->Speed->Distance	0	0.045
#veh->Mode->Distance	-0.063	0
#veh->Mode->Speed->Distance	0.115	
Comp->Mode->Distance	-0.008	0
Comp->Mode->Speed->Distance	0.015	0
Mode->Speed->Distance	0.207	
O2->Mode->Speed	-0.013	0.029
O5->Mode->Speed	0.015	0
O7->Mode->Speed	-0.019	0
O7->Comp->Mode->Speed		0.039
D3->Mode->Speed	0.02	0.07
D4->Mode->Speed	-0.025	0.001
D4->Comp->Mode->Speed	-0.002	0.035
D6->Mode->Speed	-0.04	0
Age->Mode->Speed	0	0
Children->Mode->Speed	-0.033	0
Children->Comp->Mode->Speed	-0.002	0
Sex->Comp->Mode->Speed	-0.001	0.022
Comp->Mode->Speed	0.027	0
#Veh->Mode->Speed	0.2	0
Sex->Comp->Mode	-0.002	0.021
Income->Comp->Mode	0.002	0.044
Age->Mode->Energy	0.084	0
Age->Speed->Energy	0.011	0
Age->Distance->Energy	0.047	0
Age->Mode->Speed->Energy	-0.009	0
Age->Mode->Distance->Energy	-0.019	0
Age->Speed->Distance->Energy	-0.045	0
Age->Mode->Speed->Distance->Energy	0.035	0
Worker->Comp->Energy	-0.011	0.005
Worker->Mode->Energy	0.068	0
Worker->Speed->Energy	-0.006	0.001
Worker->Distance->Energy	0.072	0
Worker->Comp->Mode->Distance-> Energy	0	0.01
Worker->Mode->Speed->Energy	-0.007	0

Worker->Comp->Distance->Energy	0.011	0.005
Worker->Mode->Distance->Energy	-0.016	0
Worker->Speed->Distance->Energy	0.023	0.001
Worker->Comp->Mode->Speed->Distance->Energy	0.001	0.01
Children->Comp->Energy	0.02	0
Children->Mode->Energy	-0.039	0
Children->Speed->Energy	-0.003	0.08
Children->Comp->Mode->Energy	-0.002	0
Children->Mode->Speed->Energy	0.004	0
Children->Comp->Distance->Energy	-0.02	0
Children->Mode->Distance->Energy	0.009	0
Children->Speed->Distance->Energy	0.013	0.075
Children->Comp->Mode->Speed->Energy	0	0.001
Children->Comp->Mode->Distance->Energy	0.001	0.002
Children->Mode->Speed->Distance->Energy	0.001	0
Children->Comp->Mode->Speed->Distance->Energy	-0.001	0
Sex->Comp->Energy	0.008	0.015
Sex->Speed->Energy	-0.003	0.089
Sex->Distance->Energy	0.027	0.001
Sex->Comp->Mode->Energy	-0.001	0.022
Sex->Comp->Distance->Energy	-0.008	0.014
Sex->Speed->Distance->Energy	0.01	0.084
Sex->Comp->Mode->Speed->Energy	0	0.026
Sex->Comp->Mode->Distance->Energy	0	0.033
Sex->Comp->Mode->Speed->Distance->Energy	0	0.022
Income->Comp->Energy	-0.009	0.036
Income->Mode->Energy	-0.026	0
Income->Comp->Mode->Energy	0.001	0.045
Income->Mode->Speed->Energy	0	0
Income->Comp->Distance->Energy	0.009	0.035
Income->Mode->Distance->Energy	0.006	0
Income->Comp->Mode->Speed->Energy	0	0.05
Income->Comp->Mode->Distance->Energy	0	0.054
Income->Mode->Speed->Distance->Energy	-0.011	0
Income->Comp->Mode->Speed->Distance->Energy	0	0.045
Mode->Speed->Energy	-0.044	0
Mode->Distance->Energy	-0.098	0
Mode->Speed->Distance->Energy	0.178	0
#Veh->Mode->Energy	0.236	0
#Veh->Distance->Energy	0.051	0.001
#Veh->Mode->Speed->Energy	-0.025	0

#Veh->Mode->Distance->Energy	-0.054	0
#Veh->Mode->Speed->Distance->Energy	0	0
Comp->Mode->Energy	0.031	0
Comp->Distance->Energy	0.266	0
Comp->Mode->Speed->Energy	-0.003	0
Comp->Mode->Distance->Energy	-0.007	0
Comp->Mode->Speed->Distance->Energy	0.013	0
Speed->Distance->Energy	0.497	0
Race->Mode->Energy	0.022	0
Race->Mode->Speed->Energy	-0.002	0
Race->Mode->Distance->Energy	-0.005	0
Race->Mode->Speed->Distance->Energy	0.009	0

Appendix V-2 Decomposed indirect effects of all auto tours

	Standard Coefficient	P-Value
O1->Speed->Distance	-0.086	0
O2->Type->Distance		
O2->Speed->Distance	0.032	0.019
O2->Type->Speed->Distance		
O5->Type->Distance		
O5->Type->Speed->Distance		
O7->Complexity->Distance		
O7->Type->Distance		
O7->Count->Type->Distance		
O7->Type->Speed->Distance		
O7->Comp->Type->Speed->Distance		
D3-> Type-> Distance		
D3->Type->Speed-> Distance		
D4->Comp->Distance		
D4->Type->Distance		
D4->Speed->Distance		
D4->Comp->Type->Distance		
D4->Type->Speed->Distance		
D4->Comp->Type->Speed->Distance		
D6->Type->Distance		
D6->Speed->Distance	-0.117	0.000
D6->Type->Speed->Distance		
Age->Type->Distance		
Age->Speed->Distance	-0.038	0.000
Age->Type->Speed->Distance		
Worker->Type->Distance		
Worker->Speed->Distance	0.067	0.000
Worker->Count->Type->Distance		
Worker->Count->Type->Speed->Distance		
Children->Comp->Distance	-0.024	0.000
Children->Type->Distance	0.006	0.000
Children->Speed->Distance		
Children->Comp->Type->Distance		
Children->Type->Speed->Distance		
Children->Comp->Type->Speed->Distance		
SEX->Comp->Distance	-0.01	0.039
SEX->Speed->Distance	0.02	0.004
SEX->Comp->Type->Distance		
SEX->Comp->Type->Speed->Distance		

