IMPACT ANALYSIS OF SITE DEVELOPMENT AND MILEAGE FEE

By

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To my parents

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This dissertation focuses on two types of impact studies: one is related to site developments; the other examines the socioeconomic effects of mileage fees. More specifically, in the first part, the link distribution percentage and special generator methods for performing traffic impact analysis are compared and enhanced; and in the second part, the impacts of adopting a mileage fee in Florida are assessed.

In Florida, both the link distribution percentage and special generator methods are used to conduct traffic impact analysis. However, there is no systematic research to show whether these two methods produce similar results or if one outperforms the other. This dissertation describes an empirical study that compares these two methods. Based on the study, these two methods are observed to produce fairly consistent estimates of traffic impacts caused by the chosen hypothetical scenarios. As the link distribution percentage approach is easier to implement, this dissertation recommends this less cumbersome approach.

However, both of the above mentioned approaches estimate development trips on each link from the path flow or origin-destination (O-D) specific link flow distribution. Since these two flow distributions may not be uniquely determined, an open question

remains regarding the selection of a particular flow distribution as the basis for traffic impact studies. This dissertation suggests using the mean of all the path or O-D specific user equilibrium solutions as the basis for traffic impact studies.

The second part of the dissertation examines the impacts of implementing mileage fees in Florida. Four different mileage fee structures are tested. The result shows that the distributional impacts of the revenue-neutral fee are negligible. However, flat fees are found to be regressive at higher rates. In contrast, step fee, a two-level tariff structure is found to be less regressive. Fees based on vehicle fuel efficiency and vehicle type are found to be environmentally friendly, but are as regressive as flat fees. This dissertation suggests that a complex mileage fee structure is needed to balance the spatial distribution of the impacts, reduce the regressive nature of the fee, generate sufficient revenue, protect the environment, and achieve other objectives simultaneously.

CHAPTER 1
INTRODUCTION

1.1 Background

Good road networks are essential for any country, especially for the United States, where residents are heavily dependent on automobiles. However, providing and maintaining a high standard transportation facility is not an easy task. Many factors can affect travel demand, transportation supply and the performance of road networks. As an example, new development can generate additional travel demands, negatively affecting the level of service on the existing transportation networks. On the other hand, highway improvement projects are costly and related fee-structure changes (e.g., changes in the gasoline tax and in vehicle registration fees, implementation of vehicle miles traveled fees, etc.) can impose substantial socioeconomic impacts. Since the government or concerned authority must clearly understand all these ramifications in order to take appropriate action, impact studies are essential for the decision making process. This dissertation involves two types of impact studies: one examines the influence of site development on vehicular traffic patterns; the other assesses the socioeconomic effects of mileage fees on Florida residents.

A new site development generates additional travel demands that may stress the adequacy of existing road networks. Under the concurrency law of Florida (s. 163.3180, FS), a local government cannot approve a new development unless there will be sufficient transportation facilities to serve the traffic created as a result. The law requires that the level of service (LOS) of the transportation system should not decline when the new development becomes active. If the new development will produce a significant increase in the amount of traffic and impairs the performance of the affected transportation infrastructures, the developer is responsible for any improvement (e.g., additional lane(s), new signal(s) and other transportation facilities) necessary to maintain the original LOS. Therefore, traffic impact analysis (TIA) is required to assess the impacts of the traffic generated from the new development according to the guidelines specified by the concerned state and local government.

The Institute of Transportation Engineers (ITE) has provided general guidelines for performing TIA for any site development (ITE, 2010), but usually state and local governments have more specific requirements and procedures. In Florida, the Department of Transportation has its own site impact handbook (FDOT, 1997) for performing TIA in the state. According to the handbook, the TIA may be performed either via a manual technique or by using a travel demand model (FDOT, 1997). In the former, the total number of trips generated from the proposed development is determined using the trip rates from the Institute of Transportation Engineers' (ITE) Trip Generation report (ITE, 2008) and the size of the new development. Then, trip distribution and assignment are performed to obtain the development trips on each link. One the other hand, when a travel demand model is used, only the required input variables (e.g., number of dwelling units, number of employees, size of the shopping center) are needed as input, and the development traffic on each link is obtained from the model output. Using a travel demand model minimizes the potential bias from a manual procedure and gives better consideration of the level of growth in the region and potential improvements to the transportation network. However, the number of development trips, one of the major requirements for TIA by many authorities, generated from the model often does not match the number calculated manually using the ITE's trip generation rates. As a remedy, two methods are practiced in Florida, the link distribution percentage and the special generator approaches.

In the former, the numbers of dwelling units and employees of a new development are estimated and inserted into the trip generation input file, followed by a travel demand model run to derive the development traffic percentage for each link in the impact area. The percentages are then applied to the external ITE-based trip generation for the new development to quantify its traffic impact. In the special generator approach, the new development is treated as a special generator, whose attraction and possible production are manually calculated based on the ITE Trip Generation report. These are then further adjusted using an iterative method until the trips reported in the model match those in the ITE-based trip generation. Traffic assignment is subsequently conducted to quantify the impact of the proposed development on the traffic network. Both approaches have pros and cons, and there has been no systematic research to show whether the two approaches generate similar results or if one outperforms the other.

There is also another problem in using the travel demand model. Irrespective of the method, commercial software uses the "Select Zone Analysis" module to obtain the development trips (trips to/from the development site) on each link. During the model run, the path flow information is stored, and the development trips are determined from this path flow. However, it is well known that the path flow distributions may not be uniquely determined from the deterministic user equilibrium (UE) assignment, even though the formulation has a unique aggregate link flow solution under mild conditions (Smith, 1979). Despite the occurrence of multiple solutions, the path flow distribution obtained from the select zone analysis is commonly used in practice to conduct traffic impact analysis. Consequently, the results may only represent one out of a number of possible spatial impacts.

TIA is a practical tool to assess the impacts from a new development on the transportation network and to determine the impact fees charged to the developers. But based on the current practice, the impact results may be different for different methods and different software, making it difficult for the concerned authority to defend its analysis. Therefore, one aim of this dissertation is to assess and enhance the current TIA methodology.

Another area of concern is the possible implementation of mileage fees, especially in the state of Florida. The mileage fee concept has gained considerable attention among federal and state governments, because the revenue collected from the gasoline tax is not sufficient to meet transportation funding need in the USA. Due to the unadjusted gasoline tax rate, increasing construction costs, and the introduction of more fuel efficient and hybrid vehicles, the gap between the revenue generated from gasoline taxes and the revenue required for transportation investment is increasing. According to the National Surface Transportation Infrastructure Financing Commission (NSTIFC) formed by the Congress, the total funding gap will be $2.3 trillion for the period 2010 to 2035 (NSTIFC, 2009). Several federal and state studies (TRB, 2006; NSTPRSC, 2007; NSTIFC, 2009; NCF 2005; NCHRP, 2006) have recommended a user fee, more specifically a mileage fee or vehicle miles traveled (VMT) fee, as an alternative to the gasoline tax for long-term transportation needs. The pilot studies, especially Oregon’s Pilot program, have demonstrated the technical feasibility and public acceptability of such fees as the fuel tax replacement. However, equity issues remain as a matter of concern for actual implementation of a mileage fee in real life. The new fee should be equitable among groups who have different incomes and reside in different locations. Although a few studies (e.g., ODOT, 2008) have been performed to assess the socioeconomic impacts of such a fee, no impact study has been conducted for Florida, and results from other states may not be applicable. Given that Florida is one of the states that participated in the mileage fee pilot program and has a strong interest in the mileage fee system, the second aim of this dissertation is the assessment of the effects of mileage fees on drivers in Florida.

1.2 Research Objectives

The objectives of this dissertation are twofold: (1) to examine the methodology of the traffic impact analysis for new site developments; (2) to assess the socioeconomic impacts of implementing statewide mileage fees on residents in Florida. More details of the objectives are described in the following paragraphs.

Impacts of site developments. In this part, we assess and enhance the procedures of traffic impact analysis for new site developments. In particular, we perform the following two tasks: (i) compare two modeling approaches, i.e., the link distribution percentage method and the special generator method, for performing traffic impact analyses for proposed developments in Florida; (ii) provide specific paths or O-D specific user equilibrium solutions that can be used as the basis for conducting traffic impact analysis.

Impacts of mileage fees. In this part, we assess the socioeconomic impacts of implementing mileage fees in Florida. Four mileage fee structures (flat fees, step fees, fees based on vehicle fuel efficiency and fees based on vehicle type) are examined.

The income and spatial equity effects are assessed for different mileage fee scenarios in Florida.

1.3 Dissertation Outline

This dissertation is organized as follows. Chapter 2 reviews the existing literature on traffic impact analysis and the implementation and assessment of mileage fees. Chapter 3 compares two methods of performing TIA: the link distribution percentage and the special generator approaches. Enhancement of the TIA technique is described in Chapter 4. Chapter 5 presents the impact assessments of mileage fees in Florida. Finally, conclusions and recommendations are provided in Chapter 6.

CHAPTER 2
LITERATURE REVIEW

Traffic impact studies are very important in transportation sectors. Without the proper understanding and techniques, it is very difficult to assess the impacts of changes and to improve the system. This dissertation focuses on two impacts on transportation systems: site development and the socioeconomic impacts of mileage fee implementation. This chapter reviews the current Traffic Impact Analysis (TIA) procedures and literature related to site impacts and mileage fees.

2.1 Impact Analysis of Site Development

Every new development generates additional traffic, which often creates congestion and requires improvements in the existing transportation facilities. For that reason, traffic impact analyses are performed to assess the effects of site development and to mitigate the negative impacts. Traffic impact analysis, which is also known as a site impact study, is defined as follows:

> Any effort by the Department to prepare an analysis of or conduct review of an analysis prepared by another party to estimate and quantify the specific transportation-related impacts of a development proposal, regardless of who initiates the development proposal, on the surrounding transportation network (FDOT, 1997).

Under the concurrency law of Florida (s. 163.3180, FS), a local government cannot approve a new development unless transportation facilities are sufficient to serve the traffic created from the new development at the time of occupancy. Moreover, the law requires that the level of service (LOS) of the transportation system not worsen due to the new development. If, however, the new development will produce a large amount of traffic, impairing the performance of the transportation infrastructures, the developer is responsible for any improvement necessary to maintain the original LOS.

Often, developers are required to pay traffic impact fees for improving roads, installing new signals and providing other transportation facilities.

Traffic impact fees are charged to the developers and are used by the local governments. These fees are now considered as a good source of financing for highway networks in many parts of the USA (CMS 2010, PennDOT 2009). Impact fees are generally classified as: “(1) Flat fees that are proportional to some measure of the development’s size; (2) Variable fees that are related to development’s impact; or (3) negotiated fees” (Rosi et al., 1989). Flat fees can be charged based on size, type and location of the development. For example, the city of Orlando has a set fee rate (City of Orlando, 2012). Variable fees are more desirable, as the developers are charged based on the actual impact of the development, and when multiple developments are occurring simultaneously, developers are charged according to their portions of the impacts. Therefore, it is very important to determine the traffic which will arise from the development site.

2.1.1 General Procedure for Traffic Impact Analysis

Traffic impact analysis is performed under the general guidelines recommended by the Institute of Transportation Engineers (ITE, 2010), although states and local governments have their own guidelines and procedures. A typical basic framework for TIA is provided in Figure 2-1, which is adopted from the FDOT's Site Impact Handbook (FDOT, 1997).

In the first step, the developers propose the methodology to perform TIA according to the guidelines of the local government agency. This should be conducted prior to starting of the actual development.

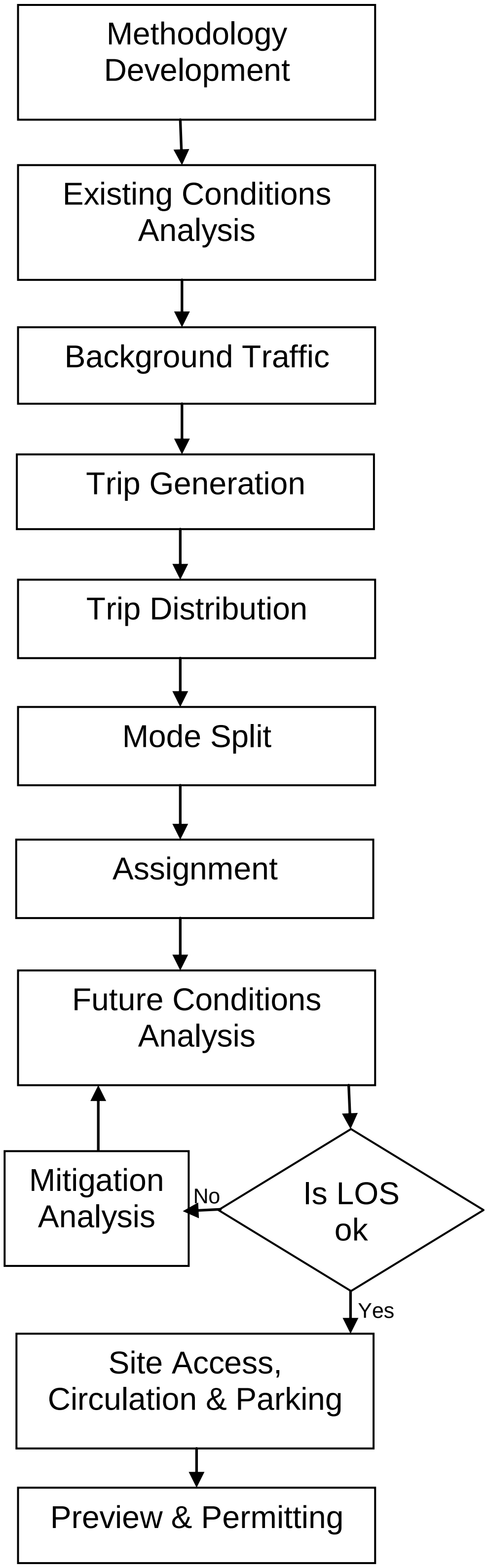

Figure 2-1. Typical basic framework for traffic impact analysis (Source: FDOT, 1997)

The next step is analysis of the existing conditions, including identification of the physical characteristics of the transportation system and traffic operating conditions (i.e., LOS) of roadways and intersections. These analysis results are used as a basis for comparing the condition after the proposed development.

The third step is the determination of background traffic, which is the expected future traffic (without the traffic from development site) at the end of development completion. This can be obtained manually or as part of the modeling process. In determining the impacts of the development on the transportation system, this background traffic is used as the base condition.

The trip generation step estimates the amount of travel associated with the proposed land use, based on the Institute of Transportation Engineers' (ITE) trip generation rates (ITE, 2008). The internal capture (percentage of trips that occur within the site) is also determined at this step using a predetermined percentage.

After the trip generation, trip distribution is performed. At this step, total generated trips are allocated to origins, destinations, and external sites. In the manual process, trip distribution can be performed at the same time as the assignment. Pass-by trips, which are external to the development but are already on the transportation system (i.e., not new trips on the roadway) are then estimated. Since these trips enter the site as an intermediate stop, they are not considered for the TIA.

The mode split step estimates the usages of the various modes available to the site. In the manual method, the amount of travel that uses modes other than automobiles is estimated from regional and local guidelines based on the existing transit usage.

Following the mode split step, an assignment of vehicle trips and transit riders (person-trips) to the transportation system is performed manually or by using a computer-aided travel demand model. The manual assignment process is performed based on engineering judgment.

After the traffic assignment, the impacts of the development-generated traffic on the transportation system are assessed using the LOS guidelines and standards. If the development causes unacceptable LOS on a roadway, the effects of the traffic impacts should be mitigated (i.e. through physical or operational improvements, travel demand management strategies, fair-share contributions, or a combination of these and other strategies).

The site access, site circulation and parking plan are sometimes modified as part of the mitigation analysis. This is an important element in the preparation and review of site impact analyses. Access points are designed in accordance with access management and driveway permitting requirements. Parking is considered if on-street parking will be employed or parking operations have the potential to impact other functions.

Finally, traffic impact analysis is reviewed by the concerned authority for the final approval.

2.1.2 Methods Used by FDOT

In Florida, TIA follows the basic framework described in the previous section, but the implementation may be performed manually (manual calculation) or by using a sophisticated computer-aided travel demand model (FDOT, 1997). The following sections will discuss both of the methods and their pros and cons.

2.1.2.1 Manual method

In the manual method, forecasted background traffic is estimated using existing traffic data trends. Development trips are then determined by applying the Institute of Transportation Engineers' (ITE) trip generation rates (ITE, 2008) according to the size of the development (e.g. gross leasable area). Internal capture and pass-by trips are deducted from the development trips to obtain the net development trips. Finally, net development trips are added to the background trips, and trip distribution and assignments are performed based on experience and judgments.

The manual method has some advantages. It is usually more reliable when development horizons are less than ten years in the future and development size is small (less than 500 peak-hour trips). Another advantage is that the calculations can be performed by technical personnel in a reasonable period of time.

However, this method also has disadvantages. This process assumes that the proposed development will not cause significant diversions in background traffic flow patterns, but this is not always true. More importantly, this method cannot be used for large networks and, as most developments are large in size, this method has little practical use.

2.1.2.2 Travel demand model method

Demand modeling is convenient for large developments with extensive street systems and numerous traffic analysis zones (TAZs). But in this method, the number of development trips, a major requirement for TIA by many authorities, generated by the trip generation module usually does not match the total number of trips calculated manually using the ITE trip generation rates (ITE-based trips). As a remedy, two methods are practiced: the link distribution percentage approach and the special generator approach (FDOT, 1997). These two methods are presented in the following subsections.

Link distribution percentage method. Every travel demand model needs specific input variables for production and attraction estimation (MTPO, 2005). Typical production-related variables are the number of dwelling units, total population, etc, and typical attraction-related variables are the size of the shopping mall, the number of employees and so on. These input variables are required for every Traffic Analysis Zone (TAZ) of the study area. When a new development is proposed in a specific TAZ, the input variables of that TAZ need to be updated. The travel demand model uses predefined production and attraction rates to calculate the number of productions and attractions (FDOT, 1997 and FDOT, 1980). Trip balancing, trip distribution, mode split and traffic assignment are performed according to the model structure. After the model run, total trips (productions plus attractions) generated from the development site are obtained from the trip generation summary, and the trips on each link from the development site are obtained by using “Select Zone Analysis”. The analysis reports the number trips on each link contributed by the proposed development site. The total number of trips generated from the development site obtained from the model usually does not match the value calculated manually using ITE trip generation rates. Therefore, the development trips on each link obtained from the “Select Zone Analysis” cannot be used directly for TIA. In this case, the number of development trips on each link is divided by the total number of generated trips produced by the model to obtain the percentage of development trips on each link. Finally, the ITE-based trips are multiplied by the link percentages to obtain the development trips on each link.

Special generator method. In this approach, the new development is treated as a special generator, whose trip generation characteristics are not fully captured by the trip generation sub-model. The first phase of the method is same as that for the link distribution percentage method. The input variables for productions and attractions for the proposed development are inserted into the model. After the model run, the total number of trips generated from the development site is compared with the ITE-based total. If they do not match, adjustment is performed through the special generator input files, according to the algorithm of the model (FDOT, 2010). Typical adjustment is made by adding/subtracting some number of productions and/or attractions from the TAZ of the proposed development zone. The number added or subtracted is then divided among different trip purposes. Often, this adjustment is an iterative process until the trips reported from the model match the ITE-based trips. The “Select Zone Analysis” is then used to obtain the development trips on each link.

2.1.3 Select Zone Analysis

“Select zone analysis” is a tool used in commercial software (e.g., cube voyager) to determine the number of trips associated with any particular zone. During the traffic impact analysis, flows originating from and/or destined for the new development site are determined by using this tool. The software stores the path flows or origin-destination (O-D) specific link flow distribution across the network with the new development as one of the centroids. Subsequently, the stored path flow information is used to construct the link flows across the network for use in the traffic impact analysis. Therefore, the entire TIA depends on the path flow information generated during the deterministic user equilibrium (UE) assignment. However, it is well known that these path flow and O-D specific link flow distributions may not be uniquely determined from the deterministic user equilibrium (UE) assignment, although the formulation has a unique aggregate link flow solution under mild conditions (Smith, 1979). Despite the nonuniqueness, the path flow distribution obtained during the traffic assignment procedure is commonly used in practice to conduct the select zone analysis. Consequently, the results may only represent one of the multiple possible spatial impacts. Variants of the select zone analysis, i.e., the select node or link analysis, suffer the same limitation.

As a remedy, Rossi et al. (1989) proposed an entropy maximization approach to identify the most likely path flow distribution, which forms the basis for traffic impact studies. Their formulation was path based. In order to overcome the time consuming task of path enumeration, Akamatsu (1997) presented a link-based formulation for finding the entropy-maximizing O-D specific link flow distribution. The entropy maximization approach was recently further explored by Bar-Gera and Boyce (1999), Lu and Nie (2010) and Bar-Gera (2010) among others. In particular, Bar-Gera and Boyce (1999) introduced an interesting behavioral interpretation for the entropy-maximizing path flow distribution: travelers should distribute in the same proportion on each of the two alternative segments regardless of their origins or destinations. Lu and Nie (2010) showed that under certain continuity and strict monotonicity assumptions of the link cost function, the entropy-maximizing path flow distribution is a continuous function of the inputs to a traffic assignment problem, namely the travel demand and parameters in the link cost function. Consequently, small perturbations to those inputs only lead to small changes in the path flow distribution. In this sense, the entropy-maximizing path flow distribution is stable. Bar-Gera (2010) presented an informative review and discussion on computing UE solutions and developed a new algorithm that achieves quick precision and practically equivalent entropy-maximizing solutions.

Despite the above connection and the behavioral interpretation of proportionality, it remains an open question whether the real travel behavior leads to an entropy-maximizing path flow. In fact, entropy maximization is a concept originating from statistical mechanics. To our best knowledge, there is no behavioral evidence to support its applicability to the identification of a path or O-D specific flow solution for traffic impact analysis. Moreover, according to Leung and Yan (1997), compared with the systems in statistical mechanics whose scale are usually in the order of more than 10^{19}, the scale of the spatial interaction system is generally small (e.g., the O-D demand is at most of the order of 10^6, while the path flow is relatively large). The consequence is that the actual probability of the most probable path flow distribution under the entropy maximizing principle is actually very small, although it is large relative to other probabilities. Using an example of O-D trip distribution estimation, Leung and Yan (1997) estimated that the probability of the entropy-maximizing O-D distribution is less than e^{-20}, if the total demand is 5×10^6 and there are 10 origins and 10 destinations. With such a scale of probability, it is difficult to defend use of the entropy-maximization solution as a basis for traffic impact studies: the traffic impact fees are charged based on a flow distribution that may never actually be realized.

2.1.4 Summary

TIA is a mandatory task before the approval of any new development. TIA can be performed either by a manual technique or by a travel demand model. As the manual method is suitable only for small-sized developments in small networks, it has no practical use for large developments or networks. Therefore, a better option for TIA is the use of a travel demand model, in which all analyses are performed on an integrated model network. This process minimizes any potential bias that may result from a manual method. Analysis with the travel demand model is generally performed in two ways: one is the link distribution percentage method and the other is the special generator method. Both methods have pros and cons, and there is no systematic research to show whether the two approaches generate similar results or one outperforms the other. On the other hand, both methods use “Select Zone Analysis” to obtain the number of development trips on each link. Because “Select Zone Analysis” uses the path flow or O-D specific link flow information, the number of development trips obtained from this method may correspond to one of many possible solutions.

As the developers are charged impact fees based on TIA, if different methods yield different results, it is very difficult for the concerned authorities to justify their decisions. Therefore, this dissertation attempts to answer the following questions:

- Between the link distribution percentage and special generator methods, which method should be recommended for TIA?
- Is there a better way or more sound technology to conduct “Select Zone Analysis”?

2.2 Impact Analysis of Mileage Fees

2.2.1 Need for Mileage Fees

Since the 1920s, the primary means of collecting revenue to finance construction, operation and maintenance of US highways has been the fuel tax. But currently, revenue collected from the gasoline tax is not sufficient for highway financing in the USA. Due to political reasons, the gasoline tax has not been increased in proportion to the inflation. The same federal tax rate (18.4 cents per gallon) has been in use since 1993, while construction costs have increased many times. The federal gasoline tax has experienced a cumulative loss in purchasing power of 33% since 1993 (NSTIFC, 2009). In addition, introduction of more fuel efficient and hybrid vehicles causes the tax revenue to decrease even more. Therefore, the gap between the revenue and required funding is increasing daily. According to the National Surface Transportation Policy and Revenue Study Commission (NSTPRSC), the highway account balance (which was positive $9.2 billion in 2006) was projected to be negative $26 billion by 2012 (NSTPRSC, 2007). The National Surface Transportation Infrastructure Financing Commission (NSTIFC) showed that total funding gap will be $2.3 trillion for the period 2010 to 2035 (NSTIFC, 2009). In order to overcome the deficit, federal and state governments are seeking alternatives to current transportation revenue sources with a special focus on an alternative to the fuel tax. Several studies have been performed on this issue, and the recommendations of the major studies are presented below:

The fuel tax and alternatives for transportation funding (TRB, 2006). The main goals of the study were to assess the long-term viability of fuel taxes for transportation finance and to identify finance alternatives. That report concluded:

> A reduction of 20 percent in average fuel consumption per vehicle mile is possible by 2025 if fuel economy improvement is driven by regulation or sustained fuel price increases . . .The willingness of legislatures to enact increases (in fuel tax rates to compensate for reductions in fuel consumption) may be in question. . . Although the present highway finance system can remain viable for some time, travelers and the public would benefit greatly from a transition to a fee structure that more directly charged vehicle operators for their actual use of roads . . . Ultimately, in the fee system that would provide the greatest public benefit, charges would depend on mileage, road and vehicle characteristics, and traffic conditions, and they would be set to reflect the cost of each trip to the highway agency and the public… Road use metering and mileage charging appear to be the most promising approach to this reform within a comprehensive fee scheme that will generate revenues to cover the cost of an efficient highway program in a fair and practical manner.

