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Methodology To Convert A Transportation Planning Origin-Destination Matrix Into A Microscopic Traffic Simulation Origin-Destination Matrix

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Dedication

A mi amada esposa Erika

A mis amados hijos Paúl y Jóse.

A mi Padre Héctor Vidaña

A mis Hermanos Eva, Héctor, Hilda y Perla

En memoria de mi Madre Armida Eloisa

METHODOLOGY TO CONVERT A TRANSPORTATION PLANNING ORIGIN-DESTINATION MATRIX INTO A MICROSCOPIC TRAFFIC SIMULATION ORIGIN-DESTINATION MATRIX

by

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Abstract

Microscopic traffic simulation (MTS) is a cost-effective approach for the evaluation of traffic conditions in urban highways networks. In MTS models, traffic demand that is entered into the network is specified by one or several Origin-Destination (O-D) matrices. A major challenge in the application of MTS for large urban networks is the specification of the O-D matrices. This dissertation proposes a methodology that may be used to transform a O-D matrix from a transportation planning model (which is based on Traffic Analysis Zone, or TAZ, and is readily available) into a O-D matrix for a MTS model (which is traffic zone based, requires a higher resolution and larger matrix size).

The main concepts of the methodology are the discrete choice approach, followed by path analysis in a geographic information system. The discrete choice model predicts a driver's route choice preference based on the socioeconomic and trip characteristics of the driver. The path analysis matches the driver's route choice preference to an access point along a main street at the boundary of the TAZ. By applying the concept to every parcel in a TAZ, the volume and percentage splits of all the access points at the boundary of the TAZ is then estimated, from which the limited number of access points are selected to form the traffic zones and zone connectors for the MTS model. Once the traffic zones of all the TAZs have been identified, the trips generated from and attracted to each TAZ are proportioned among the traffic zones. The gravity model is applied to perform trip distribution analysis to produce the O-D matrix for the MTS model.

The proposed methodology has been developed based on a primarily residential TAZ within the City of El Paso, Texas. The morning peak hour home based trips made by drivers in the residential parcels in this TAZ have been predicted. The volume splits between all the access points have been

validated against field traffic counts. To methodology was then applied to a network with five TAZs to demonstrate its use to construct a O-D matrix for MTS of a relatively larger network.

This research contributes to the application of MTS models to large urban networks by adapting the O-D matrix from transportation planning models, saving the analyst time to construct a O-D from scratch. The methodology is flexible enough to be transferred to other metropolitan areas and also able to forecast O-D matrices for future years.

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Chapter 1: Introduction

1.1 Background and Motivation

A detailed analysis of large transportation networks is usually complicated, time consuming, and costly. It is also not easy to perform sensitivity analysis to account for uncertainties in the system. Under these circumstances, Microscopic Traffic Simulation (MTS) provides a cost-effective methodology (Hordous, et al., 2008). Microscopic traffic simulation is an analysis methodology that uses a computer model involving the detailed movement of every vehicle as they move across a highway network. Figure 1.1 shows a typical MTS in progress where vehicle are moving through a road network.

Figure 1.1 Microscopic simulation traffic using PARAMICS

In MTS models, the movement of vehicles is based on car-following and lane changing theories (Dowling, et al., 2004). The characteristics of vehicles and driver's behavior are assigned in a stochastic

way to each vehicle as they enter the network (Seung, 2006). The combination of the movement (car following and lane changing) theories and the characterization of each vehicle help to create, in a microscopic level of detail, a realistic network scenario with different vehicle types and driving behavior. In this way, MTS models are used as computer experiments in order to save time, budget and yet obtain acceptable results (FHWA , 2003).

It has been mentioned that MTS is a cost-effective methodology for the evaluation of traffic conditions in urban highways networks. The evaluations may be used to make decisions on how to manage existing roadway networks, to optimize current operations of transportation facilities, and to predict potential outcomes for highway design alternatives. The accuracy of the results obtained from the MTS models depends on the quality of the model (in representing the road geometry and traffic control), parameter calibration and input data. That is, the more accurate input data, the more accurate will be the simulated results.

In a MTS model, vehicles are released from traffic zones (or into the entry links) to travel through the main network to reach other traffic zones (or destination links). Figure 1.2 shows a portion of a relatively large MTS network with several traffic zones. Each traffic zone is connected to the network by a connector or link. The traffic demand is specified by one or several Origin-Destination (O-D) matrices in which the rows represent the origin zones and the columns represent the destination zones. The O-D matrices are usually obtained from one of the two main sources: traffic count or Transportation Planning Model (TPM).

Figure 1.2 Traffic zones in a microscopic traffic simulation model

The traffic count method relies on the data obtained from volume counters in the streets (links) to derive an O-D matrix. This methodology typically employs an iterative process that uses the data from the volume counters to update an initial O-D matrix to produce a new O-D matrix (Abrahamsson, 1998). The new matrix is constructed from the initial O-D matrix but the estimation algorithm modifies the trips produced from and attracted to the zones and also redistributes the trips between the O-D zones using the so-called proportional factors. The proportional factors are, in turn, estimated using one of two trip assignments techniques: proportional assignment (shortest path) and equilibrium assignment (Ortuzar, et al., 2011) (Abrahamsson, 1998). The advantages of this traffic count approach are the relatively fast and lower cost of data acquisition compared to conducting household surveys. However the main disadvantage is that there is no way to validate the estimated O-D matrix. Another disadvantage is that this method is based on existing traffic counts, and therefore it is difficult to forecast the O-D matrices for future years in order for the MTS models to simulate future scenarios.

Transportation planning model is a set of methodology used by planners to forecast travel demand in a road network. The methodology first involves defining homogeneous economic activity zones (called Traffic Analysis Zones or TAZs) in the city. The number of residents per TAZ is suggested to be greater than 1,200 but less than 3,000 and less than 15,000 person trips (Cambridge Systematics, 2007). In addition, the minimum number of employed residents is 600 per TAZ or the minimum number of employees (at commercial establishments) is 600 per TAZ (U.S. Department of Transportation, 2011). The zoning exercise is followed by an inventory study about land use, population and road network characteristics supplemented by a field survey to understand the trip making behavior among road users. Trips from each TAZ originate and terminate in one point that represents the centroid of all the activities within a TAZ. Vehicles are assumed to connect from this point to the main network through links called centroid connectors. The number of centroid connectors is small because each of them typically carries 10,000 to 15,000 vehicles per day (Cambridge Systematics, 2007). Figure 1.3 shows several TAZs bounded by the green lines where the rectangular area within the dash lines is showed in Figure 1.2. Comparing Figures 1.2 and 1.3, it can be observed that the TAZs in Figure 1.3 are larger than the traffic zones in Figure 1.2.

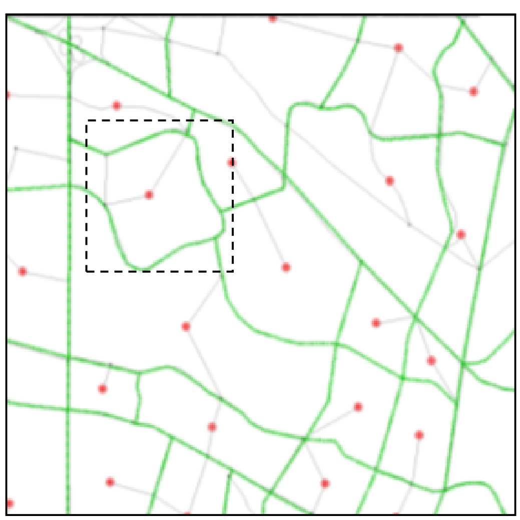

Figure 1.3 Traffic analysis zones in a transportation planning model

In the TPM, the forecasted inventory is entered into a so-called four step Urban Transportation Planning System (UTPS) procedure, also known simply as the four-step procedure. The four steps are trip generation, trip distribution, mode choice and traffic assignment (Ortuzar, et al., 2011). An O-D matrix is derived at the end of the trip distribution or mode choice step. The advantages of using the TPM are (1) it is possible to validate the estimated O-D matrix by comparing it against the TAZ's inventory data; (2) the consideration of socioeconomic factors in each TAZ makes it possible to forecast the O-D matrix in future years. Usually the O-D matrix in the base year is calibrated or validated with household survey data in the TAZs. The economic forecast models are calibrated independently using historical data. The disadvantages of this TPM method are (1) census data is only updated once every ten years, and (2) the incompatibility between the size of the TAZs in a TPM and the traffic zones of a MTS model. The O-D matrix obtained from the TPM represents the trips that begin from or end in each of the TAZs. The TAZ in a TPM is usually larger than the traffic zones in a MTS model. In fact, there are usually several traffic zones in a TAZ, each connected by a traffic zone connector to the road network (as illustrated in Figures 1.2 and 1.3). This complicates the transfer of the TAZ's trip origins and trips ends to the entering and exit links (traffic zone connectors), respectively, in the microscopic traffic network.

Popular MTS software such as PARAMICS (Quadstone, 2009), VISSIM (PTV, 2007) and AIMSUN (TSS, 2006), employ traffic zones and zone connectors to input vehicles similar to the example as shown in Figure 1.2. On the other hand, the TPMs (in the traffic assignment step) assign vehicles to the network through TAZ centroids connected to much fewer nodes (such as the example shown in Figure 1.3). This difference creates an incompatibility in the size of the O-D matrices and the values of the matrix elements between the TPM and the MTS model for the same coverage area, city or

region. Among the MTS software, VISSIM may be the exception from this problem because it has the capability to share the same O-D matrix with its parallel TPM called VISUM, developed by the same company (PTV, 2006). However, in this case, both VISSIM and VISUM must have exactly the same TAZs and traffic zones.

1.2 Problem Description

In the past ten years there have been advances in TPM. There have also been some advances and improvements in MTS software. However, far less attention has been paid to the incompatibility in the network coding when transferring the O-D data between the TPMs and MTS models. This lack of attention is because, until recently, almost all users (except a few researches and original software developers) use MTS programs to model small networks (due to the software or hardware limitation to process the numerous events in a detailed MTS model of a large network). Nevertheless, increased computer memory and speed has enabled a desktop computer to perform MTS for a relatively large network in real-time. The availability of an accurate O-D matrix that represents traffic demand in a MTS model is becoming a limitation that prevents the wide spread use of MTS model for large urban networks.

In U.S., cities with population of at least 50,000 must have a TPM (either developed or maintained by the metropolitan planning organization or the department of transportation) (USDOT, 2009). Therefore, it is important to devise a methodology that converts or transfers the O-D matrix of a TPM into an O-D matrix for large scale microscopic traffic simulation purpose. The methodology should semi-automatically or automatically convert an O-D matrix from a TPM (which is TAZ based) to be used in a MTS model (which is traffic zone based). The O-D matrices of MTS and TPM have

different sizes when covering the same network. The O-D matrix from a TPM is smaller since it is developed from TAZ data while the O-D matrix for a MTS model is larger in size given that it is generated for more traffic zones which are smaller in size than the TAZs. The transferred data would provide new opportunities for planners as well as traffic engineers to perform MTS in larger urban networks for more accurate analysis of urban transportation plans. Therefore, the objective of this research is to develop a methodology to convert the O-D matrices obtained from TPMs into O-D matrices for MTS models.

Transportation planning model provides, as a final result, the traffic volume in all the links in a road network. The link volume is based on the distribution of trips between the TAZs. This trip distribution data is summarized into a table called O-D matrix. The O-D matrix for a TPM is denoted as **O-D$_\mathbf{p}$** (with the subscript p stands for planning). The **O-D$_\mathbf{p}$** matrix is an arrangement representing the trips between all the TAZs. In the **O-D$_\mathbf{p}$** matrix the rows correspond to the origin TAZs ($i = 1,2,\ldots, n$) and the columns correspond to the destination TAZs ($j = 1,2,\ldots, n$) of the trips. In Figure 1.4, O_i^p and D_j^p represent the total trips that are generated in TAZ *i* and ended in TAZ *j*, respectively. The superscript *p* in O_i^p and D_j^p denotes the planning O-D matrix. In the **O-D$_\mathbf{p}$** matrix, O_i^p and D_j^p correspond to the row total and column total, respectively. The matrix element T_{ij}^p represents the number of trips between the TAZ *i* and the TAZ *j*. In other words:

$$\sum_{i=1}^{n} T_{ij}^{p} = D_j^p \qquad [1.1]$$

$$\sum_{j=1}^{n} T_{ij}^{p} = O_i^p \qquad [1.2]$$

Trips between an O-D pair are assumed to begin at the centroid of TAZ *i* and end at the centroid of TAZ *j*. The centroid is considered as the center of activities in a TAZ. Trips that begin and end in the same TAZ are excluded from the O-D matrix (Beimborn, et al., 2006).

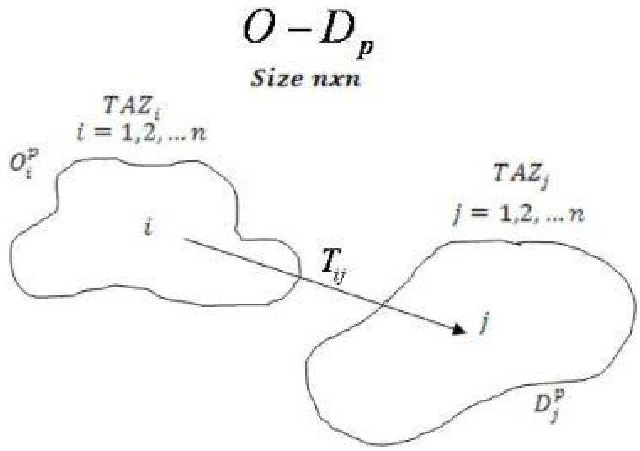

Figure 1.4 Notations of trips in a transportation planning model

On the other hand, MTS models estimate the traffic conditions in a network in a higher level of detail. The O-D matrix for a MTS model (**O-D$_{\mathbf{m}}$**, with the subscript m denoting MTS) represents the trips among the traffic zones. These traffic zones load the vehicles into the network and receive vehicles that exit the network through zone connectors. The zone connectors may be viewed as the collectors or minor streets located inside a TAZ. Each connector releases a portion of the total TAZ traffic into the road network and collects a portion of the vehicles arriving at the TAZ, through the main street surrounding the TAZ. In this way, a TAZ can have several traffic zones. In Figure 1.5, TAZ *i* is divided into several traffic zones $a = 1, 2, ..., z_i$ while TAZ *j* is divided into several traffic zones $b = 1, 2, ..., z_j$.

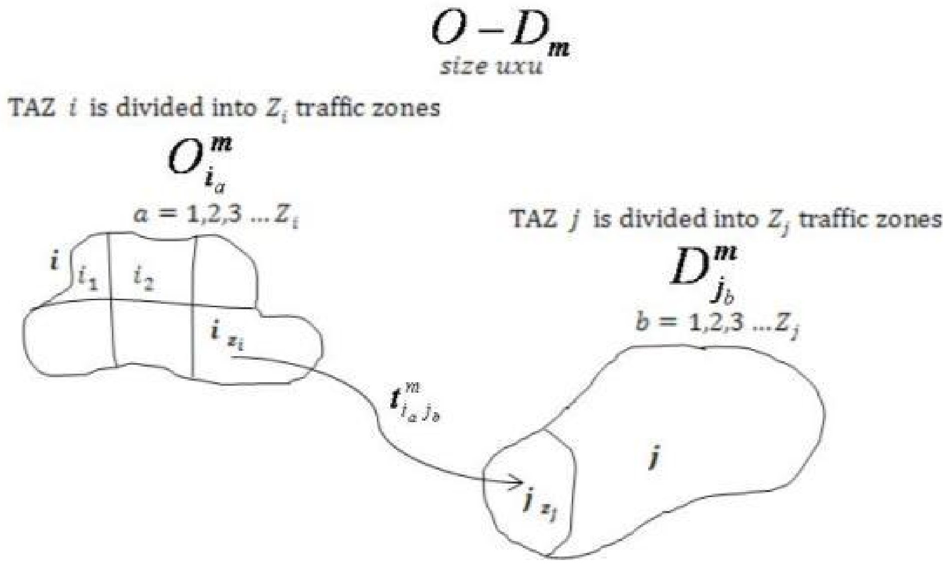

Figure 1.5 Relationships between trips between traffic analysis zones and traffic zones

An element T_{ij}^{p} in the **O-D$_\mathbf{p}$** matrix is decomposed into several elements $t^m_{i_a j_b}$ in the **O-D$_\mathbf{m}$** matrix. Note that the total trips in the modeled area are preserved in both **O-D$_\mathbf{p}$** and **O-D$_\mathbf{m}$**, such that:

$$\sum_{a=1}^{z_i}\sum_{b=1}^{z_j} t^m_{i_a j_b} = T_{ij}^{p} \qquad [1.3]$$

The problem indentified in this dissertation is the lack of systematic methodology to convert a **O-D$_\mathbf{m}$** matrix to a **O-D$_\mathbf{p}$** matrix, or to discompose T_{ij}^{p} into $t^m_{i_a j_b}$. The converted **O-D$_\mathbf{m}$** matrix could provide new opportunities to planners as well as to traffic engineers to use MTS models in order to produce more accurate analysis.

1.3 Research Objective

The objective of this research is to develop a methodology to convert a **O-D$_p$** matrix to a **O-D$_m$** matrix. A major assumption is that the **O-D$_p$** matrix for the time period of simulation (e.g., morning peak hour) has been obtained from a TPM.

The solution approach is based on the following proposed steps:

(1) Proportion the traffic demand in each TAZ into its traffic zones. Assume that this TAZ *i* is divided into $a = 1, 2, \ldots, z_i$ traffic zones. From the TPM, this TAZ generates a total number of trips O_i^p and attracted the total number of trips D_i^p. Furthermore, assume that each traffic zone generates $o_{i_a}^m$ trips and attracted $d_{i_a}^m$ trips. The problem in this step is to proportion O_i^p into $o_{i_a}^m$, $a = 1, 2, \ldots, z_i$ and D_i^p into $d_{i_a}^m$, $a = 1, 2, \ldots, z_i$. The proportional factor will be derived based on the estimated number of trips produced and attracted to each traffic zone, within the TAZ. The number and locations of the traffic zones will be selected based on the estimated traffic volume that will use each potential traffic zone. The estimation of traffic volume will be based on the discrete choice approach. With the trips produced and attracted proportions, the O_i^p and D_i^p will be split into $o_{i_a}^m$ and $d_{i_a}^m$, respectively.

(2) Trip distribution. The trip distribution is to connect the trips between traffic zones $a = 1, 2, ..., z_i$ and $b = 1, 2, ..., z_j$. The O_i^p and D_i^p will be split into $o_{i_a}^m$ and $d_{i_a}^m$ by means of the gravity model. Although in the TPM, trip distribution have been applied in the process of deriving the **O-D$_p$** matrix, once the TAZs have subdivided into traffic zones, each traffic zone pair (*a*,*b*) has a different interzonal distance or impedance. This distance is an important element in the gravity model

because if represents the cost value that will define the attractiveness between an origin-destination traffic zones pairs. At the end of this step, the $\mathbf{O\text{-}D_m}$ is said to be estimated.

1.4 Contributions

This research will provide the methodology to be employed in the transformation of a $\mathbf{O\text{-}D_p}$ matrix to a $\mathbf{O\text{-}D_m}$ matrix. This $\mathbf{O\text{-}D_m}$ matrix conversion methodology will allow MTS to be used for networks as large as TPM's. The availability of $\mathbf{O\text{-}D_m}$ will enable MTS to be performed with greater network coverage.

The methodology will provide the benefit of saving the analysts significant amount of time to construct an $\mathbf{O\text{-}D_m}$ matrix from scratch, e.g. conduct household surveyor.

As part of the methodology developed in this research, the following findings are expected:

(1) The process to locate traffic zones and zone connectors in a TAZ.

(2) Discrete choice model for driver's route choice preference when driving between his/her home and access points to the main streets.

(3) The process of allocating a TAZ's traffic demand among the traffic zones.

1.5 Scope and Limitations

The methodology is based on the following assumptions:

(1) The $\mathbf{O\text{-}D_p}$ matrix for the analysis period (hour) of interest has been provided;

(2) The hour of interest is the morning peak hour on a weekday;

(3) The TAZs selected for the methodology development are primarily residential zones;

(4) Shortest route by distance is the same as the shortest route by travel time due the lack of congestion and uniform speed limit in the TAZ.