Income->Comp->Distance	0.017	0.002
Income->Type->Distance		
Income->Comp->Type->Distance		
Income->Type->Speed->Distance	0	0.097
Income->Comp->Type->Speed->Distance		
#veh->Type->Distance	0.003	0.028
#veh->Type->Speed->Distance		
#veh->Comp->Distance	-0.022	0.000
#Veh->Speed->Distance	0.018	0.000
Comp->Type->Distance		
Comp->Type->Speed->Distance		
Type->Speed->Distance		
O2->Type->Speed		
O5->Type->Speed		
O7->Type->Speed		
O7->Comp->Type->Speed		
D3->Type->Speed		
D4->Type->Speed		
D4->Comp->Type->Speed		
D6->Type->Speed		
Age->Type->Speed		
Children->Type->Speed		
Children->Comp->Speed	0.002	0.077
Children->Comp->Type->Speed		
Sex->Comp->Type->Speed		
Comp->Type->Speed		
#Veh->Type->Speed		
Income->Comp->Speed	-0.002	0.093
Sex->Comp->Type		
Income->Comp->Type		
Age->Type->Energy	-0.002	0.002
Age->Speed->Energy	0.002	0.002
Age->Distance->Energy		
Age->Type->Speed->Energy		
Age->Type->Distance->Energy		
Age->Speed->Distance->Energy	0	0.000
Age->Type->Speed->Distance->Energy		
Worker->Comp->Energy	-0.008	0.038
Worker->Type->Energy		

Worker->Speed->Energy	-0.003	0.012
Worker->Distance->Energy	0.057	0.065
Worker->Comp->Type->Distance-> Energy		
Worker->Type->Speed->Energy		
Worker->Comp->Distance->Energy	0.009	0.037
Worker->Type->Distance->Energy		
Worker->Speed->Distance->Energy	0.054	0.000
Worker->Comp->Type->Speed->Distance->Energy	0	0.000
Children->Comp->Energy	0.016	0.000
Children->Type->Energy	0.006	0.003
Children->Speed->Energy		
Children->Comp->Type->Energy		
Children->Type->Speed->Energy		
Children->Comp->Distance->Energy	-0.02	0.02
Children->Type->Distance->Energy		
Children->Speed->Distance->Energy		
Children->Comp->Type->Speed->Energy		
Children->Comp->Type->Distance->Energy		
Children->Type->Speed->Distance->Energy	0	0.083
Children->Comp->Type->Speed->Distance->Energy		
Sex->Comp->Energy	0.007	0.04
Sex->Speed->Energy	-0.001	0.059
Sex->Distance->Energy	0.017	0.06
Sex->Type->Distance->Energy	0.005	0.018
Sex->Comp->Type->Energy		
Sex->Comp->Distance->Energy	-0.008	0.039
Sex->Speed->Distance->Energy	0.018	0.004
Sex->Comp->Type->Speed->Energy		
Sex->Comp->Type->Distance->Energy		
Sex->Comp->Type->Speed->Distance->Energy		
Income->Comp->Energy	-0.012	0.003
Income->Type->Energy		
Income->Comp->Type->Energy		
Income->Type->Speed->Energy		
Income->Comp->Distance->Energy	0.014	0.002
Income->Type->Distance->Energy		
Income->Comp->Type->Speed->Energy		
Income->Comp->Type->Distance->Energy		
Income->Type->Speed->Distance->Energy		
Income->Comp->Type->Speed->Distance->Energy		
Type->Speed->Energy		

Type->Distance->Energy	0.015	0.000
Type->Speed->Distance->Energy		
#Veh->Type->Energy		
#Veh->Distance->Energy		
#Veh->Type->Speed->Energy		
#Veh->Type->Distance->Energy		
#Veh->Type->Speed->Distance->Energy		
Comp->Type->Energy		
Comp->Distance->Energy	0.286	0.000
Comp->Type->Speed->Energy		
Comp->Type->Distance->Energy		
Comp->Type->Speed->Distance->Energy		
Speed->Distance->Energy	0.458	0.000
Race->Type->Energy		
Race->Type->Speed->Energy		
Race->Type->Distance->Energy		
Race->Type->Speed->Distance->Energy		