Transportation for tomorrow (NSTPRSC, 2007). The National Surface Transportation Policy and Revenue Study Commission (NSTPRSC) was established in the Safe, Accountable, Flexible and Efficient Transportation Equity Act-A Legacy for Users (SAFETEA-LU). One of the goals of the commission was to find long-term alternatives to replace or supplement the fuel tax as the principal revenue source to support the highway trust fund. Some related comments include:

> The Commission agrees with others who have looked at long-term alternatives to the fuel tax that a VMT [Vehicle Mile Travel] fee has many promising features; but, until more is known about collection and administrative costs, ways to minimize evasion and the acceptability of such a mechanism to the tax payers, it is premature to rule out other types of taxes and fees to supplement traditional fuel tax revenues… The Commission recommends that the next surface transportation authorization act should fund a major national study to develop a strategy for transitioning to an alternative to the fuel tax to fund highway and transit programs.

Paying our way - a new framework for transportation finance (NSTIFC, 2009). The National Surface Transportation Infrastructure Financing (NSTIF) Commission was established by Congress to provide recommendations for policy and action. The task of the commission was to assess future federal highway and transit investment needs, evaluate the future of the federal Highway Trust Fund, and explore alternative funding and financing mechanisms for surface transportation. The report concluded:

> The current federal surface transportation funding structure that relies primarily on taxes imposed on petroleum-derived vehicle fuels is not sustainable in the long term and is likely to erode more quickly than previously thought…A federal funding system based on more direct forms of 'user pay' charges, in the form of a charge for each mile driven (commonly referred to as a vehicle miles traveled or VMT fee system), has emerged as the consensus choice for the future…commence the transition to a new, more direct user charge system as soon as possible and commit to deploying a comprehensive system by 2020…establish VMT technology standards and require original equipment vehicle manufacturers to install standardized technology by a date certain that will accommodate the desired 2020 comprehensive implementation.

Future highway and public transportation financing (NCF, 2005). The future highway and public transportation finance study was commissioned by the U.S. Chamber of Commerce through the National Chamber Foundation (NCF). The objective of the study was to identify funding mechanisms to meet national highway and transit investment needs. The report concluded:

> Short-Term Strategies: The study finds that indexing federal motor fuel taxes would have the most immediate impact. The motor fuel tax is the only major existing tax that is not indexed to inflation…Midterm Strategies: A new approach to transportation user fees should help meet our nation's transportation needs from 2010 to 2015… Long-Term Strategies: The federal government should provide leadership for state and local governments to implement new systems of financing transportation funding that reduce reliance on the motor fuels tax… the federal government should provide incentives for the states to develop and test new mileage-based revenue systems. This process could lead to the eventual phasing out of the federal motor fuel tax and replacing it with a federal VMT tax.

Future financing options meet highway and transit needs (NCHRP, 2006). The National Cooperative Highway Research Program (NCHRP) conducted research studies on this topic, as requested by the Association of State Highway and Transportation Officials (AASHTO). The objective was to present options for all levels of government to reduce the highway and transit funding deficit. The report concluded:

> For the longer-term, fuel taxes will be vulnerable to fuel efficiency improvements and penetration of alternative fuels and propulsion systems for motor vehicles. Further, continuing reliance on more use of fossil fuel will likely run counter to long-term environmental and energy needs and policies. Several recent national policy studies have recommended shifting to nonfuel-based revenue sources such as VMT fees over the next 15 to 20 years.

The Road User Fee Task Force in Oregon also examined 28 alternative highway financing mechanisms and concluded that a mileage fee was the only broad revenue source that could ultimately replace the fuel tax (ODOT, 2005). But implementing a mileage fee will not be an easy task. There are issues related to technology, institution and public acceptance. In order to assess the feasibility of implementing a mileage fee, several pilot studies have been carried out, as described in the next section.

2.2.2 Pilot Studies on Mileage Fees

Oregon's pilot program (ODOT, 2007). The Oregon Department of Transportation (ODOT) launched a 12-month pilot program in April of 2006 to test the technological and administrative feasibility of implementing the mileage fee concept. The program also tested the feasibility of using this system to collect congestion charges. In Portland, 285 vehicles, 299 motorists and two service stations were recruited for the test.

In the test, ODOT implemented the Vehicle Miles Traveled Collected at Retail (VMTCAR) system. Under this system, both mileage data and fee collection occurred at the gas pump. When a vehicle arrived for gas, a central reader at the station detected whether the vehicle was equipped with the mileage fee technology. If non-equipped vehicles were detected, the vehicles were served as usual and charged using the existing gasoline tax. If an equipped vehicle entered, the stored mileage totals driven in each zone were electronically (short-range radio frequency) transferred to the station’s point-of-sale (POS) system for application of the mileage fee rates. For that purpose, test vehicles were outfitted with GPS-based receivers that identified zones for allocation of miles driven within various predefined regions. Although the position of the vehicle was identified by the global positioning system, the number of miles driven was calculated using the vehicle’s odometer. The system also communicated with the central database via a high speed internet connection to determine the vehicle’s last mileage reading for each zone. By using the mileage fee rates from the central database and the difference between the vehicle’s last and current mileage readings, the total mileage fees were calculated. After the fuel transaction, the customers were given a bill for payment that included both the mileage fee and the fuel purchase price less the state fuel tax. In the Portland study, a flat rate of 1.2 cents per mile was charged, which was said to be equivalent to the existing state fuel tax (24 cents per gallon). The major findings from the study are provided below:

- The concept was found viable with 91% of the pilot program participants agreeing to continue paying the mileage fee if implemented statewide.
- The pilot mileage fee system was successfully integrated with the service station point-of-sale system and the current gasoline tax collection system.
- The mileage fee could be phased in gradually alongside the gas tax.
- Congestion and other pricing options were also found viable. The rush-hour group (charged extra fees for driving during a peak period) reduced peak period travel by about 22% relative to the mileage group (no peak period charge).
- As no specific vehicle point location or trip data were stored, privacy was protected.
- The study also found the system to present minimal burden on businesses, minimal evasion potential, and low cost to implement and administer.

Although the main objective of the pilot study was to assess the feasibility of implementing a mileage fee system, the ODOT also studied motorists’ behavioral changes due to the mileage fee. The study showed that the total mileage driven by the group of participants (who were charged a mileage fee equivalent to the existing gas tax) was reduced by 11% (ODOT, 2007 and Rufolo et al., 2008).

Puget Sound's pilot project (PSRC, 2008). The Puget Sound Regional Council conducted a pilot project from 2005 to 2007 to assess how travelers change their travel behavior (e.g., number, mode, route, and time of vehicle trips) in response to variable charges for road use (variable or congestion-based tolling). In the greater Seattle Region, 450 vehicles from 275 households were equipped with onboard units (GPS receivers, digital roadmaps and cellular communications) to conduct the study. The participants were given a particular budget that they could use. In this study, the tolls were varied by time and location. The onboard units recorded the travel, and corresponding charges were subtracted from the pre-allotted travel budget. The remaining balance from a participant's pre-allotted budget was given to him/her at the end of the study. Some primary findings are stated below:

- Variable charges can significantly reduce traffic congestion and raise revenues for investment.
- The core technology for a satellite-based toll system was found mature and reliable.
- A proven system, viable business model and public acceptance will be required for large-scale deployment.

University of Iowa road user study (Report not available). The University of Iowa Public Policy Center conducted a federally funded study in twelve different states to assess the feasibility and public acceptance of a mileage-based charging system. The field trials were conducted in two phases: the first phase (1200 participants from Austin, Baltimore, Boise, eastern Iowa and the Research Triangle in North Carolina) ended in August 2009; the second phase (1450 participants from Albuquerque, Billings, Chicago, Miami, Portland and Wichita) ended in July 2010. The study considered technology, robustness, privacy and security, transition/phase-in, public policy ramifications and public acceptance to assess the feasibility and efficiency. For the 10-month study, each vehicle was equipped with an electrical unit consisting of an on-board computer system, a global positioning system (GPS) receiver, a simple geographic information system identifying the boundaries of road-use charge jurisdictions, an associated rate table containing the current per-mile charge rate for each vehicle, and a cellular wireless transmitter-receiver. As the vehicle traveled, the charge was calculated by the electrical unit and maintained for each jurisdiction in which the vehicle traveled. The charges were periodically uploaded to a billing and dispersal center via the wireless communication link. In this system, no detailed route or time information was collected. Moreover, data encryption techniques were used to further enhance system privacy and security. Within the system, a different number of vehicle classes could be created and integrated with the electric tolling system. As the final report is not available, we are including some preliminary observations:

- The level of acceptance of the mileage-based fee increased among the participants after a few months of participation in the study.
- GPS was markedly less accurate than the vehicle odometer for measuring the number of miles traveled.
- Retrofitting the onboard unit to a wide variety of vehicles was very difficult.

The mileage fee was being considered to be the most promising alternative to the gasoline tax as a long-term financial mechanism. But there were some issues related to technology, institution and public acceptance. One of the most difficult hurdles was overcoming the technological barrier. Although several studies (Forkenbrock, 2004; Porter et al., 2005) provided technological solutions to implementation of a mileage fee, most government and transport officials were skeptical about the real-life implementation until completion of pilot studies. The findings of the pilot studies indicate that a mileage fee can be implemented in real life with some modification and enhancement of the technology.

2.2.3 Impact Studies on Mileage Fees

Although the pilot studies indicated that the implementation of a mileage fee is technically possible and feasible, there are still some issues which need to be addressed. One of the major concerns of policymakers is the equity issue. The new mileage fee should not adversely affect low income people, and those in rural areas should not suffer more than urban dwellers. Many studies have been undertaken to address these issues.

By using 2001 National Household Travel Survey (NHTS) data, Zhang et al. (2009) showed that short-term and long-term distributional effects of a $0.012/mile flat mileage fee (equivalent to the existing Oregon’s State gas tax of $0.24/gallon) would be small for people with different income levels or in different locations. However, the study expressed concern about the flat rate mileage fee, as this may discourage car owners from buying fuel efficient vehicles, making it difficult to achieve carbon reduction in the future.

In order to promote more fuel efficient vehicles, McMullen et al. (2010) tried a “step” fee policy, in which lower fuel efficiency vehicles were charged more than the higher fuel efficiency vehicles. With 2001 NHTS data from Oregon, the study showed that the step fee structure was more regressive than the flat mileage fee, as low income drivers owned less efficient vehicles.

Larsen et al. (2012) found that an environmentally friendly fee would be horizontally less equitable (rural household contributing a higher percentage of revenue) than a gasoline tax, although they found it equitable among different economic classes. A spatially equitable mileage fee was also assessed and found to be vertically equitable. For their study, the 2009 NHTS data of Texas were used.

Instead of a flat mileage fee, Sana et al. (2010) used mileage-based fees that varied with vehicle type and time of day (peak and off-peak). Nationwide 2001 NHTS data were used in their study. By trial and error, they set fees that could generate sufficient funds to replace the federal gas tax of $0.184/gallon. The authors found that the vehicle miles traveled by every economic class was decreased with the mileage fee. And the mileage fee was also found equitable among the different income classes.

Zhang et al. (2012) assessed the impact of a marginal mileage fee. By using 2009 NHTS data from Oregon, the authors showed that the marginal mileage fee was significantly higher than a mileage fee equivalent to the existing state gas tax. Although the marginal mileage fee would reduce vehicle miles traveled by 27%, the fee was found to be somewhat regressive in nature.

2.2.4 Other Studies on Mileage Fees

By using travel demand and highway expenditure data from the State of Indiana, Oh et al. (2007) studied the mileage fee rate for self-financing highway pricing schemes. The study showed that, with federal aid, a mileage fee of 2.9 cents per mile would cover current expenditures for state-administered highways in the absence of any other revenue source, and that a fee of 2.2 cents per mile would be sufficient if revenue from vehicle registration were maintained.

The Minnesota Department of Transportation conducted a pay-as-you-drive experiment to observe the changes in driving behavior as a result of a mileage fee (Abou-Zeid et al., 2008 and MnDOT, 2006). The study found that the fee had the largest effect on weekend and peak weekday travel.

Litman (1999) showed that total vehicle miles traveled would decline by approximately 25% by imposing different types of mileage fees: weight-distance charges 7.6%, distance-based insurance 12.6%, distance-based registration fees 3.3% and emission fees 6.6%.

DeCorla-Souza (2002) mentioned that converting fixed vehicle charges (such as taxes, insurance, registration and lease fees) into distance-based charges could reduce vehicle miles travel and generate revenue of $44 billion in 20 years. Moreover, this fee would be more equitable and affordable.

2.2.5 Summary

The fuel tax has proven to be a viable mechanism for highway financing for many years. However, many studies (TRB, 2006, NSTPRSC, 2007, NSTIFC, 2009 and others) have indicated that the existing gasoline tax rate is not sufficient to meet the financial needs for building and maintaining road networks in the USA. Short-term deficits can be minimized by increasing the fuel tax, but due to the increasing number of fuel-efficient and hybrid vehicles, the conventional fuel tax is not a viable financing mechanism for the long-term. Therefore, a road-user based fee, more specifically mileage fee or VMT fee, was thought to be most promising alternative to the gasoline tax by most of the study committees.

Pilot programs, especially Oregon’s pilot study, proved that the concept was possible and feasible to implement, and that the fee can be integrated with the current gasoline tax collection system with ease and small cost. Many states, including Florida, are now considering the possibilities of switching from a gasoline tax to a mileage fee (FDOT, 2005). It is critical to know the possible impacts of the new system before its implementation. Although a few studies have been performed on the impacts of mileage fee implementation, none was conducted in the context of Florida. As the state gasoline taxes are different in different states, the required mileage fee to replace the gasoline tax would be different. Moreover, the equity impact would be different in different demographic locations. Therefore, this dissertation attempts to answer the following questions:

- What would be the mileage fees that could replace Florida’s state and local gasoline tax?
- What would be the socioeconomic impacts, if Florida switches from a gasoline tax to mileage fees?
- Can we design a mileage fee structure that is more environmentally friendly and equitable?

CHAPTER 3
COMPARISON OF TRAFFIC IMPACT ANALYSIS METHODS

3.1 Background

In Florida, traffic impact analysis is performed both manually and by using travel demand models. Using the Florida Standard Urban Transportation Model Structure (FSUTMS), which is often used for large networks with large developments, the analysis can be performed in two ways: the link distribution percentage approach and the special generator approach. Detailed descriptions of the methods and their pros and cons are presented in Chapter 2. In this chapter, we describe an empirical study that compares these two methods to determine whether these two approaches generate similar results or if one outperforms the other. The Alachua/Gainesville MPO model is used as the test bed. A number of scenarios of new developments are created by changing various characteristics of two hypothetical developments. The traffic impacts of those hypothetical developments are estimated by implementing these two methods, respectively. A qualitative comparison between these two methods is also presented.

3.2 Qualitative Comparison of the Two Methods

In general, the link distribution percentage method is easier to implement. A single model run is sufficient, and the resulting link distribution percentage pattern can be used in different scenarios. However, this method makes an implicit assumption that the link distribution percentage pattern remains the same, even if a larger number of trips is generated in the new development. The assumption may not be valid, particularly when the network is congested, and the estimates of trip production from the model and the ITE Trip Generation report are substantially different.

The special generator method does not require such an assumption. However, for the special generator, the number of trips needs to be adjusted iteratively until the numbers reported from the travel demand model match the estimates based on the ITE rates. Moreover, the distribution of trip purpose needs to be estimated externally, while in the link distribution percentage method, it is automatically determined by the model. In addition, there are several precautions needed when using the special generator adjustment in a travel demand model: (1) during the adjustment process for special generators, the model should not double count the trips of special generators (one from the regular model and the other from the special generator); (2) if the balancing is performed on the total number of adjusted productions and attractions, significant addition or deletion of trip attractions for special generators will impact the number of trip attractions for zones without special generators; (3) when determining special generator rates from the ITE Trip Generation report, it is important to note that the ITE rates provide vehicle trips, while travel demand models deal with person trips.

3.3 Empirical Study

3.3.1 Study Site

The Alachua/Gainesville MPO (MTPO, 2005) model was selected, given that we were most familiar with the region and had no success in obtaining a real-world new development from another region. The model was built upon Cube Voyager and has been validated using Year 2000 data. In this model, the region is divided into 446 TAZs. With an intention to find an under-developed TAZ to locate the hypothetical new development, the area was carefully searched in Google Map, and all the TAZs having a small amount of trip production and attraction in the model were examined. A few TAZs were identified as potential sites for the case study, located in the northwestern, southwestern, northeastern and southeastern parts of the study area, respectively. Among those potential sites, TAZs 225 and 148 were selected for the empirical study. TAZ 225 is located in the northeast part of the town, near NE Waldo Road, with a total production equal to 243 person trips and total attraction of 90 person trips. TAZ 148 is located in the southeast section, near SE Williston Road and S Main Street, with a total production equal to 64 person trips and total attraction of 158 person trips. Although both zones are currently under-developed, their surrounding areas and road characteristics are different. TAZ 225 is on the outskirt of the city, and the surrounding areas are all under-developed. In contrast, TAZ148 is near downtown, where there is substantial business development and the road network nearby is dense. The study site from Google Map is presented in Figure 3-1 and the TAZ configuration is presented in Figure 3-2.

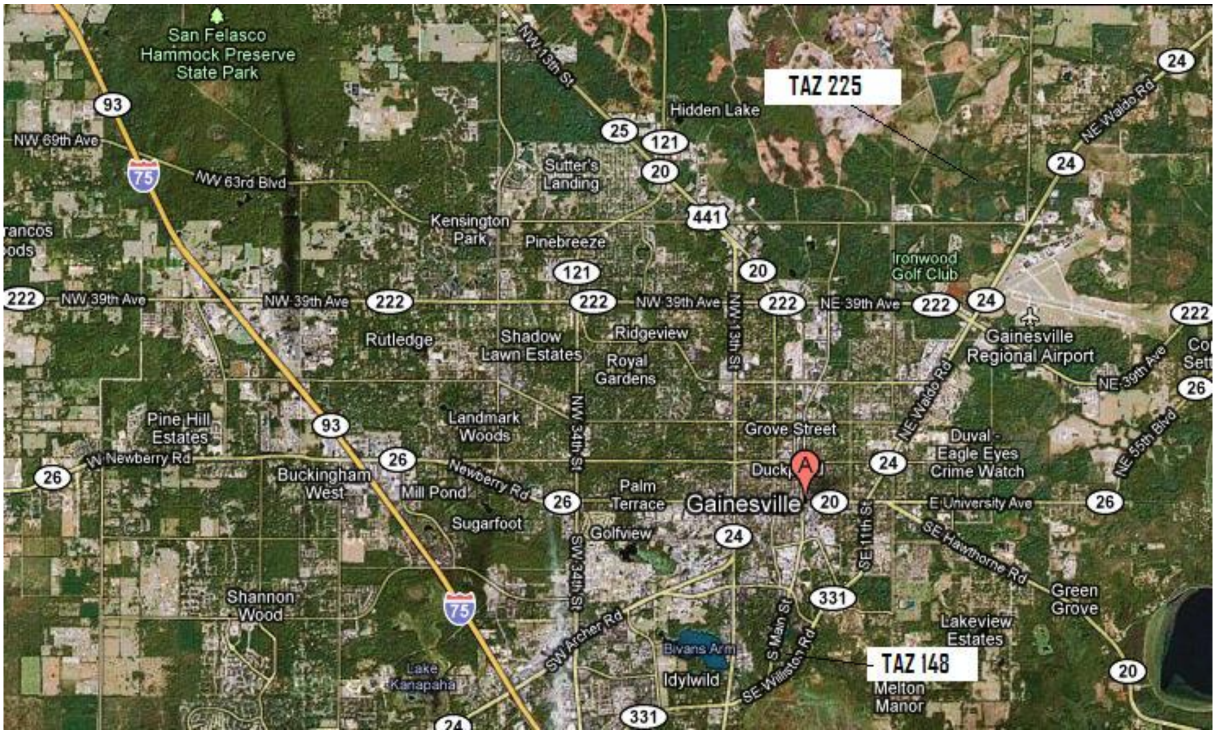

Figure 3-1. Map of the study site (Source: Google map)

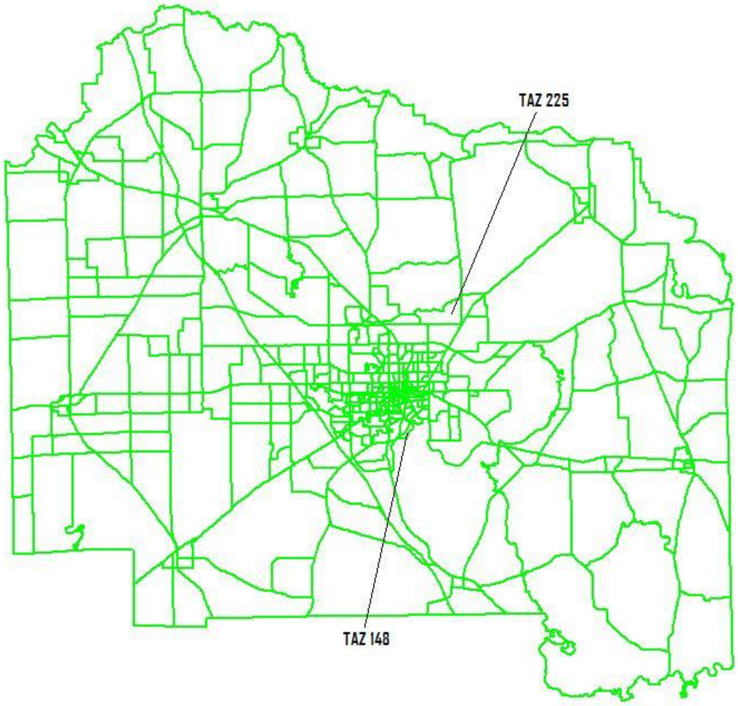

Figure 3-2. TAZ configuration in the Alachua/Gainesville MPO model

3.3.2 The Alachua/Gainesville Model

The Alachua/Gainesville model follows the framework of the Florida Standard Urban Transportation Model Structure (FSUTMS), which is a traditional four-step model (FDOT, 1997). The model uses four zonal data files: ZDATA1 (trip production data), ZDATA2 (trip attraction data), ZDATA3 (special generator data), and ZDATA4 (internal-external production data). The model parameters and trip production and attraction rates are provided within the model. By using the zonal files, parameters and rates, the GEN module generates person trips for seven trip purposes (home-based work, home-based shop, home-based social/recreation, home-based others, non-home-based, truck-taxi and internal-external). Although the GEN module contains a set of default trip attraction rates for all seven trip purposes, customized rates can also be specified in the second part of the GRATE file. After calculating the number of trip productions and attractions by zone and trip purpose using user-supplied or default trip rates, the GEN module adds the special generator trips specified in the ZDATA3 file. The GEN module then adjusts the number of trip attractions in each travel analysis zone, so that total number of trip attractions for each purpose matches the trip production totals for the same purpose.

3.3.3 Implementation of the Two Methods

In our case study, the proposed development is a shopping center, an attraction-only site. Therefore, the input variables related to attraction (ZDATA2 file) need to be updated before executing the model. The relevant input variables are: manufacturing industrial employment by place-of-work (MFGEMP), commercial employment by place-of-work (COMEMP), service employment by place-of-work (SERVEMP), and total employment by place-of-work (TOTEMP). Eight scenarios are created for the new development at either TAZ 225 or 148. The maximum development size is made the same as that of TAZ 237, which contains the Oaks Mall (largest shopping mall in Gainesville), while the other seven are determined arbitrarily, with the size of the shopping mall ranging from 50,000 to 100,000 square feet. The input data for these eight scenarios and the current situation of both TAZs are provided in Tables 3-1 and 3-2, respectively.

Table 3-1. Input data for hypothetical development scenarios

Scenario	OIEMP	MGEMP	COMEMP	SEREMP	TOTEMP
1	0	10	170	20	200
2	0	20	250	30	300
3	0	26	500	50	576
4	0	26	700	70	796
5	0	36	1000	100	1136
6	0	36	1200	130	1366
7	0	36	1500	150	1686
8	0	36	2358	238	2632

Table 3-2. Current situation in TAZs 225 and 148

TAZ	OIEMP	MGEMP	COMEMP	SEREMP	TOTEMP
225	0	6	0	0	6
148	0	0	0	30	30

Link distribution percentage method. The employment data for the development site is updated in ZDATA2 file according to a specific development scenario. After executing the model, the development traffic on each link attributable to the new development is obtained from the “Select Zone Analysis”. The total trip generation (both production and attraction) of the development site is retrieved from the “Generation Summary”. Consequently, the link percentage, i.e., the percentage of new development trips coming to each link, is calculated as the ratio between the development traffic on each link and the total generation of the site. Finally, the "real" number of development trips on each link is obtained by multiplying an external estimate of the total trips generated from the new development by the link percentages. The external estimate can be made with reference to the ITE Trip Generation report. In this analysis, the estimates are made using the rates recommended by FDOT (FDOT, 1980), instead of the ITE rates. The relevant shopping trip rates are summarized in Table 3-3.

Table 3-3. Trip rates recommended by FDOT (Source: FDOT, 1980)

Retail shopping centers	Recommended attraction trip rates	Recommended major trip purposes
200,000 sq. ft. or more	13 Trips/Employee	Home-Based Shop
100,000-200,000 sq. ft.	33 Trips/Employee	Home-Based Shop
50,000-100,000 sq. ft.	30 Trips/Employee	Home-Based Shop

* Assuming that the size of the hypothetical shopping center is between 50,000 and 100,000 sq. ft, the rate of 30 trips per employee is used in our analysis.