1.6 Organization of Dissertation

This dissertation comprises eight chapters and is organized as follows:

- Chapter 1 introduces the background, problem statement, objective, contributions, scope and limitations of this research.
- Chapter 2 comprises a summary of the literature reviewed and tools to be used in the order to propose the method to convert a **O-D$_p$** matrix to a **O-D$_m$** matrix.
- Chapter 3 describes the research methodology adopted for this dissertation.
- Chapter 4 documents the efforts to gather the data necessary for this research.
- Chapter 5 provides the information related to the development of the discrete choice model to be used in the selection of the access points (intersections at the boundary of each TAZ) that forms the traffic zones and zone connectors.
- Chapter 6 describes the methodology to select the traffic zone and zone connectors in the MTS model.
- Chapter 7 demonstrates the application of the methodology to a group of TAZs for use in a MTS model. This chapter includes the conversion of O_i^p and D_i^p into $o_{i_a}^m$ and $d_{i_a}^m$
- Chapter 8 presents the conclusions and recommendations resulting of this research.

Chapter 2: Literature Review

2.1 Microscopic Traffic Simulation

Microscopic traffic simulation models simulate the behavior of individual vehicles within a predefined road network. They are used to estimate the likely changes in traffic patterns in the network resulting from changes to traffic flow patterns, physical improvements, and etc (Krogscheepers, et al., 2001). Microscopic traffic simulation models represent each vehicle unit (such as car, bus, truck and bicycle) with their own behavioral characteristics.

Microscopic traffic simulations move the vehicle units based on the statistical behavior of vehicles/drivers. The models generate pseudo-random numbers in order to produce stochastic behaviors in the model (Margison, et al., 2009). This differs from macroscopic traffic simulation models, which are based on fluid-flow theory and assumes that traffic behaves like a fluid. This fluid-flow assumption averts the possibility of evaluating in detail the outcome of some traffic phenomena like delays, queues, intersections etc, where stochastic car/diver behavior is one of the main contributing factors.

In recent years, MTS models have become one of the standard methodologies for the evaluation of road traffic management and control systems. This is due to the high fidelity in the modeling of dynamic traffic flow of complex intersections, incidents, managed lanes, work zones, corridors with coordinated signals, and etc.

Today, there are different software tools in the market that provide the environment to create MTS models. In this section, two of the most popular (and probably the two most popular) MTS

software, PARAMICS and VISSIM, are reviewed due the consistent performance trends in their results (Park, et al., 2004).

PARAMICS (Parallel Microscopic simulator) is a suite of MTS tools. The different modules within the suite are Modeller, Processor, Analyser, Estimator, Designer, Converter, Monitor, Programmer and Urban Analytical Framework (UAF) (Quadstone, 2009). PARAMICS Modeller is the main module where the network is built and simulated. The network structure in PARAMCIS is based on nodes (intersections) and links. Links that are interfaced with traffic zones are called connectors. Vehicles are loaded from traffic zones into the road network via the connectors, and travel to other traffic zones. Once the vehicles are loaded into the network, their route choice behavior to the respective destinations may follow the all-or-nothing, stochastic, dynamic feedback, or a combination of these assignment techniques as specified by the users. The traffic demands are specified in several O-D matrices, one for each class of vehicles (cars, trucks, buses, and etc). Figure 2.1 shows a screen shot of PARAMICS Modeller when the simulation is being executed.

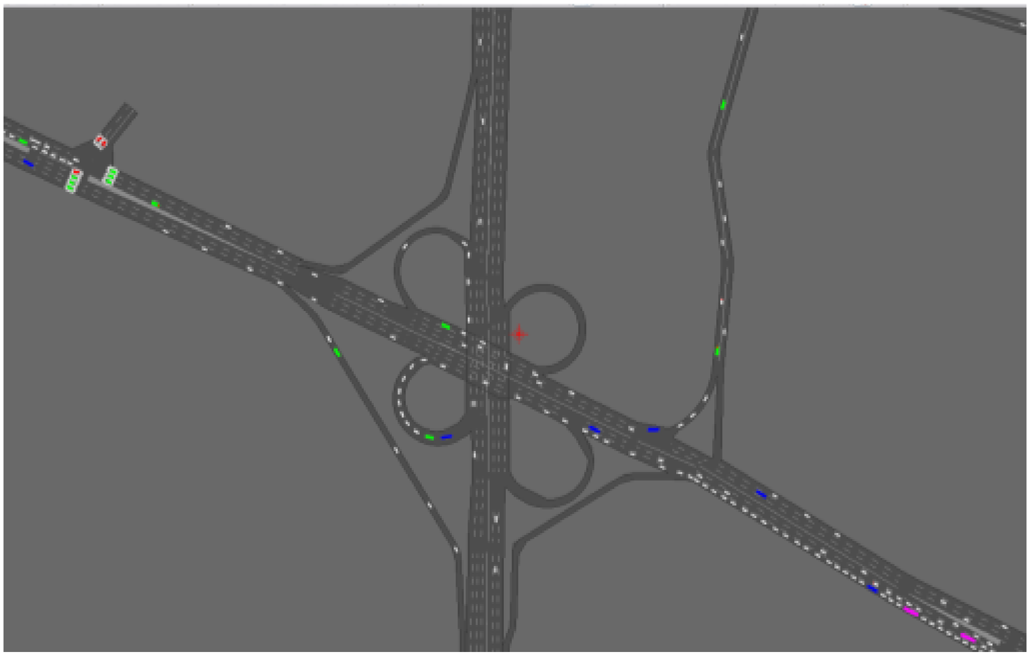

Figure 2.1 Screen shot of PARAMICS Modeller performing simulation

VISSIM is a MTS software developed by PTV AG in Germany (PTV, 2007). In VISSIM, the network is represented by links and link connectors. Instead of using nodes to connect the links (in this case vehicles are allow to make different turning movements at a node), vehicles travel from one link to another via one-directional link connectors. Therefore, in VISSIM, an intersection is modeled by several link connectors. Like most other MTS models, VISSIM uses “entry link” to load vehicles from traffic zones into the network. Users may specify the vehicle paths (and their percent splits between the paths) between every O-D pair. Therefore, the network’s traffic demands may be prescribed in O-D matrices. Figure 2.2 shows a screen shot of VISSIM graphical user interface when the simulation is being executed.

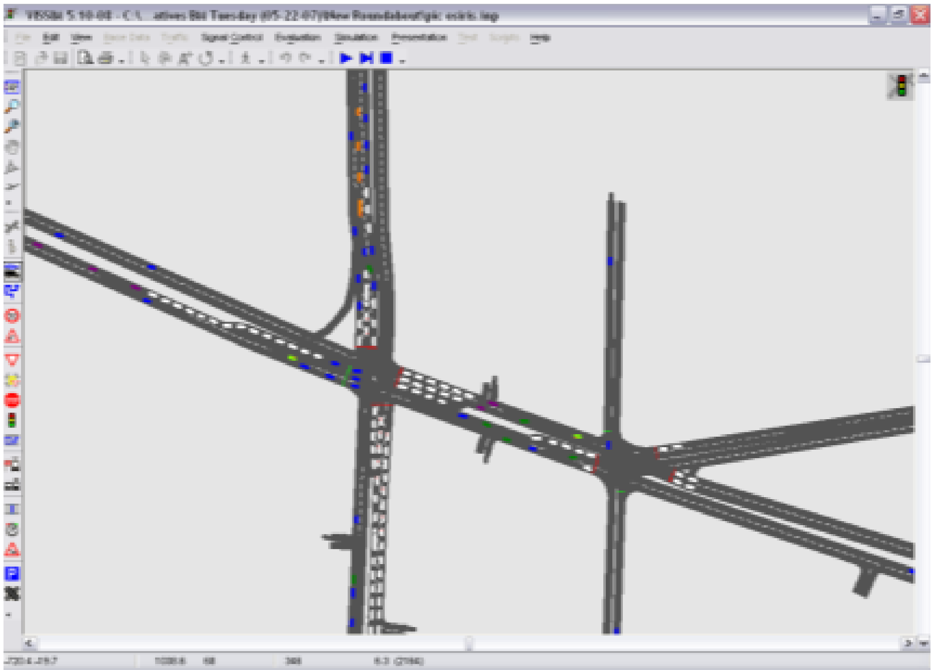

Figure 2.2 Screen shot of VISSIM performing simulation

The developer of VISSIM and the corresponding TPM named VISUM has designed both VISUM and VISSSIM to share the same O-D matrices. This means that no conversion of $\textbf{O-D}_\textbf{p}$ matrix into $\textbf{O-D}_\textbf{m}$ matrix is necessary. The $\textbf{O-D}_\textbf{p}$ matrix only needs to be exported from VISUM to VISSIM (Nokel, 2007).   However, this also imposes a condition that both VISSIM and VISUM must share the same traffic zones or TAZs.

2.2 Origin-Destination Matrix for Microscopic Traffic Simulation

Microscopic traffic simulation models attempt to replicate the traffic pattern in a very high resolution – at vehicle level. One key element to success in modeling is the accuracy of the travel demand data. In MTS, travel demand specifies the flow of vehicles that cross the area modeled between all the O-D pairs. The feeding of traffic into the network is from traffic zones through entry links or zone connectors. Usually, each entry link is associated with a traffic zone. Once the vehicles are loaded

into the network, the vehicles need their respective destinations so that they can travel through the network. This origin-destination pattern is defined by the O-D matrix. The O-D matrix comprises a tabular arrangement where the destination traffic zones are arranged in columns and the origin traffic zones are in rows. Cells in the tabular arrangement correspond to the trips between different O-D traffic zones. There are different methods of specifying the path chosen by a vehicle from its origin traffic zone to its destination traffic zone: shortest path (assign the vehicles to the respective shortest paths), stochastic (splits the vehicles between alternate routes assuming random variations in the perceived travel time on each route), or dynamic feedback (vehicles update the routes as traffic condition changes, or at specified intervals). (Caltrans, 2002) (FHWA , 2003) (Krogscheepers, et al., 2001).

As mentioned, there is a difference in the O-D matrices between TPM and MTS. The **O-D**$_{\mathbf{p}}$ matrix relates the trips among TAZs considering the travel distance between centroids of each TAZ pair. The **O-D**$_{\mathbf{m}}$ matrix represents the trips among traffic zones, and the distance between each traffic zone pair is calculated from the connectors associated with the traffic zones. The concept of traffic zones is implemented in MTS because MTS models are initially developed to analyze street networks covering smaller areas than TPMs. The MTS models are used to evaluate street networks at a relatively shorter period (e.g. peak hour) when the data can easily be obtained from the field. To use MTS to evaluate larger-scale street networks, the model needs a much larger data set, which is costly and difficult to obtain. Therefore, current practice of using large-scale MTS models employs alternatives to gather the **O-D**$_{\mathbf{m}}$ matrix into the network. The most frequently used methodology is the combination of a seed **O-D**$_{\mathbf{m}}$ matrix and traffic counts. This methodology is called O-D Estimation and has the advantage of updating the seed **O-D**$_{\mathbf{m}}$ matrix, which is obtained from a prior planning process, using the latest traffic count data. However, the disadvantage is the need of a seed **O-D**$_{\mathbf{m}}$ matrix (FHWA , 2003).

The O-D Estimation process predicts an $\mathbf{O\text{-}D_m}$ matrix from traffic volumes in links on the network. This is the reverse process of traffic assignment, where the traffic is assigned to the network based on an O-D matrix. The O-D Estimation process searches for O-D matrix that assigns traffic in the network within reasonable accuracy using traffic counts. In this way, the estimation process consists of an iterative procedure that assigns a proportion of the trips between traffic zone pairs through a route, and then compares the total link volume obtained from all traffic zone pairs with the total observed traffic volume in the link. The iteration procedure requires an updated actual traffic counts in selected links on the network and usually a seed $\mathbf{O\text{-}D_m}$ matrix. The seed $\mathbf{O\text{-}D_m}$ matrix provides the pattern of trips between traffic zones pairs. If a seed $\mathbf{O\text{-}D_m}$ matrix is not available, the intersection turning movement data can be used to derive the seed $\mathbf{O\text{-}D_m}$ matrix, but the data collection and derivation process requires high costs and long time (Ortuzar, et al., 2011) (Caltrans, 2002).

2.3 Origin-Destination Matrix for Transportation Planning

One of the purposes of transportation planning is to forecast the traffic volume in a street network. Travel demand, which represents the number of trips between different TAZs, are specified in one or several O-D matrices. The process of obtaining the O-D matrices is through two main methodologies: empirical and analytical. The first one is based on household surveys. The second one applies indirect ways to obtain the O-D matrix. The analytical method involves a series of activities. The first activity is zoning, where the urban area is divided into homogeneous zones depending on land use pattern. The second activity consists of collection of socioeconomic and land use data. Finally, the third activity is the application of the first two or three steps of the four-step UTPS procedure. The UTPS procedure consists of four steps: trip generation, trip distribution, mode choice and traffic assignment. The O-D matrix is obtained at the end of trip distribution or mode choice.

2.3.1 Traffic analysis zones

Traffic analysis zones (TAZs) are small geographic areas that have homogenous characteristics, such as socioeconomic and land use attributes. The purpose of dividing an area to be studied into TAZs is to estimate the generation and attraction of trips from similar land use within each TAZ. These TAZ's cover areas from 0.25 $mile^2$ to one $mile^2$ or even bigger with smaller areas in high population (resident or commercial) density areas and larger areas in rural districts (Cambridge Systematics, 2007). Other criteria to define the boundaries of the TAZ's are natural boundaries such as major roads, rivers, airports boundaries, military zones, parks, etc. (TMIP, 2007). Figure 2.3 shows the TAZ's in the urban area of El Paso Texas as defined by El Paso Metropolitan Planning Organization.

2.3.2 Trip generation models

Trip generation describes the number and type of trips produced from or attracted to a TAZ. Results of trips generation can be measured in vehicle-trips or person-trips. A trip is assumed as a single one-way movement from one TAZ to another TAZ (ITE, 2004).

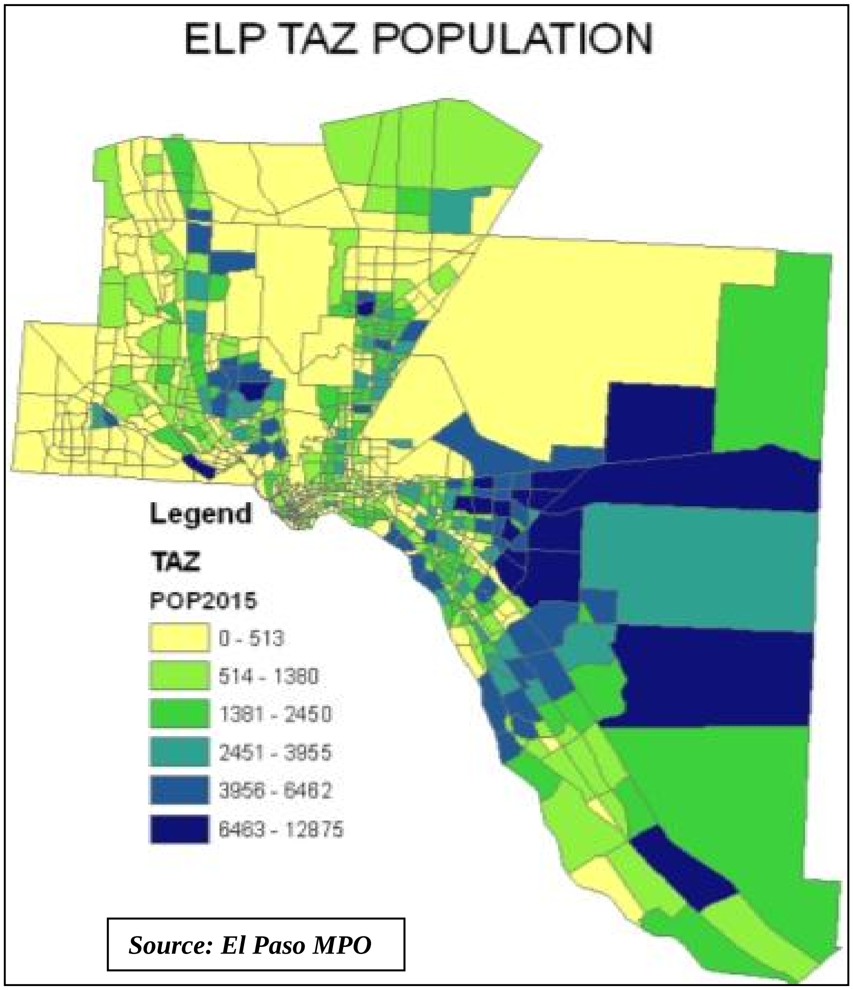

Figure 2.3 Traffic analysis zones in the El Paso travel demand model

For home-based work trips, different methods are employed to estimate trips produced from and attracted to each TAZ. Trips produced are predicted with the TAZ's socioeconomic variables such as household income, auto ownership, workers per household, residential density, and distance from central business district (CBD) (Meyer, et al., 2001). The variables are usually recommended after a multivariable regression analysis. Trips attracted to a TAZ are determined by the trip purpose in a similar manner.

2.3.4 Trip distribution

After estimating the total trips produced from and attracted to each TAZ, the next step is to perform trip distribution analysis. The distribution process links the trip productions O_i^P from TAZ *i* to the trip attractions D_j^P to TAZ *j* to obtain the number of trips between all the TAZs. The end product of the trip distribution is T_{ij}^P.

The trips are normally represented in a *n* x *n* matrix, where *n* is the number of TAZs in the network. That is, *i*=1, 2, …, *n*; *j*=1, 2, …, *n*. The rows in the matrix indicate the origin TAZs while the columns in the matrix represent the destination TAZs. The arrangement is known as O-D matrix (TRB, 1998). Each matrix cell represents the number of trips from TAZ *i* to TAZ *j*. To obtain these values a model is applied in order to distribute the trips produced by each TAZ to itself and to the rest of the TAZs according with their attractiveness. Many models have been proposed to distribute the trips between the TAZs. The most frequently used is the gravity model. This model assumes that the trips between two TAZs is directly related to activities in these zones (represented by trip production O_i^p and trip attractions D_j^p) and inversely related to the physical separation between the zones (Ortuzar, et al., 2011). A typical gravity model is (Meyer, et al., 2001):

$$T_{ij}^p = O_i^p \left(\frac{D_j^p F_{ij} k_{ij}}{\sum_{l=1}^{n} A_l F_{il} K_{il}} \right) \qquad [2.1]$$

where:

T_{ij}^p = Number of trips from TAZ *i* to TAZ *j*

O_i^p = Total number of trips produced from TAZ *i*

D_j^p = Total number of trips attracted to TAZ *j*

F_{ij} = Friction factor between TAZs *i* and *j*

K_{ij} = Optional adjustment factor for trip interchanges between TAZs *i* and *j*

The friction factor is an inverse function of the disutility (time, distance, or cost) expressed as generalized cost which may take the following function:

$$F_{ij} = e^{-\beta c_{ij}} \quad [2.2]$$

where

c_{ij} = Generalize cost of travel between TAZs *i* and *j*

β = Calibration parameter

The adjustment factor K_{ij} is employed to match the outputs of the gravity model with the real counts obtain in the household survey.

2.4 Discrete Choice Models

Discrete choice models mimic a user's selection from among a finite set of distinct alternatives. In transportation, these models allow planners to represent different decision making processes. Among the different decisions are to make or not to make a trip, the time to make the trip, the destination, the path, the mode of transportation to use, and other transportation user's choices.

The probability of a user selecting an alternative is based on its attractiveness to the user or the sum of the weighted attributes. This weighted sum is called utility. The higher the utility the higher probability the alternative is being selected.