Appendix V-3 Decomposed indirect effects of all work tours

	Standard Coefficient	P-Value
O1->Speed->Distance	-0.099	0.000
O2->Mode->Distance		
O2->Speed->Distance		
O2->Mode->Speed->Distance	-0.009	0.2
O5->Mode->Distance		
O5->Mode->Speed->Distance	0.01	0.02
O7->Complexity->Distance		
O7->Mode->Distance		
O7->Count->Mode->Distance		
O7->Mode->Speed->Distance	-0.028	0.000
O7->Comp->Mode->Speed->Distance		
D3-> Mode-> Distance		
D3->Mode->Speed-> Distance		
D4->Comp->Distance		
D4->Mode->Distance		
D4->Speed->Distance		
D4->Comp->Mode->Distance		
D4->Mode->Speed->Distance		
D4->Comp->Mode->Speed->Distance		
D6->Mode->Distance		
D6->Speed->Distance	-0.11	0.000
D6->Mode->Speed->Distance	-0.03	0.000
Age->Mode->Distance		
Age->Speed->Distance		
Age->Mode->Speed->Distance	0.036	0.000
Worker->Mode->Distance		
Worker->Speed->Distance		
Worker->Count->Mode->Distance		
Worker->Count->Mode->Speed->Distance		
Children->Comp->Distance		
Children->Mode->Distance		
Children->Speed->Distance	0.03	0.04
Children->Comp->Mode->Distance		
Children->Mode->Speed->Distance		
Children->Comp->Mode->Speed->Distance		
SEX->Comp->Distance		
SEX->Speed->Distance	0.04	0.005
SEX->Comp->Mode->Distance		

SEX->Comp->Mode->Speed->Distance		
Income->Comp->Distance		
Income->Mode->Distance		
Income->Comp->Mode->Distance		
Income->Mode->Speed->Distance		
Income->Comp->Mode->Speed->Distance		
#veh->Mode->Distance		
#veh->Mode->Speed->Distance	0.196	0.000
Comp->Mode->Distance		
Comp->Mode->Speed->Distance	0.02	0.09
Mode->Speed->Distance	0.3	0.000
O2->Mode->Speed		
O5->Mode->Speed	0.02	0.02
O7->Mode->Speed		
O7->Comp->Mode->Speed		
D3->Mode->Speed		
D4->Mode->Speed		
D4->Comp->Mode->Speed		
D6->Mode->Speed	-0.05	0.000
Age->Mode->Speed	0.06	0.000
Children->Mode->Speed	-0.02	0.062
Children->Comp->Mode->Speed		
Sex->Comp->Mode->Speed		
Comp->Mode->Speed	0.04	0.08
#Veh->Mode->Speed	0.31	0.000
Sex->Comp->Mode		
Income->Comp->Mode		
Age->Mode->Energy	0.08	0.000
Age->Speed->Energy		
Age->Distance->Energy		
Age->Mode->Speed->Energy		
Age->Mode->Distance->Energy		
Age->Speed->Distance->Energy		
Age->Mode->Speed->Distance->Energy		
Worker->Comp->Energy		
Worker->Mode->Energy	-0.007	0.000
Worker->Speed->Energy	0.07	0.01
Worker->Distance->Energy	0.04	0.07
Worker->Comp->Mode->Distance-> Energy		

Worker->Mode->Speed->Energy		
Worker->Comp->Distance->Energy		
Worker->Mode->Distance->Energy		
Worker->Speed->Distance->Energy	0.04	0.007
Worker->Comp->Mode->Speed->Distance->Energy	0.001	0.000
Children->Comp->Energy		
Children->Mode->Energy	-0.03	0.06
Children->Speed->Energy		
Children->Comp->Mode->Energy		
Children->Mode->Speed->Energy		
Children->Comp->Distance->Energy		
Children->Mode->Distance->Energy		
Children->Speed->Distance->Energy	0.03	0.04
Children->Comp->Mode->Speed->Energy		
Children->Comp->Mode->Distance->Energy		
Children->Mode->Speed->Distance->Energy	-0.01	0.06
Children->Comp->Mode->Speed->Distance->Energy		
Sex->Comp->Energy		
Sex->Speed->Energy	-0.005	0.01
Sex>Distance->Energy		
Sex->Comp->Mode->Energy		
Sex->Comp->Distance->Energy		
Sex->Speed->Distance->Energy		
Sex->Comp->Mode->Speed->Energy		
Sex->Comp->Mode->Distance->Energy		
Sex->Comp->Mode->Speed->Distance->Energy		
Income->Comp->Energy		
Income->Mode->Energy		
Income->Comp->Mode->Energy		
Income->Mode->Speed->Energy		
Income->Comp->Distance->Energy		
Income->Mode->Distance->Energy		
Income->Comp->Mode->Speed->Energy		
Income->Comp->Mode->Distance->Energy		
Income->Mode->Speed->Distance->Energy		
Income->Comp->Mode->Speed->Distance->Energy		
Mode->Speed->Energy	-0.05	0.000
Mode->Distance->Energy		
Mode->Speed->Distance->Energy	0.3	0.000
#Veh->Mode->Energy	0.42	0.000
#Veh->Distance->Energy	-0.15	0.000

#Veh->Mode->Speed->Energy		
#Veh->Mode->Distance->Energy		
#Veh->Mode->Speed->Distance->Energy	0.18	0.000
Comp->Mode->Energy		
Comp->Distance->Energy	0.51	0.000
Comp->Mode->Speed->Energy		
Comp->Mode->Distance->Energy		
Comp->Mode->Speed->Distance->Energy	0.02	0.09
Speed->Distance->Energy	0.56	0.000
Race->Mode->Energy	0.03	0.000
Race->Mode->Speed->Energy	-0.002	0.018
Race->Mode->Distance->Energy		
Race->Mode->Speed->Distance->Energy	0.000	0.008