Special generator method. Similar to the link distribution percentage approach, the employment data for the development site are updated in ZDATA2. The new development is then treated as a special generator, and its attraction is further adjusted in ZDATA3 during iterative runs of the model until the number of trips reported from the model matches the external estimate of ITE trip generation. Instead of assigning all the adjusted trips to be home-based shopping trips, those attractions are distributed among five trip purposes as follows: 14% for home-based work, 44% for home-based shopping, 4% for home-based social recreation, 12% for home-based others and 26% for non-home-based. Final adjustments made in ZDATA3 file are provided in Table 3-4. After the final adjustment, the development traffic on each link attributable to the new development is obtained from the "Select Zone Analysis".

Table 3-4. Adjustment for special generator (Number of trips added)

TAZ	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
225	2800	4500	8000	11000	16000	19000	23000	36000
148	3000	4300	8500	11000	16000	19000	23500	36000

3.4 Results

The traffic impacts of the proposed eight hypothetical scenarios in two different TAZs (TAZ 148 and TAZ 225) were estimated by implementing both the link distribution percentage and special generator methods. The number of productions and attractions of the development TAZs obtained from the model run and manually calculated number of ITE-based trips are summarized in Tables 3-5 and 3-6. As expected, the number of trip attractions predicted from the MPO model does not match the number of ITE-based trip attractions, thereby justifying the need for these two methods.

Table 3-5. Summary of trip generation (TAZ 225)

Scenario no.	Total production from model	Total attraction from model	Total ITE attraction
1	1055	1908	6000
2	1444	2781	9000
3	2620	5388	17280
4	3564	7476	23880
5	2988	10608	34080
6	5954	12724	40980
7	7350	15752	50580
8	11409	24473	78960

Table 3-6. Summary of trip generation (TAZ 148)

Scenario no.	Total production from model	Total attraction from model	Total ITE attraction
1	817	1831	6000
2	1205	2703	9000
3	2379	5310	17280
4	3325	7395	23880
5	4748	10530	34080
6	5715	12648	40980
7	7110	15675	50580
8	11169	24395	78960

Figures 3-3 to 3-11 show graphical representations of the flow distribution across the network, and the volumes from TAZ 225 or 148, both without and with a new development (only scenario 8) before and after the special generator trip adjustments. From Figures 3-3 to 3-7, we can see that the traffic pattern across the network looks similar before and after the development, even though the maximum size development was used. This is due to the fact that additional trips generated from the development sites are distributed within the entire network, giving a false impression about the effect of new development. For that reason, select zone analysis is performed to determine the development traffic from the new site. From Figures 3-8 to 3-11, the traffic flow distribution from the new development site is not same before and after the special generator adjustment. The differences in these before and after comparisons may be a source of concern when using the link distribution percentage method.

Figure 3-3. Flow distribution without new development

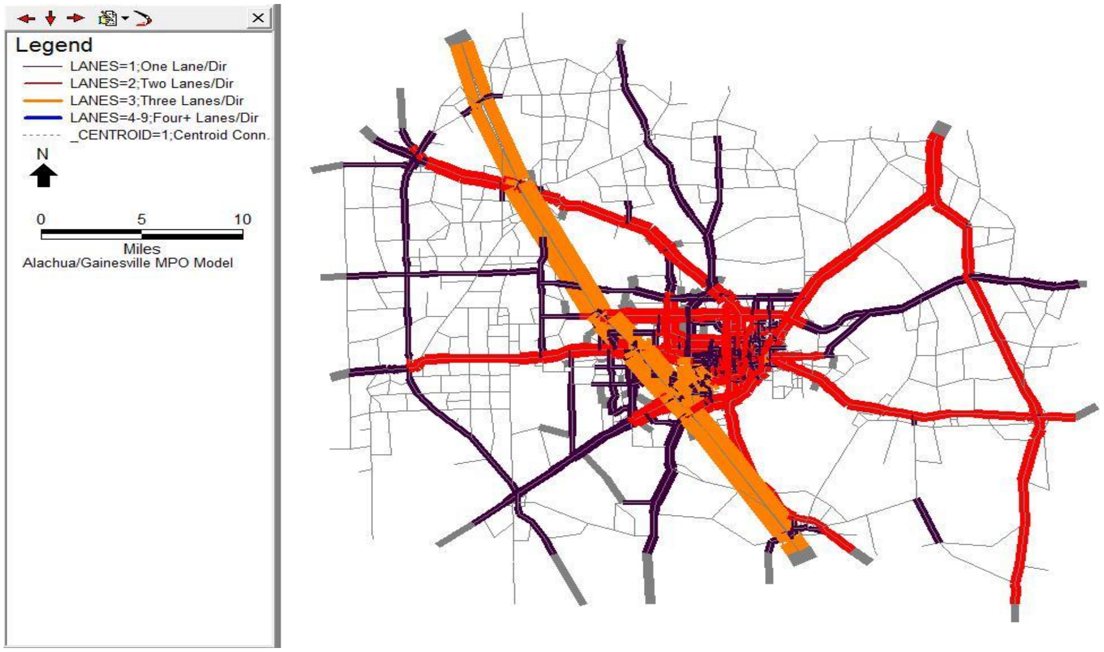

Figure 3-4. Flow distribution with development scenario 8 in TAZ 225 before special generator adjustments

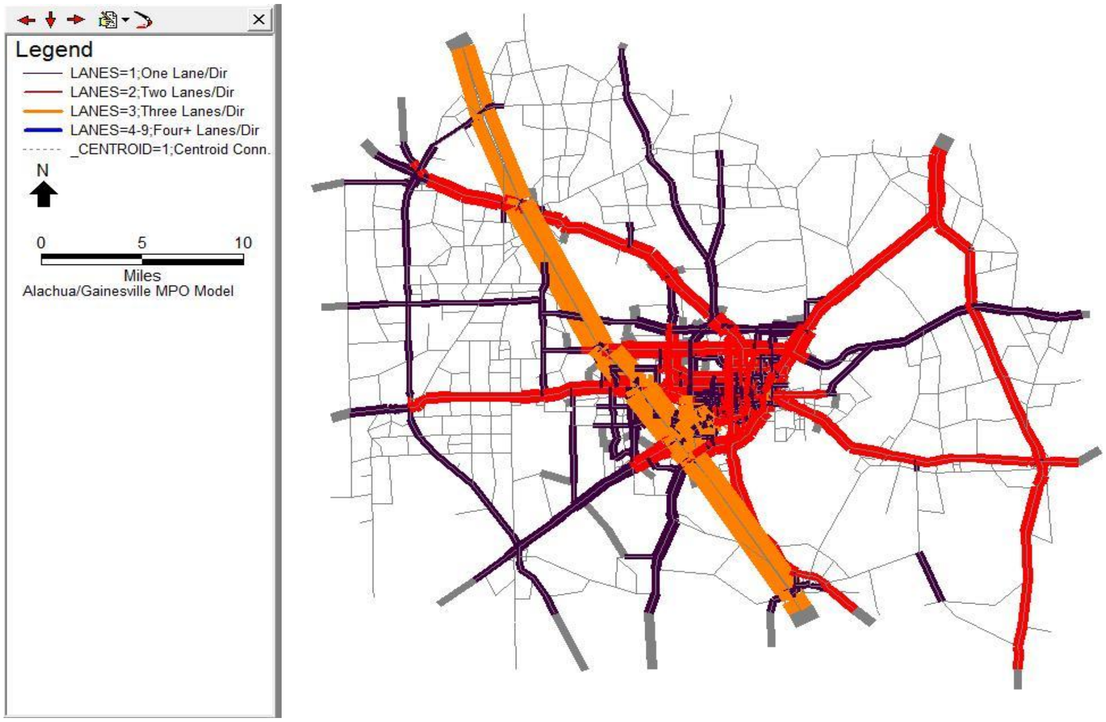

Figure 3-5. Flow distribution with development scenario 8 in TAZ 225 after special generator adjustments

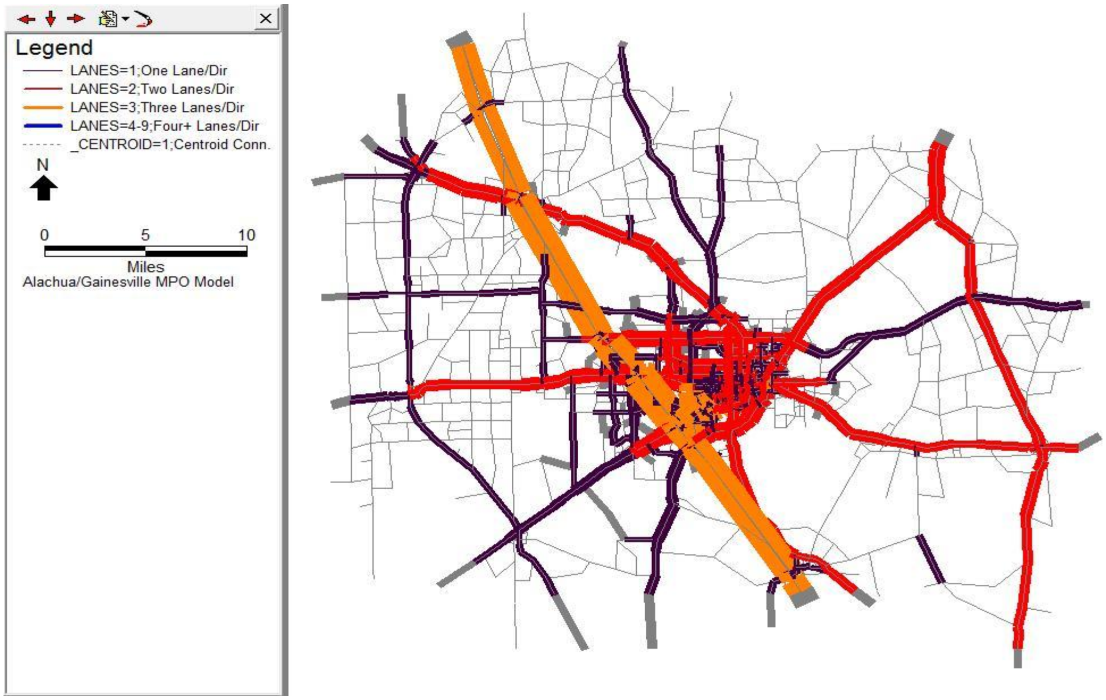

Figure 3-6. Flow distribution with development scenario 8 in TAZ 148 before special generator adjustments

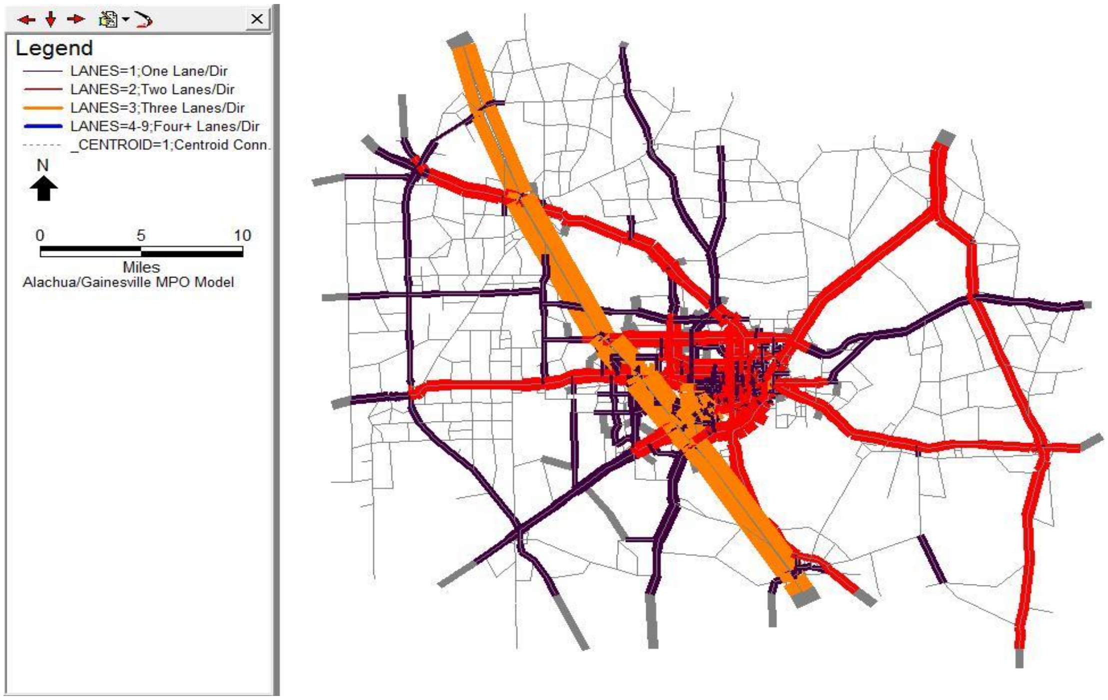

Figure 3-7. Flow distribution with development scenario 8 in TAZ 148 after special generator adjustments

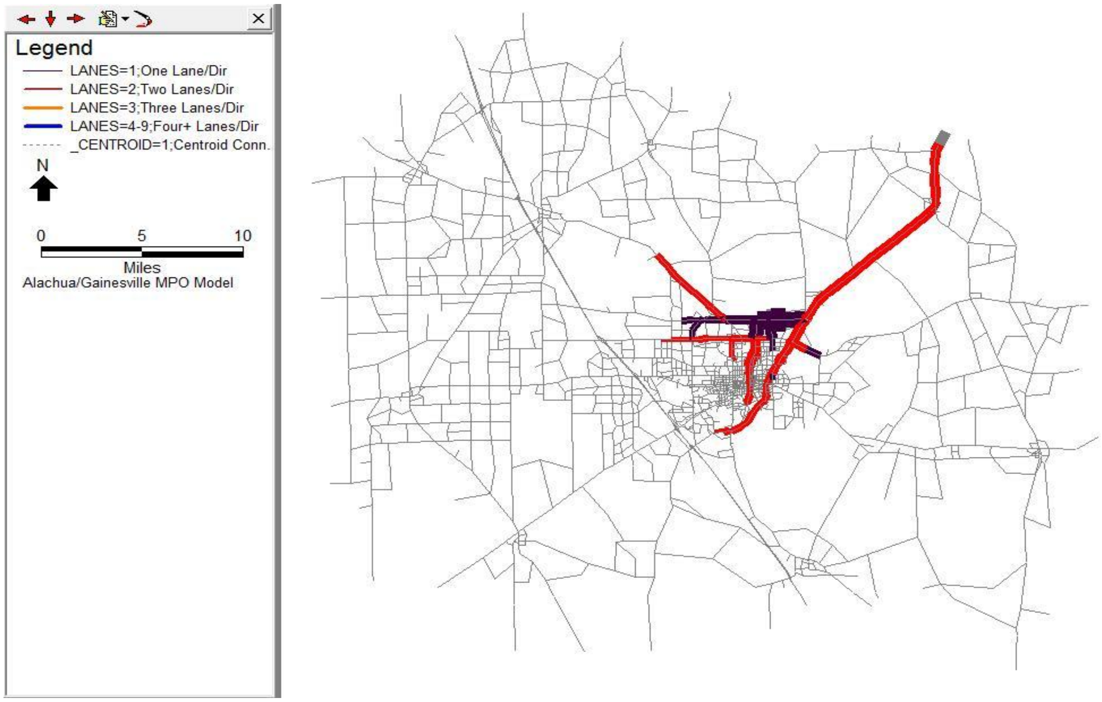

Figure 3-8. Traffic volumes from TAZ 225 with development scenario 8 before special generator adjustments

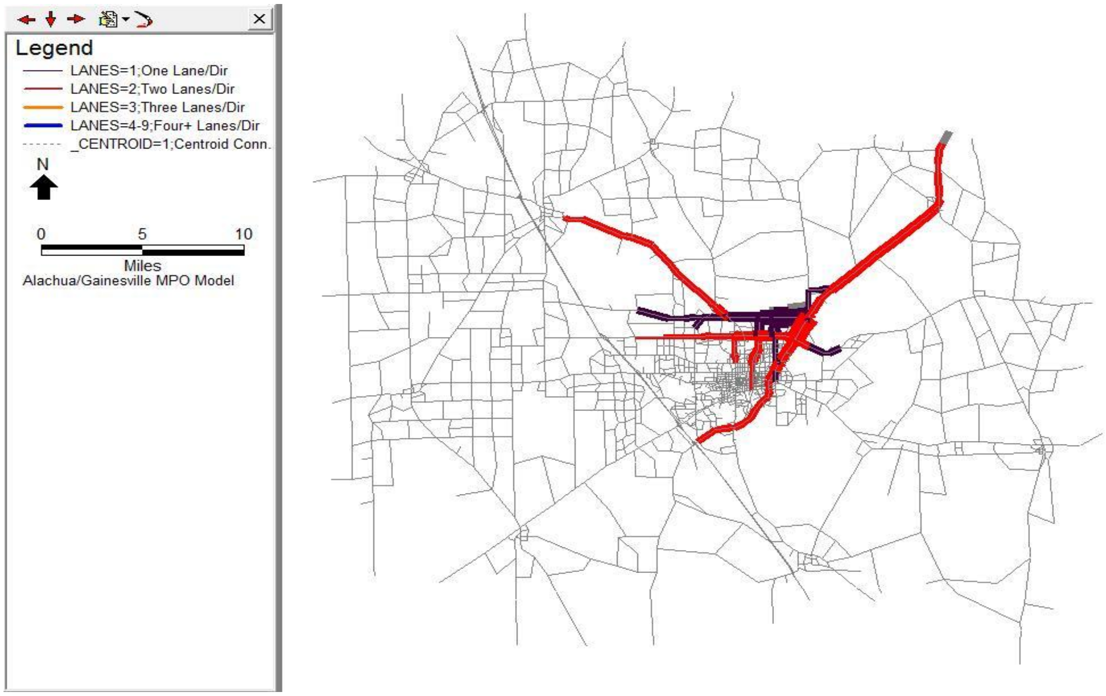

Figure 3-9. Traffic volumes from TAZ 225 with development scenario 8 after special generator adjustments

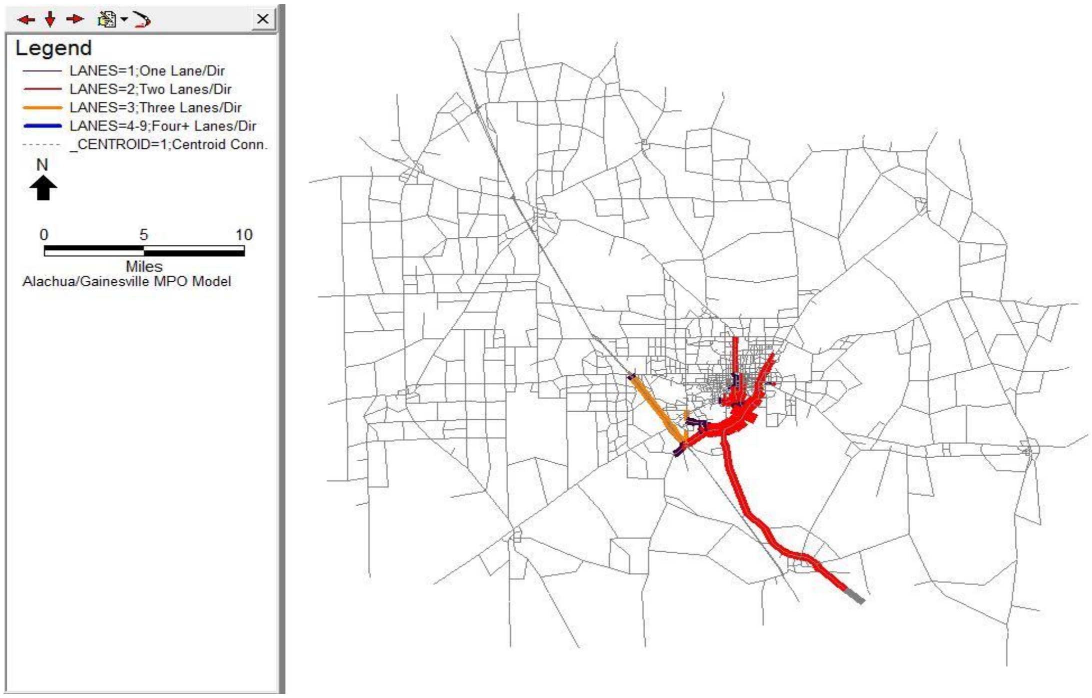

Figure 3-10. Traffic volumes from TAZ 148 with development scenario 8 before special generator adjustments

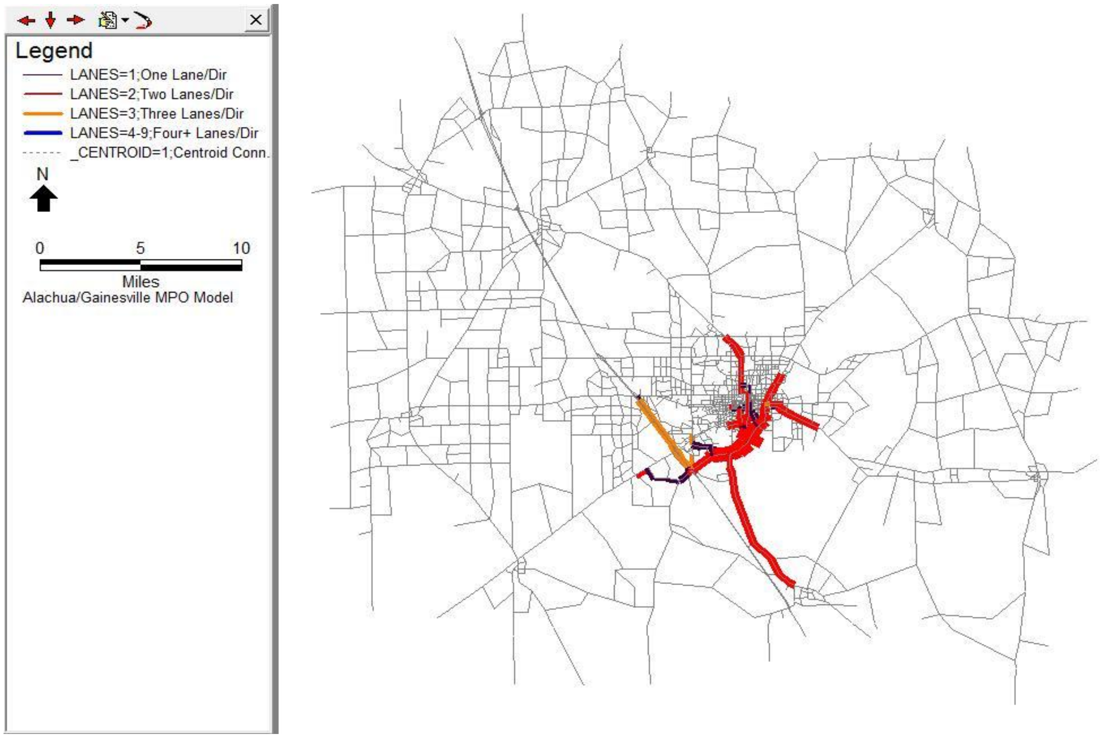

Figure 3-11. Traffic volumes from TAZ 148 with development scenario 8 after special generator adjustments

The link volumes obtained from the link distribution percentage and special generator methods are provided in Tables 3-7 to 3-10. Note that there are 6252 links in the network, and the analyses are performed for all the 8 scenarios. However, only the top 10 links with large development traffic for scenarios 1 (smallest size development) and 8 (largest size development) are presented here. The numbers of development trips on each link obtained from both methods are consistent up to scenario 7 for both of the sites (TAZ 148 and TAZ 225). However, for scenario 8, the number of development trips on each link for TAZ 148 is consistent, but there is a significant difference for TAZ 225 (Table 3-9). Although both of the sites use the same development size, their locations are different; TAZ 148 is located in a developed area and TAZ 225 is located in an under-developed area. With a large-scale development, the assumption of the constant link distribution percentage pattern unlikely holds in the link distribution percentage method in TAZ 225. On the other hand, the large amount of attraction to the new development may cause the special generator approach to produce a distorted trip distribution pattern for the originally under-developed area (TAZ 225). Both factors and possibly others act together and result in the observable discrepancy. The sum of the total number of development trips obtained from both methods is also compared and found to be consistent with the ITE-based trips (Tables 3-11 and 3-12).