The utility function is represented by a linear equation that combines its different attributes values or socioeconomic characteristics of the user or the characteristics of the alternative. The attributes are identified as variables. Each attribute has a different weight that represents the relative importance of the attribute to the users. Because the attributes cannot represent at all the influences in the utility equation, an error term is added in the equation. The error term is represented by ε which corresponds to all the unobserved influences such as driver's idiosyncrasies. In this way, the utility expression is represented by (Cascetta, 2009):

$$U_{in} = \boldsymbol{\beta}_i \mathbf{x}_{in} + \varepsilon_{in} \quad [2.3]$$

where

U_{in} = Utility or dependent variable provided by alternative *i* to a driver *n*

$\boldsymbol{\beta}_i$ = Row vector of estimable parameters obtained from choice survey for alternative *i* corresponding to driver *n*

$\mathbf{x}_{in}$ = Column vector of measured attribute value for alternative *i* for driver *n*

ε_{in} = Not measureable or unobserved attributes known as residual which is assumed randomly

From the Equation [2.3] the deterministic component can be written as:

$$V_{in} = \boldsymbol{\beta}_i \mathbf{x}_{in} \quad [2.4]$$

Then the utility is express as the addition of two elements:

$$U_{in} = V_{in} + \varepsilon_{in} \quad [2.5]$$

Once the utility value of all the alternatives for driver *n* is obtained, the next step of the discrete choice modeling process is to obtain the probability that the driver *n* will select each of the alternatives. The probability of driver *n* choosing alternative *i* is (Washington, et al., 2011):

$$P_{in} = \frac{e^{U_{in}}}{\sum_j e^{U_{jn}}} \quad [2.6]$$

The coefficients β_i are estimated by means of the method of maximum likelihood (Washington, et al., 2011).

There are different types of discrete choice models. Each of them has a different assumption on the probability distribution function of ε_{in}. Logit model is one of the most commonly used discrete choice models. The logit model has different variants according to the driver's choice structure. The remaining parts of this subsection describe the MultiNomial Logit (MNL) model, the Nested (hierarchical) Logit Model (MLM) and the Mixed Logit Model (MLM).

2.4.1 Multinomial logit model

The MNL model considers that each residual value is independent and identically distributed extreme value and has a Gumbel distribution (Cascetta, 2009). Based on this distribution, the probability of a user *n* choosing an alternative *i* is expressed as (Washington, et al., 2011):

$$P_{in} = \frac{e^{\boldsymbol{\beta}_{in}\mathbf{x}_{in}}}{\sum_j e^{\boldsymbol{\beta}_{jn}\mathbf{x}_{jn}}} \quad [2.6]$$

One-tailed t-test is used to evaluate the approximate significance of the parameters (β_{in}) of the MNL model. Also, the log-likelihood ratio test is employed to evaluate the model. The test compared the log-likelihood value (*LL*) of the estimation with zero parameter values in the restricted model (β_r)

and unrestricted model ($\boldsymbol{\beta}_u$). The expression is a statistic which follows a Chi-square (χ^2) distribution (Washington, et al., 2011):

$$\chi^2 = -2\left[LL(\boldsymbol{\beta}_r) - LL(\boldsymbol{\beta}_u)\right] \qquad [2.7]$$

Other measurement to evaluate the model is the McFadden ρ^2 statistic. The ρ^2 is a scalar measure which varies between 0 and 1. The ideal value is ρ^2=1. The calculation follows

$$\rho^2 = 1 - \frac{LL(\boldsymbol{\beta}_u)}{LL(\boldsymbol{\beta}_r)} \qquad [2.8]$$

Finally, marginal effect is used to evaluate the variable's impact in the utility equation. The marginal effect represents the change in probability of one alternative relative to a rate (a unit) increment in a variable. The formula is expressed as follows (Hensher, et al., 2005):

$$M_{x_{ki}}^{P_i} = \frac{\partial P_i}{\partial x_{ki}} \qquad [2.9]$$

where $M_{x_{ki}}^{P_i}$ is the marginal effect of probability of alternative i, P_i, due to a unit change in x_{ki}, the value of attribute k for alternative i. The higher the marginal effect value, the higher significance or effect of the variable in changing the probability of the outcome.

2.4.2 Nested logit model

The NLM can group in a nest structure the utilities of alternatives that are suspected to have share unobserved (ε_{in}) values. The restriction of residual independence applies only to utility equations

in the same nest group. The probability expression is structured by unconditional and conditional cases that form the decision tree of the model. The expressions are as follows:

$$P_{in} = \frac{e^{\boldsymbol{\beta}_i \mathbf{x}_{in} + \phi_i LS_{in}}}{\sum_j e^{\boldsymbol{\beta}_j \mathbf{x}_{jn} + \phi_j LS_{jn}}} \quad [2.10]$$

$$P_n(k \mid i) = \frac{e^{\boldsymbol{\beta}_{k|i} \mathbf{x}_{jn}}}{\sum_j e^{\boldsymbol{\beta}_{j|i} \mathbf{x}_{jn}}} \quad [2.11]$$

$$LS_{in} = LN\left[\sum_j e^{\boldsymbol{\beta}_{j|i} \mathbf{x}_{jn}}\right] \quad [2.12]$$

where

$P_i(k \mid i)$ = conditional probability of alternative k given the alternative i

LS_{in} = log-sum or inclusive value

ϕ_i = parameter associated with the inclusive value; 0< ϕ_y <1.

2.4.3 Mixed logit model

This MLM considers random variation of certain parameters (i.e., β_i is a random variable that follows a certain distribution across observations). In this way, the coefficients $\boldsymbol{\beta}_i$ have a mixed distribution. This model, at difference of MNL model, allows that coefficient values vary across observations. The probably expression represents weighted average of probabilities of the MNL model. The weights are determined by the probability density function $f(\boldsymbol{\beta}_m \mid \boldsymbol{\beta}_v)$, where $\boldsymbol{\beta}_m$ is the mean and $\boldsymbol{\beta}_v$ the variance of the coefficient (Washington, et al., 2011). The probability expression is as follows:

$$P_{in} = \int \frac{e^{\boldsymbol{\beta}_i \mathbf{x}_{in}}}{\sum_j e^{\boldsymbol{\beta}_j \mathbf{x}_{jn}}} f(\boldsymbol{\beta}_m \mid \boldsymbol{\beta}_v) d\boldsymbol{\beta}_i \quad [2.13]$$

2.5 Geographic Information Systems

Geographic Information Systems (GIS) is a computational suite consists of different tools to capture, edit, store query, analyze, share and project geospatial data. The geospatial data is managed in vector and raster formats. Vector data represents continuous features and raster data represents spatial variation among the features. The vector composes points, lines and polygons whereas the raster is represented by a grid of cells. Both formats must be based on a coordinate system in order to project the data on a geospatial plane. GIS has the ability of managing data associated with features in the geospatial database. This allows data to be combined to perform evaluation and analysis. Among the GIS functions related to this research are the geocoding, allocation and query of data from land use. Geocoding is transformation of spatial referenced data such as ZIP codes, parcels and address locations into a (x,y) coordinate system. Allocation is the study of spatial distribution of objects across the network. Finally data query is a process to obtain specific information from different data sources such as socioeconomic data (Chang, 2008).

2.5.1 ArcGIS

Components in a GIS software suite may be developed by different companies. However, one of the software most widely used is ArcGIS which is developed by ESRI, Inc (Nag, et al., 2007) (Coyle, 2011). ArcGIS suite allows users to work with geographic data through a pre-established set of tools. The suite consists of ArcMap, ArcCatalog and Arc Toolbox (ESRI, 2011). Arc Map is an application to create and analyze maps, to make feature selections, edit and manipulate data. ArcCatalog is an application to manage the GIS information. Finally, ArcToolbox is an application that comprises tools to

develop different operations such as feature overlay, feature selection and analysis, topology processing and data conversion.

In addition with these three applications, there are some software extensions for ArcGIS to add functionality or to provide specific uses. Some extensions are Network Analyst and Business Analyst.

2.5.2 Business Analyst

This is an extension of ArcGIS that provides analysis tools and a database for marketing and business decision making. The data library is updated yearly and encloses more than 5000 variables of demographic, lifestyle segmentation, spending, business, tapestry segmentation groups, aerial images and street network. The data is provided by different companies: demographic is by ESRI, business locations by InfoUSA, shopping centers by directory of major malls (DMM), national street network by TeleAtlas, address geocoder by ESRI and aerial imagery by GlobeXplorer (Hincy, 2008).

The data is provided to users in by reports that condense the information of user-defined geographic groups such as state, Zip code and block groups or customized areas such TAZs. Due to the availability to extract socioeconomic data from the updated database, Business Analyst is used in this research.

2.5.3 Network Analyst

This software extension provides the analysis of networks in a network spatial base. Network analyst employs a geometric network dataset to perform route problems. The solution is based on

network restrictions, such as barriers and height restrictions and attributes such as speed, travel time, street hierarchy. Among the spatial analysis functions are drive-time analysis, shortest path, service area definition, optimum route, closest facility, travel directions and location-allocation. (ESRI, 2010) (Ormsby, et al., 1999).

2.6 Existing Approaches to Divide Traffic Analysis Zones

Some transportation planners have tried to use MTS models as a tool to evaluate with higher level of detail the current and future scenarios in urban highway networks. One limitation of using MTS as a planning tool is the mismatch between the $\mathbf{O\text{-}D_m}$ matrix and the $\mathbf{O\text{-}D_p}$ matrix. One of the first steps to develop an $\mathbf{O\text{-}D_m}$ matrix is the matching of traffic loading zones between TPM and MTS models. To ensure a match these is a need to find a way to subdivide each TAZ into several and smaller traffic zones. The following authors have suggested methods to perform the subdivision.

Shull and Cain (1999) have proposed a TAZ subdivision approach to solve the trip assignment problem when the land use within a TAZ is different and their trip loading into the main network from different parts of the TAZ is not uniform. The technique is called Multi-Point Assignment (MPA). It creates connection nodes on links around the TAZ's to load traffic from part of the TAZ into the main network. The location and number of the connection nodes is defined by the user. The trips per connector node to be loaded into the main network are calculated from population density and retail activity. Unfortunately, this approach is limited in describing the general idea. Shull and Cain (1999) did not discuss the methodology in detail, such as the criteria of selecting and defining connection nodes and the calculation of trip loading factors.

Sun and Cooney (2007) have provided an approach similar to Shull & Cain (1999). They propose to increase the number of zones to reduce the distance between TAZ centroids and the links in the network and then obtain a more precise traffic assignment through the network. The increment of zones is the result of a TAZ's subdivision. Each subdivision, again, has its own centroid connector. The number of centroid connectors and their locations are also decided manually by the user. The TAZ trips are proportioned equally among the connectors unless there are data that indicates a more accurate factor.

Another author with the same objective is Horowitz (2001), who proposed the subdivision of a TAZ around links that create a TAZ's boundary. The TAZ is subdivided into service areas (similar to traffic zones) by polygons. The polygons are created by means of bisecting the area bounded by streets inside the TAZ. Each service area consists of one intersection. The size of the service area of the TAZ is measured using the GIS raster methods (grid arrangement). The TAZ trips are proportioned into the service areas and loaded into the network through the intersections.

Friedericht and Galster (2009) proposed three methods to select traffic zone centroids. The first method divides the TAZ into similar subdivisions and obtains their centroids. The second method selects the TAZ internal nodes with higher link density. Finally the third method selects the traffic node connectors that are equidistant from the TAZ centroid.

Finally, Mann (2001) developed software to create subzones from a TAZ arrangement. The software, called B-Node, has the function to create zone connectors from each TAZ. Zone connectors are the result of the subdivision process. Three options have been offered in the creation of subzones: land activity, equal weights or the reciprocal of the travel time from the centroid. Once the subzones are

obtained, the traffic connectors (new subdivisions), the trip table and its assignment are calculated. No other detail is provided.

2.7 Summary

This chapter presented the theories and current approaches related to the methodologies to convert a **O-D$_p$** matrix into a **O-D$_m$** matrix. Some authors have proposed in separate ways methods to subdivide the TAZs. The methodologies are based on geometric approaches and/or focus on improving the results of traffic assignment in TPMs. These methods are not focused on the demographic, socioeconomic or trip patterns within a TAZ. Some methodologies and tools that have the potential to be used in converting a **O-D$_p$** matrix into a **O-D$_m$** matrix are also reviewed in this chapter. Based on the assessments, a research methodology is proposed in Chapter 3 to develop a new method to convert a **O-D$_p$** matrix into a **O-D$_m$** matrix.

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Chapter 3: Research Methodology

3.1 Introduction

This chapter presents the methodology followed in this dissertation in order to propose a method to convert a $\mathbf{O\text{-}D_p}$ matrix into a $\mathbf{O\text{-}D_m}$ matrix to be used in MTS models.

3.2 Methodology

The methodological framework of this research consists of five tasks. Each task may further be divided into different subtasks. The flow chart of the methodology is shown in Figure 3.1. The description of the methodology is mentioned in the subsections below.

3.2.1 Literature review

Literatures that cover the concepts related to this research namely MTS, O-D matrices, TAZ, the two steps of UTPS modeling (trip distribution and mode choice), discrete choice models and GIS were reviewed in this task. This task also included a review of existing approaches to subdivide TAZs.

3.2.2 Establish area of study and data collection

A TAZ in the City of El Paso, Texas, was selected in order to assist in the development of the method proposed in this research. Data from the TAZ selected was collected from different public

agencies. Among the information collected was socioeconomic data, parcels data, TPM, and network geometry and traffic data.

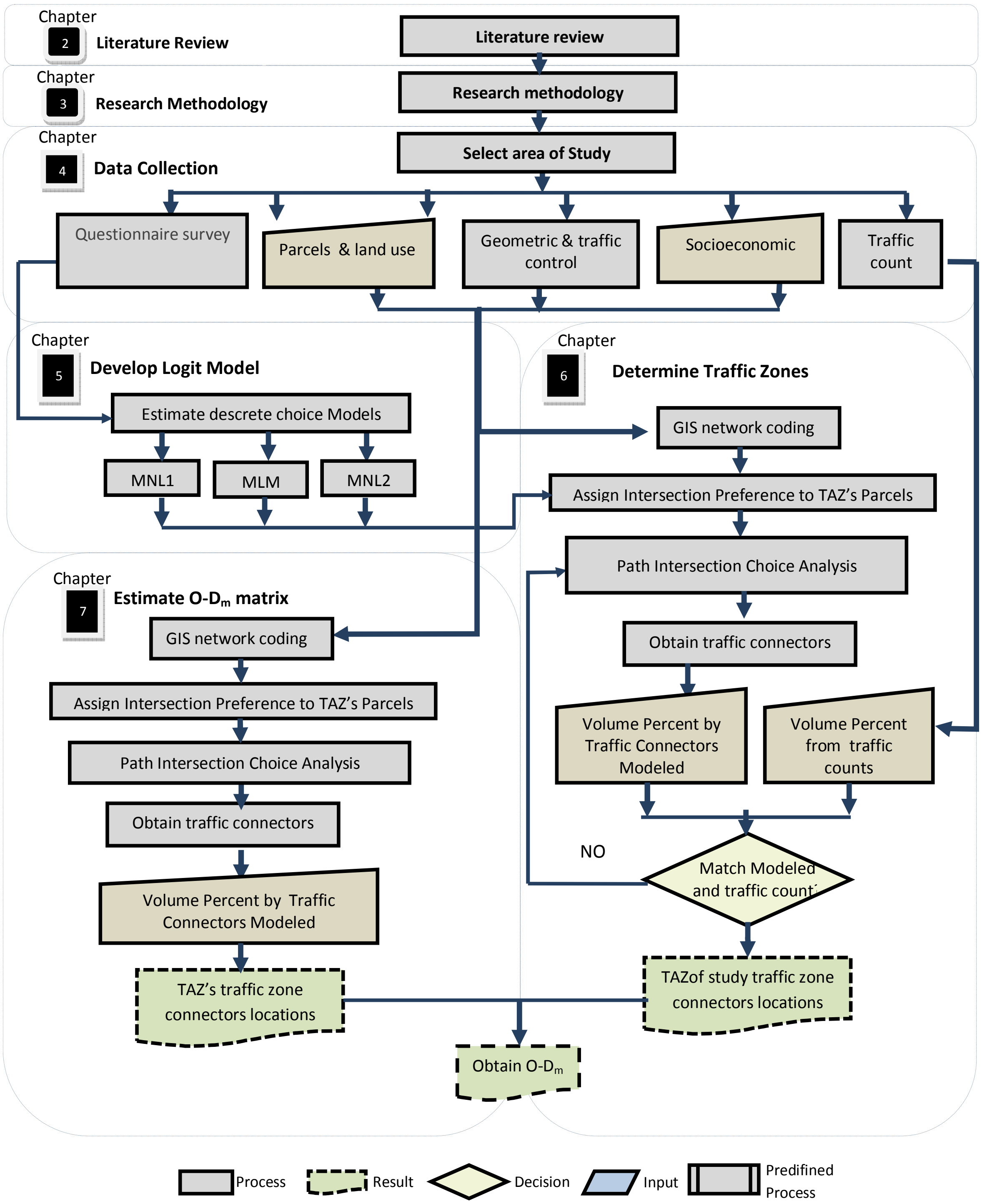

Figure 3.1 Flow chart of research methodology

Two data collection efforts were conducted in the field. The first one was the traffic count of vehicle volume in the area. This process consisted of (1) automatic counts using pneumatic tube recorders; and (2) manually traffic counts at intersections. The purpose of the traffic count was to obtain the different volume of vehicles entering and exiting of the area of study through the different intersections. The second data collection exercise consisted of questionnaire survey to gather driver's demographic and route choice information. The purpose of the questionnaire survey was to obtain data to develop a discrete choice model to be used to obtain route choice preferences of drivers living in the TAZ.

3.2.3 Develop discrete choice model

A discrete choice model was developed to calculate the probabilities of drivers using different routes that lead to access points to the main streets surrounding a TAZ. The model evaluated drivers' route choice preferences based on their different socioeconomic characteristics and other attributes.

3.2.4 Determine traffic zone and traffic connectors

The limited number of traffic zone and zone connectors were selected from among the access points along the main streets surrounding a TAZ. This task used GIS tools, specifically Network Analyst and Business Analyst, combined with the discrete choice approach developed in the previous task. The zone connector selection process consisted of five subtasks, (1) creation of the network dataset; (2) determination of the route choice preference driver in each parcel; (3) calculation of traffic volume at each access points; (4) selection of the traffic zones and zone connectors from the available

access points; and (4) estimate the percentage volume splits among the zone connectors for the division of the **O-D$_p$** matrix into the **O-D$_m$** matrix.

3.2.5 Conversion of matrix

The final step the proposed method is to illustrate how the methodology could be applied to a TPM with multiple TAZs to derive the **O-D$_m$** matrix.

CHAPTER 4: DATA COLLECTION

This chapter described the data collection effort and the data collected in this research. The data collection process is shown in the flow diagram in Figure 4.1. It has two main parts: (1) selection of an area of study and (2) data collection/survey. Section 4.1 presents the TAZ selection process while Section 4.2 focuses on the data collection procedure.