Appendix V-4 Decomposed indirect effects of mixed tours

	Standard Coefficient	P-Value
O1->Speed->Distance		
O2->Mode->Distance		
O2->Speed->Distance		
O2->Mode->Speed->Distance		
O5->Mode->Distance		
O5->Mode->Speed->Distance		
O7->Complexity->Distance	-0.04	0.004
O7->Mode->Distance	0.02	0.003
O7->Count->Mode->Distance	0.009	0.005
O7->Mode->Speed->Distance	-0.02	0.002
O7->Comp->Mode->Speed->Distance	-0.008	0.005
D3-> Mode-> Distance	-0.05	0.01
D3->Mode->Speed-> Distance	0.04	0.012
D4->Comp->Distance		
D4->Mode->Distance	0.03	0.06
D4->Speed->Distance		
D4->Comp->Mode->Distance		
D4->Mode->Speed->Distance	-0.02	0.06
D4->Comp->Mode->Speed->Distance		
D6->Mode->Distance	0.08	0.000
D6->Speed->Distance	-0.09	0.000
D6->Mode->Speed->Distance	-0.07	0.000
Age->Mode->Distance	-0.06	0.000
Age->Speed->Distance	-0.11	0.000
Age->Mode->Speed->Distance	0.05	0.000
Worker->Mode->Distance	-0.04	0.000
Worker->Speed->Distance	0.06	0.002
Worker->Count->Mode->Distance	-0.037	0.000
Worker->Count->Mode->Speed->Distance		
Children->Comp->Distance	-0.05	0.006
Children->Mode->Distance	0.05	0.000
Children->Speed->Distance	0.03	0.083
Children->Comp->Mode->Distance	0.01	0.007
Children->Mode->Speed->Distance		
Children->Comp->Mode->Speed->Distance		
SEX->Comp->Distance		
SEX->Speed->Distance		
SEX->Comp->Mode->Distance		
SEX->Comp->Mode->Speed->Distance		

Income->Comp->Distance		
Income->Mode->Distance	0.04	0.000
Income->Comp->Mode->Distance		
Income->Mode->Speed->Distance	-0.04	0.000
Income->Comp->Mode->Speed->Distance		
#veh->Mode->Distance	-0.26	0.000
#veh->Mode->Speed->Distance	0.23	0.000
#veh->Comp->Distance		
#Veh->Speed->Distance		
Comp->Mode->Distance	-0.12	0.000
Comp->Mode->Speed->Distance	0.1	0.000
Mode->Speed->Distance		
O2->Mode->Speed		
O5->Mode->Speed		
O7->Mode->Speed		
O7->Comp->Mode->Speed	-0.01	0.004
D3->Mode->Speed	0.06	0.012
D4->Mode->Speed	-0.03	0.05
D4->Comp->Mode->Speed		
D6->Mode->Speed	-0.09	0.000
Age->Mode->Speed	0.07	0.000
Children->Mode->Speed	-0.06	0.000
Children->Comp->Speed		
Children->Comp->Mode->Speed	-0.01	0.007
Sex->Comp->Mode->Speed		
Comp->Mode->Speed	0.14	0.000
#Veh->Mode->Speed	0.3	0.000
Income->Comp->Speed		
Sex->Comp->Mode		
Income->Comp->Mode		
Age->Mode->Energy	0.06	0.000
Age->Speed->Energy	0.08	0.000
Age->Distance->Energy	0.17	0.000
Age->Mode->Speed->Energy	0.02	0.000
Age->Mode->Distance->Energy	-0.08	0.000
Age->Speed->Distance->Energy		
Age->Mode->Speed->Distance->Energy	0.07	0.000
Worker->Comp->Energy	-0.14	0.000
Worker->Mode->Energy	0.04	0.000

Worker->Speed->Energy	-0.04	0.004
Worker->Distance->Energy		
Worker->Comp->Mode->Distance-> Energy		
Worker->Mode->Speed->Energy	-0.02	0.000
Worker->Comp->Distance->Energy	0.26	0.000
Worker->Mode->Distance->Energy	-0.05	0.000
Worker->Speed->Distance->Energy	0.08	0.000
Worker->Comp->Mode->Speed->Distance->Energy	0.05	0.000
Children->Comp->Energy	0.04	0.000
Children->Mode->Energy	-0.05	0.000
Children->Speed->Energy	-0.02	0.000
Children->Comp->Mode->Energy	-0.01	0.000
Children->Mode->Speed->Energy	0.03	0.000
Children->Comp->Distance->Energy	-0.07	0.006
Children->Mode->Distance->Energy	0.07	0.085
Children->Speed->Distance->Energy	0.04	0.085
Children->Comp->Mode->Speed->Energy	0.01	0.009
Children->Comp->Mode->Distance->Energy	-0.06	0.000
Children->Mode->Speed->Distance->Energy		
Children->Comp->Mode->Speed->Distance->Energy	-0.01	0.008
Sex->Comp->Energy		
Sex->Speed->Energy		
Sex->Distance->Energy		
Sex->Mode->Distance->Energy		
Sex->Comp->Mode->Energy		
Sex->Comp->Distance->Energy		
Sex->Speed->Distance->Energy		
Sex->Comp->Mode->Speed->Energy		
Sex->Comp->Mode->Distance->Energy		
Sex->Comp->Mode->Speed->Distance->Energy		
Income->Comp->Energy		
Income->Mode->Energy	-0.04	0.000
Income->Comp->Mode->Energy		
Income->Mode->Speed->Energy	0.03	0.000
Income->Comp->Distance->Energy		
Income->Mode->Distance->Energy	0.06	0.000
Income->Comp->Mode->Speed->Energy		
Income->Comp->Mode->Distance->Energy		
Income->Mode->Speed->Distance->Energy	-0.05	0.000
Income->Comp->Mode->Speed->Distance->Energy		
Mode->Speed->Energy	-0.28	0.000