Table 3-7. Link volumes of top 10 links (TAZ 225 with scenario 1)

Rank	Link		Development volume on each link	
	Node A	Node B	Link percentage method	Special generator method
1	225	2873	2637	2741
2	2873	225	2637	2741
3	2802	2799	2096	2161
4	2873	2802	2096	2161
5	2799	2802	2095	2159
6	2802	2873	2095	2159
7	2799	2675	1590	1596
8	2675	2799	1581	1582
9	2675	2657	1129	1069
10	2657	2675	1153	1040

Table 3-8. Link volumes of top 10 links (TAZ 148 with scenario 1)

Rank	Link		Development volume on each link	
	Node A	Node B	Link percentage method	Special generator method
1	148	2445	2653	2868
2	2445	148	2653	2868
3	2583	2445	1644	1794
4	2586	2583	1644	1794
5	2445	2583	1621	1772
6	2583	2586	1621	1772
7	2431	2432	1132	1125
8	2432	2434	1132	1125
9	2434	2586	1132	1125
10	2432	2431	1106	1102

Table 3-9. Link volumes of top 10 links (TAZ 225 with scenario 8)

Rank	Link		Development volume on each link	
	Node A	Node B	Link percentage method	Special generator method
1	2873	225	27106	24150
2	225	2873	27106	23915
3	2802	2799	18055	14585
4	2873	2802	18055	14585
5	2799	2802	18037	14506
6	2802	2873	18037	14506
7	2927	2938	4412	10314
8	2938	2927	4393	10235
9	2899	2901	4025	10099
10	2901	2927	4025	10099

Table 3-10. Link volumes of top 10 links (TAZ 148 with scenario 8)

Rank	Link		Development volume on each link	
	Node A	Node B	Link percentage method	Special generator method
1	148	2445	31043	32261
2	2445	148	31043	32261
3	2583	2445	18925	19015
4	2586	2583	18925	19015
5	2445	2583	18679	18834
6	2583	2586	18679	18834
7	2445	2325	11995	13028
8	2325	2445	11748	12847
9	2201	2185	11414	11813
10	2203	2201	11414	11813

Table 3-11. Sum of total development trips on each link (TAZ 225)

Scenario	Link distribution percentage method	Special generator method
1	137879	139387
2	201779	207687
3	368514	368992
4	495303	499519
5	742180	701632
6	802607	831169
7	963182	1014026
8	1429331	1629316

Table 3-12. Sum of total development trips on each link (TAZ 148)

Scenario	Link distribution percentage method	Special generator method
1	138166	149192
2	205705	214804
3	389945	405600
4	532974	556633
5	750133	796274
6	892270	951532
7	1095832	1171383
8	1631178	1818451

The numbers of development trips on each link obtained from the link distribution percentage and special generator methods are compared for every link in the network. For this purpose, the root mean square errors (RMSEs), defined below (Equation 3-1), are calculated for every scenario using the special generator method as the base case:

$$RMSE = \frac{\sqrt{\sum_a (x_a^S - x_a^L)^2}}{\sum_a x_a^S} \tag{3-1}$$

where x_a^S denotes the development trips on link a by the special generator method (base case), and x_a^L denotes the development trips on link a by the link distribution percentage method.

Calculated RMSEs are presented in Tables 3-13 and 3-14 and in Figures 3-12 and 3-13. These tables and figures indicate that these two methods produce fairly consistent estimates of traffic impacts caused by the different development scenarios in both of the two hypothetical development sites (TAZ 148 and TAZ 225). The RMSEs between the results from these two approaches are very small, ranging from 0.0058 to 0.0219.

Table 3-13. Comparison of two methods (TAZ 225)

Scenario	ITE attractions of development zone	RMSE
1	6000	0.0063
2	9000	0.0063
3	17280	0.0107
4	23880	0.0145
5	34080	0.0185
6	40980	0.0166
7	50580	0.0163
8	78960	0.0219

Table 3-14. Comparison of two methods (TAZ 148)

Scenario	ITE attractions of development zone	RMSE
1	6000	0.0064
2	9000	0.0058
3	17280	0.0059
4	23880	0.0063
5	34080	0.0073
6	40980	0.0075
7	50580	0.0081
8	78960	0.0103

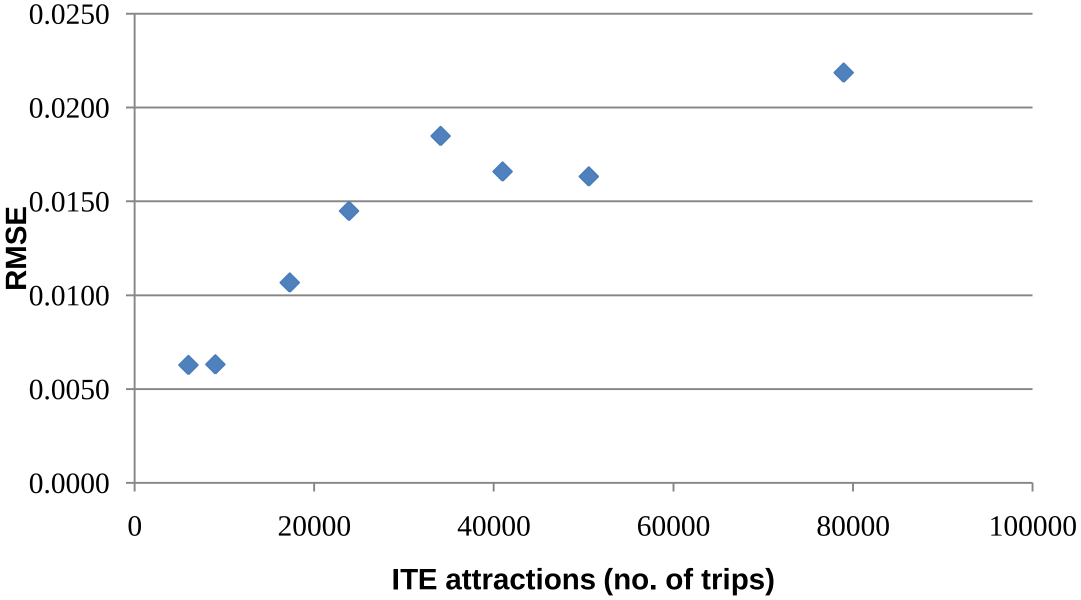

Figure 3-12. RMSE of development link flows from two methods (TAZ 225)

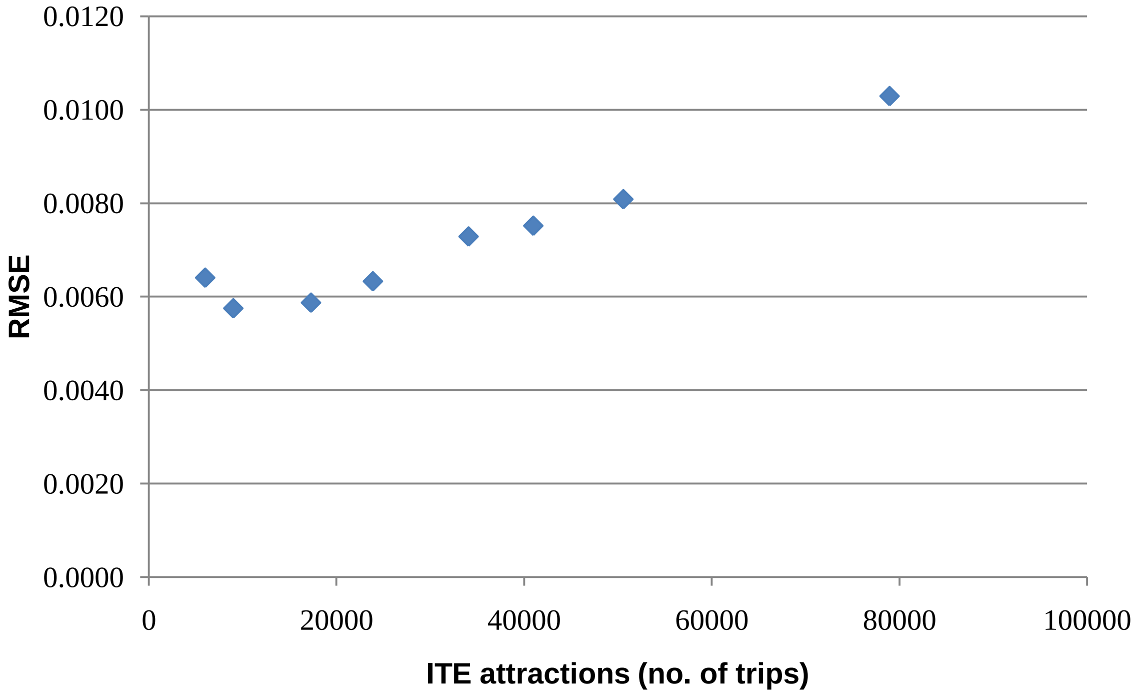

Figure 3-13. RMSE of development link flows from two methods (TAZ 148)

To investigate how the link percentage pattern varies across different scenarios, the link percentages obtained from different scenarios are also compared. Only the 10 links with the largest percentage of development traffic are presented in Tables 3-15 and 3-16. RMSEs are calculated for every scenario relative to the link percentages from scenario 1. The comparisons are presented in Table 3-17 and Figure 3-14. The RMSE values are very small in this case study, but the RMSE increases with increasing development size. This implies that the link percentages obtained from different scenarios are fairly consistent as long as the difference between the number of trips generated from the model and number of ITE-based trips is not significant.

Table 3-15. Link percentages of top 10 links (TAZ 225)

Node A	Node B	Link % (S1)	Link % (S2)	Link % (S3)	Link % (S4)	Link % (S5)	Link % (S6)	Link % (S7)	Link % (S8)
225	2873	37.38	36.94	35.49	34.52	38.25	32.67	31.83	29.99
2873	225	37.38	36.94	35.49	34.52	38.25	32.67	31.83	29.99
2802	2799	29.71	29.24	27.89	26.86	29.11	24.50	22.74	19.98
2873	2802	29.71	29.24	27.89	26.86	29.11	24.50	22.74	19.98
2799	2802	29.70	29.24	27.19	26.86	28.97	23.83	22.62	19.96
2802	2873	29.70	29.24	27.19	26.86	28.97	23.83	22.62	19.96
2799	2675	22.54	22.14	21.10	20.42	22.63	19.27	18.65	14.95
2675	2799	22.41	21.95	21.09	20.44	22.63	19.29	18.71	15.05
2657	2675	16.34	15.88	14.98	14.33	15.36	13.08	12.23	8.92
2675	2657	16.00	16.05	14.89	14.08	14.62	12.35	12.32	8.86

Table 3-16. Link percentages of top 10 links (TAZ 148)

Node A	Node B	Link % (S1)	Link% (S2)	Link % (S3)	Link % (S4)	Link % (S5)	Link % (S6)	Link % (S7)	Link % (S8)
148	2445	38.92	38.71	37.99	37.47	36.80	36.38	35.81	34.44
2445	148	38.92	38.71	37.99	37.47	36.80	36.38	35.81	34.44
2583	2445	24.11	23.97	23.64	23.19	22.90	22.44	22.19	21.00
2586	2583	24.11	23.97	23.64	23.19	22.90	22.44	22.19	21.00
2445	2583	23.77	23.61	23.15	22.87	22.49	22.15	21.84	20.72
2583	2586	23.77	23.61	23.15	22.87	22.49	22.15	21.84	20.72
2431	2432	16.60	16.48	16.21	15.76	15.54	15.23	14.98	13.87
2432	2434	16.60	16.48	16.21	15.76	15.54	15.23	14.98	13.87
2434	2586	16.60	16.48	16.21	15.76	15.54	15.23	14.98	13.87
2432	2431	16.22	16.10	15.74	15.54	15.24	14.90	14.60	13.54

Table 3-17. Variations of link distribution percentages of different scenarios

Scenario	RMSE (TAZ 225)	RMSE (TAZ 148)
1	N/A (Base Case)	N/A (Base Case)
2	0.0028	0.0022
3	0.0049	0.0027
4	0.0063	0.0035
5	0.0065	0.0041
6	0.0117	0.0049
7	0.0147	0.0055
8	0.0207	0.0083

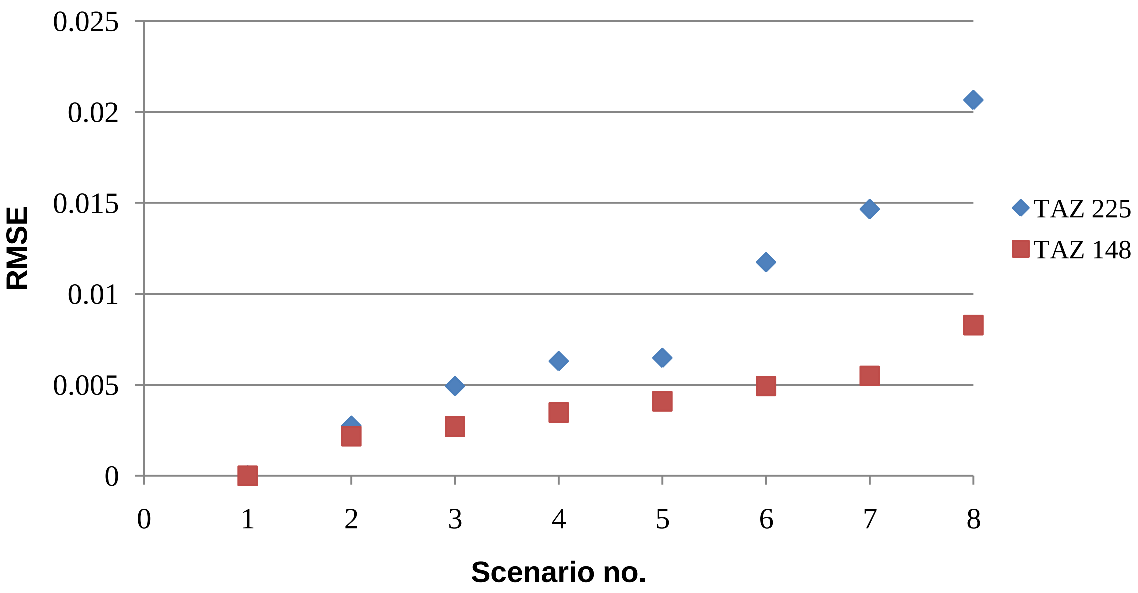

Figure 3-14. Variations of link distribution percentages of different scenarios

3.5 Summary

Both the link distribution percentage and special generator methods are used for performing traffic impact studies in Florida. In this chapter, we present an empirical study to compare these two methods. The Alachua/Gainesville MPO model used for this study is a traditional four step model built upon Cube Voyager software. Eight hypothetical development scenarios are built in two sites to compare these two methods.

Based on this empirical study, the link distribution percentage method and the special generator method produce fairly consistent estimates of traffic impacts caused by different scenarios created in two hypothetical development sites. The RMSEs between the results from these two approaches are very small, ranging from 0.0058 to 0.0219. As the link distribution percentage method is easier to implement than the special generator method, we recommend the link distribution percentage method for TIA.

The link distribution percentage method makes an implicit assumption that the link distribution percentage pattern remains the same, even if a larger number of trips is generated in the new development. The assumption may not be valid, particularly when the network is congested, and the estimates of trip production from the travel demand model and the ITE Trip Generation report are substantially different. However, this is not evident in our experiment. More specifically, the link percentage patterns obtained for the different scenarios are also very consistent, with the RMSE ranging from 0.0022 to 0.0207.

The quality of the results produced by the link distribution percentage method depends on how well the trip generation module replicates the real scenario of the modeling area. With a well-developed trip generation module, there is no need to rely on the ITE Trip Generation report to estimate the trip generation from the new development. Consequently, the link distribution percentage method will produce accurate estimates. Indeed, since there is no need to introduce a special generator to capture the difference, these two methods coincide again.

However, both of the above mentioned methods are based on the “Select Zone Analysis”. For the analysis, the planning software stores the path flows during the traffic assignment procedure and then estimates the number of development trips based on the stored path flows. Since the path flow patterns from traffic assignment are not unique, the estimates may represent one of many possibilities. The analysis should be performed with extreme caution (Bar-Gera et al., 2010). As a remedy, we propose using the average path flow distribution (see Chapter 4) as the basis for the “Select Zone Analysis”.

CHAPTER 4
ENHANCING SELECT ZONE ANALYSIS

4.1 Background

The “Select Zone Analysis” examines the spatial impacts of a new development and plays a critical role in traffic impact studies. More specifically, it estimates the link flows that originate from and/or are destined for the new development (i.e., the link uses created by the new development). Doing so requires knowledge of the path flow distribution or origin-destination (O-D) specific link flow distribution across the network with the new development as one of the centroids. However, it is well known that these two flow distributions may not be uniquely determined from a deterministic user equilibrium (UE) assignment, although the formulation has a unique aggregate link flow solution under mild conditions (Smith, 1979). As a remedy, Rossi et al. (1989) proposed an entropy maximization approach to identify the most likely path flow distribution and suggested using it as the basis for traffic impact studies. After a further discussion on the entropy maximization approach, we propose using another path flow or O-D specific link flow distribution as the basis for the select zone analysis and the subsequent traffic impact studies. Given that there is no behavioral evidence to favor one particular solution over another, in this dissertation all solutions are treated equally with the same merit. In other words, each solution is assumed to have an equal probability of occurrence. Consequently, the mean of all the path or O-D specific link flow solutions, which is essentially the center of gravity of the UE polyhedron, seems a logical selection for the basis of traffic impact studies. Numerical examples are provided to demonstrate the proposed approach and to compare it with the entropy-maximizing approach.

4.2 Impact of Nonuniqueness on Select Zone Analysis

Bar-Gera and Luzon (2007) conducted a computational study on the Chicago network to demonstrate the nonuniqueness of UE path flow solutions. The network consists of 93,513 O-D pairs and 127,248 UE paths. Their computational study revealed that flows on 41% of the UE paths, carrying 13% of the total demand, are not uniquely determined.

In a similar spirit, this section presents a small example to highlight the impact of nonunique path flow solutions on the outcome of the select zone analysis. We estimate the upper and lower bounds of the link use by a new development on each link. Coincidence of the two bounds of one link implies that the link use can be uniquely determined for that particular link. Otherwise, the distance between these two bounds reflects the severity of the nonuniqueness.

To present the mathematical formulations for estimating these bounds, we define $G=(N,A)$ as a strongly connected road network, with N and A being the sets of nodes and links respectively. There are two methods for representing the traffic flows on a road network, namely link-based and path-based. For the former, let Δ denote the node-link incidence matrix of the road network. By definition, Δ must be of size $|N|\times|A|$ where $|\circ|$ denotes the cardinality of a set. We use w as the index for O-D pairs and W as the set of all O-D pairs, with q^w denoting the travel demand for O-D pair w. It is assumed that q^w is given for all w. Let $o(w)$ and $d(w)$ represent the origin and destination of O-D pair w, and D^w the demand vector whose elements satisfy the requirement that $D^w_{o(w)}=q^w$ or $D^w_{d(w)}=-q^w$ and $D^w_i=0$ for all the other nodes i.

Additionally, link is denoted as a or by the pair of its starting and ending nodes, i.e., (i, j). For O-D pair w, x_a^w or x_{ij}^w represents the traffic flow on link $a = (i, j)$ from users traveling from the origin to the destination of O-D pair w. The vector $x^w \in R^{|A|}$ having x_a^w as its elements denotes the link flow vector for the O-D pair w with x as a vector with the link flows for all O-D pairs as its elements. The sum $v = \sum_w x^w$ is the associated aggregate link flow vector. Then, the set of all feasible flow distributions can be described as follows: $V^x = \{v \mid v = \sum_w x^w, \Delta x^w = D^w, x^w \geq 0, \forall w\}$.

Let f_r^w denote the amount of flow on path r that connects O-D pair w and δ_{ar} (equals 0 or 1) indicates whether link a is on path r. Then, the following set is equivalent to V^x:

$V^f = \{v \mid v_a = \sum_w \sum_{r \in P^w} \delta_{ar} f_r^w; \sum_{r \in P^w} f_r^w = q^w, \forall w; f_r^w \geq 0, \forall w, r\}$ where P^w is the set of paths for O-D pair w.

Let $t_a(v_a)$ denote the time or cost to traverse link a and $t(v)$ is a vector of these link travel times. It is further assumed that $t_a(v_a)$ is strictly monotone. It is well known that $v^{UE} = \arg\min_{v} \left\{ Z_1 = \sum_a \int_0^{v_a} t_a(z)dz : v \in V^f \text{ or } v \in V^x \right\}$ is the UE flow distribution. We further define $X = \{x \mid v^{UE} = \sum_w x^w, \Delta x^w = D^w, x^w \geq 0, \forall w\}$ as the set of all O-D specific link flow solutions associated with the aggregate UE flow distribution, and $F = \{f \mid v_a^{UE} = \sum_w \sum_{r \in P^w} \delta_{ar} f_r^w; \sum_{r \in P^w} f_r^w = q^w, \forall w; f_r^w \geq 0, \forall w, r\}$ as the set of UE path flow solutions. Both X and F are polyhedral convex sets.

Assuming that the new development is located in node s, the upper (maximum) and lower (minimum) bounds of the use of link a by node s can be estimated by solving the following linear programs: $\max/\min\left\{\sum_{s=o(w)\,\mathrm{or}\,d(w)} x_{ij}^{w} : x \in X\right\}$. The objective function is to maximize or minimize the sum of the O-D specific flows whose origin or destination is node s. This linear program is solved for every link in the network to obtain the upper and lower bound of the development flow on the link.

For comparison, we also compute the link uses estimated based on the maximum entropy user equilibrium (MEUE) solution to the following nonlinear convex program (Akamatsu, 1997): $\min\left\{\sum_{w}\sum_{ij} x_{ij}^{w}\ln x_{ij}^{w} - \sum_{w}\sum_{j}\left(\sum_{i} x_{ij}^{w}\right)\ln\left(\sum_{i} x_{ij}^{w}\right) : x \in X\right\}$

The nine-node network, as illustrated in Figure 4-1, is used in our numerical example. The free-flow travel times and capacities of each link are provided in parenthesis in the figure. The BPR (Bureau of Public Road) travel cost function is used, and the O-D demands are $q^{1-3} = 10$, $q^{1-4} = 20$, $q^{1-8} = 10$, $q^{2-3} = 30$, $q^{2-4} = 40$, $q^{2-7} = 20$, $q^{5-4} = 10$ and $q^{6-3} = 20$.

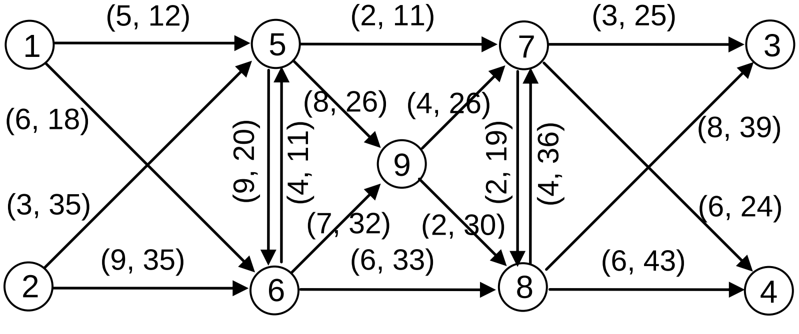

Figure 4-1. The Nine-node network

With node 1 being the new development, Table 4-1 presents different estimates of number of link uses, including the upper bound, lower bound and the values based on the notion of entropy maximization. The results show that the number of link uses of 10 links (out of 18 total) by node 1 cannot be uniquely determined. The distances between the upper and lower bounds are substantial, indicating that there will be a larger error if we arbitrarily select one particular path or O-D specific flow solution to conduct the select zone analysis. On the other hand, the estimates based on the entropy-maximizing solution are always between the upper and lower bounds, which is intuitively correct and consistent with the notion of “no route will be left behind” in the entropy-maximizing solution described by Bar-Gera (2010).

Table 4-1. Link uses of node 1

Link	UE aggregate link flow	Upper bound of link use	Lower bound of link use	Link use based on MEUE
1-5	11.22	11.22	11.22	11.22
1-6	28.78	28.78	28.78	28.78
2-5	50.32	0.00	0.00	0.00
2-6	39.68	0.00	0.00	0.00
5-6	0.00	0.00	0.00	0.00
5-7	31.11	11.22	0.00	2.52
5-9	40.42	11.22	0.00	8.70
6-5	0.00	0.00	0.00	0.00
6-8	52.36	28.78	0.00	17.09
6-9	36.10	28.78	0.00	11.69
7-3	36.21	10.00	0.00	6.26
7-4	10.84	10.85	0.00	2.41
7-8	0.00	0.00	0.00	0.00
8-3	23.79	10.00	0.00	3.74
8-4	59.16	20.00	9.16	17.59
8-7	0.00	0.00	0.00	0.00
9-7	35.94	20.85	0.00	6.16
9-8	40.58	40.00	0.00	14.23

4.3 Entropy-Maximizing Flow Distribution

Before presenting an alternative basis for the select zone analysis, this section offers a further discussion on the maximum entropy solution.

The notion of maximum entropy has been widely used in spatial distribution modeling (e.g., Wilson, 1970). In our context, it estimates the most probable path or

O-D specific link solution. Previous research efforts have produced efficient solution algorithms for computing the flow distribution (see Bar-Gera, 2010 and references therein). At the same time, Bar-Gera and Boyce (1999) introduced a behavioral interpretation for the solution, i.e., the proportionality assumption. The following discussion of the connection between the stochastic user equilibrium (SUE) flow distribution and the entropy-maximizing flow distribution may provide additional insight into the entropy-maximizing approach.

Consider the following logit-based SUE formulation (Fisk, 1980):

$$\min\left\{Z_2(f)=\sum_a\int_0^{v_a}t_a(z)dz+\frac{1}{\theta}\sum_w\sum_{r\in P_w}f_r^w\ln f_r^w : v\in V^f\right\}$$

where θ is a positive dispersion parameter and the expression $f_r^w \ln f_r^w$ is assigned the value zero at $f_r^w=0$. It is known that Z_2 is strictly convex with respect to *f*, and thus both the path and link flow solutions, denoted as f^{SUE} and v^{SUE}, are unique (Fisk, 1980).

As $\theta\to\infty$, the first term in Z_2 dominates the second, and Z_2 reduces to $Z_1=\sum_a\int_0^{v_a}t_a(z)dz$. Therefore, the solution will approach the deterministic user equilibrium solution, i.e., $v^{UE}=\lim_{\theta\to\infty}v^{SUE}(\theta)$ (Fisk, 1980). We naturally wonder whether the unique path flow distribution converges to a particular path flow solution. Larsson et al. (2001) proved that it approaches the MEUE path solution. In the following, we present another proof that $f^{MEUE}=\lim_{\theta\to\infty}f^{SUE}(\theta)$ where $f^{MEUE}=\arg\min\left\{Z_3(f)=\sum_w\sum_{r\in P_w}f_r^w\ln f_r^w : f\in F\right\}$. Note that the solution is unique (e.g., Rossi et al., 1989).