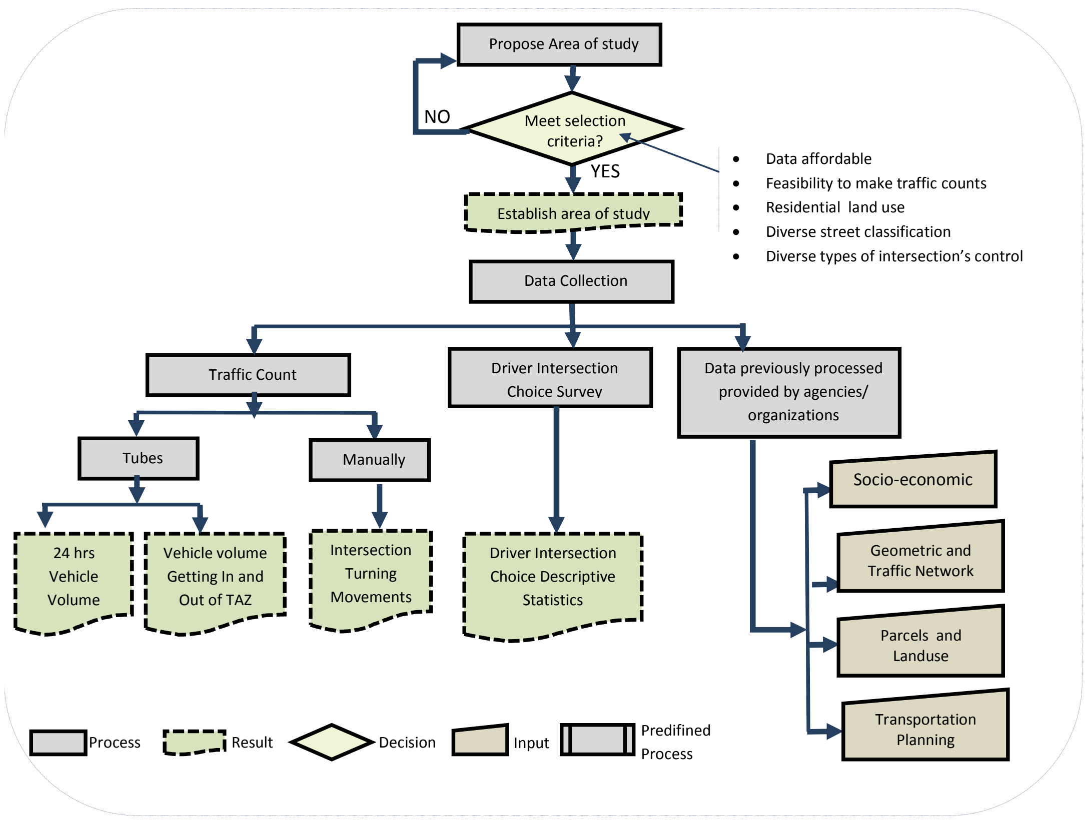

Figure 4.1 Flow chart of data collection

4.1 Area of Study

In order to evaluate the different route choice options that a driver has when he/she travel between his/her home (parcel) and the intersection at the boundary of the TAZ (the access points), an area of study (TAZ) was selected. The selection process consisted of evaluating different TAZs within the City of El Paso. The selection was based on the following criteria:

- The TAZs must be selected from the TAZs used in the El Paso travel demand model.
- The land use within the TAZs is predominantly residential.
- Each TAZ must contain common types of intersection control at its access points: traffic signals, two-way stop and four-way stop.
- Majority of the residential parcels must have multiple routes between each parcel with the access points along the main streets.

4.2 Description of Area of Study Selected

Among the different potential TAZs, an area located in the west side of the City of El Paso was selected. This TAZ is surrounded by four mains streets: Resler, Westwind, Escondido and Belvidere. Figure 4.2 shows the location of this TAZ within the City of El Paso. This is a residential area with a street pattern considered as “Loops and Lollipops” or “Suburban Hills” street arrangement which represents the majority of the residential areas in the City of El Paso. The TAZ’s street network includes connecting streets and curl-de-sacs. The connections (access roads) to the four surrounding main streets have different types of intersection control. Figure 4.3 shows the different types of intersection control in the area of study.

The TAZ contains 1116 parcels which are classified as single houses (1077 parcels), multifamily (9 parcels), commercial (12 parcels), church (1 parcel), elementary school (1 parcel), vacant (5 parcels) and channel (11 parcels). Figure 4.3 shows the land uses and street patterns of the TAZ.

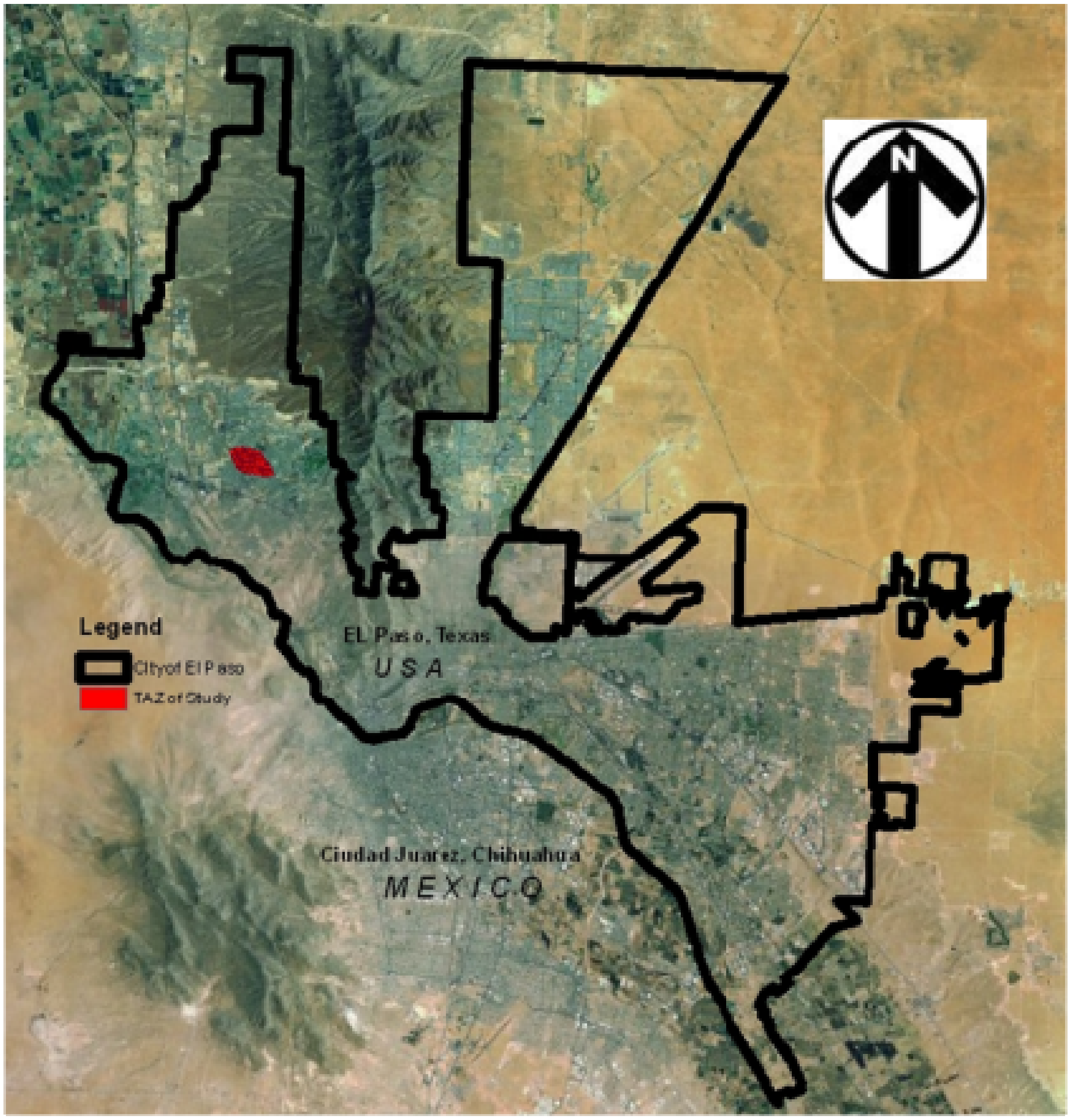

Figure 4.2 Location of selected TAZ

Figure 4.3 Intersections and street network of the TAZ of study

4.3 Data Collection

Data collections consisted of two stages: (1) requesting data from public agencies and organizations and (2) collecting data in the field.

4.3.1 Data previously processed

The data collected in this stage was the data previously processed by public organizations or/and agencies. This data included GIS files (street network shapefiles, parcels shapefiles, and etc), the travel demand model of the El Paso Metropolitan Planning Organization, and the hourly $\mathbf{O\text{-}D_p}$ matrix.

4.3.2 Field data collection

The second stage, data collected in the field, surveyed traffic volume and driver's route choice. Traffic counts were obtained by automatic tube counters and manual count. The driver's route choice data was gathered through a questionnaire survey.

Tube counters

This subtask was to obtain the volume counts at access points, i.e., the intersections that connect the neighborhoods within the TAZs with the surrounding main streets. Twenty five tube counters were installed in the TAZ of study. The tube counters were installed in the approach of each access street inside the TAZ (see Figure 4.4). After a counting period of 72 hrs, the data of the two traffic directions (entering and going out the TAZ) were extracted to detect the morning peak hour and the traffic flow consistency during the three weekdays. Figure 4.5 shows the process of installation of the tube counter. Note that, because of the limited counters available, the 25 counting locations did not have the same date for the 72 hour counting period. The counts were made between 4/27/2010 and 6/2/2010.

From the data it was determined that the morning peak hour in the neighborhood was from 7:00 a.m. to 8:00 a.m. Also, the hourly patterns at the same locations on different days were consistent. Figure 4.5 shows, as an example, the daily volume profiles on different weekdays at one location.

Figure 4.4 Location of tube counters during data collection

Other issues identified from the traffic counts data was the relatively high volume of traffic in some streets. One particular case was the streets around the elementary school. Traffic in the streets around the elementary school was heavy between 7:40 a.m. and 8:00 a.m. because the school started at 7:45 a.m. As many parents were dropping of their children, movement counts at the intersections around the school impact area were made so as to detect the behavior of drivers using the streets to reach/leave the school. The movement count data revealed that a big number of vehicles used the neighborhood streets as a “through fare” to access the school from outside the TAZ.

In order to perform the case study (described in Chapter 8), traffic data was also collected from the streets surrounding the TAZ of study. The manual turning count data was collected at five signalized intersections along the main streets that surround the TAZ of study. Figure 4.6 indicates the location of these intersections.

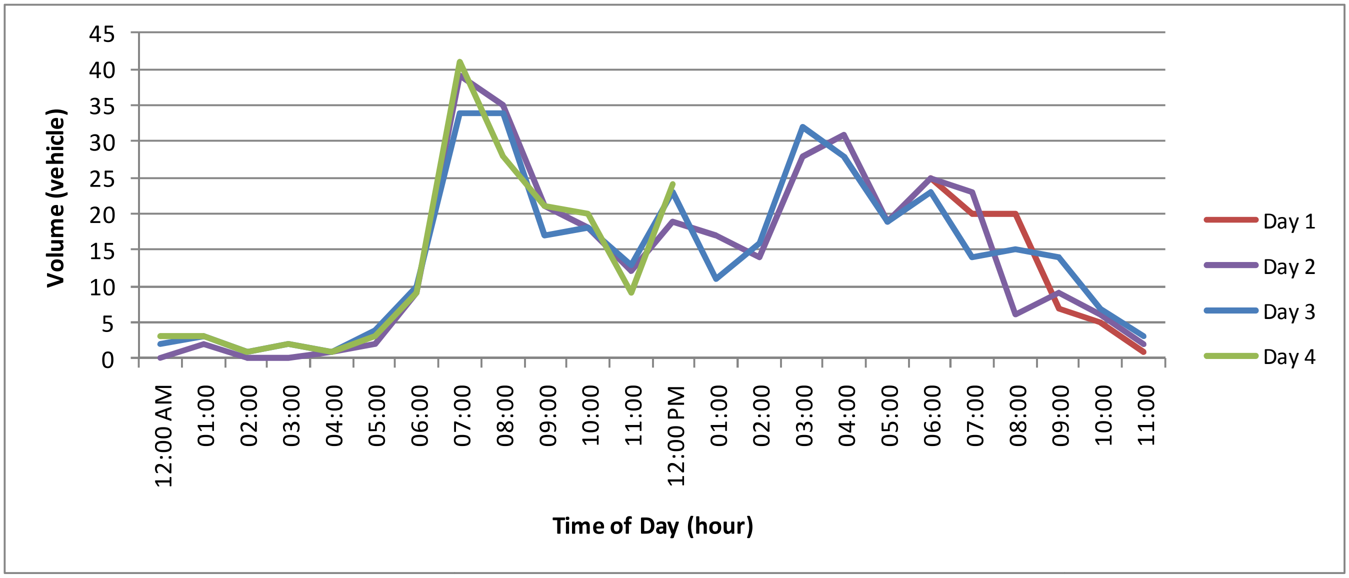

Figure 4.5 Time of day volume profile at Tepic Street intersection

Figure 4.6 Location of signalized intersections

Figure 4.7 shows the volume of vehicles entering and leaving all the access points connecting the neighborhoods with the main streets. This figure also shows the intersections where movement counts were made.

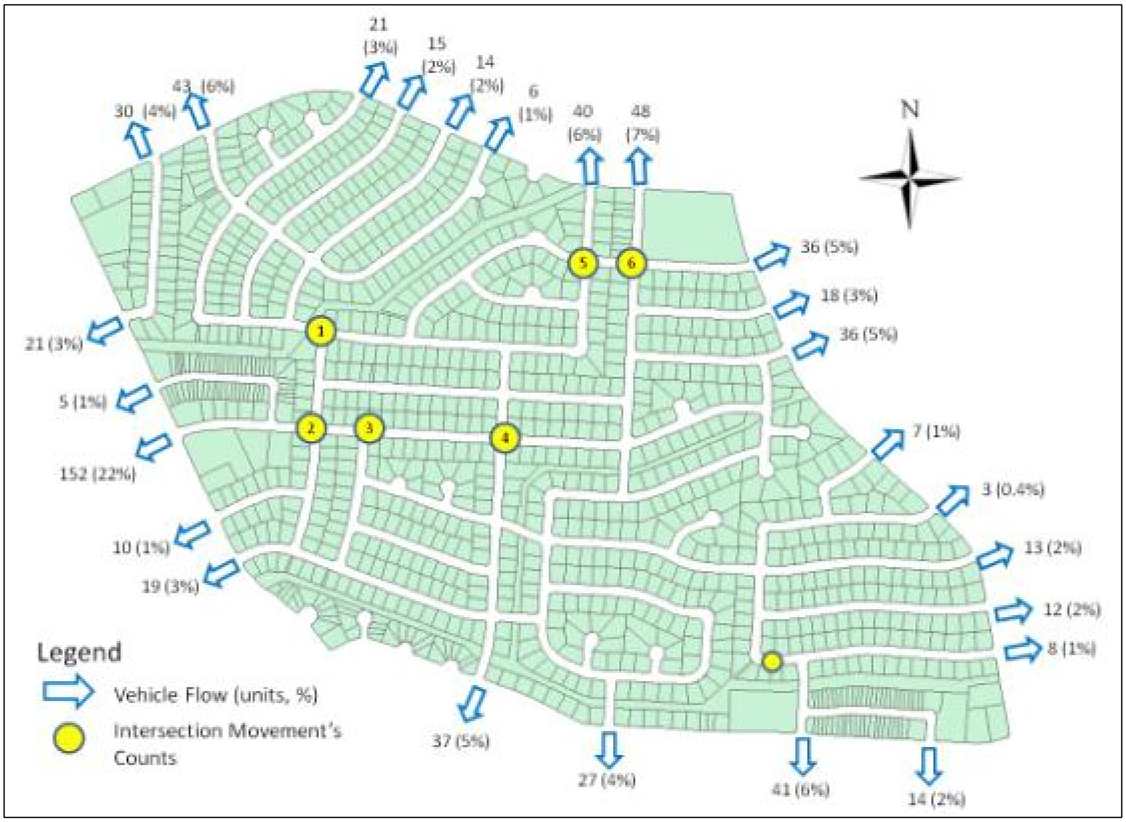

Figure 4.7 Average volume of traffic leaving the TAZ in the morning peak hour

4.4 Questionnaire Survey

This survey concerns with how residents in a neighborhood choose the routes to the access points when they leave or come home, i.e., how they travel between their parcels and the main streets that are surrounding the TAZ. In this survey, the main streets are the streets that form the TAZ boundary.

4.4.1 Survey design

The target population of the survey was divided in two groups: subjects who lived within the TAZ of study and those who reside out of the TAZ but in the City of El Paso. These subjects possessed valid driver licenses and were more than 18 years old.

The potential participants were approach personally, either in their residence in the TAZ, or at public areas (e.g., outside shopping malls). They were offered the options of fill out the forms themselves or be interviewed by surveyors. Due the bilingual population of the City of El Paso, the survey was conducted in English and Spanish in both the questionnaire as well as in the interviews.

A pilot survey was conducted with a sample size of 40 persons. From the results of this pilot survey, the questions and language were improved. The final questionnaire contained 16 questions in two pages. The questions (and answers) were structured to gather information in four main areas. The questionnaire in both languages is included in Appendix.

The first few questions of the survey concerned with socioeconomic data. Here, the purpose was to obtain participant's gender, age, household income, highest education, ZIP code, household size and number of vehicles in the household. The participants answered the multiple-choice questions according to the ranges provided in the forms in order to protect their privacy.

The second part of the survey covered the morning trip habits. Because the TAZ of study lacks commercial attractions such as offices or stores, it appeared (from the pilot survey) that several residents made round trips to and back from gyms, daycares, and etc. In order to capture this behavior, questions

were added about the trip characteristics: times leaving, times returning, purpose of the trips and number of stops in the neighborhood.

The third segment covered in the questionnaire was related to the route choice. The aim of this segment was to assess the preferences of survey participants with regards to the type of intersection control or other factors that could inference their route choice between their homes and access points. The questions were further grouped into three categories: Driver who base their decisions on the type of intersection control (*Intersection*), drivers not influenced by type of intersection control but by other factors (*Not Intersection*), and finally drivers without an alternate route to connect with the main street network (*No Multiple*); for example, whose who live near a main street. The participant was limited to select only *Intersection*, *No Intersection* or *No Multiple*. If a participant selected *Intersection*, he/she was further asked to specify the type of intersection he/she prefers: traffic signal, two-way stop control, or four-way stop control. If the participant answered *No Intersection*, he/she was asked to select one of the following route choice criteria: shortest route by distance, minimize the number of stops and turns, avoid pedestrian zones or drive through wider streets.

The last part of the questionnaire comprised two questions. The first one was the name of the street that the participant used most frequently in the morning on weekday to access the main street. The reason of this question was to visualize in a map the different locations of the intersections and their frequency of use. The answer to this question served to check against the route choice preference as stated by the participant. The second question was the ideal intersection control. This question was included in order to provide information for future residential development projects.

4.4.2 Results of questionnaire survey

A total of 1,133 El Paso residents participated in this survey, of which 484 participants (43%) said they decided on their routes based on the type of intersection control, 429 participants (38%) used other factors that have nothing to do with the type of intersection control, and finally, 218 participants (19%) answered that they have no multiple routes to connect to the main street.

Among the drivers who choose *Intersection*, the percentage splits between the four types of intersection control are presented in the Figure 4.8.

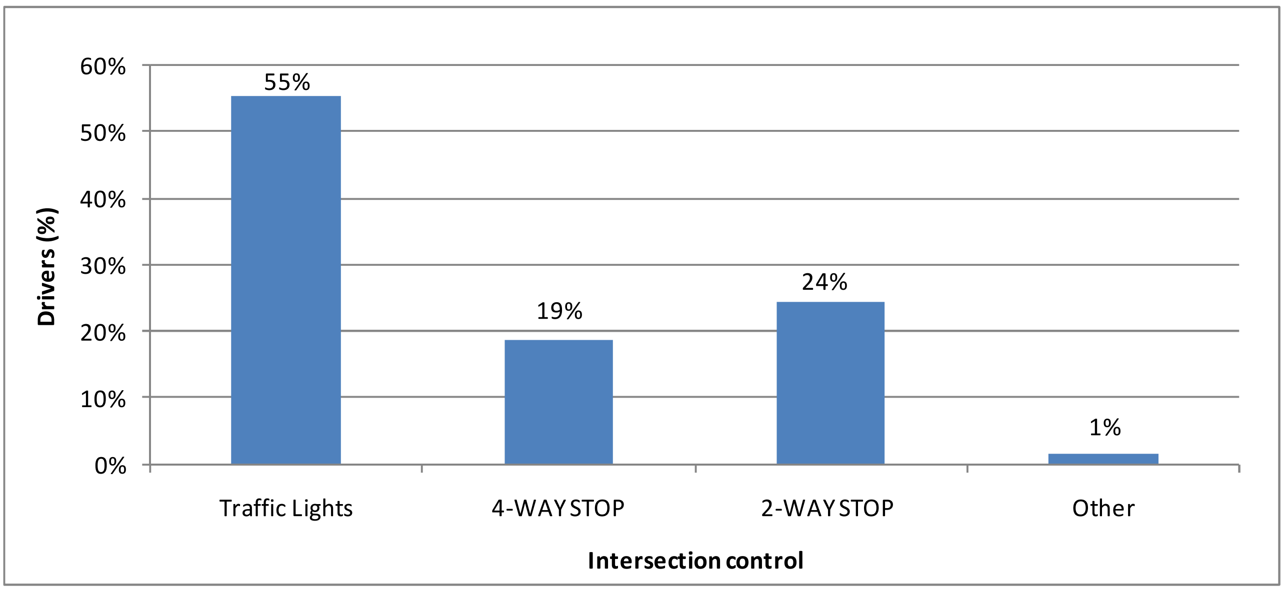

Figure 4.8 Preference distribution of drivers who chose Intersection

For those participants who select their routes by factors other than intersection control, the distribution of the factors are shown in Figure 4.9.