Mode->Distance->Energy	-0.63	0.000
Mode->Speed->Distance->Energy	0.54	0.000
#Veh->Mode->Energy	0.26	0.000
#Veh->Distance->Energy	0.3	0.000
#Veh->Mode->Speed->Energy	-0.17	0.00
#Veh->Mode->Distance->Energy	0.33	0.000
#Veh->Mode->Speed->Distance->Energy	0.004	0.000
Comp->Mode->Energy	0.12	0.000
Comp->Distance->Energy	0.85	0.000
Comp->Mode->Speed->Energy	-0.08	0.000
Comp->Mode->Distance->Energy	-0.17	0.000
Comp->Mode->Speed->Distance->Energy	0.15	0.000
Speed->Distance->Energy		
Race->Mode->Energy		
Race->Mode->Speed->Energy		
Race->Mode->Distance->Energy		
Race->Mode->Speed->Distance->Energy		

Appendix V-5 Decomposed indirect effects of all non-work tours

	Standard Coefficient	P-Value
O1->Speed->Distance	-0.05	0.01
O2->Mode->Distance	0.01	0.07
O2->Speed->Distance		
O2->Mode->Speed->Distance		
O5->Mode->Distance		
O5->Mode->Speed->Distance		
O7->Complexity->Distance		
O7->Mode->Distance		
O7->Count->Mode->Distance		
O7->Mode->Speed->Distance		
O7->Comp->Mode->Speed->Distance		
D3-> Mode-> Distance		
D3->Mode->Speed-> Distance		
D4->Comp->Distance		
D4->Mode->Distance		
D4->Speed->Distance		
D4->Comp->Mode->Distance		
D4->Mode->Speed->Distance		
D4->Comp->Mode->Speed->Distance		
D6->Mode->Distance		
D6->Speed->Distance	-0.08	0.000
D6->Mode->Speed->Distance		
Age->Mode->Distance	-0.05	0.000
Age->Speed->Distance	-0.07	0.000
Age->Mode->Speed->Distance		
Worker->Mode->Distance	-0.03	0.000
Worker->Speed->Distance		
Worker->Count->Mode->Distance	-0.001	0.02
Worker->Count->Mode->Speed->Distance		
Children->Comp->Distance		
Children->Mode->Distance	0.016	0.001
Children->Speed->Distance	-0.04	0.006
Children->Comp->Mode->Distance		
Children->Mode->Speed->Distance		
Children->Comp->Mode->Speed->Distance		
SEX->Comp->Distance		
SEX->Speed->Distance		
SEX->Comp->Mode->Distance		
SEX->Comp->Mode->Speed->Distance		

Income->Comp->Distance		
Income->Mode->Distance		
Income->Comp->Mode->Distance		
Income->Mode->Speed->Distance		
Income->Comp->Mode->Speed->Distance		
#veh->Mode->Distance	-0.002	0.02
#veh->Mode->Speed->Distance		
#veh->Comp->Distance	0.02	0.000
#Veh->Speed->Distance		
Comp->Mode->Distance		
Comp->Mode->Speed->Distance		
Mode->Speed->Distance		
O1->Comp->Mode	-0.01	0.05
Worker->Comp->Mode	0.007	0.02
O2->Mode->Speed		
O5->Mode->Speed		
O7->Mode->Speed		
O7->Comp->Mode->Speed		
D3->Mode->Speed		
D4->Mode->Speed		
D4->Comp->Mode->Speed		
D6->Mode->Speed		
Age->Mode->Speed		
Children->Mode->Speed		
Children->Comp->Speed		
Children->Comp->Mode->Speed		
Sex->Comp->Mode->Speed		
Comp->Mode->Speed		
#Veh->Mode->Speed		
Income->Comp->Speed		
Sex->Comp->Mode		
Income->Comp->Mode		
Age->Mode->Energy		
Age->Speed->Energy	-0.007	0.000
Age->Distance->Energy	0.05	0.02
Age->Mode->Speed->Energy		
Age->Mode->Distance->Energy	-0.05	0.000
Age->Speed->Distance->Energy	-0.07	0.000

Age->Mode->Speed->Distance->Energy		
Worker->Comp->Energy	--0.003	0.01
Worker->Mode->Energy		
Worker->Speed->Energy		
Worker->Distance->Energy	0.05	0.01
Worker->Comp->Mode->Distance-> Energy		
Worker->Mode->Speed->Energy		
Worker->Comp->Distance->Energy	0.000	0.01
Worker->Mode->Distance->Energy	-0.03	0.000
Worker->Speed->Distance->Energy		
Worker->Comp->Mode->Speed->Distance->Energy		
Children->Comp->Energy		
Children->Mode->Energy		
Children->Speed->Energy	-0.004	0.007
Children->Comp->Mode->Energy		
Children->Mode->Speed->Energy		
Children->Comp->Distance->Energy		
Children->Mode->Distance->Energy	0.015	0.001
Children->Speed->Distance->Energy		
Children->Comp->Mode->Speed->Energy		
Children->Comp->Mode->Distance->Energy		
Children->Mode->Speed->Distance->Energy		
Children->Comp->Mode->Speed->Distance->Energy		
Sex->Comp->Energy		
Sex->Speed->Energy		
Sex->Distance->Energy		
Sex->Mode->Distance->Energy		
Sex->Comp->Mode->Energy		
Sex->Comp->Distance->Energy		
Sex->Speed->Distance->Energy		
Sex->Comp->Mode->Speed->Energy		
Sex->Comp->Mode->Distance->Energy		
Sex->Comp->Mode->Speed->Distance->Energy		
Income->Comp->Energy		
Income->Mode->Energy		
Income->Comp->Mode->Energy		
Income->Mode->Speed->Energy		
Income->Comp->Distance->Energy		
Income->Mode->Distance->Energy		
Income->Comp->Mode->Speed->Energy		
Income->Comp->Mode->Distance->Energy		