Lemma 1. The entropy of the SUE path flow distribution is the upper bound of the entropy associated with the UE path flow solution, i.e., $Z_3\left(f^{SUE}(\theta)\right) \le Z_3\left(f^{MEUE}\right)$.

Proof: Given that f^{MEUE} is a feasible path flow distribution, by definition we have $Z_2(f^{SUE}) \le Z_2(f^{MEUE})$, which is equivalent to the following:

$$Z_1(f^{SUE}) + \frac{1}{\theta} Z_3(f^{SUE}) \le Z_1(f^{MEUE}) + \frac{1}{\theta} Z_3(f^{MEUE}) \tag{4-1}$$

Since f^{MEUE} is in user equilibrium and f^{SUE} is a feasible path flow distribution, we obtain:

$$Z_1(f^{SUE}) \ge Z_1(f^{MEUE}) \tag{4-2}$$

Combining (4-1) and (4-2) yields:

$$\frac{1}{\theta} Z_3(f^{SUE}) \le \frac{1}{\theta} Z_3(f^{MEUE})$$

Because $\theta > 0$, it implies that $Z_3\left(f^{SUE}(\theta)\right) \le Z_3\left(f^{MEUE}\right)$.

Theorem 1. The entropy-maximizing path flow distribution is the limit of the SUE path flow distribution as the dispersion parameter approaches infinity, i.e., $f^{MEUE} = \lim_{\theta \to \infty} f^{SUE}(\theta)$.

Proof: Since $f^{SUE}(\theta)$ is a continuous function with respect to θ, and is bounded, we have $f^0 = \lim_{\theta \to \infty} f^{SUE}(\theta)$. Given that $v^{UE} = \lim_{\theta \to \infty} v^{SUE}(\theta)$, f^0 is a UE path flow solution, i.e., $f^0 \in F$. We then prove $f^0 = f^{MEUE}$ by contradiction. To do so, we assume that $f^0 \ne f^{MEUE}$. Because Z_3 is continuous with respect to the path flow and is bounded, $\lim_{\theta \to \infty} Z_3\left(f^{SUE}(\theta)\right) = Z_3\left(f^0\right)$. From Lemma 1, we know $Z_3\left(f^0\right) \le Z_3\left(f^{MEUE}\right)$. This contradicts the fact that f^{MEUE} is a unique minimum solution to the maximum entropy problem. Therefore, the assumption $f^0 \neq f^{MEUE}$ is false, and thus $f^{MEUE} = \lim_{\theta \to \infty} f^{SUE}(\theta)$.

It can be interpreted that the above theorem provides additional support for using the maximum entropy flow distribution as the basis for the select zone analysis, since it is the limit of the SUE path flow, which is based upon a sound behavioral foundation. The connection also provides another perspective for the proportionality assumption, which seems to relate to the property of independence of irrelevant alternatives (IIA) of the multinomial logit model. Following the definition of the proportionality described by Bar-Gera (2010), we assume that s_1 and s_2 represent an arbitrary pair of alternative segments in the network; r_o is a path segment from origin $o(w)$ to the diverge node of s_1 and s_2; r_d is a path segment from the merge node of s_1 and s_2 to destination $d(w)$. Consequently, $r_1 = r_o + s_1 + r_d$ is a path between O-D pair w using segment s_1, and similarly $r_2 = r_o + s_2 + r_d$ is another path from $o(w)$ to $d(w)$ using s_2 instead. Denoting the flow on these two paths as $f_{r_1}^w$ and $f_{r_2}^w$ respectively, it is easy to show that at SUE, $f_{r_1}^w / f_{r_2}^w = \exp\left(\theta(t_{s_2} - t_{s_1})\right)$ where t_{s_2} and t_{s_1} are the travel times of segments s_1 and s_2. The ratio is independent of the O-D pair *w* and the other path segments r_o or r_d. This implies that the proportionality property exists in a regular SUE path flow distribution. Therefore, it is not surprising to observe the same property at its limit.

Despite the above connection and the behavioral interpretation of proportionality, it remains an open question whether real travel behavior leads to an entropy-maximizing path flow. As noted in Chapter 2, entropy maximization is a concept originating from statistical mechanics, in which the scale of computation is much higher than that of a spatial flow distribution system (Leung and Yan, 1997). The consequence is that the actual probability of the most probable path flow distribution under the entropy maximizing principle is actually very small, less than e^{-20} for a total demand of 5×10^{6} with 10 origins and 10 destinations (Leung and Yan, 1997). Moreover, there is no behavioral evidence to support its applicability to the identification of a path or O-D specific flow solution for traffic impact analysis.

4.4 Average Flow Distribution

Given that there is no behavioral foundation to favor one particular solution over another, it seems plausible to view each solution as having the same merit. In other words, we assume that the solutions are uniformly distributed in the solution polyhedron. We then propose using the mean of all the solutions as the basis for the select zone analysis. In the following, we focus on the O-D specific link flow solution to develop the idea. The average of all the O-D specific solutions is essentially the center of gravity of the polyhedron X .

4.4.1 Definition

To facilitate the presentation, we first rewrite X in a more concise format. Define Γ as a matrix consisting of $|W|$ identity matrices, i.e., $\Gamma=(E,\cdots,E,\cdots,E)$. Let $\Lambda=$ diag $(\Delta,\cdots,\Delta,\cdots,\Delta)$ with $|W|$ node-link incidence matrices in total. Let D denote a column vector with D^{w} as its element. D is of size $(|N|\times|W|)\times1$. Further, define $B=\begin{pmatrix}\Gamma\\ \Lambda\end{pmatrix}$ and $b=\begin{pmatrix}v^{UE}\\ D\end{pmatrix}$. Then X can be written as $X=\{x|\ Bx=b, x\geq0\}$.

Let $G[X]$ denote the mean of O-D specific link flow solutions over the polyhedron X . Mathematically,

$$G[X] = \frac{1}{m(X)} \int_X x dx \tag{4-3}$$

where $m(X)$ is the measure of X.

The analytic center of the polyhedron may be also of interest, e.g., for comparison purposes. The center is the solution to the following problem:

$$L[X] = \arg\max\left\{-\sum_w \sum_a \ln x_a^w : x \in X\right\} \tag{4-4}$$

4.4.2 Stability

Stability here implies that small perturbations of model inputs will lead only to small changes in the outcome of the select zone analysis. It is an important property first discussed by Lu and Nie (2010). If the basis (a particular selection of O-D specific solution) for the select zone analysis is not stable, a small perturbation to the model inputs could result in a dramatic change in the outcome, thereby causing doubts on the credibility of the analysis.

Lu and Nie (2010) showed that the entropy-maximizing solution is a continuous function of the model inputs and is thus stable. In the following, we demonstrate that $G[X]$ is also stable.

Let u denote the parameters in the link cost function (and q denote the O-D travel demand). Suppose that the link travel cost is continuous with respect to u. According to Theorem 1 in Lu and Nie (2010), the UE link flow distribution $v^{UE}(u,q)$ is a continuous function with respect to u and q. Moreover, $X(u,q)$ is a continuous multifunction with respect to u and q (Theorem 2, Lu and Nie, 2010). Additionally, the measure function $m(X)$ is continuous with respect to X. Given bounded dom u and dom q, the polyhedron X is also bounded. Therefore $m(X)$ and $G[X]$ are bounded. Further, $G[X(u,q)]$ is continuous with respect to $X(u,q)$.

Theorem 2. Assume that the link travel cost function is strictly monotone to link flow and continuous with respect to u and q. The average function $G[x(u,q)]$ is continuous with respect to u and q.

Proof: Let $\{(u^n, q^n), n=1,2,\cdots\}$ be a sequence converging to (u^0, q^0). We need to prove that $\lim_{n\to\infty} G[X(u^n,q^n)] = G[X(u^0,q^0)]$. Note that $X(u,q)$ is continuous on dom u × dom q, then $\lim_{n\to\infty} X(u^n,q^n) = X(u^0,q^0)$. Since $G[X]$ is a continuous function and $X(u,q)$ is bounded on dom u × dom q, $G[X(u^n,q^n)]$ converges to $G[X(u^0,q^0)]$ (Theorem 4.26, Rockafellar and Wets, 1998). Consequently, $G[x(u,q)]$ is continuous with respect to u and q.

Continuity of the average O-D specific flow solution implies that small perturbations to model inputs lead only to small changes in the flow distribution. If we use the average O-D specific link flow solution as the basis for the select zone analysis, the estimate of the spatial impacts of a new development will therefore be stable. Note that the analytic center of the polyhedron can also be proved to be stable in a similar manner.

4.4.3 Computation

The average O-D specific flow solution can be numerically computed via sampling. In this study, we adopt the extended “hit-and-run” sampling algorithm developed by Ban et al. (2009). The algorithm was initially proposed by Smith (1984) and is a Monte Carlo procedure to generate samples from a full dimensional convex set. Starting from an initial point $x_0 \in X$, the extended hit-and-run algorithm generates a random direction d based on the basis of the null space of the matrix B, and then obtains a new sample as $x_1 = x_0 + \lambda \cdot d$, where λ is a scalar randomly generated while ensuring $x_1 \geq 0$. The iteration proceeds until a sufficient number of samples has been generated from X.

Instead of working with the full system, we remove the links that are not utilized in the UE solution and generate a reduced system $\hat{X} = \{\hat{x} | \hat{B}\hat{x} = b, \hat{x} \geq 0\}$. This improves the sampling efficiency to a great extent. Let $l(y, j)$ denote the j^{th} element of a vector y, and the sampling algorithm is as follows.

Step 1: *(Construction of the reduced system and the basis)* The problem of $\max\{x_a^w : B \cdot x = b, x \geq 0\}$ for each O-D pair and each link is solved. If the maximum solution is zero, the O-D specific link flow is removed from the initial system. A reduced system $\hat{B} \cdot \hat{x} = b$ is created when all the zero-flow O-D specific links are removed. The basis of the null of the matrix $\hat{B}$ is computed and denoted as $U = Null(\hat{B})$, which is assumed to consist of a number of k column vectors, i.e., $U(1)$, $U(2), \ldots, U(k)$.

Step 2: (*Initialization*) An initial point x_0 in $\hat{X}$ is generated, and m and n are both set zero.

Step 3: (*Generation of a random direction*) A set of k random numbers is generated from the standard normal distribution $N(0,1)$, say, $\gamma_1, \gamma_2, \ldots, \gamma_k$. The random direction can then be calculated as: $d_m = \dfrac{\sum_{i=1}^{k} \gamma_i U(i)}{\sqrt{\sum_{i=1}^{k} \gamma_i^2}}$.

Step 4: (*Generation of a step size and new sample*) The minimal and maximal step sizes are calculated as follows:

$$\lambda_{\max} = \min\left\{ \frac{-l(\hat{x}_m, j)}{l(d_m, j)}, \forall j \text{ and } l(d_m, j) < 0 \right\}$$

$$\lambda_{\min} = \max\left\{ \frac{-l(\hat{x}_m, j)}{l(d_m, j)}, \forall j \text{ and } l(d_m, j) > 0 \right\}$$

A random scalar λ_m is generated that follows the uniform distribution between $[\lambda_{\min}, \lambda_{\max}]$. The new sample is thus $\hat{x}_{m+1} = \hat{x}_m + \lambda_m d_m$.

Step 5: (*Verification of the convergence*) If $m \geq 100$, the average of the previous m samples is used to calculate the standard deviation of the sample mean, denoted as τ. If $\max(\tau)$<0.00001, convergence is complete the sample mean is returned. Otherwise, m is set to $m+1$ and the process is repeated from Step 3.

Ban et al. (2009) demonstrated that the samples generated via the above procedure follow a uniform distribution over the polyhedron $\hat{X}$.

4.5 Numerical Example

We applied the above sampling procedure to the nine-node network in Section 4.2 to obtain the average O-D specific link flow solution, and then estimated the number of link uses of node 1 (the new development) based on the average. The estimates are reported in Table 4-2, together with the estimates based on the entropy-maximizing (MEUE) solution and the analytic center. The estimates are given only for those 10 links whose numbers of link uses cannot be uniquely determined. For each link, the table also presents the relative difference (RD), calculated as:

$$RD = \frac{|y - x|}{h - l} \tag{4-5}$$

where,

$y =$ Number of link uses based on the average solution

$x =$ Number of link uses based on either the MEUE solution or analytic center

$h =$ Upper bound of link uses

$l =$ Lower bound of link uses

It can be observed that the number of link uses based on the average and MEUE solutions are substantially different. The maximum relative difference is as high as 15% and the average is about 6%. The average relative difference from the analytic center is 36%. We also computed the average relative difference between the MEUE solution and analytic center, which is 38%.

Table 4-2. Comparisons of link uses of node 1

Link	UE aggregate link flow	Upper bound of link use	Lower bound of link use	Link use based on avg. solution	MEUE		Analytic center	
					Link use	Relative difference	Link use	Relative difference
5-7	31.11	11.22	0.00	4.17	2.52	15%	10.00	52%
5-9	40.42	11.22	0.00	7.05	8.70	15%	1.22	52%
6-8	52.36	28.78	0.00	17.36	17.09	1%	28.78	40%
6-9	36.10	28.78	0.00	11.42	11.69	1%	0.00	40%
7-3	36.21	10.00	0.00	5.65	6.26	6%	10.00	44%
7-4	10.84	10.85	0.00	2.92	2.41	5%	0.85	19%
8-3	23.79	10.00	0.00	4.35	3.74	6%	0.00	44%
8-4	59.16	20.00	9.16	17.08	17.59	5%	19.15	19%
9-7	35.94	20.85	0.00	4.41	6.16	8%	0.85	17%
9-8	40.58	40.00	0.00	14.06	14.23	0%	0.37	34%

We conducted the same analysis for the Sioux Falls network (Figure 4-2) to further examine how average flow and MEUE solutions differ in a larger network. In our example, the network topology is the same as the one in LeBlanc et al. (1975). The network characteristics, including the free-flow travel time and capacity of each link, and the O-D demands are provided in appendices A and B. It is assumed that a new development is located in node 10. Our computation shows that the number of uses of 56 links by the new development cannot be uniquely determined. For these links, Table 4-3 presents the estimates of the link uses including the upper and lower bounds, as well as the link uses based on the analytic center, entropy-maximizing and average solutions. The results confirm the observation from the first example that the average and entropy-maximizing solutions lead to substantially different estimates of spatial impacts of the new development. The maximum and average relative differences are approximately 51% and 16%, respectively. The average relative difference from the analytic center is 21%.

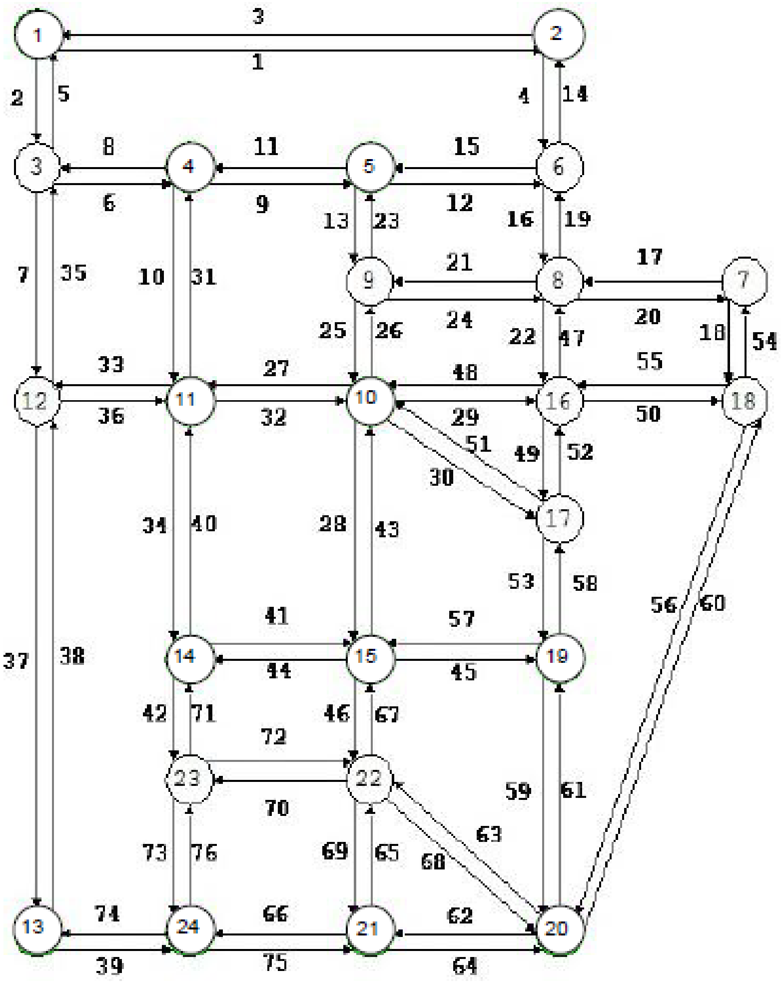

Figure 4-2. Sioux Falls network

Table 4-3. Comparisons of link uses of node 10

Link	UE aggregate link flow	Upper bound of link use	Lower bound of link use	Link use based on avg. Solution	MEUE		Analytic center	
					Link use	Relative difference	Link use	Relative difference
1-2	27.21	0.21	0.00	0.07	0.03	19%	0.18	52%
3-1	49.55	3.21	3.00	3.07	3.03	19%	3.18	52%
3-4	89.63	8.46	7.00	7.09	7.08	1%	7.00	6%
4-3	85.35	5.21	5.00	5.07	5.03	19%	5.18	52%
4-5	90.68	12.46	0.00	8.24	5.33	23%	4.97	26%
4-11	38.62	11.19	0.00	2.85	5.75	26%	6.03	28%
5-4	96.30	9.21	0.35	7.83	9.00	13%	9.18	15%
5-6	68.76	8.00	2.07	7.02	7.60	10%	7.15	2%
5-9	50.06	20.08	5.00	13.33	10.33	20%	9.97	22%
6-2	33.45	4.00	3.79	3.93	3.97	19%	3.82	52%
6-5	41.70	4.08	0.00	0.09	0.00	2%	0.00	2%
6-8	100.61	8.00	3.92	7.91	8.00	2%	8.00	2%
8-6	59.99	5.72	0.00	0.91	0.37	9%	0.66	4%
8-9	54.90	13.00	8.92	12.91	13.00	2%	13.00	2%
9-5	77.76	20.00	5.63	17.85	19.60	12%	19.34	10%
9-8	39.52	9.72	4.00	4.91	4.38	9%	4.66	4%
9-10	97.64	36.46	24.00	32.24	29.33	23%	28.97	26%
10-9	107.95	30.00	21.35	28.76	29.98	14%	30.00	14%
10-11	75.53	35.65	14.00	17.73	15.58	10%	14.90	13%
10-15	107.56	35.00	14.00	29.93	28.20	8%	26.10	18%
10-16	40.46	14.00	12.69	13.92	13.99	5%	14.00	6%
10-17	33.31	14.31	5.00	7.65	10.25	28%	13.00	57%
11-4	33.71	8.65	0.00	1.24	0.03	14%	0.00	14%
11-10	79.13	39.82	13.54	19.16	28.97	37%	30.95	45%
11-14	41.61	13.00	0.00	2.50	1.54	7%	0.90	12%
12-3	76.63	1.46	0.00	0.09	0.08	1%	0.00	6%
12-11	43.31	10.00	8.54	9.91	9.92	1%	10.00	6%
14-11	47.59	13.82	0.00	1.40	8.30	50%	9.92	62%
14-15	42.10	14.00	0.00	7.09	1.72	38%	0.08	50%
14-23	32.56	10.00	0.00	5.11	2.37	27%	2.84	23%
15-10	116.38	41.00	21.06	35.68	27.70	40%	26.08	48%
15-14	36.77	13.00	0.00	5.61	3.83	14%	4.94	5%
15-19	31.95	8.00	0.00	3.39	2.75	8%	0.00	42%
15-22	59.12	23.00	9.00	15.93	16.63	5%	16.16	2%
16-10	48.83	18.00	11.82	17.77	18.00	4%	18.00	4%
16-17	46.18	6.18	0.00	0.23	0.00	4%	0.00	4%
17-10	39.83	17.88	6.00	10.15	11.00	7%	11.00	7%
17-16	36.97	1.31	0.00	0.08	0.00	6%	0.00	6%
17-19	47.05	8.00	0.00	2.57	5.25	34%	8.00	68%

Table 4-3. Continued

Link	UE aggregate link flow	Upper bound of link use	Lower bound of link use	Link use based on avg. solution	MEUE		Analytic center	
					Link use	Relative difference	Link use	Relative difference
19-15	21.39	6.12	0.00	1.20	0.00	20%	0.00	20%
19-17	57.35	6.12	0.00	3.92	5.00	18%	5.00	18%
19-20	34.55	4.00	0.00	1.96	4.00	51%	4.00	51%
20-19	21.29	1.12	0.00	0.13	0.00	12%	0.00	12%
20-21	39.95	2.95	0.00	0.03	0.01	1%	0.00	1%
20-22	44.74	6.00	1.93	5.84	5.99	4%	6.00	4%
21-22	39.60	11.95	5.00	5.70	5.01	10%	5.00	10%
21-24	43.81	5.00	0.00	1.64	2.67	21%	2.16	10%
22-15	80.16	26.00	15.88	22.39	20.98	14%	21.00	14%
22-20	35.80	4.00	0.00	2.04	0.00	51%	0.00	51%
22-21	26.13	9.00	4.00	5.64	6.67	21%	6.16	10%
22-23	40.14	10.00	0.00	3.25	4.95	17%	5.00	18%
23-14	35.88	9.00	0.00	3.48	5.02	17%	5.00	17%
23-22	41.76	9.00	0.00	4.85	3.98	10%	4.00	9%
23-24	33.81	5.00	0.00	3.36	2.33	21%	2.84	10%
24-21	42.32	4.00	0.00	0.67	0.00	17%	0.00	17%
24-23	33.75	4.00	0.00	3.33	4.00	17%	4.00	17%

4.6 Summary

The “Select Zone Analysis” examines the spatial impacts of a new development and requires knowledge of the path flow distribution or origin-destination (O-D) specific link flow distribution. Since these two flow distributions may not be uniquely determined from the deterministic user equilibrium assignment, selection of a particular flow distribution as the basis for the select zone analysis remains an open question. This dissertation suggests using the mean of all the paths or the O-D specific user equilibrium solutions as the basis for traffic impact analysis and proves its stability. A modified extended hit-and-run sampling algorithm is proposed to compute the average O-D specific link flow distribution.

It is noted that such an alternative basis is proposed as a remedy in situations where there is no empirical evidence to support a particular selection of solution.

Compared with the entropy-maximizing basis, we believe that the proposed basis is more intuitively appealing to practitioners, and the result should be easier to defend. However, it is more computationally intensive, given that efficient algorithms exist to solve for the entropy-maximizing solutions. The major challenge is to construct a linear system of very large size for the sampling procedure.

CHAPTER 5
IMPACT ASSESSMENT OF MILEAGE-BASED USER FEES IN FLORIDA

5.1 Background

The combination of ever-improving fuel efficiency of gasoline-powered vehicles and the increasing use of those with alternative fuels or other sources of energy have eroded the fuel tax system in the United States. In order to overcome the revenue deficit, vehicle mileage fees have been suggested as one of the most promising mechanisms to replace the fuel tax (Chapter 2). In this system, drivers would be charged based on the miles traveled, instead of paying the conventional gasoline tax. As discussed in Chapter 2, the proposed system has many positive attributes over the gasoline tax. Studies completed for Oregon, Iowa, Texas, etc, have also demonstrated the technical feasibility and public acceptability of such fees as the fuel tax replacement. However, no impact study has been conducted for Florida, and results from other states may not be applicable in this state. In this chapter, we analyze the socioeconomic impacts of mileage fees in Florida. Four different mileage fee structures (flat fee, step fee, fee based on vehicle fuel efficiency and fee based on vehicle type) are assessed for different scenarios. While the step mileage fee aims to achieve a more equitable structure, a fee based on vehicle fuel efficiency and vehicle type will be more environmentally friendly.

5.2 Data

5.2.1 Description of the Data

The 2009 National Household Travel Survey (NHTS) data for Florida are used for this impact analysis. The data consist of four files: household, person, trip and vehicle files. There are 15884 household entries, 30952 person entries, 114910 trip entries and

29457 vehicle entries in the dataset. Our analysis is performed at the household level. Consequently, some attributes from the vehicle and person data files are merged into the household data file. After data cleaning, 13086 household data are used for the analysis. The key points in data preparation are provided below:

- The NHTS data does not have the specific household income value. For the model estimation, the average value of the income range is used. For example, if the household is in income range \$5000 to \$9999, \$7500 is taken as household income for the analysis.
- In the type of vehicle field, there are two different types of trucks. However, for our analysis, we consider both pickup and truck as "truck".
- In the vehicle data file, there are two types of annual mile data, one is ANNMILES (self-reported annualized mile estimate), and other is BESTMILE (best estimate of annual miles). We use BESTMILE for our analysis.
- In our analysis, Energy Information Administration (EIA) fuel efficiency measures are used, rather than Environmental Protection Agency (EPA) fuel efficiency.
- If any information used in the model is missing in the household data file, that household is excluded from the analysis.
- If any vehicle information for a household used in the model is missing, that corresponding household is excluded from the analysis.
- The weighted average of the vehicle characteristics are used in the analysis for the households having more than one vehicle.
- Mileage fee has not been implemented yet. Therefore, the data do not contain any information about a mileage fee. We do not know how people will react and change their travel demands with the new fee. For our analysis, we assume that the travel demand sensitivity with respect to mileage fee is similar to the sensitivity with respect to gasoline fees.