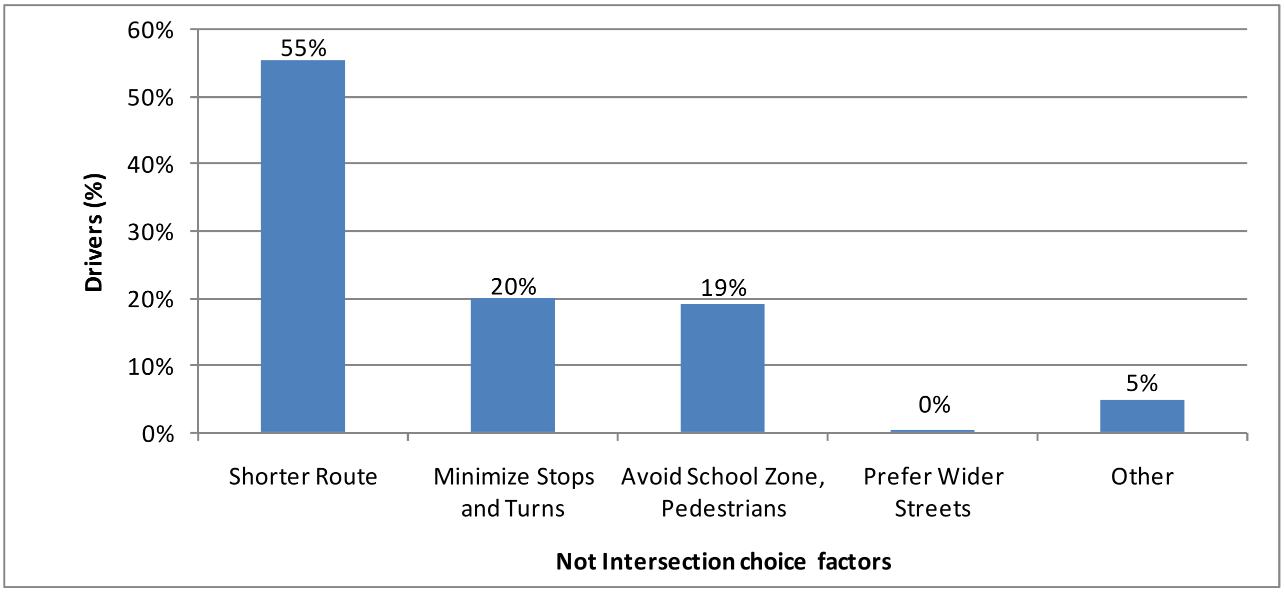

Figure 4.9 Preference distribution of drivers who chose Not Intersection

The distribution by ZIP codes among the participants is shown in the Figure 4.10.

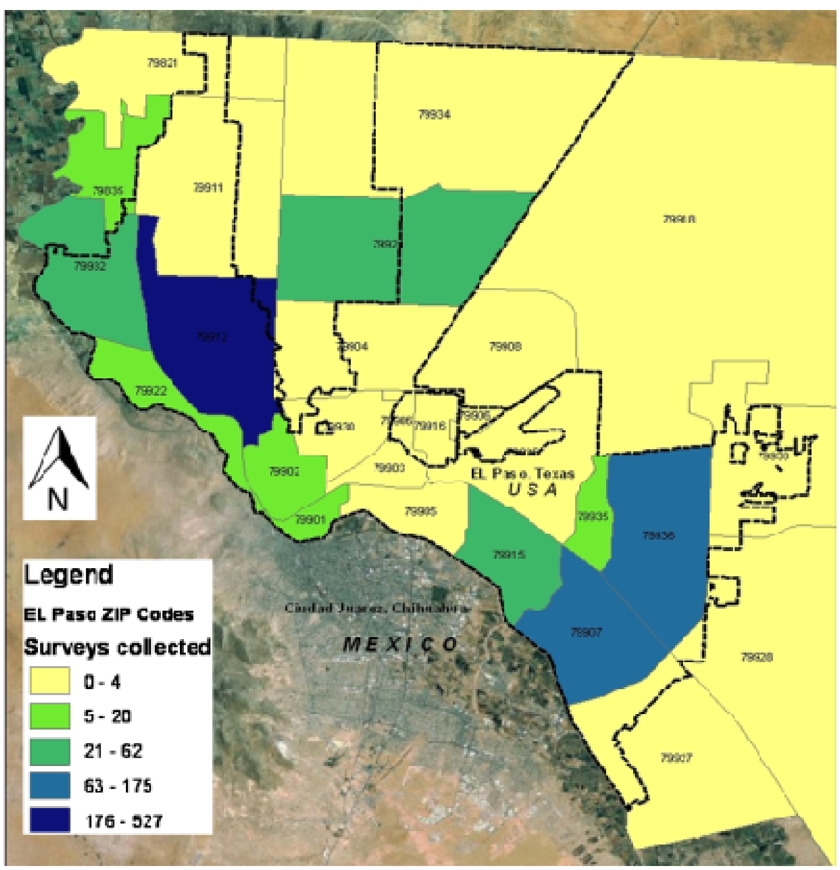

Figure 4.10 Distribution of ZIP code among survey participants

The socioeconomic attributes of the participants are summarized in the Table 4.1. This first column of the table lists the socioeconomic attribute, the second column lists the attribute categories and the third column indicates the total number of responses per category per question. Then, three groups of results are presented based on the driver's route choice preferences. The first group of columns identifies proportions of participants who answer *Intersection*, *Not Intersection* and *No Multiple*. The second group of columns shows the breakdowns of participants who answered *Intersection*. The third group of columns contains the breakdowns among the participants who said they selected their routes based on factors other than the type of intersection control (*Not Intersection*). In the second and third groups, the percentages of the different choices in each row summed to a total of 100%. Values in parenthesis correspond to the total number of responses.

Some results observed in Table 4.1 are summarized as follows:

- Gender. Females participated more in the survey (56%). Females are also more likely to choose their routes by the type of intersection control, compared to males (23.8% compared to 18.6%). More than half the males and females who said they selected their routes by the type of intersection control preferred traffic signals; with the females notably higher at 59%. Among the drivers who did not select the routes by the type of intersection (*Not Intersection*), at least 52% selected the routes by shortest distance, with males notably higher at 59.9%.

Table 4.1 Results of questionnaire survey: demographic data

Attribute	Category	Total Response	Total Preference Distribution: Intersection	Total Preference Distribution: Not Intersection	Total Preference Distribution: No Choice	Intersection Preference: Traffic lights	Intersection Preference: 4 Way Stop	Intersection Preference: 2 Way Stop	Intersection Preference: Other	Not Intersection Preference: Shorter Distance	Not Intersection Preference: Minimize stops	Not Intersection Preference: Avoid Pedestrians	Not Intersection Preference: Drive Through Wider Streets	Not Intersection Preference: Other
Gender	Male	44.0% (486)	18.6% (205)	16.1% (178)	9.3% (103)	50% (99)	20.2% (40)	27.3% (54)	2.55 (5)	59.9% (106)	19.8% (35)	14.1% (25)	0.0% (0)	6.2% (11)
	Female	56.0% (618)	23.8% (263)	22.1% (244)	10.1% (111)	59.8% (155)	18.5% (48)	20.8% (54)	0.8% (2)	52.1% (124)	20.6% (49)	22.3% (53)	0.8% (2)	4.2% (10)
Age	<25 yrs	17.2% (193)	7.1% (80)	7.0% (79)	3.0% (34)	53.8% (42)	20.5% (16)	24.4% (19)	1.3%(1)	61.5% (48)	17.9% (14)	17.9% (14)	1.3% (1)	1.3% (1)
	25 to 34 yrs	24.0% (270)	10.0% (112)	9.3% (104)	4.8% (54)	47.2% (51)	20.4% (22)	31.5% (34)	0.9% (1)	52.5% (53)	18.8% (19)	24.8% (25)	0.0% (0)	4% (4)
	35 to 49 yrs	26.0% (292)	10.4% (117)	10.9% (123)	4.5% (51)	54.3% (63)	19% (22)	25.9% (30)	0.9(1)	52.5% (64)	19.7% (24)	18.9% (23)	0.0% (0)	9% (11)
	50 to 64 yrs	22.8% (257)	11.4% (128)	6.9% (77)	4.6% (52)	55.2% (63)	19.2% (22)	22.4% (28)	7% (3)	57.9% (44)	25.0% (19)	14.5% (11)	0.0% (0)	2.6% (2)
	65 & older	10.0% (113)	4.0% (45)	3.7% (42)	2.3% (26)	79.1% (34)	14.0% (6)	7.0% (3)	0% (0)	56.1% (23)	14.6% (6)	19.5% (8)	2.4% (1)	7.3% (3)
Income	< $20,000	15.3% (167)	6.5% (71)	5.7% (62)	3.1% (34)	55.4% (36)	20.0% (13)	23.1% (15)	1.5% (1)	59.7% (37)	21.0% (13)	17.7% (11)	0.0% (0)	1.6% (1)
	$20,000 - $39,999	28.7% (313)	12.0% (131)	10.8% (118)	5.9% (640	56.9% (74)	21.5% (28)	20.8% (27)	0.8% (1)	46.1% (53)	21.7% (25)	29.6% (34)	0.9% (1)	1.7% (2)
	$40,000 - $69,999	32.8% (358)	14.1% (154)	12.2% (133)	6.5% (71)	55.0% (83)	17.9% (27)	26.5% (40)	0.7% (1)	55.0% (72)	20.6% (27)	15.3% (20)	0.8% (1)	8.4% (11)
	$70,000 - $89,000	13.8% (151)	6.0% (66)	5.4% (59)	2.4% (26)	49.2% (32)	20.0% (13)	30.8% (20)	0.0% (0)	54.2% (32)	22.0% (13)	16.9% (10)	0.0% (0)	6.8% (4)
	$90,000 - $150,000	8.0% (87)	3.4% (37)	3.1% (34)	1.5% (16)	55.6% (20)	16.7% (6)	22.2% (8)	5.6% (2)	69.7 (23)	15.2% (5)	12.1% (4)	0.0% (0)	3.0% (1)
	over $150,000	1.5% (16)	0.5% (6)	0.5% (5)	0.5% (5)	66.7% (4)	0.0% (0)	16.7% (1)	16.7% (1)	100.0% (4)	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
Education	High school	28.0% (311)	11.4% (126)	11.4% (127)	5.1% (57)	56.6% (69)	24.6% (30)	17.2% (21)	1.6% (2)	51.6% (64)	27.4% (34)	16.9% (21)	0.8% (1)	3.2% (4)
	Community Collegu	26.4% (293)	11.9% (132)	9.4% (104)	5.1% (57)	51.6% (66)	18.8% (24)	28.9% (37)	0.8% (1)	57.8% (59)	19.6% (20)	19.6% (20)	0.0% (0)	2.9% (3)
	Undergraduate	36.8% (409)	15.9% (176)	14.3% (159)	6.7% (74)	57.0% 998)	16.3% (28)	26.2% (45)	0.6% (1)	53.5% (85)	16.4% (26)	23.9% (38)	0.6% (1)	5.7% (9)
	Graduate	8.8% (98)	3.9% (43)	2.9% (32)	2.1% (23)	55.8% (24)	16.3% (7)	20.9% (9)	7.0% (3)	71.0% (22)	12.9% (4)	3.2% (1)	0.0% (0)	12.9% (4)
Familiy Size	1	5.4% (61)	2.6% (290	1.7% (19)	1.2% (13)	70.4% (19)	18.5% (5)	11.1% (3)	0.0% (0)	55.6% (10)	22.2% (4)	11.1% (2)	0.0% (0)	11.1% (2)
	2	18.4% (206)	7.4% (83)	6.8% (76)	4.2% (47)	72.0% (59)	11.0% (9)	14.6% (12)	2.4% (2)	56.8% (42)	16.2% (12)	18.9% (14)	1.4% (1)	6.8% (6)
	3	19.5% (219)	9.1% (102)	7.1% (80)	3.3% (37)	57.6% (57)	17.2% (17)	23.2% (23)	2.0% (2)	60.8% (48)	19.0% (15)	13.9% (11)	1.3% (1)	5.15 (4)
	4	29.9% (336)	11.7% (131)	13.1% (147)	5.2% (58)	52.8% (67)	17.3% (22)	29.9% (38)	0% (0)	52.1% (75)	22.2% (32)	21.5% (31)	0.0% (0)	4.2% (6)
	5	19.7% (221)	9.2% (103)	7% (78)	3.6% (40)	42.2% (43)	28.4% (29)	28.4% (29)	1% (1)	57.7% (45)	19.2% (15)	20.5% (16)	0.0% (0)	2.6% (2)
	6	4.5% (50)	1.7% (19)	1.5% (17)	1.2% (14)	52.6% (10)	31.6% (6)	10.5% (2)	5.3% (1)	47.1% (8)	11.8% (2)	29.4% (5)	0.0% (0)	11.8% (2)
	7	1.3% (15)	0.4% (5)	0.4% (5)	0.4% (5)	40.0% (2)	20.0% (1)	20.0% (1)	20.0% (1)	60.0% (3)	40.0% (1)	0.0% (0)	0.0% (0)	0.0% (0)
	8	0.9% (10)	0.3% (3)	0.3% (3)	0.4% (4)	66.7% (2)	0.0% (0)	33.3% (1)	0.0% (0)	66.7% (2)	0.0% (0)	33.3% (1)	0.0% (0)	0.0% (0)
	9	0.3% (3)	0.2% (1)	0.1% (1)	0% (0)	0.0% (0)	50.0% (1)	50.0% (1)	0.0% (0)	100.0% (1)	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
	10 or more	0.1% (1)	0.1% (0)	0.0% (0)	0% (0)	0.0% (0)	0.0% (0)	100% (1)	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
Household Vehicles	1	16.9% (190)	7.9% (89)	5.3% (60)	3.7% (41)	56.8% (50)	22.7% (20)	20.5% (18)	0.0% (0)	58.6% (34)	24.1% (14)	13.85 (8)	0.0% (0)	3.4% (2)
	2	50.0% (561)	22.2% (249)	18.8% (211)	9.0% (101)	56.0% (136)	16.9% (41)	25.5% (62)	1.6% (4)	54.5% (115)	17.5%(37)	22.3% (47)	0.9% (2)	4.7% (10)
	3	24.7% (277)	9.7% (109)	10.0% (112)	5.0% (56)	53.8% (57)	18.9% (20)	25.5% (27)	1.9% (2)	57.4% (62)	17.6% (19)	17.6% (19)	0.0% (0)	7.4% (8)
	4 or more	8.4% (94)	2.9% (32)	3.7% (42)	1.8% (20)	51.6% (16)	25.8% (8)	19.4% (6)	3.2% (1)	53.7% (22)	29.3% (12)	143.6% (6)	0.0% (0)	2.4% (%)

- Age. The age group with the most responses in the survey was participants between 35 and 49 years old. Across all the age groups, the most preferred factor in route selection was based on the type of intersection control (except for the group between 35 and 49 years old). Traffic signal was the most preferred intersection option for this group of drivers. Among the factors not belonging to the intersection type, the most frequently selected option was shortest distance.

- Income. From the six annual income categories, the category of $40,000 to $69,900 had more responses in the survey (32.8%). Among the income groups, *Intersection* was the highest option selected as the route choice factors with exception of the annual income group of over $150,000 (that had a uniform distribution among the choices). For those who selected their routes by type of

intersection control, traffic signal was the most preferred type of control across the age groups (49.2% to 66.7%). Among all the respondents who said they selected their routes not by the type of intersection control, more than 55% used shortest distance as the criterion.

- Education. Four education levels were offered as answers in the survey. Undergraduate degree has the highest frequency of returns (36.8%). Again, across the education levels, traffic signal is the most preferred type of intersection control, and shortest distance is the most frequently used factors not related to intersection control type in route choice decisions.

- Family size. The survey showed that a family of size of four has the highest frequency (29.9%). There are more drivers in this household category (13.1%) that selected the routes based on other factors than the intersection type (11.7%)

- Household Vehicles. Fifty percent of the participants came from households that have two vehicles. Again, traffic signal and shortest distance are the two most frequently selected intersection type and non-intersection factors, respectively, in their route choice decisions.

The characteristics of the morning trips are shown in the Table 4.2. This table follows similar format as in Table 4.1.

Table 4.2 Results of questionnaire survey: morning trip habits

Attribute	Category	Response Total	Total Preference Distribution			Intersection Preference				Not Intersection Preference				
			Intersection	Not Intersection	No Choice	Traffic lights	4 Way Stop	2 Way Stop	Other	Shorter Distance	Minimize stops	Avoid Pedestrians	Drive Through	Other
Purpose ot the Weekday Trip (more than one option)	Work	71.9% (813)	19.1% (365)	15.0% (287)	8.4% (161)	53.5% (192)	18.7% (67)	27.0% (97)	0.8% (3)	56.4% (159)	21.3% (60)	17.7% (50)	0.0% (0)	4.6% (13)
	School	45.5% (515)	12% (228)	10.0% (191)	5% (96)	48.9% (108)	18.6% (41)	32.1% (71)	0.5% (1)	51.0% (98)	21.9% (42)	20.3% (390	0.5% (1)	6.3% (12)
	Shopping / Grocery	31.5% (356)	8.4% (161)	6.6% (126)	3.6% (69)	55.3% (88)	16.4% (26)	25.8% (41)	2.5% (4)	50.4% (61)	21.5% (26)	22.3% (27)	0.8% (1)	5.0% (6)
	Gym	11.9% (135)	2.3% (44)	2.9% (55)	1.9% (36)	48.8% (21)	23.3% (7)	25.6% (11)	2.3% (1)	54.5% (30)	21.8% (12)	20.0% (11)	0.0% (0)	3.6% (2)
	Other	7.8% (88)	2.0% (38)	1.8% (34)	0.8% (16)	70.3% (26)	18.9% (7)	5.4% (2)	5.4% (2)	56.3% (18)	25.0% (8)	15.6% (5)	3.1% (1)	0.0% (0)
Stop in the Neighborhood	No Stop	29..5% (334)	10.0% (113)	12.6% (143)	6.9% (78)	57.9% (66)	17.5% (20)	22.8% (26)	1.85 (2)	58.9% (83)	14.2% (20)	18.4% (26)	0.0% (0)	8.5% (12)
	Stop	70.5% (797)	32.8% (371)	25.3% (286)	12.4% (140)	54.5% (195)	19.6% (70)	24.6% (88)	1.4% (5)	53.7% (151)	22.8% (64)	19.9% (84)	0.7% 92)	3.2% (9)
Stop Locations (more than one option)	Gas station	79.5% (627)	22.8% (301)	16.3% (215)	8.4% (111)	50.2% (146)	21.0% (61)	27.1% (79)	1.7% (5)	54.0% (114)	24.2% (51)	18.0% (38)	0.9% (2)	2.8% (6)
	Coffee shop	18.0% (142)	5.28% (69)	3.7% (49)	1.8% (24)	59.1% (39)	16.7% (11)	19.7% (13)	4.5% (3)	52.1% (25)	16.7% (8)	20.8% (10)	2.1% (1)	8.3% (4)
	Day care	9.5% (75)	2.9% (38)	2.1% (28)	0.7% (9)	56.4% (22)	20.5% (8)	20.5% (8)	2.6%(1)	53.8% (14)	19.2% (5)	23.1% (6)	0.0% (0)	3.8% (1)
	Grocery store	45.1% (356)	13.6% (180)	9.4% (124)	3.9% (52)	56.3% (99)	20.5% (36)	21.6% (38)	1.75 (3)	44.6% (54)	28.9% (35)	23.1% (28)	0.8% (1)	2.5% (3)
	Restaurant	11.5% (91)	4.2% (55)	17% (22)	1.1% (14)	43.4% (23)	26.4% (14)	24.5% (13)	5.7% (3)	45.5% (10)	18.2% (4)	22.7% (5)	0.0% (0)	13.6% (3)
	Other	3.9% (31)	1.0% (13)	0.9% (12)	0.5% (6)	53.8% (7)	30.8% (4)	0.0% (0)	15.4% (2)	33.3% (4)	50.0% (6)	8.3% (1)	0.0% (0)	8.3% (12)
Times Leaving in the Morning	0	4.8% (54)	2.0% (23)	1.8% (20)	1.0% (11)	56.6% (13)	26.1% (6)	13.0% (3)	4.3% (1)	61.1% (11)	11.1% (2)	5.6% (1)	5.6% (1)	16.7% (3)
	1	40.3% (456)	15.7% (178)	16.9% (191)	7.7% (87)	53.7% (94)	20.6% (36)	24.0% (42)	1.7% (3)	55.3% (104)	19.7% (37)	19.1% (36)	0.5% (1)	5.3% (10)
	2	32.7% (370)	15.7% (177)	11.2% (127)	5.8% (66)	49.7% (86)	19.7% (34)	30.1% (52)	0.6% (1)	58.1% (72)	18.5% (23)	18.5% (23)	0.0% (0)	4.8% (6)
	3	10.2% (115)	3.4% (39)	4.3% (49)	2.4% (27)	76.9% (30)	15.4% (6)	7.7% (3)	0.0% (0)	42.95 (21)	28.6% (14)	28.6% (14)	0.0% (0)	0.0% (0)
	4 or more	12% (136)	5.9% (67)	3.79% (42)	2.4% (27)	61.3% (38)	12.9% (8)	22.6% (14)	3.2% (2)	60.5% (26)	18.6% (8)	16.3% (7)	0.0% (0)	4.7% (2)
Times Returning in the Morning	0	38.3% (433)	14.7% (166)	17.0% (192)	6.6% (75)	56.6% (90)	19.1% (31)	24.1% (39)	1.2% (2)	57.4% (108)	19.1% (36)	16.5% (31)	1.1% (2)	5.9% (11)
	1	28.4% (321)	13.1% (148)	9.5% (108)	5.7% (65)	51.4% (76)	24.3% (36)	22.3% (33)	2.0% (3)	55.8% (58)	16.3% (17)	21.2% (22)	0.0% (0)	6.7% (7)
	2	19.5% (220)	8.8% (100)	6.7% (76)	3.9% (44)	56.3% (54)	12.5% (12)	31.3% (30)	0.0% (0)	51.9% (40)	26.0% (20)	13.0% (3)	0.0% (0)	1.3% (1)
	3	4.9% (55)	1.7% (19)	2.1% (24)	1.1% (12)	73.7% (14)	15.8% (3)	10.5% (2)	0.0% (0)	56.5% (13)	26.1% (6)	28.6% (14)	0.0% (0)	4.3% (1)
	4 or more	9.0% (102)	4.5% (51)	2.6% (29)	1.9% (22)	57.4% (27)	17.0% (8)	21.3% (10)	4.3% (2)	50.0% (15)	16.7% (5)	30.0% (9)	0.0% (0)	3.3% (1)