Income->Mode->Speed->Distance->Energy		
Income->Comp->Mode->Speed->Distance->Energy		
Mode->Speed->Energy		
Mode->Distance->Energy	-0.13	0.000
Mode->Speed->Distance->Energy		
#Veh->Mode->Energy		
#Veh->Distance->Energy	0.06	0.01
#Veh->Mode->Speed->Energy		
#Veh->Mode->Distance->Energy	-0.01	0.01
#Veh->Mode->Speed->Distance->Energy		
Comp->Mode->Energy		
Comp->Distance->Energy	0.29	0.000
Comp->Mode->Speed->Energy		
Comp->Mode->Distance->Energy	0.01	0.000
Comp->Mode->Speed->Distance->Energy		
Speed->Distance->Energy	0.47	0.000
Race->Mode->Energy		
Race->Mode->Speed->Energy		
Race->Mode->Distance->Energy		
Race->Mode->Speed->Distance->Energy		

Appendix V-6 Decomposed indirect effects of all work auto tours

	Standard Coefficient	P-Value
O1->Speed->Distance	--0.15	0.000
O2->Type->Distance		
O2->Speed->Distance	0.032	0.019
O2->Type->Speed->Distance		
O5->Type->Distance		
O5->Type->Speed->Distance		
O7->Complexity->Distance		
O7->Type->Distance		
O7->Count->Type->Distance		
O7->Type->Speed->Distance		
O7->Comp->Type->Speed->Distance		
D3-> Comp-> Distance	-0.76	0.004
D3->Type->Speed-> Distance		
D4->Comp->Distance		
D4->Type->Distance		
D4->Speed->Distance		
D4->Comp->Type->Distance		
D4->Type->Speed->Distance		
D4->Comp->Type->Speed->Distance		
D6->Type->Distance		
D6->Speed->Distance	-0.098	0.000
D6->Type->Speed->Distance		
Age->Type->Distance		
Age->Speed->Distance		
Age->Type->Speed->Distance		
Worker->Type->Distance		
Worker->Speed->Distance	0.1	0.000
Worker->Count->Type->Distance		
Worker->Count->Type->Speed->Distance		
Children->Comp->Distance		
Children->Type->Distance		
Children->Speed->Distance		
Children->Comp->Type->Distance		
Children->Type->Speed->Distance		
Children->Comp->Type->Speed->Distance		
SEX->Comp->Distance		
SEX->Speed->Distance	0.06	0.000
SEX->Comp->Type->Distance		

SEX->Comp->Type->Speed->Distance		
Income->Comp->Distance		
Income->Type->Distance		
Income->Comp->Type->Distance		
Income->Type->Speed->Distance		
Income->Comp->Type->Speed->Distance		
#veh->Type->Distance		
#veh->Type->Speed->Distance		
#veh->Comp->Distance		
#Veh->Speed->Distance		
Comp->Type->Distance		
Comp->Type->Speed->Distance		
Type->Speed->Distance		
O2->Type->Speed		
O5->Type->Speed		
O7->Type->Speed		
O7->Comp->Type->Speed		
D3->Type->Speed		
D4->Type->Speed		
D4->Comp->Type->Speed		
D6->Type->Speed		
Age->Type->Speed		
Children->Type->Speed		
Children->Comp->Speed		
Children->Comp->Type->Speed		
Sex->Comp->Type->Speed		
Comp->Type->Speed		
#Veh->Type->Speed		
Income->Comp->Speed		
Sex->Comp->Type		
Income->Comp->Type		
Age->Type->Energy		
Age->Speed->Energy		
Age->Distance->Energy		
Age->Type->Speed->Energy		
Age->Type->Distance->Energy		
Age->Speed->Distance->Energy		
Age->Type->Speed->Distance->Energy		
Worker->Comp->Energy		

Worker->Type->Energy		
Worker->Speed->Energy		
Worker->Distance->Energy	0.08	0.000
Worker->Comp->Type->Distance-> Energy		
Worker->Type->Speed->Energy		
Worker->Comp->Distance->Energy		
Worker->Type->Distance->Energy		
Worker->Speed->Distance->Energy	0.09	0.000
Worker->Comp->Type->Speed->Distance->Energy	0	0.000
Children->Comp->Energy		
Children->Type->Energy		
Children->Speed->Energy		
Children->Comp->Type->Energy		
Children->Type->Speed->Energy		
Children->Comp->Distance->Energy	-0.02	0.02
Children->Type->Distance->Energy		
Children->Speed->Distance->Energy		
Children->Comp->Type->Speed->Energy		
Children->Comp->Type->Distance->Energy		
Children->Type->Speed->Distance->Energy	0	0.083
Children->Comp->Type->Speed->Distance->Energy		
Sex->Type>Energy	0.005	0.08
Sex->Speed->Energy		
Sex->Distance->Energy		
Sex->Type->Distance->Energy		
Sex->Comp->Type->Energy		
Sex->Comp->Distance->Energy	-0.008	0.039
Sex->Speed->Distance->Energy	0.000	0.004
Sex->Comp->Type->Speed->Energy		
Sex->Comp->Type->Distance->Energy		
Sex->Comp->Type->Speed->Distance->Energy		
Income->Comp->Energy		
Income->Type->Energy		
Income->Comp->Type->Energy		
Income->Type->Speed->Energy		
Income->Comp->Distance->Energy		
Income->Type->Distance->Energy		
Income->Comp->Type->Speed->Energy		
Income->Comp->Type->Distance->Energy		
Income->Type->Speed->Distance->Energy		
Income->Comp->Type->Speed->Distance->Energy		