5.2.2 Descriptive Statistics of the Data

Descriptive statistics of the data are presented in Tables 5-1 to 5-5. From the tables, we can observe that the average fuel efficiency of vehicles per household is 20.79 MPG in the rural area and 21.40 MPG in the urban area. The average fuel efficiencies are also similar among different income groups. However, the number of vehicles and total annual miles driven per household are both greater in the rural area and among higher income groups. For vehicle composition, the households in rural areas own a higher percentage of trucks and a lower percentage of cars, compared to households in urban areas. The lower income groups have a higher percentage of cars and lower percentage of SUVs. The average fuel efficiency and average annual vehicle miles driven for each county are presented in Table 5-5.

Table 5-1. Descriptive statistics by location

	No.HH	Tot. annual income per HH ($)	No. veh. per HH	Avg. veh. MPG per HH	Tot. annual VMT per HH
Rural	2775	59984	2.20	20.79	25552
Urban	10311	63706	1.88	21.40	19905
Overall Avg.	-	62917	1.93	21.27	21056

Table 5-2. Descriptive statistics by income group

Income group	Household			No. veh. per HH	Avg. veh. MPG per HH	Tot. annual VMT per HH
	Total HH	Rural HH	Urban HH			
$0 - $19,999	2119	475	1644	1.40	20.64	12187
$20,000 - $39,999	3288	737	2551	1.64	21.04	15926
$40,000 - $59,999	2468	537	1931	1.91	21.49	21035
$60,000 - $79,999	1800	373	1427	2.16	21.78	24650
$80,000 - $200,000	3411	653	2758	2.42	21.46	29629

Table 5-3. Percent of vehicles by type and location

	Car	Van	SUV	Truck	RV	Motor Cycle	Total
Rural	42.69	8.02	18.81	25.76	0.78	3.94	100
Urban	55.17	8.32	19.61	13.23	0.68	2.98	100

Table 5-4. Percent of vehicles by type and income group

Income group	Car	Van	SUV	Truck	RV	Motor Cycle	Total
$0 - $19,999	60.11	9.29	11.51	16.56	0.54	1.99	100
$20,000 - $39,999	54.91	9.53	15.12	17.12	0.71	2.62	100
$40,000 - $59,999	52.09	8.28	18.09	17.69	0.85	3.01	100
$60,000 - $79,999	49.78	7.85	20.58	17.08	0.80	3.91	100
$80,000 - $200,000	48.97	7.22	25.32	14.04	0.64	3.81	100

Table 5-5. Descriptive statistics by county

County name	No. of HH	Avg. MPG	Avg.VMT	County name	No. of HH	Avg. MPG	Avg.VMT
Alachua	203	21.74	22215	Lee	420	21.08	19261
Baker	35	19.60	28692	Leon	274	21.56	25573
Bay	157	20.27	24143	Levy	65	21.08	32177
Bradford	42	20.37	31243	Liberty	5	19.82	31286
Brevard	373	21.56	18338	Madison	28	19.67	21641
Broward	1091	22.13	20500	Manatee	180	20.75	16495
Calhoun	20	20.14	28195	Marion	257	20.94	19098
Charlotte	129	22.10	20010	Martin	117	20.94	22000
Citrus	299	20.88	21920	Miami-dade	1256	21.74	19607
Clay	175	20.92	25895	Monroe	170	20.80	21281
Collier	209	21.17	18020	Nassau	67	21.71	28517
Columbia	66	21.25	26898	Okaloosa	182	20.92	24101
DeSoto	44	19.54	19390	Okeechobee	51	20.10	19154
Dixie	21	18.74	32041	Orange	432	21.92	23271
Duval	523	21.97	22077	Osceola	104	21.50	25155
Escambia	280	21.31	22062	Palm Beach	815	21.92	18712
Flagler	124	23.05	24678	Pasco	309	20.75	19315
Franklin	24	18.62	20832	Pinellas	690	21.32	15846
Gadsden	35	21.59	24346	Polk	340	21.23	19687
Gilcrist	25	20.54	48320	Putnam	129	20.87	26888
Glades	15	19.36	25541	St. Johns	178	21.33	26101
Gulf	29	19.72	23260	St. Lucie	235	21.45	19940
Hamilton	25	19.40	27880	Santa Rosa	170	20.67	25298
Hardee	22	20.98	27697	Sarasota	249	21.95	19347
Hendry	38	20.44	23109	Seminole	250	21.19	20663
Hernando	109	21.77	20598	Sumter	62	21.33	16216
Highlands	224	20.50	18780	Suwannee	92	19.99	26018
Hillsborough	657	21.42	21346	Taylor	32	19.40	41091
Holmes	35	20.71	24735	Union	14	18.93	24759
Indian River	94	20.64	23064	Volusia	384	21.38	18281
Jackson	69	19.70	28926	Wakulla	21	21.83	32001
Jefferson	35	21.24	22825	Walton	62	21.77	25177
Lafayette	9	18.49	23346	Washington	41	21.26	23709
Lake	169	21.18	20774				

5.3 Methodology

5.3.1 Model Estimation

Different modeling structures have been used in previous studies. For example, McMullen et al. (2010) used both a static model and a multiple regression model; Zhang et al. (2009) used a discrete choice model; and Sana et al. (2010) used previously estimated elasticity values to estimate the mileage fee impacts. Zhang and McMullen (2010) compared different modeling structures from the perspective of behavioral realism, policy sensitivity and practicality. While the static models are very easy to use, they perform poorly with regard to behavioral realism. On the other hand, discrete continuous models capture behavioral realism well, but they are more data demanding and difficult to use. Multiple regression models are capable of capturing behavioral realism and are easy to execute, and they work well for policy analyses. Therefore, in this research we use a multiple regression model.

The total annual miles driven by a household, i.e., the travel demand of a household, is assumed to be a function of the social characteristics of the household and attributes of the transportation services. For simplicity, it is assumed that the household vehicle ownership is fixed. A log-log linear regression model is used to avoid a negative value of vehicle miles driven by a household. Generally, people with high incomes are less sensitive to price changes than those at the low end of the income scale. In order to capture this effect, an interaction term between the fuel cost per mile and income is included in the model. If a household has more than one vehicle, the household has the option to switch vehicles. When the fuel price is high, they can drive the more fuel efficient vehicle, and vice versa. Therefore, this type of household is less sensitive to the fuel price than a household with a single type of vehicle, and this effect is captured by an interaction term between fuel cost per mile and the substitute dummy variable. The functional form is described below:

$$\ln(M) = \beta_0 + \beta_1 \times \ln(PM) + \beta_2 \times \ln(hhtotinc) + \beta_3 \times \ln(hhvehcnt) + \beta_4 \times U + \beta_5 \times \ln(hhtotinc) \times \ln(PM) + \beta_6 \times SUB + \beta_7 \times \ln(PM) \times SUB + \beta_8 \times wrkcnt + \beta_9 \times hhchild \tag{5-1}$$

where,

$M =$ Total annual miles driven by all vehicles in a household (mile)

$PM =$ Weighted average of fuel cost in per mile for a household (\$/mile),

calculated as follows: $= \sum_i PM_i \times M_i / \sum_i M_i$, where $PM_i = \frac{NetGasPrice\ + StateGasTax}{MPG_i} + VMTFee$, ($i$ represents individual vehicles in a household)

$PM\_GasTAX = PM$, when $VMTFee = 0$ (\$/mile)

$PM\_VMTFee = PM$, when $StateGasTax = 0$ (\$/mile)

$hhtotinc =$ Total annual household income (\$)

$hhvehcnt =$ Household vehicle count

$U = 1$ if household is located in urban area, 0 otherwise

$SUB = 1$ if household has different types of vehicles among car, van, SUV, truck and RV; 0 otherwise

$wkrcnt =$ Number of workers in a household

$hhchild =$ Number of children in a household

The model is estimated with the clean data set described in Section 5.2. The adjusted R-square is 0.56, and all the coefficients have the correct sign and are statistically significant at the 99% confidence level. The coefficients of the estimated model are provided in Table 5-6, and the resulting demand elasticity is provided in

Table 5-7. From the elasticity values, we can observe that lower income people are more sensitive to fuel cost than those with higher incomes, and households with only one type of vehicle are more sensitive than households with multiple types of vehicles. The elasticity is calculated as follows:

$$e = (\Delta M / M)/(\Delta PM / PM) = (\delta M / \delta PM) \times (PM / M) = \beta_1 + \beta_5 \times \ln(hhtotinc) + \beta_7 \times SUB \tag{5-2}$$

Table 5-6. Estimated model

Variable Name	Coefficient	Std. error	t-statistic
Constant	-2.4787	0.6472	-3.8298
ln(PM)	-5.4067	0.3416	-15.8274
ln(hhtotinc)	0.7612	0.0620	12.2745
ln(hhvehcnt)	0.9188	0.0196	46.9485
U	-0.1821	0.0147	-12.3627
ln(hhtotinc)*ln(PM)	0.3449	0.0327	10.5518
SUB	1.6881	0.1163	14.5149
ln(PM)*SUB	0.7499	0.0607	12.3453
wrkcnt	0.1509	0.0084	18.0693
hhchild	0.1023	0.0079	12.8797

Table 5-7. Elasticity by income group based on average income

Income group	Avg. income ($)	Elasticity with SUB	Elasticity without SUB
$0- $19,999	10000	-1.40	-2.15
$20,000- $39,999	30000	-1.10	-1.85
$40,000- $59,999	50000	-0.92	-1.67
$60,000- $79,999	70000	-0.80	-1.55
$80,000 -$200,000	140000	-0.59	-1.34

5.3.2 Socioeconomic Measures

In this study, we consider the change in consumer surplus, revenue and social welfare to estimate the socioeconomic impacts. The change in consumer surplus is estimated to capture the impacts of mileage fees on households, whereas the change in revenue is estimated to see the feasibility of the new system. The total change in social welfare is simply the sum of change in consumer surplus and change in revenue. With the estimated model, the changes in consumer surplus, revenue and social welfare are estimated as follows:

$$\Delta CS = 0.5 \times (PM\_GasTax - PM\_VMTFee) \times (Miles\_GasTax + Miles\_VMTFee) \quad (5\text{-}3)$$

$$\Delta \mathrm{Revenue} = VMTFee \times Miles\_VMTFee - (StateGasTax / AvgMPG) \times Miles\_GasTax \quad (5\text{-}4)$$

$$\Delta SW = \Delta CS + \Delta \mathrm{Re}venue \quad (5\text{-}5)$$

where,

$PM\_GasTAX = PM$, under gasoline tax ($)

$PM\_VMTFee = PM$, under mileage fee ($)

$Miles\_GasTax =$ Annual miles driven by a household under gasoline tax (mile)

$Miles\_VMTFee =$ Annual miles driven by a household under mileage fee (mile)

$\Delta CS =$ Change in consumer surplus ($)

$\Delta \mathrm{Re}venue =$ Change in revenue ($)

$\Delta SW =$ Change in social welfare ($)

Income and spatial equity are also assessed. In previous studies (e.g., Zhang et al., 2009; McMullen et al., 2010; Zhang and Lu, 2012), equity is assessed mainly based on the change in consumer surplus and change in consumer surplus as a percentage of average income. In this study, we use the latter method to judge the equity. For county-wise distributional impact evaluation, the Lowrenz curve and Gini coefficient (Larsen et al., 2012) are used.

5.4 Impact Analysis

5.4.1 Flat Mileage Fee

The current average gasoline tax in Florida is 52.9 cents/gallon with the federal tax and 34.5 cents/gallon without the federal tax, i.e., the sum of the state and county taxes.

Using 21 miles per gallon (MPG) as the average fuel efficiency of vehicles in Florida, the current state gas tax of 34.5 cents/gallon is equivalent to 1.64 cents/mile, if all other factors remain the same.

Note that the above calculation does not consider travel behavior changes due to changes in the gasoline price. To obtain a revenue-neutral impact fee and fees for other purposes, the model is executed multiple times, and the resulting socioeconomic impacts are summarized in Table 5-8.

Table 5-8. Changes in consumer surplus, revenue, social welfare and VMT under different mileage fees

Mileage fee (cents/mile)	Total change in consumer surplus ($)	Total change in revenue ($)	Total change in social welfare ($)	% VMT reduction
1.60	151780	-16177	135602	0.49
1.61	127431	5030	132461	0.57
1.62	103102	26204	129306	0.65
1.63	78791	47345	126136	0.73
1.64	54500	68452	122953	0.81
1.70	-90849	194409	103560	1.30
2.00	-807692	807027	-666	3.70
2.20	-1276853	1200298	-76555	5.29
2.80	-2646108	2313856	-332252	10.04
4.10	-5445869	4437238	-1008631	20.14

It can be observed from Table 5-8 that a flat mileage fee of 1.61 cents/mile is sufficient to maintain the current revenue level (without considering the difference in the collection and administrative costs). The mileage fees of 2.8 and 4.1 cents/mile can reduce annual vehicle miles traveled by approximately 10% and 20%, respectively. In the following section, we present the socioeconomic impacts of 1.61, 2.8 and 4.1 cents/mile mileage fees across different income groups and counties.

Mileage fee of 1.61 cents/mile (Revenue-neutral fee). The socioeconomic impacts are presented in Tables 5-9 to 5-11 and in Figure 5-1. It can be observed that the average change in consumer surplus and the average change in consumer surplus as a percentage of average income are negligible in all income groups (Table 5-9). The residents in rural areas receive slightly more benefits than those in the urban areas (Table 5-10), although the difference is not significant. Across different counties, the average change in consumer surplus ranges from -$13.92 to $77.93 (Table 5-11). Other than Flagler, Hernando, Broward and Charlotte counties, the average changes in consumer surplus are positive. Due to the higher fuel efficiency of vehicles, those counties are negatively affected to a small extent. On the other hand, counties with less fuel efficient vehicles are benefitting from the new policy.

Table 5-9. Average changes in consumer surplus, revenue and social welfare by income group

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0- $19,999	2.18	(45.50)	0.02	0.49	2.67
$20,000- $39,999	4.47	(64.20)	0.01	1.12	5.59
$40,000- $59,999	5.94	(72.90)	0.01	2.99	8.94
$60,000- $79,999	8.62	(86.82)	0.01	5.24	13.86
$80,000 -$200,000	22.85	(101.47)	0.02	-4.84	18.01

Table 5-10. Average changes in consumer surplus, revenue and social welfare by location

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	22.30	(95.21)	-5.73	16.57
Urban	6.36	(72.94)	2.03	8.39

Table 5-11. Average changes in consumer surplus, revenue and social welfare by county

Sl. no.	County name	No. of HH	Avg. change in consumer surplus ($)	Avg. change in revenue ($)	Avg. change in social welfare ($)
1	Alachua	203	10.75	4.47	15.22
2	Baker	35	54.44	-30.51	23.94
3	Bay	157	25.27	-12.34	12.92
4	Bradford	42	25.52	-0.54	24.98
5	Brevard	373	2.89	6.39	9.27
6	Broward	1091	-1.46	7.92	6.46
7	Calhoun	20	32.15	-19.49	12.66
8	Charlotte	129	-1.04	8.68	7.64
9	Citrus	299	13.36	-2.36	11.00
10	Clay	175	13.75	-1.76	12.00
11	Collier	209	11.99	-1.37	10.62
12	Columbia	66	15.59	-3.41	12.18
13	DeSoto	44	33.99	-20.55	13.44
14	Dixie	21	77.93	-47.34	30.59
15	Duval	523	4.67	5.00	9.67
16	Escambia	280	10.52	2.47	12.99
17	Flagler	124	-13.92	24.14	10.21
18	Franklin	24	51.43	-29.89	21.54
19	Gadsden	35	0.13	8.27	8.40
20	Gilcrist	25	74.57	-33.37	41.20
21	Glades	15	35.10	-19.52	15.57
22	Gulf	29	39.75	-30.35	9.40
23	Hamilton	25	31.18	-17.34	13.84
24	Hardee	22	27.27	-9.53	17.74
25	Hendry	38	31.18	-10.54	20.64
26	Hernando	109	-4.78	13.59	8.80
27	Highlands	224	20.20	-10.99	9.21
28	Hillsborough	657	13.18	-3.27	9.92
29	Holmes	35	14.88	-5.72	9.16
30	Indian River	94	20.50	-5.87	14.63
31	Jackson	69	42.87	-20.13	22.74
32	Jefferson	35	1.28	9.52	10.79
33	Lafayette	9	61.30	-40.97	20.34
34	Lake	169	6.92	1.33	8.26

Table 5-11. Continued

Sl. no.	County name	No. of HH	Avg. change in consumer surplus ($)	Avg. change in revenue ($)	Avg. change in social welfare ($)
35	Lee	420	11.75	-2.55	9.20
36	Leon	274	10.80	3.27	14.07
37	Levy	65	20.91	-0.09	20.82
38	Liberty	5	40.92	-23.11	17.81
39	Madison	28	41.71	-24.43	17.27
40	Manatee	180	11.95	-4.16	7.79
41	Marion	257	9.67	-2.70	6.97
42	Martin	117	14.14	-3.95	10.19
43	Miami-dade	1256	1.12	4.78	5.90
44	Monroe	170	27.72	-7.45	20.27
45	Nassau	67	13.61	-0.54	13.07
46	Okaloosa	182	29.96	-12.76	17.21
47	Okeechobee	51	25.52	-9.40	16.12
48	Orange	432	2.78	5.10	7.88
49	Osceola	104	19.46	-5.53	13.93
50	Palm Beach	815	1.35	5.14	6.50
51	Pasco	309	10.83	-2.46	8.37
52	Pinellas	690	5.89	-0.33	5.56
53	Polk	340	11.44	-1.84	9.60
54	Putnam	129	12.33	-1.32	11.01
55	St. Johns	178	19.65	-2.74	16.90
56	St. Lucie	235	4.93	5.04	9.97
57	Santa Rosa	170	28.40	-11.24	17.16
58	Sarasota	249	8.73	2.60	11.32
59	Seminole	250	13.37	-2.32	11.06
60	Sumter	62	4.33	3.62	7.95
61	Suwannee	92	29.09	-8.98	20.11
62	Taylor	32	59.73	-43.39	16.35
63	Union	14	67.21	-41.73	25.48
64	Volusia	384	7.22	3.21	10.43
65	Wakulla	21	39.15	6.93	46.08
66	Walton	62	18.39	9.70	28.09
67	Washington	41	23.05	-5.43	17.63

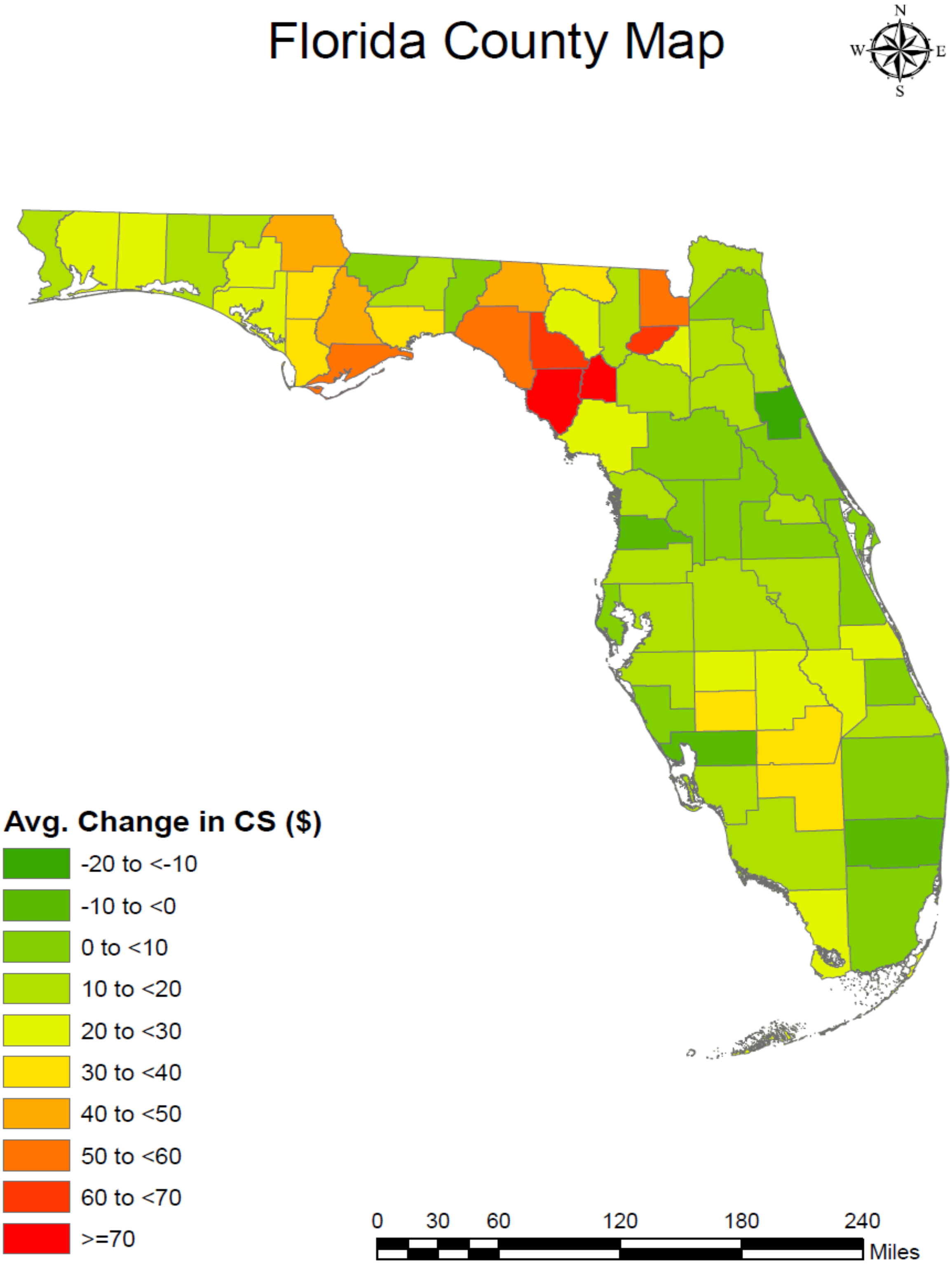

Figure 5-1. Spatial distribution of impacts of mileage fee of 1.61 cents/mile

Mileage fee of 2.8 cents/mile (10% VMT reduction). The impacts of a flat mileage fee of 2.8 cents/mile are presented in Tables 5-12 to 5-14 and in Figure 5-2. Such a high fee would lead to negative changes in consumer surpluses for all income groups and locations. The impacts are regressive, i.e., the lower income people suffer more than those with higher income, and residents in rural areas suffer more than those in urban areas. The distributional impacts are presented in Table 5-14 and in Figure 5-2. The dispersion of the impacts yields a Gini coefficient of 0.17, suggesting that the spatial equity is not a major concern. Note that the NHTS data has a weight factor for each entry to avoid sampling bias. However, in this study we have not used the weight factors to estimate the model. We believe that the amount of data in each income group is sufficiently large that the average effect is not affected by the sampling bias. However, as many counties have small numbers of data entries, the changes in consumer surpluses are adjusted according to weight factors before computing the Gini coefficient.