The observed trip characteristics are discussed in the following paragraphs:

- During this survey, participant could select more than one trip purpose for trips that leave home in a typical weekday morning. The trip purposes, in decreasing order, were work (71.9%), followed by school (45.55), shopping/grocery (31.5%), gym (11.9%) and others (7.8%).

- Stop in the neighborhood. Seventy five percent of the participants stopped in the neighborhood in their morning trips. For trips that include at least a stop in the neighborhood, the most frequently selected route choice factor is shortest distance. The 29.5% respondents who did not make a stop in the neighborhood had traffic signals as their most frequently cited factor in route choice decisions.

- Stop locations. Among the reasons to make a stop in the neighborhood, gas stations received the highest frequency (79%) followed by grocery store (45%), coffee shop (18.0%), restaurant (11.5%), and day care (9.5%).

- Times leaving in the morning. The number of trips taken by a survey participant in an average morning is: 4.8% did not make any trip, 40.8% one trip, 32.7% two trips; 10.2% three trips and 12.0% four trips or more.

- Times returning in the morning. Thirty eight percent of the respondents (38.3%) did not leave home or leave home without return in the morning. Another 28.4% return to home once.

- Ideal intersection control. Table 4.3 shows the distribution of responses for the last question which asked the participant to state the ideal intersection control. Drivers selected the traffic signal options were the highest proportion (48.6%), followed by four-way stop sign and then two-way stop control (65%). This distribution is consistent with the results of the earlier cross tabulation.

Table 4.3 Results of questionnaire survey: ideal intersection control

Attribute	Range	Response Total	Total Preference Distribution			Intersection Preference				Not Intersection Preference				
			Intersection	Not Intersection	No Choice	Traffic lights	4 Way Stop	2 Way Stop	Other	Shorter Distance	Minimize stops	Avoid Pedestrians	Drive Through Wider Streets	Other
Ideal intersection Preference	Traffic Lights	48.6% (542)	21.2% (236)	17.2% (192)	10.2% (114)	75.1% (175)	13.3% (31)	9.4% (22)	2.1% (5)	55.3% (104)	18.1% (34)	21.3% (40)	1.1% (2)	4.35 (8)
	2-WAY STOP	20.2% (225)	9.4% (105)	7.4% (82)	3.4% (38)	24%.0% (24	10.0% (10)	65.0% (65)	1.0% (1)	53.8% (43)	22.5% (18)	23.85 (19)	0.0% (0)	0.0% (0)
	4-WAY STOP	22.1% (246)	8.8% (98)	10.0% (111)	3.3% (37)	47.4% (45)	36.8% (35)	15.8% (15)	0.0% (0)	54.5% (60)	16.45 (18)	17.3% (19)	0.0% (0)	11.8% (13)
	Roundabout	9.1% (102)	3.4% (98)	3.6% (40)	2.2% (24)	42.1% (16)	28.9% (11)	26.3% (10)	2.6% (1)	55.3% (231)	19.9% (83)	19.4% (81)	0.5% (2)	5.0% (21)

4.5 Summary

This chapter has described the data collection efforts made as part of this research. A TAZ in the west side of the City of El Paso, Texas had been selected as the TAZ to collect data and developed the methodology to convert a $\mathbf{O\text{-}D_p}$ matrix to a $\mathbf{O\text{-}D_m}$ matrix.

The GIS layers for the demographic and parcel data, travel demand model of the El Paso region, and other relevant electronic data had been collected from public agencies and organizations. Traffic counts using automated tube counters were performed at 25 locations within and at the boundary of the TAZ. Manual turning counts had also been performed at major intersections surrounding the TAZ.

A questionnaire survey was conducted for the residents in the TAZ as well as drivers in the City of El Paso. A total of 1130 participants responded to the survey. The survey collected the demographic profiles of the respondents and more importantly the factors that influence their route choice between their homes to the main streets access points at the boundary of their TAZs. The questionnaire survey data will be used to develop a discrete choice model which is described in Chapter 5 of this dissertation.

Chapter 5: Discrete Choice Modeling

5.1 Introduction

This chapter describes the estimation of a discrete choice model to predict route choice preferences of drivers when they travel from homes to the access points (i.e., intersections along the main streets that bound the TAZ).

For years discrete choice models have been utilized to mimic real life behavior, especially in transportation planning. From the context of this research some of the most recent works have focused on the influence of specific traffic control such as traffic signal, the effects of mode of transportation, and the choice effects under intelligent transportation systems. For example, Shenpei et al. (2008) evaluated the influence of traffic signal delay in driver's behavior path, Wan et al. (2011) estimated a NLM to model the impact of land use and traffic resource supply on the commuting travel mode choice, and Xu et al. (2010) developed a MNL to model route choice behavior under the provision of travel information.

Under this premise, a logit based modeling approach is chosen to analyze drivers' route choice preferences when make up the paths from homes to access points. The model's attributes are based on socioeconomic characteristics and morning trip habits of the drivers. The data was obtained from a questionnaire survey described in Chapter 4.

5.2 Discrete Choice Modeling Approach

A logit based modeling approach is selected to capture the intersection preferences of drivers. Intersection preferences are based on the socioeconomic characteristics and driving habits of the drivers. The preference is obtained as the driver's probability to select a specific access point to enter a main street at the boundary of the TAZ. In this work it is assumed that a resident of a TAZ is well informed of the various paths, street characteristics and traffic conditions. Choices among the different alternative paths to travel from or to his/her parcel (home) to the access points are based on his/her own criteria.

The factors that influence a driver's decision are (1) safety, which is provided by intersection traffic control (traffic signal, four-way stop control and two-way stop control); (2) comfort by traveling through wide streets or streets with low frequency to yield to pedestrians who are crossing streets; (3) the number of stops and turns; and (4) distance (or travel time) between the driver's parcel with the main street. This research assumes that the route in a TAZ with the shortest distance is the same as the route with the fastest travel time because of the low or lack of congestion (the free-flow speed is uniform within a TAZ).

Three different sub-models were developed to try to capture the decision process of a driver. The reason three sub-models were estimated instead of one is that there were limitations due data availability and the number of observations being too few. The models estimated were two nested logit models, and a mixed logit model (see Chapter 2 for descriptions). Figure 5.1 illustrates the conceptual structure of the model, which embeds three sub-models. The first (highest) level is a binary decision where the driver decide from two choices (1) he/she has no multiple routes to access the main streets (*No Multiple*) or, (2) he/she has multiple routes to access the main streets (*Multiple*). If the driver has multiple route

choices, he/she then makes a decision on the route based on (1) the type of intersection control (*Intersection*) or, (2) the factor that is not related to intersection control (*Not Intersection*). If the driver's choice is *Intersection*, the next decision is modeled by a MLM model with three choices of intersection control consisting of a traffic signal, four-way stop or two-way stop. If the driver's decides to base his/her route by a factor other than intersection control (*Not Intersection*), the next decision is modeled by a NLM with two branches consisting of a shortest distance and the avoidance of pedestrians. Under the shortest distance option, there are two more branches, the shortest route, or minimize stops and turns. Driving through wider streets and other also were discarded due the low frequency of driver preferences. The description and results of each of the three sub-models are described with more detailed in the subsequent sub-sections in this chapter.

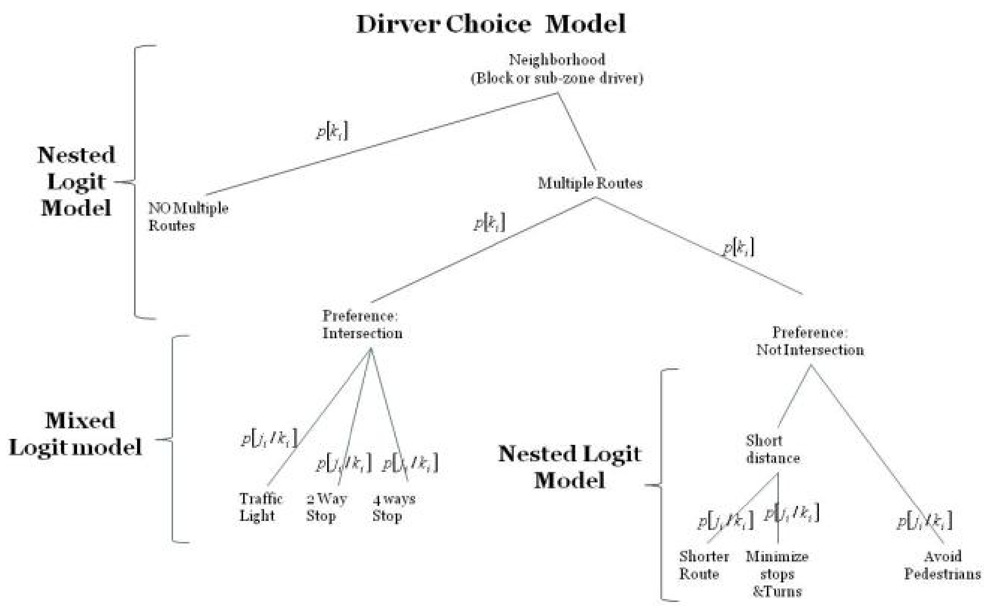

Figure 5.1 Structure of discrete choice model in the City of El Paso

5.2.1 Data

A driver intersection choice survey was described in Chapter 4. This survey collected demographic, morning trip patterns and route choice preference data from 1130 respondent throughout the City of El Paso.

5.2.2 Explanatory variables

The explanatory variables, obtained from the survey, that were used to develop the different models are described in Table 5.1. The dependent variables that were created for the model estimation, are included in Table 5.2. The selection criteria of the variables to be considered in each utility model were restricted to t-statistics of between >1.28 or <-1.28 (i.e., 0.20 level of significance). The decision of 0.20 level of significance is due to data availability.

Table 5.1 Explanatory variables in discrete choice model

Variable	Description
Gender	1 – male, 0 – female
Age	1 – less than 25, 2 – 25 to 34, 3 – 35 to 49, 4 – 50 to 64, 5 – 65 or older
Hinc	Annual household income, 1 – less $20k, 2 – $70k to $89k, 3 – $20k to $39k, 4 – $90k to $150k, 5 – $40k to $69k, 6 – greater than $150k
Educ	Highest education, 1 – high school, 2-some college, 3 – college graduate, 4 – post graduate
ZIP	Zip code, 1 to 24 (see actual survey for which zone)
Hsize	Household size, 1 to 10
Hveh	Number of household vehicles - 1, 2, 3, 4 or more
Leave	How many times they leave home in a weekday – 1, 2, 3, 4 or more
Retunr	How many times they return home in a weekday – 1, 2, 3, 4 or more
Work	Binary variable indicating if 1 – work, 0 – Otherwise.
School	Binary variable indicating if 1 – school, 0 – Otherwise.
Shop	Binary variable indicating if 1 – shop, 0 – Otherwise.
Gym	Binary variable indicating if 1 – gym, 0 – Otherwise.
Other1	Binary variable indicating if 1 – other, 0 – Otherwise.
Stop	Binary variable indicating if 1 – stop, 0 – Otherwise.
Gas	Binary variable indicating if 1 – gas, 0 – Otherwise.
Coffee	Binary variable indicating if 1 – coffee, 0 – Otherwise.
Daycare	Binary variable indicating if 1 – daycare, 0 – Otherwise.
Grocstor	Binary variable indicating if 1 – grocery store, 0 – Otherwise.
Rest	Binary variable indicating if 1 – restaurant, 0 – Otherwise.
Other2	Binary variable indicating if 1 – other, 0 – Otherwise.
IntPref	Preferred intersection control in neighborhood, 1- traffic signal, 2- 2-way stop, 3 - 4-way stop, 4 – roundabout

Table 5.2 Dependent variables in discrete choice model

Variable	Description
Multiple	When choosing your route in the neighborhood streets between your home and the main street, which of the following BEST describe your route choice criteria?
	1 – No multiple routes, 2 – Intersections, 3 - Not Intersection
Inters	When choosing your route in the neighborhood streets between your home and the main street, which of the following best describe your route choice criteria?
	1 – traffic signal, 2 – 2-way stop, 3 – 4-way stop
Streets	When choosing your route in the neighborhood streets between your home and the main street, which of the following best describe your route choice criteria? 1 – shortest path, 2 – minimize stops & turns, 3- avoid pedestrians, 4 – wide streets
	Inter – binary
TraL	Binary variable indicating if 1 – traffic signal, 0 – Otherwise.
TwoS	Binary variable indicating if 1 – 2-way stop, 0 – Otherwise.
FurS	Binary variable indicating if 1 – 4-way stop, 0 – Otherwise.
	Not intersection - binary
Shrt	Binary variable indicating if 1 – shortest path, 0 – Otherwise.
MinST	Binary variable indicating if 1 – minimize stops and turns, 0 – Otherwise.
AvPed	Binary variable indicating if 1 – avoid pedestrians, 0 – Otherwise.
WideS	Binary variable indicating if 1 – wide streets, 0 – Otherwise.

5.3 No Multiple or Multiple Routes Decision Model

The first branch of the model structure (*Multiple* or *No Multiple*) was evaluated using a NLM as the sub-model. During the survey some drivers selected *No Multiple* assuming that they were consistent with their routes during weekdays. Because of this, an IIA violation could be present with the other two options: *Intersection* and *Not Intersection*. In order to avoid this problem, a NLM was proposed to evaluate these choices. This NLM is denoted as NLM1. In the nested model the first branch contains the *No Multiple* and *Multiple* choices. Below the *Multiple* choices, the choices of *Intersection* and *Not Intersection* choices were evaluated. This tree is illustrated in the upper section of Figure 5.1.

5.3.1 Methodology

The NLM1 was estimated due to possible IIA violations. The dependent variables in the first branch were: *No Multiple* and *Multiple*. *No Multiple* represents the driver is without choice of routes to access the main street. *Multiple* means the driver has choices to decide among different route alternatives to connect from his/her home with the access points to the main streets. The second branchs, under the *Multiple* choice, has two dependent variables: *Intersection* and *Not Intersection*. Intersection represents the option that the driver prefers to access the main street based on the type of intersection control at the access points. *Not Intersection* is the alternative that the driver does not consider the type of intersection control when choosing his/her access point.

During the modeling process, variables were created from the survey data set. The method of maximum likelihood was applied to solve for the coefficients of the utility functions. The estimated coefficients were tested for their significance by means of the t-statistics. These variables are described in Tables 5.3, 5.4, 5.5 and 5.6.

Table 5.3 Independent variables created for *No Multiple*

Independent Variable	**Description**
Hsize4	Driver with household size of four
leave4	Driver who leaves home four or more times
Rest	Driver who regularly stops at restaurant
Hinc6	Driver with annual household income >$150k
IntPref4	Driver ideally prefers roundabouts

Table 5.4 Independent variables for *Intersection*

Independent Variable	**Description**
Hsize4	Driver with household size of four
School	Driver who has school as destination
Daycare	Driver who regularly stops at day care
Age34	Driver from 35 to 64 years old
Leav3	Driver who leaves home three or more times

Table 5.5 Independent variables for *Not Intersection*

Independent Variable	**Description**
leave4	Driver who leaves home four or more times
Rest	Driver who regularly stops at restaurant
HighS	Driver with high school education level

Table 5.6 Independent variable for *Multiple*

Independent Variable	**Description**
Retn1	Driver returning home one time in the morning
Hsize6	Driver with household size of six
Int1	Driver ideally prefers traffic light
Grocstor	Driver who regularly stops at grocery store

5.3.2 Results

The results of the NLM1 estimation are presented in this section. The selection criteria of the variables included in the utility functions consisted of t-statistic >1.28 or <-1.28, which corresponds to 0.20 level of significance. Table 5.7 shows the descriptive statistics of all the independent variables.

Table 5.8 lists all the independent variables with their estimated coefficients, t-statistics and marginal effects.