Type->Speed->Energy		
Type->Distance->Energy		
Type->Speed->Distance->Energy		
#Veh->Type->Energy		
#Veh->Distance->Energy		
#Veh->Type->Speed->Energy		
#Veh->Type->Distance->Energy		
#Veh->Type->Speed->Distance->Energy		
Comp->Type->Energy		
Comp->Distance->Energy	0.76	0.000
Comp->Type->Speed->Energy		
Comp->Type->Distance->Energy		
Comp->Type->Speed->Distance->Energy		
Speed->Distance->Energy	0.54	0.000
Race->Type->Energy		
Race->Type->Speed->Energy		
Race->Type->Distance->Energy		
Race->Type->Speed->Distance->Energy		

Appendix V-7 Decomposed indirect effects of all mixed auto tours

	Standard Coefficient	P-Value
O1->Speed->Distance	-0.06	0.01
O2->Type->Distance		
O2->Speed->Distance		
O2->Type->Speed->Distance		
O5->Type->Distance		
O5->Type->Speed->Distance		
O7->Complexity->Distance		
O7->Type->Distance		
O7->Count->Type->Distance		
O7->Type->Speed->Distance		
O7->Comp->Type->Speed->Distance		
D3-> Type-> Distance		
D3->Type->Speed-> Distance		
D4->Comp->Distance		
D4->Type->Distance		
D4->Speed->Distance		
D4->Comp->Type->Distance		
D4->Type->Speed->Distance		
D4->Comp->Type->Speed->Distance		
D6->Type->Distance		
D6->Speed->Distance	-0.12	0.000
D6->Type->Speed->Distance		
Age->Type->Distance		
Age->Speed->Distance	-0.06	0.000
Age->Type->Speed->Distance		
Worker->Type->Distance		
Worker->Speed->Distance	0.06	0.000
Worker->Count->Type->Distance		
Worker->Count->Type->Speed->Distance		
Children->Comp->Distance	-0.03	0.01
Children->Type->Distance		
Children->Speed->Distance		
Children->Comp->Type->Distance		
Children->Type->Speed->Distance		
Children->Comp->Type->Speed->Distance		
SEX->Comp->Distance		
SEX->Speed->Distance		
SEX->Comp->Type->Distance		
SEX->Comp->Type->Speed->Distance		

Income->Comp->Distance		
Income->Type->Distance		
Income->Comp->Type->Distance		
Income->Type->Speed->Distance		
Income->Comp->Type->Speed->Distance		
#veh->Type->Distance		
#veh->Type->Speed->Distance		
#veh->Comp->Distance		
#Veh->Speed->Distance		
Comp->Type->Distance		
Comp->Type->Speed->Distance		
Type->Speed->Distance		
O2->Type->Speed		
O5->Type->Speed		
O7->Type->Speed		
O7->Comp->Type->Speed		
D3->Type->Speed		
D4->Type->Speed		
D4->Comp->Type->Speed		
D6->Type->Speed		
Age->Type->Speed		
Children->Type->Speed		
Children->Comp->Speed		
Children->Comp->Type->Speed		
Sex->Comp->Type->Speed		
Comp->Type->Speed		
#Veh->Type->Speed		
Income->Comp->Speed		
Sex->Comp->Type		
Income->Comp->Type		
Age->Type->Energy		
Age->Speed->Energy	-0.006	0.000
Age->Distance->Energy		
Age->Type->Speed->Energy		
Age->Type->Distance->Energy		
Age->Speed->Distance->Energy	-0.05	0.000
Age->Type->Speed->Distance->Energy		
Worker->Comp->Energy	0.01	0.000
Worker->Type->Energy		

Worker->Speed->Energy		
Worker->Distance->Energy		
Worker->Comp->Type->Distance-> Energy		
Worker->Type->Speed->Energy		
Worker->Comp->Distance->Energy	0.12	0.000
Worker->Type->Distance->Energy		
Worker->Speed->Distance->Energy	0.05	0.000
Worker->Comp->Type->Speed->Distance->Energy		
Children->Comp->Energy	-0.004	0.04
Children->Type->Energy	0.02	0.000
Children->Speed->Energy		
Children->Comp->Type->Energy		
Children->Type->Speed->Energy		
Children->Comp->Distance->Energy	-0.03	0.000
Children->Type->Distance->Energy		
Children->Speed->Distance->Energy		
Children->Comp->Type->Speed->Energy		
Children->Comp->Type->Distance->Energy		
Children->Type->Speed->Distance->Energy		
Children->Comp->Type->Speed->Distance->Energy		
Sex->type->Energy	0.16	0.000
Sex->Speed->Energy		
Sex->Distance->Energy		
Sex->Type->Distance->Energy		
Sex->Comp->Type->Energy		
Sex->Comp->Distance->Energy		
Sex->Speed->Distance->Energy		
Sex->Comp->Type->Speed->Energy		
Sex->Comp->Type->Distance->Energy		
Sex->Comp->Type->Speed->Distance->Energy		
Income->Comp->Energy		
Income->Type->Energy		
Income->Comp->Type->Energy		
Income->Type->Speed->Energy		
Income->Comp->Distance->Energy		
Income->Type->Distance->Energy		
Income->Comp->Type->Speed->Energy		
Income->Comp->Type->Distance->Energy		
Income->Type->Speed->Distance->Energy		
Income->Comp->Type->Speed->Distance->Energy		
Type->Speed->Energy		

Type->Distance->Energy		
Type->Speed->Distance->Energy		
#Veh->Type->Energy	0.01	0.007
#Veh->Distance->Energy		
#Veh->Type->Speed->Energy		
#Veh->Type->Distance->Energy		
#Veh->Type->Speed->Distance->Energy		
Comp->Type->Energy		
Comp->Distance->Energy		
Comp->Type->Speed->Energy		
Comp->Type->Distance->Energy		
Comp->Type->Speed->Distance->Energy		
Speed->Distance->Energy	0.47	0.000
Race->Type->Energy		
Race->Type->Speed->Energy		
Race->Type->Distance->Energy		
Race->Type->Speed->Distance->Energy		