Table 5-12. Average changes in consumer surplus, revenue and social welfare by income group

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0- $19,999	-106.43	(104.14)	-0.84	77.84	-28.59
$20,000- $39,999	-149.67	(145.02)	-0.49	120.95	-28.72
$40,000- $59,999	-200.53	(160.81)	-0.40	171.68	-28.84
$60,000- $79,999	-246.95	(180.34)	-0.35	221.42	-25.53
$80,000 -$200,000	-289.97	(201.56)	-0.22	272.35	-17.62

Table 5-13. Average changes in consumer surplus, revenue and social welfare by location

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	-238.21	(211.16)	214.76	-23.44
Urban	-192.52	(165.70)	166.61	-25.91

Table 5-14. Average changes in consumer surplus, revenue and social welfare by county

Sl. no.	County name	No. of HH	Avg. change in consumer surplus ($)	Avg. change in revenue ($)	Avg. change in social welfare ($)
1	Alachua	203	-258.80	232.58	-26.28
2	Baker	35	-222.00	208.79	-12.33
3	Bay	157	-186.40	167.44	-19.01
4	Bradford	42	-267.90	252.05	-15.87
5	Brevard	373	-198.50	172.90	-25.69
6	Broward	1091	-215.30	184.28	-31.06
7	Calhoun	20	-200.50	179.42	-21.08
8	Charlotte	129	-201.40	170.42	-31.04
9	Citrus	299	-189.00	163.24	-25.80
10	Clay	175	-230.90	206.54	-24.42
11	Collier	209	-184.50	162.80	-21.75
12	Columbia	66	-211.60	185.21	-26.43
13	DeSoto	44	-146.20	129.10	-17.19
14	Dixie	21	-211.00	200.72	-10.28
15	Duval	523	-224.30	196.19	-28.12
16	Escambia	280	-209.70	187.48	-22.30
17	Flagler	124	-252.60	220.78	-31.84
18	Franklin	24	-188.30	176.67	-11.63
19	Gadsden	35	-228.80	193.36	-35.45
20	Gilcrist	25	-169.10	175.67	6.48
21	Glades	15	-182.90	169.29	-13.68
22	Gulf	29	-161.20	136.43	-24.78
23	Hamilton	25	-204.20	183.20	-20.02
24	Hardee	22	-216.90	195.84	-21.14
25	Hendry	38	-189.90	175.77	-14.20
26	Hernando	109	-195.80	166.49	-29.31
27	Highlands	224	-150.00	129.31	-20.75
28	Hillsborough	657	-201.50	177.10	-24.42
29	Holmes	35	-190.10	161.52	-28.66
30	Indian River	94	-181.10	163.99	-17.20
31	Jackson	69	-222.00	208.89	-13.15
32	Jefferson	35	-248.50	221.49	-27.04
33	Lafayette	9	-179.60	171.55	-8.12

Table 5-14. Continued

Sl. no.	County name	No. of HH	Avg. change in consumer surplus ($)	Avg. change in revenue ($)	Avg. change in social welfare ($)
34	Lake	169	-176.20	151.59	-24.63
35	Lee	420	-183.60	160.13	-23.48
36	Leon	274	-241.80	220.20	-21.63
37	Levy	65	-275.50	247.03	-28.55
38	Liberty	5	-216.00	194.12	-21.94
39	Madison	28	-170.30	154.04	-16.29
40	Manatee	180	-162.70	141.34	-21.37
41	Marion	257	-172.70	145.05	-27.69
42	Martin	117	-197.60	175.08	-22.53
43	Miami-dade	1256	-207.00	175.62	-31.43
44	Monroe	170	-189.20	178.59	-10.70
45	Nassau	67	-242.60	215.94	-26.76
46	Okaloosa	182	-226.80	208.67	-18.16
47	Okeechobee	51	-157.40	144.12	-13.30
48	Orange	432	-230.20	199.29	-30.97
49	Osceola	104	-237.80	210.65	-27.24
50	Palm Beach	815	-187.80	160.32	-27.53
51	Pasco	309	-185.90	159.79	-26.12
52	Pinellas	690	-165.50	139.95	-25.60
53	Polk	340	-189.10	163.02	-26.10
54	Putnam	129	-223.10	196.71	-26.47
55	St. Johns	178	-238.90	219.93	-19.00
56	St. Lucie	235	-190.90	168.45	-22.46
57	Santa Rosa	170	-236.20	216.10	-20.10
58	Sarasota	249	-189.20	166.23	-23.01
59	Seminole	250	-212.70	188.64	-24.09
60	Sumter	62	-140.00	117.46	-22.54
61	Suwannee	92	-223.40	203.83	-19.66
62	Taylor	32	-227.20	208.90	-18.33
63	Union	14	-214.70	205.59	-9.19
64	Volusia	384	-180.30	156.20	-24.10
65	Wakulla	21	-269.00	269.43	0.42
66	Walton	62	-245.00	233.37	-11.68
67	Washington	41	-234.00	204.99	-29.20

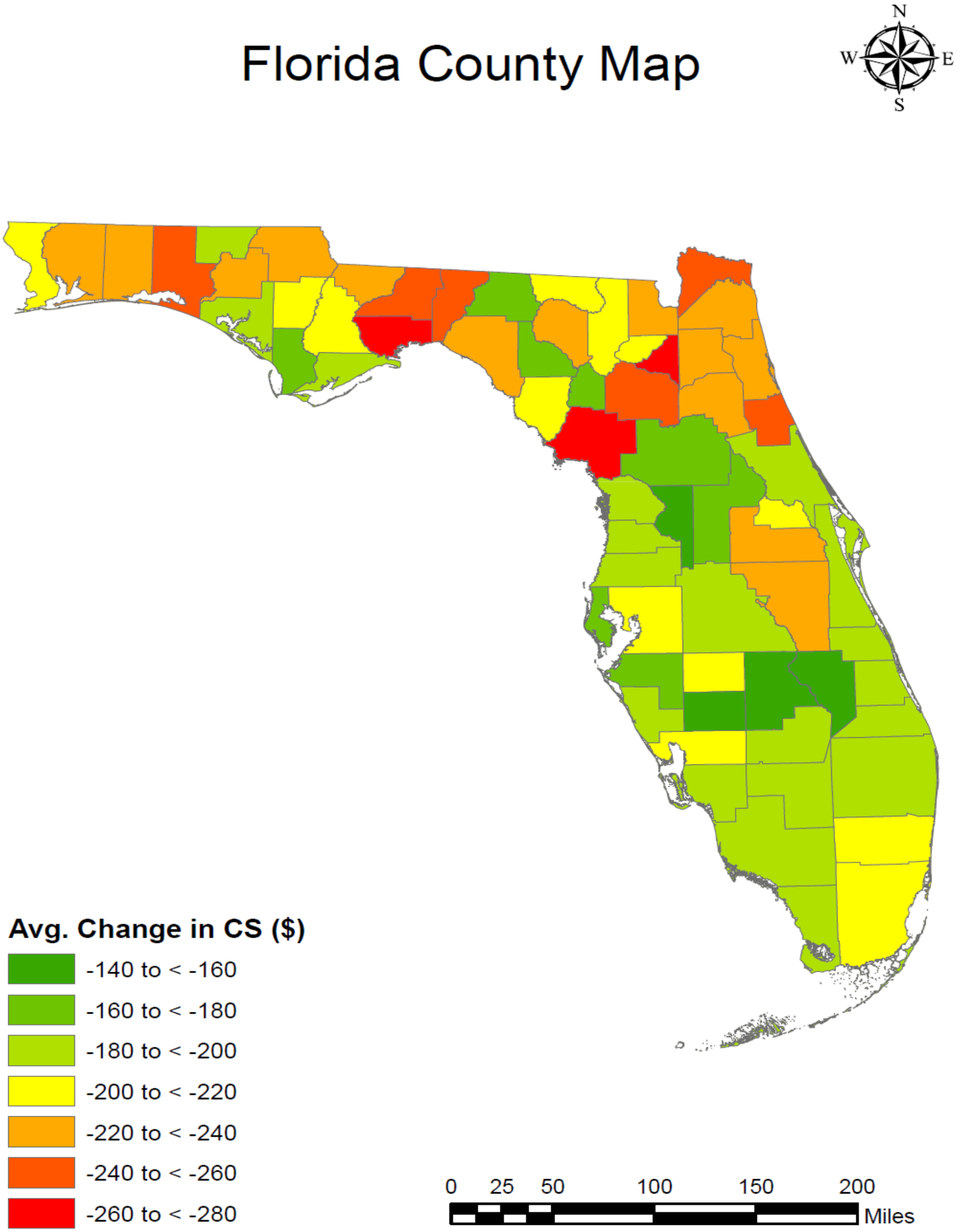

Figure 5-2. Spatial distribution of impacts of mileage fee of 2.8 cents/mile

Mileage fee of 4.1cents/mile (20% VMT reduction). The impacts of a flat fee of 4.1 cents/mile are presented in Tables 5-15 to 5-17 and in Figure 5-3. The impacts among different income groups are similar to those for the 2.8 cents/mile fee, but are more regressive. The difference between the average change in consumer surpluses as a percentage of average income of the lowest income and highest income groups is 1.19, compared to 0.62 for a mileage fee of 2.8 cents/mile. The rural residents again suffer more than the people in urban areas. The average change in consumer surpluses are -$502.54 in the rural area and -$392.91 in the urban area, compared to -$238.21 and -$192.52 for the fee of 2.8 cents/mile. As the residents of rural areas drive more than the residents of urban areas, the disparities increase as the fee level increases. However, the spatial distribution of the impacts is fairly uniform, yielding the same Gini coefficient of 0.17.

Table 5-15. Average changes in consumer surplus, revenue and social welfare by income group

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0- $19,999	-210.52	(179.25)	-1.66	138.34	-72.17
$20,000- $39,999	-301.51	(252.60)	-1.00	223.69	-77.82
$40,000- $59,999	-407.39	(285.95)	-0.81	323.56	-83.84
$60,000- $79,999	-506.37	(318.62)	-0.71	422.81	-83.55
$80,000 -$200,000	-613.16	(367.14)	-0.47	542.07	-71.10

Table 5-16. Average changes in consumer surplus, revenue and social welfare by location

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	-502.54	(392.64)	420.32	-82.22
Urban	-392.91	(303.21)	317.22	-75.69

Table 5-17. Average changes in consumer surplus, revenue and social welfare by county

Sl. no.	County name	No. of HH	Avg. change in consumer surplus ($)	Avg. change in revenue ($)	Avg. change in social welfare ($)
1	Alachua	203	-532.60	445.50	-87.10
2	Baker	35	-502.90	436.29	-66.62
3	Bay	157	-401.30	335.30	-66.14
4	Bradford	42	-567.00	490.27	-76.79
5	Brevard	373	-401.40	324.93	-76.50
6	Broward	1091	-430.60	345.41	-85.25
7	Calhoun	20	-437.10	366.23	-70.95
8	Charlotte	129	-402.90	317.04	-85.93
9	Citrus	299	-392.00	312.99	-79.08
10	Clay	175	-479.70	401.70	-78.06
11	Collier	209	-383.00	314.05	-69.00
12	Columbia	66	-440.90	358.41	-82.54
13	DeSoto	44	-327.50	265.56	-61.96
14	Dixie	21	-504.70	433.48	-71.30
15	Duval	523	-456.00	373.04	-82.97
16	Escambia	280	-432.60	358.54	-74.08
17	Flagler	124	-492.80	400.01	-92.86
18	Franklin	24	-432.40	371.10	-61.38
19	Gadsden	35	-457.50	358.89	-98.64
20	Gilcrist	25	-417.60	373.01	-44.59
21	Glades	15	-405.60	348.32	-57.36
22	Gulf	29	-363.40	288.83	-74.61
23	Hamilton	25	-443.50	373.04	-70.50
24	Hardee	22	-463.70	385.19	-78.60
25	Hendry	38	-413.80	348.46	-65.39
26	Hernando	109	-386.60	302.76	-83.88
27	Highlands	224	-321.00	256.69	-64.32
28	Hillsborough	657	-418.90	344.45	-74.53
29	Holmes	35	-395.30	311.96	-83.37
30	Indian River	94	-385.10	321.17	-64.02
31	Jackson	69	-492.50	425.76	-66.77
32	Jefferson	35	-502.30	419.54	-82.79
33	Lafayette	9	-427.50	376.72	-50.84

Table 5-17. Continued

Sl. no.	County name	No. of HH	Avg. change in consumer surplus ($)	Avg. change in revenue ($)	Avg. change in social welfare ($)
34	Lake	169	-359.80	287.35	-72.48
35	Lee	420	-380.70	309.57	-71.15
36	Leon	274	-499.60	425.23	-74.38
37	Levy	65	-574.30	473.14	-101.10
38	Liberty	5	-475.60	394.32	-81.30
39	Madison	28	-384.90	319.66	-65.27
40	Manatee	180	-338.90	275.02	-63.89
41	Marion	257	-355.00	277.34	-77.71
42	Martin	117	-412.40	341.91	-70.54
43	Miami-dade	1256	-416.30	331.02	-85.32
44	Monroe	170	-410.60	354.32	-56.34
45	Nassau	67	-503.00	418.21	-84.80
46	Okaloosa	182	-489.20	418.82	-70.47
47	Okeechobee	51	-342.00	285.45	-56.58
48	Orange	432	-465.60	378.16	-87.49
49	Osceola	104	-498.50	411.27	-87.30
50	Palm Beach	815	-377.90	301.20	-76.72
51	Pasco	309	-383.90	307.88	-76.05
52	Pinellas	690	-337.50	266.93	-70.64
53	Polk	340	-390.70	313.02	-77.75
54	Putnam	129	-461.60	380.19	-81.42
55	St. Johns	178	-503.20	431.18	-72.02
56	St. Lucie	235	-388.50	318.63	-69.91
57	Santa Rosa	170	-506.10	430.94	-75.22
58	Sarasota	249	-388.50	315.64	-72.92
59	Seminole	250	-442.10	366.59	-75.53
60	Sumter	62	-282.60	216.10	-66.50
61	Suwannee	92	-479.00	400.88	-78.19
62	Taylor	32	-522.20	451.91	-70.33
63	Union	14	-504.30	442.99	-61.33
64	Volusia	384	-368.10	294.12	-74.07
65	Wakulla	21	-582.30	515.13	-67.17
66	Walton	62	-512.30	441.71	-70.65
67	Washington	41	-492.00	395.52	-96.52

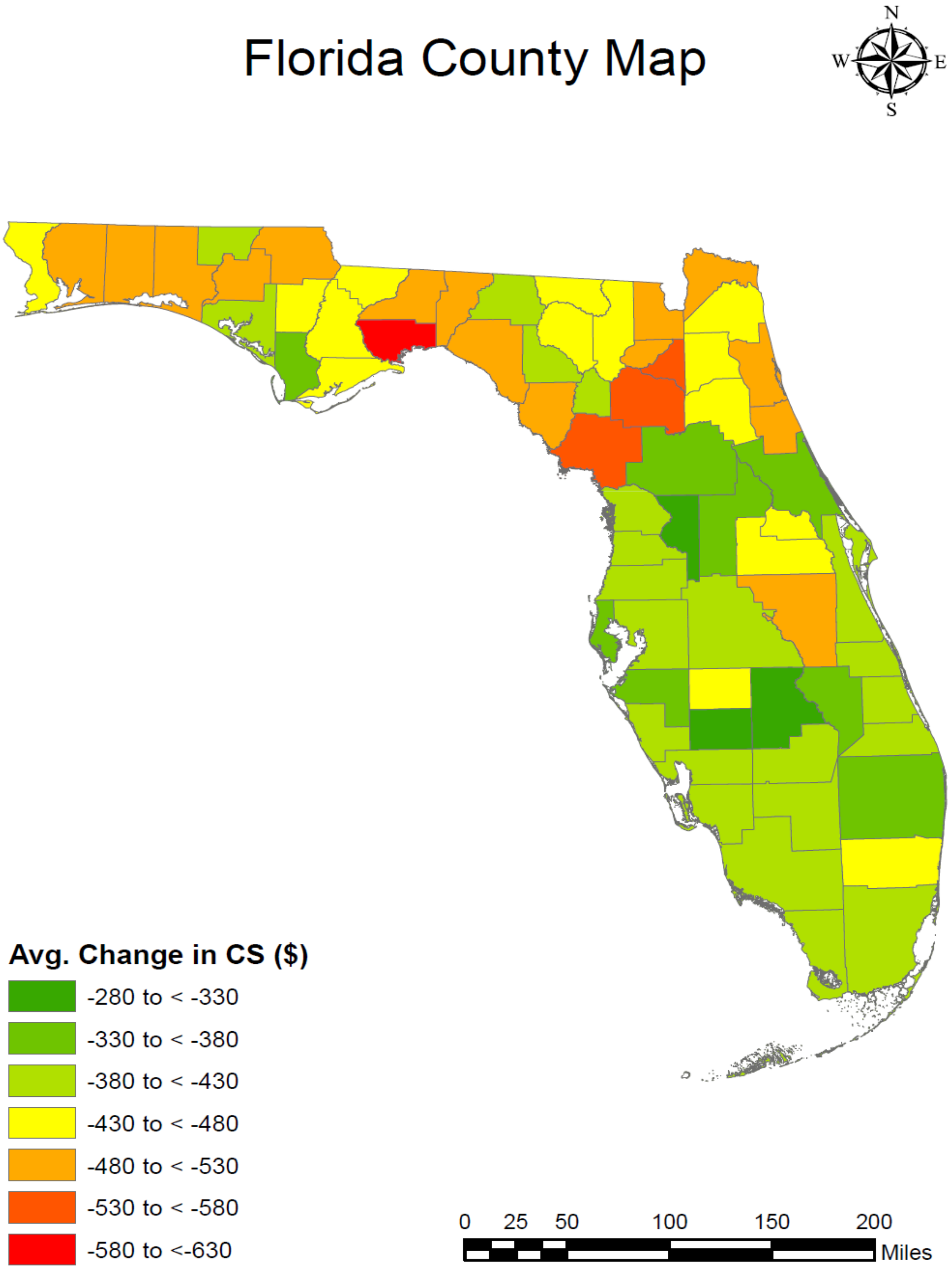

Figure 5-3. Spatial distribution of impacts of mileage fee of 4.1 cents/mile

5.4.2 Step Mileage Fee

The above analysis reveals that if a high mileage fee is implemented in Florida, its socioeconomic impacts are likely to be regressive. To make the fee less regressive, step mileage fee structures are tested below. From the descriptive statistics, we observe that the low income group generally travels less than the group with higher incomes. Therefore, a step fee structure has potential to reduce the regressiveness of the mileage fees in Florida. In the structure, vehicles are charged with a lower fee up to a certain vehicle miles traveled (VMT) level, and then a higher fee is charged on the miles beyond the threshold. In this study, the threshold VMT levels are set around the average yearly VMTs of the lowest two income groups and the fees are set by trial and error to achieve the desired level of yearly VMT reductions.

Step fee to substitute for a flat fee of 2.8 cents/mile (10% VMT reduction). In order to substitute for a flat fee of 2.8 cents/mile, three different step fee schemes are implemented. In the first scheme, the threshold is set to 12000 miles, and the lower and higher rates are set to 2.3 and 3.5 cents/mile, respectively. In the third scheme, the threshold is set to 15000 miles, and the lower and higher rates are set to 2.35 and 4.1 cents/mile, respectively. Scheme 2 is situated between schemes 1 and 3. The resulting changes in consumer surplus, revenue, social welfare and percent VMT reduction are presented in Table 5-18. The table shows that each scheme is able to reduce the annual VMT by the same amount, with similar changes in consumer surplus, revenue and social welfare. The distributional impacts of the step fee schemes presented in Tables 5-19 to 5-24 are fairly similar to those of the flat fees. Table 5-25 compares the average changes in consumer surplus as a percentage of average income and demonstrates that, although the step fee schemes are still regressive in nature, the disparity is less than that of a flat fee. It can be observed from the tables that scheme 3 is the best from the equity point of view, with the maximum difference between the lower and higher rates.

Table 5-18. Total change in consumer surplus, revenue, social welfare and VMT under different mileage fees

VMT fee Scheme	Threshold (mile)	VMT fee up to threshold (cents/ mile)	VMT fee beyond threshold (cents/ mile)	Total change in consumer surplus ($)	Total change in revenue ($)	Total change in welfare ($)	% VMT reduction
Flat fee		2.80		-2646108	2313856	-332252	10.04
Step fee scheme 1	10000	2.30	3.50	-2855742	2512368	-343374	10.04
Step fee scheme 2	12000	2.30	3.75	-2894320	2547032	-347287	10.04
Step fee scheme 3	15000	2.35	4.10	-2911453	2561617	-349836	10.03

Table 5-19. Average changes in consumer surplus, revenue and social welfare by income group (Scheme 1)

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0- $19,999	-85.69	(121.41)	-0.67	64.47	-21.22
$20,000- $39,999	-139.70	(185.78)	-0.46	114.27	-25.43
$40,000- $59,999	-210.00	(214.18)	-0.42	180.00	-30.01
$60,000- $79,999	-278.00	(244.79)	-0.39	247.39	-30.61
$80,000 -$200,000	-350.60	(284.77)	-0.27	325.56	-25.10

Table 5-20. Average changes in consumer surplus, revenue and social welfare by location (Scheme 1)

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	-276.30	(296.18)	248.20	-28.16
Urban	-202.50	(222.59)	176.86	-25.72

Table 5-21. Average changes in consumer surplus, revenue and social welfare by income group (Scheme 2)

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0- $19,999	-82.64	(122.96)	-0.65	62.33	-20.30
$20,000- $39,999	-137.10	(194.61)	-0.45	112.26	-24.91
$40,000- $59,999	-210.40	(227.31)	-0.42	180.28	-30.13
$60,000- $79,999	-282.80	(263.20)	-0.40	251.30	-31.55
$80,000 -$200,000	-363.40	(312.26)	-0.28	336.73	-26.73

Table 5-22. Average changes in consumer surplus, revenue and social welfare by location (Scheme 2)

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	-285.10	(321.72)	255.70	-29.45
Urban	-203.90	(237.10)	178.20	-25.76

Table 5-23. Average changes in consumer surplus, revenue and social welfare by income group (Scheme 3)

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0- $19,999	-81.60	(122.62)	-0.64	61.50	-20.10
$20,000- $39,999	-134.80	(202.20)	-0.45	110.25	-24.57
$40,000- $59,999	-208.20	(239.97)	-0.41	178.33	-29.87
$60,000- $79,999	-283.80	(283.63)	-0.40	251.86	-31.95
$80,000 -$200,000	-372.50	(347.32)	-0.29	344.58	-27.92

Table 5-24. Average changes in consumer surplus, revenue and social welfare by location (Scheme 3)

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	-292.40	(352.30)	261.79	-30.64
Urban	-203.60	(251.90)	177.98	-25.68

Table 5-25. Average changes in consumer surplus as a percent of average income by income group

Income group	HH#	Flat mileage fee of 2.8 cents/mile	Step mileage fee scheme 1	Step mileage fee scheme 2	Step mileage fee scheme 3
$0- $19,999	2119	-0.84	-0.67	-0.65	-0.64
$20,000- $39,999	3288	-0.49	-0.46	-0.45	-0.45
$40,000- $59,999	2468	-0.40	-0.42	-0.42	-0.41
$60,000- $79,999	1800	-0.35	-0.39	-0.40	-0.40
$80,000 -$200,000	3411	-0.22	-0.27	-0.28	-0.29

Step fee to substitute for a flat fee of 4.1 cents/mile (20% VMT reduction). Similarly, we have investigated three different step fee schemes to substitute for a flat fee of 4.1 cents/mile. The results are presented in Tables 5-26 to 5-33. All three schemes reduce the annual VMT by 20%, with similar change in consumer surplus, revenue and social welfare. Again, the schemes are found to be less regressive than the flat fees. It is also found that the scheme with the maximum difference between the lower and higher rates gives the least regressive structure. The general conclusion is that a well-designed step fee structure is able to reduce the inequality of the impacts of mileage fees in Florida.

Table 5-26. Total change in consumer surplus, revenue, social welfare and VMT under different mileage fees

VMT fee scheme	Threshold (mile)	VMT fee up to threshold (cents/ mile)	VMT fee beyond threshold (cents/ mile)	Total change in consumer surplus ($)	Total change in revenue ($)	Total change in welfare ($)	% VMT reduction
Flat fee		4.10		-5445869	4437238	-1008631	20.14
Step fee scheme 4	10000	3.50	5.07	-5719999	4697700	-1022299	20.14
Step fee scheme 5	12000	3.50	5.44	-5775401	4746358	-1029044	20.15
Step fee scheme 6	15000	3.55	6.00	-5802717	4770269	-1032448	20.11

Table 5-27. Average changes in consumer surplus, revenue and social welfare by income group (Scheme 4)

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0- $19,999	-185.30	(196.45)	-1.46	125.78	-59.57
$20,000- $39,999	-288.60	(301.88)	-0.95	217.10	-71.53
$40,000- $59,999	-418.40	(354.63)	-0.83	333.46	-84.96
$60,000- $79,999	-545.20	(405.22)	-0.77	453.70	-91.54
$80,000 -$200,000	-693.00	(484.74)	-0.53	609.12	-83.97

Table 5-28. Average changes in consumer surplus, revenue and social welfare by location (Scheme 4)

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	-551.70	(508.28)	461.75	-89.72
Urban	-406.20	(378.56)	331.33	-74.93

Table 5-29. Average changes in consumer surplus, revenue and social welfare by income group (Scheme 5)

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0- $19,999	-182.10	(197.07)	-1.43	123.85	-58.32
$20,000- $39,999	-285.40	(311.90)	-0.94	214.83	-70.58
$40,000- $59,999	-418.50	(371.23)	-0.83	333.62	-84.95
$60,000- $79,999	-551.40	(430.00)	-0.78	458.45	-92.99
$80,000 -$200,000	-711.00	(524.43)	-0.54	624.15	-86.88

Table 5-30. Average changes in consumer surplus, revenue and social welfare by location (Scheme 5)

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	-563.70	(543.79)	471.49	-92.27
Urban	-408.30	(397.97)	333.43	-74.97

Table 5-31. Average changes in consumer surplus, revenue and social welfare by income group (Scheme 6)

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0- $19,999	-180.90	(195.44)	-1.42	122.92	-58.02
$20,000- $39,999	-282.20	(320.31)	-0.93	212.42	-69.86
$40,000- $59,999	-414.90	(387.24)	-0.82	330.82	-84.10
$60,000- $79,999	-552.30	(458.45)	-0.78	458.94	-93.39
$80,000 -$200,000	-724.90	(577.74)	-0.56	635.82	-89.16

Table 5-32. Average changes in consumer surplus, revenue and social welfare by location (scheme 6)

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	-574.10	(588.89)	479.80	-94.38
Urban	-408.20	(418.69)	333.51	-74.73

Table 5-33. Average changes in consumer surplus as a percent of average income by income group

Income group	HH#	Flat mileage fee of 2.8 cents/mile	Step mileage fee scheme 1	Step mileage fee scheme 2	Step mileage fee scheme 3
$0- $19,999	2119	-1.66	-1.46	-1.43	-1.42
$20,000- $39,999	3288	-1.00	-0.95	-0.94	-0.93
$40,000- $59,999	2468	-0.81	-0.83	-0.83	-0.82
$60,000- $79,999	1800	-0.71	-0.77	-0.78	-0.78
$80,000 -$200,000	3411	-0.47	-0.53	-0.54	-0.56

5.4.3 Mileage Fee Based on Fuel Efficiency

In the previous two sections, we examined the impacts of flat and step mileage fees. As the flat fees are more regressive in nature, step fees are proposed to reduce the discrepancy. However, none of the flat and step fees is environmentally friendly, because the vehicles with less fuel efficiency benefit more in the mileage fee system. Many studies (e.g., Zhang et al., 2009; Larsen et al., 2012; Zhang and McMullen, 1010) have also shown concern that a flat mileage fee will lead to less incentive to switch to more fuel efficient vehicles. In order to promote an environmentally friendly policy, fees can be charged based on vehicle fuel efficiency. In this structure, vehicles with MPG lower than the state average are charged more than vehicles with MPG higher than state average. However, this causes a concern from the equity point- of- view, as low income households generally own less fuel efficient vehicles than those with higher incomes. Therefore in this section, we evaluate the impacts of this type of fees for 10% and 20% VMT reduction scenarios.