Table 5.7 Descriptive statistics for independent variables in NLM1

Variable	**Description of Variable**	**Mean**	**Standard Deviation**
Hsize4	Driver with household size of four	0.299	0.458
leave4	Driver who leaves home four or more times	0.104	0.306
Rest	Driver who regularly stops at restaurant	0.077	0.267
Hinc6	Driver who regularly stops to put gas	0.014	0.116
IntPref4	Driver who ideally preferred roundabouts	0.092	0.289
School	Driver who has school as destination	0.455	0.498
Daycare	Driver who regularly stops at day care	0.066	0.249
Age34	Driver from 35 to 64 years old	0.481	0..500
Leav3	Driver who leaves home three or more times	0.329	0.470
HighS	Driver with high school education level	0.276	0.447
Retn1	Driver returning home one time in the morning	0.282	0.450
Hsize6	Driver with household size of six	0.042	0.202
Int1	Driver ideally prefers traffic signals	0.480	0.500
Grocstor	Driver who regularly stops at grocery store	0.317	0.466

Table 5.8 Estimation results for NLM1

Variable	Description of Variable	Coefficient	t-Stat	Marginal Effects (%)
No Multiple				
Hsize4	Drivers with household size of four	-0.5033	-2.632	-7.774
Leave4	Driver who leaves home four or more times	0.4512	1.372	6.968
Rest	Driver who regularly stops at restaurant	-0.6214	-1.813	-9.597
Hinc6	Driver with annual household income >$150k	0.8481	1.505	13.097
IntPref4	Driver ideally prefer roundabouts	0.4700	1.753	7.258
Intersection				
Hsize4	Driver with household size of four	-0.4602	-3.143	-8.835
School	Driver who has school as destination	0.1794	1.613	3.444
Daycare	Driver who regularly stops at day care	0.3259	1.454	6.258
Age34	Driver from 35 to 64 years old	0.2183	2.173	4.192
Leav3	Driver who leaves home three or more times	0.3275	2.650	6.287
Not Intersection				
Leave4	Driver who leaves home four or more times	0.4135	1.782	7.938
Rest	Driver who regularly stops at restaurant	-0.9470	-3.389	-18.181
HighS	Driver with high school education level	0.1887	1.507	3.622
Multiple				
Retn1	Driver returning home one time in the morning	0.4221	2.543	
Hsize6	Driver with household size of six	-0.5974	-1.759	
Int1	Driver ideally prefers traffic signals	-0.3274	-1.996	
Grocstor	Driver who regularly stops at grocery store	0.5093	2.791	
Number of observations		1103		
Number of parameters		18		
log-likelihood at zero		-1377.977		
log-likelihood at convergence		-1128.317		
χ^2		499.3182		
ρ^2		0.1811		
ρ^2 adjusted		0.1744		

In order to justify the initial assumption of utilizing the NLM (i.e., IIA violation), t^* statistic and ϕ_i parameter were obtained. The ϕ_i and $\boldsymbol{\beta}$ values were estimated by LIMDEP to be equal to 0.0001 and 1.487 respectively. For the t^* statistic it was calculated using Equation [5.1]:

$$t^* = \frac{\boldsymbol{\beta} - 1}{S.E.(\boldsymbol{\beta})} = \frac{1.487 - 1}{0.2044} = 2.38 \qquad [5.1]$$

The t^* value is significantly greater than 1.28. This means that the NLM1 is suitable to be used with this group of choices. Also the ϕ_i was between 0 and 1 which means that the NLM1 was the right model structure to use. The χ^2 value was 499.3182 with 18 degrees of freedom. This corresponds to a *p*-value of about 0.0001% (essentially 0%). The McFadden ρ^2 was 0.1811 and the adjusted ρ^2 became 0.1744. A ρ^2 value between 0 and 1 suggest certainty of the model. The ρ^2 values obtained implied that the NLM fit well with the analysis of this branch.

5.3.3 Interpretation of results

The interpretation of the coefficients indicates that drivers with household size of four are less likely to consider multiple routes and are also less likely to select the routes based on the type of intersection control. The marginal effects indicates that a unit increment in the number of drivers with four members in the household, the driver's probability of selecting *No Multiple* choice will reduce by 7.774%. Similarly for *Intersection* choice it will decrease by 8.835%.

In the case of drivers leaving his/her house more than 4 times in the morning, they share the preference among the choices *No Multiple* (β=0.4512) and *Not Intersection* (β=0.4135). A possible reason is that they may not have the choice to select from more than one signalized intersection for this TAZ. The marginal effect indicates that a unit increment in drivers leaving home four times will increase the probability of *No Multiple* choice by 6.968%.

Drivers who stop during his/her route in a restaurant are less attracted to *No Multiple* (β=-0.6214) and *Not Intersection* (β=-0.947). This may indicate that these drivers prefer to select their routes based on the type of intersection. Actually a unit increment of drivers stopping in restaurants will decrease the probability of *No Multiple* by 9.59%.

For drivers with annual household income higher than $150k, were more likely to select *No Multiple* routes choices (β=0.8481). Presumably their parcels have limited access as result of higher privacy. This variable has one of the largest marginal effects, a unit increment of 1% of annual household income higher than $150k will contribute to an increase the probability of *No Multiple* choice by 13.09%.

Drivers who ideally prefer roundabouts in their trip are more likely to select *No Multiple* (β=0.4700). This group shows interest in a change of traffic control in the TAZ. The change is for a type of intersection control that could reduce delay. The marginal effect shows that installing a roundabout will contribute to the probability of its use by 7.258%.

Driver who heading to schools are more likely to connect to the main street based on the type of intersection control (β=.1794). This is probably capturing some safety concern with regard to dropping children off at schools. The marginal effect indicates that an increase in one school trip will increase the probability of *Intersection* choice by 3.444%. This situation is similar to Drivers who regularly stop at day care centers (β=0.3259). In this case, an additional trip stopping in day cares will contribute with a probability of use *Intersection* choice by 6.258%.

Age is a high contributor to the use of access points with traffic control. Drivers from 35 to 64 years old have preference by its use (β=0.2183). One unit increment of drivers with this age range will contribute to an increase in the probability of *Intersection* by 4.192%. This *Intersection* preference may be explained by the improved safety that the intersection controls provide.

Drivers who leave home three or more times are more likely to select access points by the type of intersection control (β=0.3275). The marginal effect points out that an additional driver with this kind of trip frequency will increase the probability of *Intersection* choice by 6.287%.

Drivers with high school education level are not interested to select their routes by *Intersection* (β=0.1887 for *Not Intersection*). This may suggest that drivers with a lower level of education are not as concern with safety issue. The marginal effect represents an increment of 3.622% in the probability of *No Multiple* choice with an additional driver with high school education level.

5.4 Intersection Control Type Decision Model

The second sub-model is for the drivers who base their route choice decisions on the type of intersection control (*Intersection*). The choice probability among the three types of intersection control was modeled by a MLM.

5.4.1 Methodology

The MLM was chosen to estimate the probabilities that a driver prefer the three types of intersection control: traffic signal, two-way stop and four-way stop. Considering as separately, using a

MNL model will cause an IIA problem. This model was selected because dependency between two or more variables may exist

The choice set consisted of traffic signal, two-way stop, four-way stop. The model was formulated with LIMDEP using Equations [2.3] to [2.6]. The independent variables used in this model are illustrated in Tables 5.9, 5.10 and 5.11 shown below.

Table 5.9 Independent variables created for traffic signal

Independent Variable	**Description**
Tlone	Constant
Leave4	Driver who leaves home four or more times
Gender	Male
Gas	Driver who regularly stops to put gas during trip
Age5	Driver with 65 or older years old
Hsize5	Driver living in home of five
Coffee	Driver who regularly stops at coffee shop

Table 5.10 Independent variable created for two-way stop

Independent Variable	**Description**
Rest	Driver who regularly stops at restaurant
Return2	Driver returning home two times in the morning

Table 5.11 Independent variable created for four-way stop

Independent Variable	**Description**
Leave4	Driver leaving home four times in the morning
HigS	Driver with high school education level
Age5	Driver with 65 or older years old

5.4.2 Results

After running the MLM using LIMDEP (Greene, 2007) the descriptive statistics and the coefficients (β) of the utility equations were obtained using the method of maximum likelihood. Table 5.12 shows the descriptive statistics of the variables and Table 5.13 shows the estimated parameter values. The χ^2 value of 160.78 with 15 degrees of freedom gives a *p*-value of 0.01% (essentially 0%).

Table 5.12 Descriptive statistics for variables used in MLM

Variable	**Description of Variable**	**Mean**	**Standard Deviation**
Leave4	Driver who leaves home four or more times	0.838	0.277
Gender	Male r	0.415	0.493
Gas	Driver who regularly stops to put gas during trip	0.615	0.486
Age5	Driver with 65 or older years old	0.924	0.289
Hsize5	Driver living in home of five	0.217	0.412
Coffee	Driver who regularly stops at coffee shop		
Rest	Driver who regularly stops at restaurant	0.107	0.309
Return2	Driver returning home two times in the morning	0.311	0.463
HigS	Driver with high school education level	0.258	0.438

Table 5.13 Estimation results for MLM

Variable	Description of Variable	Coefficient	t-Stat	Marginal Effects (%)
Traffic signal				
Llone	Constant	0.957	0.255	
Leave4	Driver who leaves home four or more times	1.831	1.613	1.02
Gender	Male	-0.3694* (0.4427)**	-0.835 (1.56)	-1.88
Gas	Driver who regularly stops to put gas during trip	-0.5137* (0.4101)**	-1.25 (1.832)	-3.12
Age5	Driver with 65 or older years old	1.777	1.499	1.20
Hsize5	Driver living in home of five	-1.194	-2.455	-2.93
coffee	Driver who regularly stops at coffee shop	0.986	1.495	1.13
Two-way stop				
TWone	Constant	-0.838	-3.916	
Rest	Driver who regularly stops at restaurant	0.714	1.706	1.11
Return2	Driver returning home two times in the morning	0.660	2.248	2.92
Four-way stop				
Leave4	Driver leaving home four times in the morning	-1.084	-1.459	-0.58
HigS	Driver with high school education level	-0.797	-2.489	-2.31
Age5	Driver with 65 or older years old	-1.029	-1.385	-0.46
Number of observations		465		
Number o parameters		15		
Log-Likelihood at Zero		-510.8547		
Log-Likelihood at Convergence		-430.4644		
χ^2		160.78		

* Mean of random variable
** Standard deviation of random variable

5.4.3 Interpretation of results

Two variables were found to be random and had significant values for their assumed distribution: Gender and Gas. The parameters of the probability density function $f(\boldsymbol{\beta}_i|\boldsymbol{\varphi})$ of these variables are (-0.3694, 0.4427) for Gender and (-0.5137, 0.4101) for Driver who use to stop in gas stations before they leave the neighborhood (TAZ). For Gender, the density function suggests that 20.2% of males tend to select the intersection with traffic signals. In the case of Gas, the density function suggests that 89.48% of the drivers are likely to take intersection with traffic signals to access the main streets as result of his/her detour to gas stations. Usually gas stations are located at intersections controlled by traffic signals.

The Leav4 variable coefficient indicates that drivers are more likely to use an intersection with traffic signals (β=1.831) if they leave home a minimum of four times in one morning than using a four-way stop intersections (β=-1.084). The marginal effect value exemplifies that the probability of using a signalized intersection will increase by 1.02% if the number of drivers leaving homes four times in the morning increase by a unit, while the probability of selecting a four-way stop sign will decrease by -0.58%. A possible reason is that these drivers are homemakers or retired seniors who prefer safer intersections and are in no hurry to arrive to their destinations.

For the Age variable the statistics show that drivers 65 and older are more likely to go through intersections with traffic signals (β=1.777). This may be due to the fact that since they are older they seek safer intersections which are controlled by signals. An additional driver older than 65 years old

will increase the probability of use of signalized intersections by 1.20% and the selection of a four-way stop by 0.46%.

The bigger the household size, the less likely the driver will select a route that consists of a signalized intersection. This is especially true if the house hold size is five (β=-1.194). This is because these drivers may need to drop off the rest of the household members, especially children, to different schools, which may not have a signalized intersection along the route. The marginal effect indicates that a unit increment in the number of drivers with family of five will decrease the selection of intersections with traffic signals by 2.93%.

The more drivers buy coffee in the morning, the more likely they are to pass through a signalized intersection (β=0.986). These drivers probably stop at gas station at corners of signalized intersections. A unit increment of trips to coffee stores will contribute to an increase in the probability of using an intersection with traffic signals by 1.13%.

If drivers on his/her route need to stop at a restaurant, two-way stop intersection choice is most frequently used (β=0.714) due to some of the neighborhood restaurants being located closer to this type of intersection. The increment of one restaurant implies an increment of use four-way stop intersection by 1.11%.

Drivers are more likely to go through a two-way stop intersection (β=0.660) if they decide to return home twice. This may be capturing some driver behavior concerning minimize route impedance. Increment of a driver returning home two times in the morning represents an increment in the probability of the use of two-way stop control intersection by 2.92%.

Drivers with a high school education level are also less likely to access the mains streets through four-way stop intersections. This may be due to the fact that they perceive having longer delays at four-way stops compared to other types of intersection. In addition, these drivers at this education level may have less concern about safety and accident cost. The effect of a unit increase of drivers with high school education level causes a reduction in the probability of use four-way stop intersections by 2.31%.

5.5 Not Intersection Factors Decision Model

The NLM was used to model the data related with the choice of *Not Intersection*. The reason was because there was IIA violation between shortest path and minimum stops and turns. The estimated model is denoted as NLM2.

5.5.1 Methodology

The NLM2 was formulated to represent the choice of *Not Intersection* because IIA violations were suspected to be present in the options: minimum stops and turns, and shortest path. The routes selected based on these choices were correlated. The model was formulated with LIMDEP using the Equations [2.10], [2.11] and [2.12].

The initially choice set was: shortest path, minimum stops and turns, avoid pedestrians, wide streets and others. After estimation, the choices wide street and other were omitted from the data set because they did not have enough observations. To further facilitate the modeling process and to

acquire a more accurate model, variables were created for each utility equation. These variables are listed in Tables 5.14, 5.15, 5.16 and 5.17 shown below.

Table 5.14 Independent variables for shortest path

Independent Variable	**Description**
Hveh3	Driver with three vehicles
Leave4	Driver who leaves home four or more times
School	Driver using school as their main morning trip
Other2	Driver who regularly stops at "other" locations during trip

Table 5.15 Independent variable for minimum stops and turns

Independent Variable	**Description**
Hveh2	Driver with two vehicles
Grocstor	Driver who regularly stops at the grocery store

Table 5.16 Independent variable for avoid pedestrians

Independent Variable	**Description**
AVPone	Constant
Hinc2	Driver with annual household income $70k to $89k
POSTC	Driver with education graduate education
IntPref4	Driver ideally prefers roundabouts
Gas	Driver who regularly stops to put gas

Table 5.17 Independent variable for shortest distance

Independent Variable	**Description**
Coffee	Driver who regularly stops at coffee shop
Gender	Male

5.5.2 Results

The variables chosen for the NLM2 had to meet t-statistic of greater than 1.00 or less than -1.00 in order to be considered as significant and be included in the model. Table 5.18 shows the descriptive statistics of the independent variables and Table 5.19 shows the independent variables with their coefficients (β) and estimation results for the shortest distance branch and all three utility functions, namely shortest route, minimum stops and turns, and avoids pedestrians.

In order to validate the initial assumption of the use of NLM2, t^* statistic and ϕ_i parameter were calculated by LIMDEP. ϕ_i and $\boldsymbol{\beta}$ values were estimated to be 0.7743 and 0.1108 respectively. For the t^* statistic, it was calculated using Equation [5.2].

$$t^* = \frac{\boldsymbol{\beta} - 1}{S.E.(\boldsymbol{\beta})} = \frac{0.1108 - 1}{0.3863} = -2.30 \quad [5.2]$$

Table 5.18 Descriptive statistics for variables used in NLM2

Variable	**Description of Variable**	**Mean**	**Standard Deviation**
Coffee	Driver who regularly stops at coffee shop	0.108	0.310
Gender	Male	0.417	0.493
Hveh3	Driver with three vehicles	0.251	0.433
Leave4	Driver who leaves home four or more times	0.123	0.329
School	Driver using school as their main morning trip	0.447	0.497
Other2	Driver who regularly stops at "other" locations	0.027	0.164
HVeh2	Driver with two vehicles	0.497	0.500
GROC	Driver who regularly stops at the grocery store	0.291	0.454
HInc2	Driver with annual household income $70k to $89k	0.278	0.448
POSTC	Driver with graduate education	0.067	0.251
Int4	Driver ideally prefers roundabouts	0.100	0.300
Gas	Driver who regularly stops to put gas	0.510	0.500

The ϕ_i value was between 0 and 1 which means that this was the right model structure to use. The t* statistic was found to be significant from one. Therefore the NLM2 is the correct form to fit this data. The χ^2 statistic of 275.7059 with 14 degrees of freedom satisfies a 0.01 level of significance. The McFadden ρ^2 is 0.277 which lies between 0and 1, meaning that the NLM2 fits the data of this branch.

Table 5.19 Estimation results for NLM2

Variable	Description of Variable	Coefficient	t-Stat	Marginal Effect (%)
Shortest Distance branch				
Coffee	Driver who regularly stop at coffee shop	-0.273	-0.674	
Gender	Male	0.582	0.274	
Shortest Route				
SPone	Shortest distance constant	1.196	4.203	
Hveh3	Driver with three vehicles	0.687	1.879	10.46
Leave4	Driver who leaves home four or more times	-0.539	-1.264	-8.20
School	Driver using school as their main morning trip	-0.348	-1.289	-5.28
Other2	Driver who regularly stops at "other" locations during trip	-1.846	-2.648	-28.09
Minimize Stop and Turns				
HVeh2	Driver with two vehicles	-0.518	-1.655	-7.47
Groc	Driver who regularly stops at the grocery store	0.884	3.013	12.77
Avoid Pedestrians				
AVPone	Constant	-0.948	-1.627	
HInc2	Driver with annual household income $70k to $89k	0.793	2.892	11.94
POSTC	Driver with graduate education	-1.750	-1.691	-26.37
Int4	Driver ideally prefers roundabouts	-1.284	-2.060	-19.35
Gas	Driver who regularly stop to put gas	-0.384	-1.430	-5.78
Number of observations		398		
Number of parameters		14		
log-likelihood at zero		-496.2934		
log-likelihood at convergence		-358.4404		
χ^2		275.7059		
ρ^2		0.277		
ρ^2 Adjusted		0.263		

5.5.3 Interpretation of results

The interpretation of thee parameters is as follows. A driver stopping at a coffee store is less likely to travel by route with the shortest distance (β=-0.273). Males are more likely to drive to the access points that has the shortest distance (β=0.582). This behavior is probably due to the male's aggressiveness and impatience over female.

Drivers with three vehicles in the household showed to be more likely to choose the shortest path (β=0.687). The marginal effect indicates that a unit increment of families with three vehicles will increase the probability of drivers selecting the shortest route by 10.46%

Drivers leaving home four or more times during the morning are less likely to choose the shortest distance (β=-0.539). This situation could apply to drivers that make multiple trips and are tend to want to save travel time. The marginal effect indicates that a unit increment will decrease the probability of selecting the shortest route by 8.20%.

Drivers with final destination at school or make other stopping during his/her trip are less likely to choose the shortest path. The reason could be that because the detours to their destinations make them impossible to select shortest distance paths. The marginal effect value indicates that for a unit increment of driver with destination at schools and stopping for other reasons, the probability of selecting the shortest route will be reduced by 5.28 % and 28.09 % respectively.

Drivers with two vehicles were less likely to take the routes with minimum stops and turns (β=-0.518). One unit increment of drivers with two vehicles in the household will decrease the probability of them using this choice by 7.47%.

Driver who regularly stops at the grocery stores during morning trips are more likely to take routes with minimum stops and turns (β=0.844). A possible explanation is that drivers doing groceries shopping in the morning usually are in a hurry to save time to arrive at their destinations. The marginal effects indicates that a unit increment of drivers stopping at grocery store will increase the probability of drivers avoiding turns and stops by 12.7%.

Drivers with annual household income from $70k to $89k were more likely not to drive though streets with pedestrians (β=0.793). Assuming that these drivers are considered as middle class, their houses are located close to parks and facilities where pedestrians used to visit. Then, these drivers cannot easily avoid pedestrians during his/her home-based trips. The marginal effect shows that a unit increment of middle class drivers (household) will incur a probability increment of traffic trying to avoid pedestrians by 11.94%

Drivers with graduate education were less likely to choose a route that avoids pedestrians (β=-1.750). A possible reason is that their decisions on the locations of home parcels already take this pedestrian friendly factor into consideration

Drivers who ideally prefer roundabouts to connect with the main streets are less likely to choose the avoid pedestrians route (β=-1.284). A possible reason is that roundabouts are more pedestrian friendly, and therefore these drivers expect pedestrians to present at roundabouts

Finally, commuters who stop to refuel gasoline are less likely to avoid pedestrians (β=-0.384).

5.6 Summary

The three logit sub-models have been fitted to the data collected. The following observations have been summarized:

(1) *Intersection* is widely preferred by females, drivers older than 64 years old and drivers stopping in gas stations and coffee stores. This is probably due to safety concerns and store locations.

(2) Traffic signal control is preferred by drivers older than 64 years old and also by females.

(3) Two-way stop control is only preferred by drivers who stop at restaurants and return two times during the morning.

(4) Four way stop intersection is attractive only by driver who go to grocery stores in the morning. Drivers leaving home four times in the morning, with high school level, or older than 65 years old are less likely to use this type of intersection.

(5) Shortest route is preferred by males or drivers with three vehicles in the household.