Appendix V-7 Decomposed indirect effects of all nonwork auto tours

	Standard Coefficient	P-Value
O1->Speed->Distance	-0.05	0.01
O2->Type->Distance		
O2->Speed->Distance	0.032	0.019
O2->Type->Speed->Distance		
O5->Type->Distance		
O5->Type->Speed->Distance		
O7->Complexity->Distance		
O7->Type->Distance		
O7->Count->Type->Distance		
O7->Type->Speed->Distance		
O7->Comp->Type->Speed->Distance		
D3-> Type-> Distance		
D3->Type->Speed-> Distance		
D4->Comp->Distance		
D4->Type->Distance		
D4->Speed->Distance		
D4->Comp->Type->Distance		
D4->Type->Speed->Distance		
D4->Comp->Type->Speed->Distance		
D6->Type->Distance		
D6->Speed->Distance	-0.083	0.004
D6->Type->Speed->Distance		
Age->Type->Distance		
Age->Speed->Distance	-0.08	0.000
Age->Type->Speed->Distance		
Worker->Type->Distance		
Worker->Speed->Distance	0.067	0.000
Worker->Count->Type->Distance		
Worker->Count->Type->Speed->Distance		
Children->Comp->Distance		
Children->Type->Distance		
Children->Speed->Distance	-0.04	0.009
Children->Comp->Type->Distance		
Children->Type->Speed->Distance		
Children->Comp->Type->Speed->Distance		
SEX->Comp->Distance	-0.01	0.039
SEX->Speed->Distance	0.02	0.004
SEX->Comp->Type->Distance		
SEX->Comp->Type->Speed->Distance		

Income->Comp->Distance		
Income->Type->Distance		
Income->Comp->Type->Distance		
Income->Type->Speed->Distance		
Income->Comp->Type->Speed->Distance		
#veh->Type->Distance		
#veh->Type->Speed->Distance		
#veh->Comp->Distance		
#Veh->Speed->Distance		
Comp->Type->Distance		
Comp->Type->Speed->Distance		
Type->Speed->Distance		
O2->Type->Speed		
O5->Type->Speed		
O7->Type->Speed		
O7->Comp->Type->Speed		
D3->Type->Speed		
D4->Type->Speed		
D4->Comp->Type->Speed		
D6->Type->Speed		
Age->Type->Speed		
Children->Type->Speed		
Children->Comp->Speed		
Children->Comp->Type->Speed		
Sex->Comp->Type->Speed		
Comp->Type->Speed		
#Veh->Type->Speed		
Income->Comp->Speed		
Sex->Comp->Type		
Income->Comp->Type		
Age->Type->Energy	-0.01	0.002
Age->Speed->Energy	-0.008	0.000
Age->Distance->Energy		
Age->Type->Speed->Energy		
Age->Type->Distance->Energy		
Age->Speed->Distance->Energy	-0.074	0.000
Age->Type->Speed->Distance->Energy		
Worker->Comp->Energy	-0.003	0.01
Worker->Type->Energy		

Worker->Speed->Energy		
Worker->Distance->Energy		
Worker->Comp->Type->Distance-> Energy		
Worker->Type->Speed->Energy		
Worker->Comp->Distance->Energy	-0.02	0.01
Worker->Type->Distance->Energy		
Worker->Speed->Distance->Energy		
Worker->Comp->Type->Speed->Distance->Energy		
Children->Comp->Energy		
Children->Type->Energy	0.03	0.001
Children->Speed->Energy	-0.004	0.01
Children->Comp->Type->Energy		
Children->Type->Speed->Energy		
Children->Comp->Distance->Energy		
Children->Type->Distance->Energy		
Children->Speed->Distance->Energy	-0.04	0.000
Children->Comp->Type->Speed->Energy		
Children->Comp->Type->Distance->Energy		
Children->Type->Speed->Distance->Energy		
Children->Comp->Type->Speed->Distance->Energy		
Sex->type->Energy	0.02	0.000
Sex->Speed->Energy		
Sex->Distance->Energy		
Sex->Type->Distance->Energy		
Sex->Comp->Type->Energy		
Sex->Comp->Distance->Energy		
Sex->Speed->Distance->Energy		
Sex->Comp->Type->Speed->Energy		
Sex->Comp->Type->Distance->Energy		
Sex->Comp->Type->Speed->Distance->Energy		
Income->Comp->Energy		
Income->Type->Energy		
Income->Comp->Type->Energy		
Income->Type->Speed->Energy		
Income->Comp->Distance->Energy		
Income->Type->Distance->Energy		
Income->Comp->Type->Speed->Energy		
Income->Comp->Type->Distance->Energy		
Income->Type->Speed->Distance->Energy		
Income->Comp->Type->Speed->Distance->Energy		
Type->Speed->Energy		

Type->Distance->Energy		
Type->Speed->Distance->Energy		
#Veh->Type->Energy	0.02	0.000
#Veh->Distance->Energy		
#Veh->Type->Speed->Energy		
#Veh->Type->Distance->Energy		
#Veh->Type->Speed->Distance->Energy		
Comp->Type->Energy		
Comp->Distance->Energy	0.31	0.000
Comp->Type->Speed->Energy		
Comp->Type->Distance->Energy		
Comp->Type->Speed->Distance->Energy		
Speed->Distance->Energy	0.48	0.000
Race->Type->Energy		
Race->Type->Speed->Energy		
Race->Type->Distance->Energy		
Race->Type->Speed->Distance->Energy		

Glossary

If needed.

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