Fees to substitute for a flat fee of 2.8 cents/mile (10% VMT reduction). The average fuel efficiency of vehicles in Florida is 21 MPG. Taking 21 MPG as a threshold, we have tested two different fee schemes for this scenario. In the first scheme, the difference between the less efficient vehicle's fee and more efficient vehicle's fee is less than 1 cent, while in the second scheme the difference is more than 1 cent. The fee structures, total change in consumer surplus, revenue and social welfare are provided in Table 5-34. From the table, we can observe that the total changes in consumer surplus, revenue and welfare are similar to those of flat fees. The distributional impacts are also similar to those of flat fees (Tables 5-35 to 5-38). The gasoline consumptions under different fee schemes are provided in Table 5-39. From the table we can observe that the gasoline consumptions are reduced by 0.33% and 0.73% from those in the schemes 1 and 2, respectively. As the amount of gasoline consumption is directly related to greenhouse gas (GHG) emission, the test confirms that the new fee schemes are more environmentally friendly. Moreover, as the new system charges more for less efficient vehicles, there will be an obvious incentive to switch to vehicles with higher fuel efficiency.

Table 5-34. Total change in consumer surplus, revenue, social welfare and VMT under different mileage fee

VMT fee Scheme	Thres-hold (MPG)	VMT fee for MPG> threshold (cents/ mile)	VMT fee for MPG≤ threshold (cents/ mile)	Total change in consumer surplus ($)	Total change in revenue ($)	Total change in welfare ($)	% VMT reduction
Flat fee		2.80		-2646108	2313856	-332252	10.04
Scheme 1	21	2.55	3.20	-2800080	2462436	-337643	10.06
Scheme 2	21	2.20	3.78	-3021144	2660339	-360806	10.02

Table 5-35. Average changes in consumer surplus, revenue and social welfare by income group (Scheme 1)

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0- $19,999	-109.60	(94.96)	-0.86	81.40	-28.24
$20,000- $39,999	-156.40	(135.08)	-0.52	127.69	-28.72
$40,000- $59,999	-209.30	(150.45)	-0.42	180.44	-28.94
$60,000- $79,999	-260.80	(170.92)	-0.37	234.70	-26.14
$80,000 -$200,000	-312.80	(191.47)	-0.24	293.84	-19.02

Table 5-36. Average changes in consumer surplus, revenue and social welfare by location (Scheme 1)

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	-259.10	(206.24)	233.65	-25.48
Urban	-201.80	(158.38)	175.93	-25.89

Table 5-37. Average changes in consumer surplus, revenue and social welfare by income group (Scheme 2)

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0- $19,999	-113.60	(94.86)	-0.89	84.90	-28.75
$20,000- $39,999	-165.70	(138.28)	-0.55	135.85	-29.89
$40,000- $59,999	-222.00	(159.25)	-0.44	191.70	-30.33
$60,000- $79,999	-281.00	(186.20)	-0.40	252.75	-28.28
$80,000 -$200,000	-346.30	(213.62)	-0.27	324.16	-22.24

Table 5-38. Average changes in consumer surplus, revenue and social welfare by location (Scheme 2)

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	-289.20	(227.18)	259.46	-29.78
Urban	-215.10	(170.75)	188.18	-26.98

Table 5-39. Average gasoline consumption by income group

Income group	HH#	Flat fee of 2.80 cents/mile (gallon)	Based on fuel efficiency	
			Scheme 1 (gallon)	Scheme 2 (gallon)
$0- $19,999	2119	394.31	392.89	391.75
$20,000- $39,999	3288	568.81	566.70	564.40
$40,000- $59,999	2468	765.36	763.18	760.65
$60,000- $79,999	1800	950.64	947.64	943.79
$80,000 -$200,000	3411	1208.80	1204.80	1199.50
Total		10429071	10394855	10353424

Fees to substitute for a flat fee of 4.1 cents/mile (20% VMT reduction).

Similarly, we have investigated two different fee schemes based on vehicle fuel efficiency to substitute for a flat fee of 4.1 cents/mile, and the results are presented in Tables 5-40 to 5-45. The findings are the same as those for the 2.8 cents/mile. The general conclusion is that a well-designed mileage fee based on vehicle fuel efficiency is able to maintain the desired revenue and reduce GHG emissions.

Table 5-40. Total change in consumer surplus, revenue, social welfare and VMT under different mileage fee

VMT fee Scheme	Threshold (MPG)	VMT fee for MPG> threshold (cents/ mile)	VMT fee for MPG≤ threshold (cents/ mile)	Total change in consumer surplus ($)	Total change in revenue ($)	Total change in welfare ($)	% VMT reduction
Flat fee		4.10		-5445869	4437238	-1008631	20.14
Scheme 1	21	3.83	4.50	-5575444	4564875	-1010569	20.16
Scheme 2	21	3.50	5.00	-5734839	4711769	-1023070	20.10

Table 5-41. Average changes in consumer surplus, revenue and social welfare by income group (Scheme 3)

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0- $19,999	-212.80	(172.80)	-1.67	141.44	-71.43
$20,000- $39,999	-306.90	(246.05)	-1.01	229.49	-77.47
$40,000- $59,999	-414.40	(279.58)	-0.82	330.95	-83.54
$60,000- $79,999	-517.90	(314.25)	-0.73	434.05	-83.91
$80,000 -$200,000	-633.10	(363.84)	-0.49	560.70	-72.49

Table 5-42. Average changes in consumer surplus, revenue and social welfare by location (Scheme 3)

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	-520.80	(393.26)	436.42	-84.41
Urban	-400.50	(300.07)	325.26	-75.29

Table 5-43. Average changes in consumer surplus, revenue and social welfare by income group (Scheme 4)

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0- $19,999	-215.40	(169.77)	-1.70	123.85	-58.32
$20,000- $39,999	-313.40	(244.88)	-1.03	214.83	-70.58
$40,000- $59,999	-423.10	(281.23)	-0.84	333.62	-84.95
$60,000- $79,999	-532.30	(320.85)	-0.75	458.45	-92.99
$80,000 -$200,000	-658.20	(375.08)	-0.50	624.15	-86.88

Table 5-44. Average changes in consumer surplus, revenue and social welfare by location (Scheme 4)

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	-543.40	(405.34)	455.41	-88.03
Urban	-409.90	(305.40)	334.40	-75.53

Table 5-45. Average gasoline consumption by income group

Income group	HH#	Flat fee of 4.10 cents/mile (gallon)	Based on fuel efficiency	
			Scheme 1 (gallon)	Scheme 2 (gallon)
$0- $19,999	2119	341.19	340.01	339.17
$20,000- $39,999	3288	509.15	507.42	505.80
$40,000- $59,999	2468	698.38	696.66	694.98
$60,000- $79,999	1800	880.09	877.67	875.04
$80,000 -$200,000	3411	1141.10	1137.90	1134.10
Total		9597180	9569291	9540431

5.4.4 Mileage Fee Based on Vehicle Type

In the last section, we examined the impacts of mileage fees based on vehicle fuel efficiency. Although such a fee structure would be environmentally friendly, it is difficult to implement in practice, as the fuel efficiency varies among different vehicles. One alternate option is to charge vehicles based on vehicle type. Generally, larger vehicles consume more fuel and contribute more emissions. According to the Federal Highway Cost Allocation Study (FHWA, 2000), the air pollution cost attributable to automobiles is 1.1 cents/mile; for pickups and vans the cost is 2.6 cents/mile; and for vehicles weighing more than 8500 pounds is 3 cents/mile. These rates suggest that pickups and vans are contributing air pollution at a rate about 2.5 times higher than cars, and that vehicles weighing more than 8500 pounds are contributing air pollution at a rate about 3 times that of cars. Although the report does not give exact values for motorcycles, SUVs, trucks and RVs, we assume that the effect of a motorcycle would be about 0.5 times that of a car; SUVs and trucks would be the same as pickups and vans (i.e., 2.5 times that of a car); and RVs would be 3 times that of cars (as RVs are more than 8500 pounds). In our study, the fees for cars are set to 1.90 and 2.76 cents/mile for the 10%

and 20% VMT reduction scenarios, respectively. The fees for other vehicles are obtained by multiplying by the factors provided in Table 5-46.

Table 5-46. Multiplying factors for different vehicle type

Car	Van	SUV	Truck	RV	Motorcycle
1 (base case)	2.5	2.5	2.5	3	0.5

The total changes in consumer surplus, revenue, social welfare and gasoline consumption under different fee schemes are provided in Table 5-47. From the table, we can observe that both schemes produce more revenue than the flat fees, while also reducing gasoline consumption by about 1%, which is favorable from an emission-control point of view. The distributional impacts are very similar to those of flat fees (5-48 to 5-51).

Table 5-47. Total change in consumer surplus, revenue, social welfare and gasoline consumption under different mileage fee

Scenario	Fees type	Total change in consumer surplus ($)	Total change in revenue ($)	Total change in welfare($)	Gasoline consumption (gallon)
10 % VMT reduction	Flat fee (2.80 cents/mile)	-2646108	2313856	-332252	10429071
	Fee based on veh. type- scheme 1	-3463708	3029526	-434181	10327291
20 % VMT reduction	Flat fee (4.10 cents/mile)	-5445869	4437238	-1008631	9597180
	Fee based on veh. type- scheme 2	-6514604	5331646	-1182958	9485232

Table 5-48. Average changes in consumer surplus, revenue and social welfare by income group (Scheme 1)

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0 - $19,999	-107.60	(138.06)	-0.85	79.63	-28.01
$20,000 - $39,999	-174.70	(201.10)	-0.58	142.27	-32.46
$40,000 - $59,999	-256.80	(248.86)	-0.51	219.08	-37.79
$60,000 - $79,999	-334.20	(277.40)	-0.47	297.00	-37.25
$80,000 - $200,000	-417.90	(326.74)	-0.32	386.32	-31.60

Table 5-49. Average changes in consumer surplus, revenue and social welfare by location (Scheme 1)

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	-356.50	(326.90)	313.03	-43.53
Urban	-239.90	(254.97)	209.57	-30.39

Table 5-50. Average changes in consumer surplus, revenue and social welfare by income group (Scheme 2)

Income group	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in consumer surplus as % of avg. income	Avg. change in revenue ($)	Avg. change in social welfare ($)
$0- $19,999	-210.40	(223.94)	-1.66	140.38	-70.04
$20,000- $39,999	-332.50	(329.84)	-1.10	249.02	-83.55
$40,000- $59,999	-479.80	(408.31)	-0.95	380.84	-99.03
$60,000- $79,999	-620.70	(456.43)	-0.88	516.47	-104.20
$80,000 -$200,000	-783.80	(545.29)	-0.60	687.72	-96.10

Table 5-51. Average changes in consumer surplus, revenue and social welfare by location (Scheme 2)

Location	Avg. change in consumer surplus in $ (std. dev.)		Avg. change in revenue ($)	Avg. change in social welfare ($)
Rural	-658.10	(555.20)	540.47	-117.60
Urban	-454.60	(428.17)	371.63	-83.07

5.5 Summary

A mileage fee is now being considered as the most viable alternative to the conventional gasoline tax. However, there is always a concern from the equity standpoint that lower income groups should not be disadvantaged under the new system. In this chapter, we performed a quantitative assessment of the impacts of implementing a mileage fee system in Florida. A regression model was constructed using the NHTS 2009 data of Florida. Four different mileage fee structures under different scenarios were tested.

In this study, only the state and local portion of the gasoline tax (i.e. not including the federal tax) was replaced by a mileage fee, and it was found that a flat fee of 1.61 cents/mile would be sufficient to maintain the current level of revenue (Note that we did not consider any cost difference for installation and operations.) If the new system requires additional costs, the revenue-neutral fee would be higher. With a flat fee of 1.61 cents/mile, the average change in consumer surplus as a percentage of average income is negligible in all income groups, with those in rural areas receiving slightly more benefit than those in urban areas, although the difference is not significant. Across different counties, the average change in consumer surplus ranges from -$13.92 to $77.93. Flat fees of 2.8 and 4.1 cents/mile were considered to achieve 10% and 20% VMT reductions, respectively. Under these higher fees, the impacts are regressive in nature and the disparity increases with the fee rate, with people in rural areas suffering more than urban dwellers. However, distributional impacts among counties are fairly uniform with the Gini coefficient being only 0.17.

As the flat fee is regressive in nature, a step mileage fee structure (two mileage fees with the lower being charged for travel within a certain total miles and the higher one for additional miles) was tested. From the results, we find that the step fees are less regressive than the flat fees and are capable of generating the same amount of revenue as the flat fees.

Two environmentally friendly fees (fee based on vehicle fuel efficiency and fee based on vehicle type) were tested as well. The results reveal that both fee structures are as regressive as flat fees, but they are capable of reducing gasoline consumption, thereby reducing environmental emissions.

The purpose of our study is to provide the policymakers with insights into different mileage fee structures and their impacts on society. Based on our empirical study, we find that under a flat rate mileage fee, households with less fuel efficient vehicles benefit, while those with higher fuel efficiency vehicles are negatively affected. Thus, the flat mileage fees provide no incentive to use environmentally friendly, more fuel efficient vehicles or to reduce consumer travel. Fees based on vehicle fuel efficiency can be favorable from the perspective of environmental protection, but, as the low income groups own relatively less fuel efficient vehicles, the fees are regressive in nature. The step mileage fee structure is an excellent way to discourage people from unnecessary trips, thereby relieving traffic congestion and reducing emissions. As the average yearly VMT of the low income group is less in Florida, the step fees are less regressive than the flat fees. A fee based on vehicle type seems to be better from the marginal pricing point of view, as the larger vehicles generate more externalities (e.g., produce more emissions) than the smaller ones. However, this fee structure is also as regressive as flat fees. We conclude that a step fee is the best option among the four fee structures examined. Furthermore, we believe that in order to achieve multiple objectives, a more complex fee structure is needed. For example, the step mileage fee can be charged based on vehicle type. This type of fee will allow the state to generate sufficient revenue, and it will be less regressive in nature and environmentally friendly. An even more complex structure would be a step mileage fee based on both vehicle type and vehicle age.

We would like to mention that the analyses performed here are based on a regression model, where the total demand of a household is assumed to be function of travel cost and other socioeconomic variables. This model is adequate for impact analysis of flat fees and step fees. However, for the fees based on vehicle fuel efficiency and vehicle type, there is no option to incorporate different fees for different vehicles in this simple model. Therefore, we used weighted fees in the model to capture the average impacts. It would be more appropriate to use a simultaneous regression model or a discrete continuous model to capture the travel demand changes of different types of vehicles with different fees.

Moreover, in our study we have assumed that the vehicle ownership, commuter travel behavior, and land use patterns would remain the same after the implementation of the mileage fee. Our future study will provide a more complete assessment of the impacts by incorporating all the above mentioned limitations.

CHAPTER 6
CONCLUSIONS

This dissertation involved two types of impact studies: one related to the effects of site development on vehicular traffic patterns, the other focusing on the socioeconomic impact of a mileage fee on Florida drivers. The first part examined the methodology of traffic impact analysis. More specifically, the link distribution percentage method and the special generator method were compared for performing traffic impact analysis for a new site development. In addition, a detailed analysis of path flow and O-D specific link flow distributions led to procedures to enhance the methodology. In the second part of the dissertation, we assessed the impacts of implementing mileage fees in Florida on drivers in different parts of Florida and with different socioeconomic circumstances.

Based on our empirical study, we observed that the link distribution percentage method and the special generator method produce similar estimates of traffic impacts caused by hypothetical developments in different scenarios. We found that the link percentage patterns obtained for different scenarios were also similar, which is consistent with the assumption that the link distribution percentages remain the same, regardless of the size of the development.

Although both approaches are acceptable and produce similar results, for simplicity, we recommended the link distribution percentage method for traffic impact analysis. On another note, the quality of the results produced by the link distribution percentage method depends on how well the trip generation module replicates the real scenario of the modeling area. With a well-developed trip generation module, the ITE trip generation rate does not have to be applied externally. Consequently, the link distribution percentage method will produce accurate estimates.

We worked extensively on another issue of TIA methodology. Both the link distribution percentage and special generator methods estimate the number of development trips from the path flow or O-D specific link flow information, which is obtained from the “Select Zone Analysis” module of the software. However, it is well known that these two flow distributions are not unique. As a consequence, the estimated result will be one of a number of many possible solutions. In order to obtain consistent and defendable results, we proposed using the average path flow or O-D specific link flow distribution as the basis for TIA.

In the average path flow or O-D specific link flow solution, all results are assumed to have an equal probability of occurrence. Consequently, the mean of all the path or O-D specific link flow solutions, which is essentially the center of gravity of the UE polyhedron, seems a logical selection for the basis of traffic impact studies. We also proved that the average distribution is continuous with the assignment inputs and stable. A modified extended hit-and-run sampling algorithm was proposed to compute the average O-D specific link flow distribution.

Our empirical study revealed that the results obtained using the average O-D specific link flow distribution are significantly different from those produced by the entropy-maximizing approach. We believe that the proposed basis is more intuitively appealing to practitioners, and the result should be easier to defend, as we are taking the average of all possible solutions instead of a random solution or a solution with a very low probability of occurrence. However, our proposed method is more computationally intensive, and we will be investigating more efficient sampling procedures in the future.

Due to the increasing concern about the adequacy of revenue for highway projects, we also assessed the possibility of implementing a vehicle miles traveled (VMT) fee in Florida. Four different mileage fee structures (flat fee, step fee, fee based on vehicle fuel efficiency and fee based on vehicle type) were evaluated. Based on our study, a flat fee of 1.61 cents/mile is sufficient to maintain the current level of revenue if Florida switches from the gasoline tax to a mileage fee (Note that here only the state and local portion of the gasoline tax is converted to the mileage fee and no additional cost is considered for installation and administration of the mileage fee system.) At this fee, we found that the change in consumer surplus as a percentage of average household income is negligible among the different income groups studied. The people who live rural areas gain slightly more than the people who live in urban areas, but when 2.8 and 4.1 cents/mile fees were tested, we found the fees to be regressive in nature, with the disparities becoming greater with higher mileage fees.

Given that the flat fees were regressive in nature, step mileage fees were tested. In this structure, lower fees were charged up to a preset threshold mile, with higher fees for miles traveled in excess of the threshold. As low income people travel less than those with higher incomes, the fee structure was found to be less regressive in nature.

Since none of the above mentioned fee structures was environmentally friendly, we examined two other mileage fee structures: one based on vehicle fuel efficiency and the other based on vehicle type. While both of the fee structures reduced overall household gasoline consumption, both structures were found to be as regressive as flat fees.

Based on our analysis, we observed that one cannot achieve multiple objectives with a simple mileage fee structure. A flat fee of 1.61 cents/mile can immediately be charged to convert the system from gasoline tax to mileage fee. However, in order to achieve multiple objectives, complex mileage fee structures are required. For example, step mileage fees can be charged based on vehicle type. In that case, the fee will be less regressive, and it will also reduce total vehicle miles travel, overall gasoline consumption and environmental emissions. The impacts of complex fee structures will be investigated in the future.

We believe that the outcomes of this dissertation will be very helpful for practitioners and policymakers, especially in Florida. Based on our study, the link distribution percentage approach is now the recommended method for performing traffic impact studies in Florida. We also hope that the average flow distribution will be used for traffic impact analysis in the future, when a more efficient sampling procedure becomes available. The mileage fee impact assessment will provide useful insights about the socioeconomic consequences of implementing a mileage fee system in Florida. While considering implementation of a mileage fee system, the results of our study will guide policymakers in fixing the appropriate fee structure to generate sufficient revenue without compromising equity and other policy goals (e.g. emission reduction).

APPENDIX A
NETWORK CHARACTERISTICS OF SIOUX FALLS NETWORK

Link	FFTT*	Cap**	Link	FFTT	Cap	Link	FFTT	Cap	Link	FFTT	Cap
1-2	3.6	6.02	8-7	1.8	15.68	13-24	2.4	10.18	19-17	1.2	9.65
1-3	2.4	9.01	8-9	2.0	10.10	14-11	2.4	9.75	19-20	2.4	10.01
2-1	3.6	12.02	8-16	3.0	10.09	14-15	3.0	10.26	20-18	2.4	8.11
2-6	3.0	15.92	9-5	3.0	20.00	14-23	2.4	9.85	20-19	2.4	6.05
3-1	2.4	46.81	9-8	2.0	10.10	15-10	3.6	27.02	20-21	3.6	10.12
3-4	2.4	34.22	9-10	1.8	27.83	15-14	3.0	10.26	20-22	3.0	10.15
3-12	2.4	46.81	10-9	1.8	27.83	15-19	2.4	9.64	21-20	3.6	10.12
4-3	2.4	25.82	10-11	3.0	20.00	15-22	2.4	20.63	21-22	1.2	10.46
4-5	1.2	28.25	10-15	3.6	27.02	16-8	3.0	10.09	21-24	1.8	9.77
4-11	3.6	9.04	10-16	3.0	10.27	16-10	3.0	10.27	22-15	2.4	20.63
5-4	1.2	46.85	10-17	4.2	9.99	16-17	1.2	10.46	22-20	3.0	10.15
5-6	2.4	13.86	11-4	3.6	9.82	16-18	1.8	39.36	22-21	1.2	10.46
5-9	3.0	10.52	11-10	3.0	20.00	17-10	4.2	9.99	22-23	2.4	10.00
6-2	3.0	9.92	11-12	3.6	9.82	17-16	1.2	10.46	23-14	2.4	9.85
6-5	2.4	9.90	11-14	2.4	9.75	17-19	1.2	9.65	23-22	2.4	10.00
6-8	1.2	21.62	12-3	2.4	46.81	18-7	1.2	46.81	23-24	1.2	10.16
7-8	1.8	15.68	12-11	3.6	9.82	18-16	1.8	39.36	24-13	2.4	11.38
7-18	1.2	46.81	12-13	1.8	51.80	18-20	2.4	8.11	24-21	1.8	9.77
8-6	1.2	9.80	13-12	1.8	51.80	19-15	2.4	4.42	24-23	1.2	10.16

*: *Free-flow travel time in minutes*

**: *Link capacity in* 10^3 *veh/hr*

APPENDIX B
O-D DEMANDS OF SIOUX FALLS NETWORK

O\D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	1	1	3	2	3	3	2	2	4	2	2	3	2	3	3	2	1	2	2	1	3	2	1
2	1	0	1	2	1	2	2	4	2	4	2	1	3	1	1	3	2	0	1	1	0	1	0	0
3	1	1	0	2	1	3	1	2	1	3	3	2	1	1	1	2	1	0	0	0	0	1	1	0
4	3	2	2	0	3	2	2	3	3	4	3	2	4	3	3	5	4	1	1	2	1	3	4	1
5	2	1	1	3	0	2	2	3	4	5	3	2	2	1	2	4	2	0	1	1	1	2	1	0
6	2	3	2	3	2	0	2	4	2	4	2	2	2	1	2	5	3	1	2	3	1	2	1	1
7	3	2	1	2	2	2	0	4	3	5	3	3	3	2	4	5	4	1	2	3	1	3	1	0
8	4	2	2	4	3	4	3	0	4	5	4	3	4	2	3	5	5	3	2	3	2	3	2	1
9	3	2	1	4	4	2	3	3	0	6	4	4	3	3	4	4	4	4	2	3	2	4	3	2
10	3	4	2	4	3	4	5	4	6	0	6	5	3	3	5	5	5	4	4	4	4	5	5	5
11	2	1	2	3	2	1	3	4	4	5	0	3	3	4	4	4	3	1	2	3	2	3	3	2
12	2	1	2	4	2	2	4	3	3	4	3	0	4	3	3	3	2	1	3	4	3	3	4	4
13	3	3	1	4	2	2	2	3	3	6	4	4	0	3	4	3	2	1	2	3	3	4	3	3
14	3	1	1	3	1	1	2	3	4	5	4	3	3	0	4	3	2	1	2	4	3	4	4	2
15	3	1	1	3	2	2	1	2	3	5	3	2	3	4	0	5	4	2	3	4	3	5	3	2
16	2	1	1	2	2	3	3	4	3	6	3	2	3	4	4	0	5	2	4	3	2	3	2	1
17	2	2	1	3	2	3	3	3	2	6	4	3	2	3	4	4	0	1	4	3	2	3	2	1
18	1	0	0	1	0	1	2	3	2	7	2	2	1	1	2	3	4	0	2	4	1	2	1	0
19	3	1	0	2	1	2	4	5	4	5	4	3	2	2	3	4	5	2	0	3	2	3	2	1
20	3	1	0	3	1	3	3	5	3	6	4	3	3	2	3	4	4	2	3	0	3	4	2	1
21	1	0	0	2	1	1	2	4	3	5	4	3	3	2	4	4	5	1	2	4	0	4	2	2
22	3	1	1	3	2	2	3	3	4	6	4	2	3	3	4	4	5	1	3	3	4	0	3	3
23	3	0	1	4	1	1	2	3	5	5	3	4	2	3	4	2	2	1	2	3	2	4	0	2
24	1	0	0	2	0	1	1	2	2	4	3	3	3	2	2	1	1	0	1	2	3	4	3	0

** Unit: 10^3 veh/hr*

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BIOGRAPHICAL SKETCH

Md Shahid Mamun was born in Satkhira, Bangladesh. He received his Bachelor of Science degree in civil engineering from Bangladesh University of Engineering and Technology (BUET) in 2000, and he earned his Master of Applied Science degree in civil engineering from the University of Toronto, Canada in 2003. He then moved back to Bangladesh to join the faculty of the Department of Civil Engineering at Ahsanullah University of Science and Technology. In 2008, Mamun entered the University of Florida for his Ph.D. degree in civil engineering under the supervision of Dr. Yafeng Yin. During his Ph.D. program, Mamun was appointed as a research assistant and worked on several FDOT projects. His research interests include traffic impact analysis, transportation policy analysis, network modeling and travel demand modeling.