(6) Drivers with graduate studies or drivers stopping at gas stations tend not to avoid pedestrians. Middle income drivers are more likely take a route to avoid encountering pedestrians.

The estimated discrete choice model (which consisted of three sub-models) is used in the next chapter to select traffic zones and zone connectors for a TAZ.

Chapter 6: Selection of Traffic Zones and Connectors

6.1 Introduction

This chapter describes and demonstrates the process to select traffic connectors and allocate traffic volume that originated from the TAZ to the connectors for implementation in a MTS model. This process involves the application of the discrete choice approach covered in Chapter 5, combined with path analysis using the ArcGIS Network Analyst tool.

As mentioned in Chapter 2, the **O-D$_{\mathbf{p}}$** matrix represents trips between the centroids of all the TAZs (the components of this matrix is T_{ij}^{P}), while the **O-D$_{\mathbf{m}}$** matrix represents the trips among the traffic zones (the components of this matrix is $t_{i_a j_b}^{m}$). The **O-D$_{\mathbf{m}}$** matrix has a larger dimension than the **O-D$_{\mathbf{p}}$** matrix.

In order to create a MTS model that uses traffic demand data from the corresponding TPM, it is necessary to discompose T_{ij}^{P} into $t_{i_a j_b}^{m}$. The method described in this chapter assumes that a driver starts a trip from his/her home (parcel) during the morning peak hour, and based on his/her route choice preference, travel to his/her preferred access point (intersection) to turn into a main street. In this chapter, the main streets are the streets that bound a TAZ. Access points are intersections along the main street that enable drivers to turn from the TAZ into the main streets. A few representative access points will be selected using the procedure demonstrated in this chapter for implementation in a MTS model. Traffic zones are the areas representing the trip origins or destinations in a MTS that are next to

the selected access points. Traffic zone connectors, or zone connectors, are links in a MTS that join the traffic zones with their access points.

6.2 Methodology

The methodology to select the traffic zones and zone connectors consists of nine tasks. The flow chart of the methodology is shown in Figure 6.1. The description of each task is described in the subsections below.

6.2.1 TAZ selection

The first task is to select a TAZ.

6.2.2 Data collection

The second task is to collect data to be employed in the TAZ's network analysis. This data must being geospatial vector format (i.e., shapefile). The necessary data includes the TAZ's parcels and land use, network geometry, types of traffic control at the intersections within and surrounding the TAZ and field traffic count.

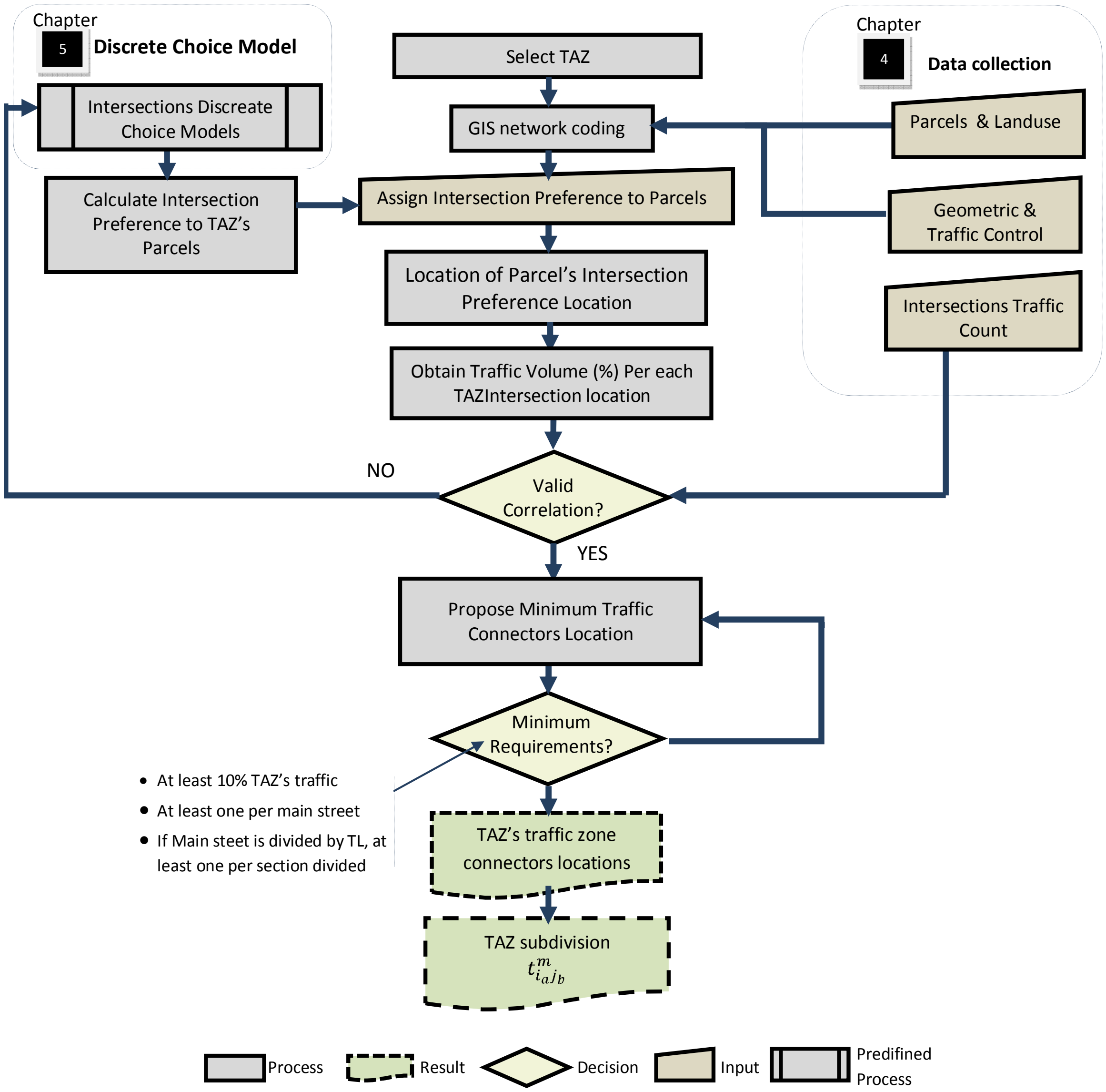

Figure 6.1 Flow chart for selection of traffic zone and zone connectors

6.2.3 GIS network coding

This task covers the different processes to input the geospatial vector data into a network dataset. The network dataset is a digital network that consists of edges, intersections and turns elements interconnected to model the paths of vehicles. The network dataset is used as a platform to evaluate driver's route choice from each parcel to the available access points. The network's geospatial vector

data was edited to provide attributes to evaluate the different route choice criteria. These necessary attributes are link speed, link travel time and street hierarchy.

6.2.4 Calculate route choice preference

The discrete choice model, obtained in Chapter 5, is utilized to estimate the route choice of each driver who lives in the TAZ. The model relies on the socioeconomic data provided by ArcGIS Business Analyst tool (reviewed in Section 2.7.2), supplemented by the data obtained from the driver route choice survey (the questionnaire survey described in Chapter 4).

6.2.5 Assign route choice preference to parcel

Once the route choice preference of the driver in each parcel is determined, this data is coded in the parcel centroid’s geospatial vector. The geospatial vectors are then added to the network dataset.

6.2.6 Select parcel’s access point

For each parcel, path analysis is carried out to find the preferred access point for the driver (that is, intersection at the boundary of the TAZ at which the driver will use to access the main street, according to his/her route choice preference). The preferred access point is selected such that the path cost between the parcel and the access point is minimized. Because each route choice preference has a different way of calculating path cost, the path analysis for different route choice preferences are performed separately, each in one GIS layer.

6.2.7 Obtain traffic volume for each access point

In this step, it is assumed that each residential parcel in the TAZ will generate one vehicular trip in a weekday morning, and all the vehicles (drivers) have selected their preferred access points. The total number of trips (parcels) within the TAZ that uses an access point is the sum of all the drivers who preferred the access point using the different route choice criteria. Based on the total volume of vehicles at the access points, the volume splits (in percent) among the access points are then calculated. The total volume split along each main street is then obtained by summing the splits of all the access points along the same street. This gives the percentages of the total number of trips departing from the TAZ that will head towards the main street in the different directions.

6.2.8 Validation

The methodology is validated by comparing the estimated splits of total number of trips (that is discharged from the TAZ) among the main streets, against the splits obtained from the traffic count data.

6.2.9 Propose minimum traffic zones and traffic connectors

Once the volume splits that are discharged from the TAZ to the main streets have been validated, the next step of the methodology is to define the best access points (along the main streets) to be designated as traffic zones, assign zone connectors and allocate the volume splits among the traffic zones. If all the access points are selected, it will result in a large $\mathbf{O\text{-}D_m}$ matrix, making the MTS model too computationally intensive. To avoid this situation, a few traffic zones and zone connectors should

be selected for a TAZ. Each traffic zone is connected by a zone connector to a selected access point. The following selection criteria are recommended:

(1) There should be at least one traffic zone (and zone connector) per main street.

(2) The access point with the highest volume split in each main street should be selected.

(3) There should be at least one traffic zone (and zone connector) between two signalized intersections, even if the two signalized intersections are along the same main street. The purpose of this is to spread the volume between the approaches of the signalized intersections.

(4) There should be at least two traffic zones (and zone connectors) if the main street on one side of the TAZ is long.

(5) There should be at least one traffic zone to represent a sub-division and a zone connector to connect this sub-division which is isolated by a geographical feature (e.g., channel) from the rest of the TAZ.

The traffic zones and zone connectors load vehicles to the main streets in a MTS model. Therefore, the locations of the traffic connectors must to reasonably precise enough to represent the way vehicles are loaded into the main network.

6.3 Discrete Choice Application

This section describes the application of the proposed methodology described in Section 6.2 to select traffic zones, zone connectors and to allocate volume splits among the selected connectors for a TAZ.

6.3.1 TAZ selection

The TAZ selected was located in the Westside of City of EL Paso. Section 4.2 has the description of this area.

6.3.2 Data collection

The parcel layer and street layer (center line of the street network) of the City of El Paso was obtained in the vector format. In order to work with the specific TAZ, the information of both geospatial vector layers were extracted from the City of El Paso area. The information provided by the parcel data included land use classification of the parcels. Figure 6.2 shows the land use of the parcels within the TAZ.

Figure 6.2 Land use of the parcels within the selected TAZ

6.3.3 GIS network coding

In order to create a GIS network data set, the processing of geospatial vectors (shapefile) was executed in a geodatabase. This process consisted of adding data to the attributes. Link speed, link travel time, link length, and link hierarchy were added as attributes for each link. Speed was uniform in the entire street network within the TAZ. The default link speed was 30 mph. The speed of links around a school was reduced to 15mph. Link travel time was calculated from the link length and the link speed. Link hierarchy was a necessary parameter to set the right-of-way of intersection approaches in order to calculate the turn delay. An approach that has priority at an intersection was given a higher hierarchy (e.g., hierarchy 2) than an approach from which vehicles have to stop or yield (e.g., hierarchy 3). Figure 6.3 illustrates the link hierarchy of the TAZ network. For each parcel to have at least a connected path to an access point to a main street, links were edited as driveways that connect the centroid of each parcel to the nearest neighborhood street within the TAZ. These "driveway" links had a speed of 5 mph and the lowest hierarchy (hierarchy 5).

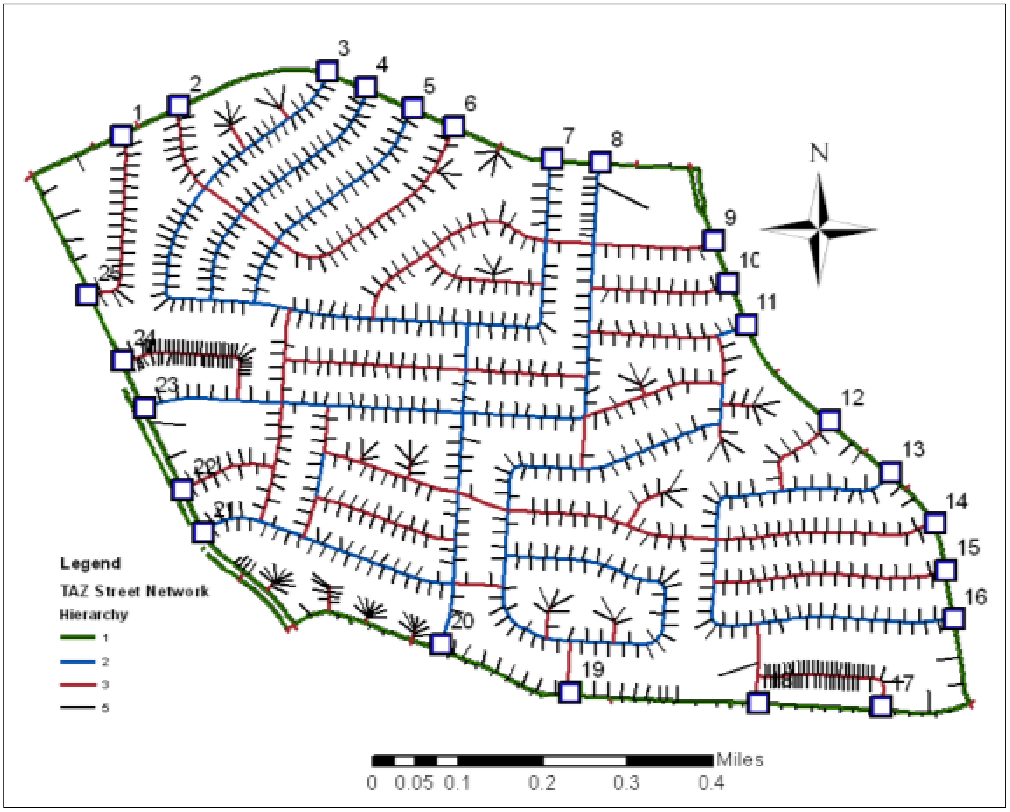

Figure 6.3 Street hierarchy of the TAZ

The delay (in seconds) of vehicles when passing an intersection with a specific turning direction is shown in the Table 6.1. The values are provided by Network Analyst.

Table 6.1 Turn and intersection crossing delay (from Network Analyst)

Direction	Description	Delay (seconds)
Straight	From Local to Local Across No Roads	0
Straight	From Local to Local Across Local Roads	2
Straight	From Local to Local Across secundary or Primary Roads	15
Straight	From Local To Secondary Road	3
Straight	From Secondary To Local Road	3
Straight	From Secondary To Secondary Road across no Roads	0
Straight	From secondary To secondary Road across Local Roads	0.5
Straight	From Secondary To Secondary Road Acreoss Secondary or Primary Road	5
Reverse	From Local To Local Road	3
Reverse	From Local To Secondary Road	15
Reverse	From Secondary To Local Road	5
Reverse	From Secondary To Secondary Road	5
Right Turn	From Local To Local road	2
Right Turn	From Local To Secondary Road	3
Right Turn	From Secondary To Local Road	2
Right Turn	From Secondary To Secondary Road	3
Left Turn	From Local To Local road	2
Left Turn	From Local To Secondary Road	10
Left Turn	From Secondary To Local Road	5
Left Turn	From Secondary To Secondary Road	8

6.3.4 Calculate route choice preference

The parcels with single family homes and multi familiar homes were next selected and their attributes transferred to a spreadsheet so as to estimate the route choice preference for drivers departing from each parcel. Each parcel was assumed to have one driver making one trip with one route choice preference. The estimation of route choice preference consisted of the following tasks. The first one was to obtain the discrete distributions of the socioeconomic attributes and driver preferences. The socioeconomic attributes were extracted from the Business Analyst tool which contained parameters such as gender, age, income, education, household size, and vehicles per household. Figure 6.5 shows the discrete distributions of these attributes, obtained from the Business Analyst tool for the selected TAZ. In the absence of an alternate data source, other attributes that significantly contributed to the

driver's route choice preferences followed the distributions in the survey data which has been described in Chapter 4. Figure 6.6 shows the discrete distributions of the attributes obtained from the survey.

For each parcel, the value of each attribute was randomly generated from its discrete distribution. The randomly generated attributes were entered into the discrete choice model (described in Chapter 5) to calculate the probability of each route choice alternative. Once the probability of all the alternatives had been obtained, another random number which followed the uniform distribution between 0 and 1 was generated. This uniform random variate was compared against the cumulative probabilities of the route choice alternatives in order to make a final decision on the route choice preference (of the Driver who left the parcel).

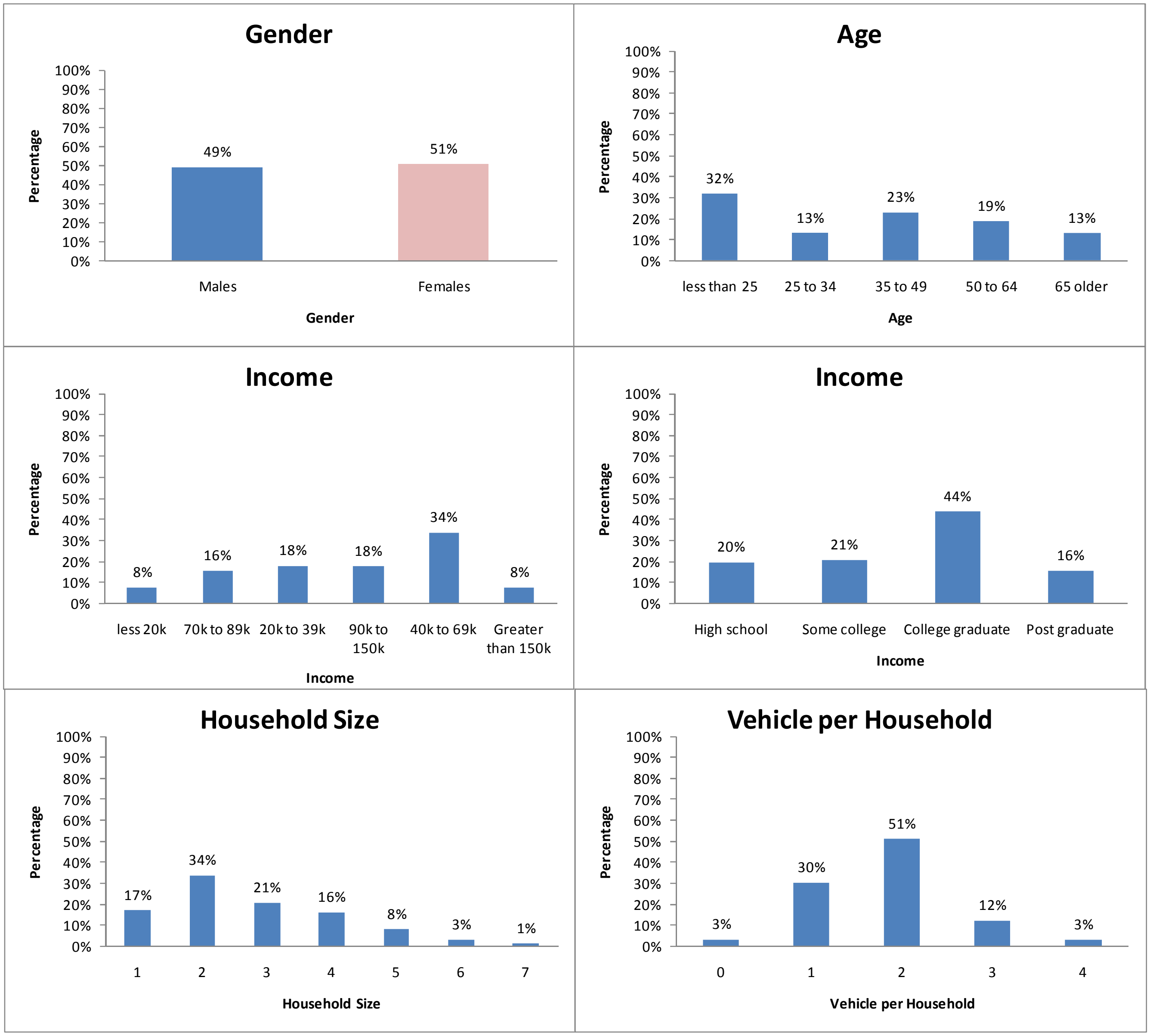

Figure 6.5 Discrete distributions of socioeconomic attributes

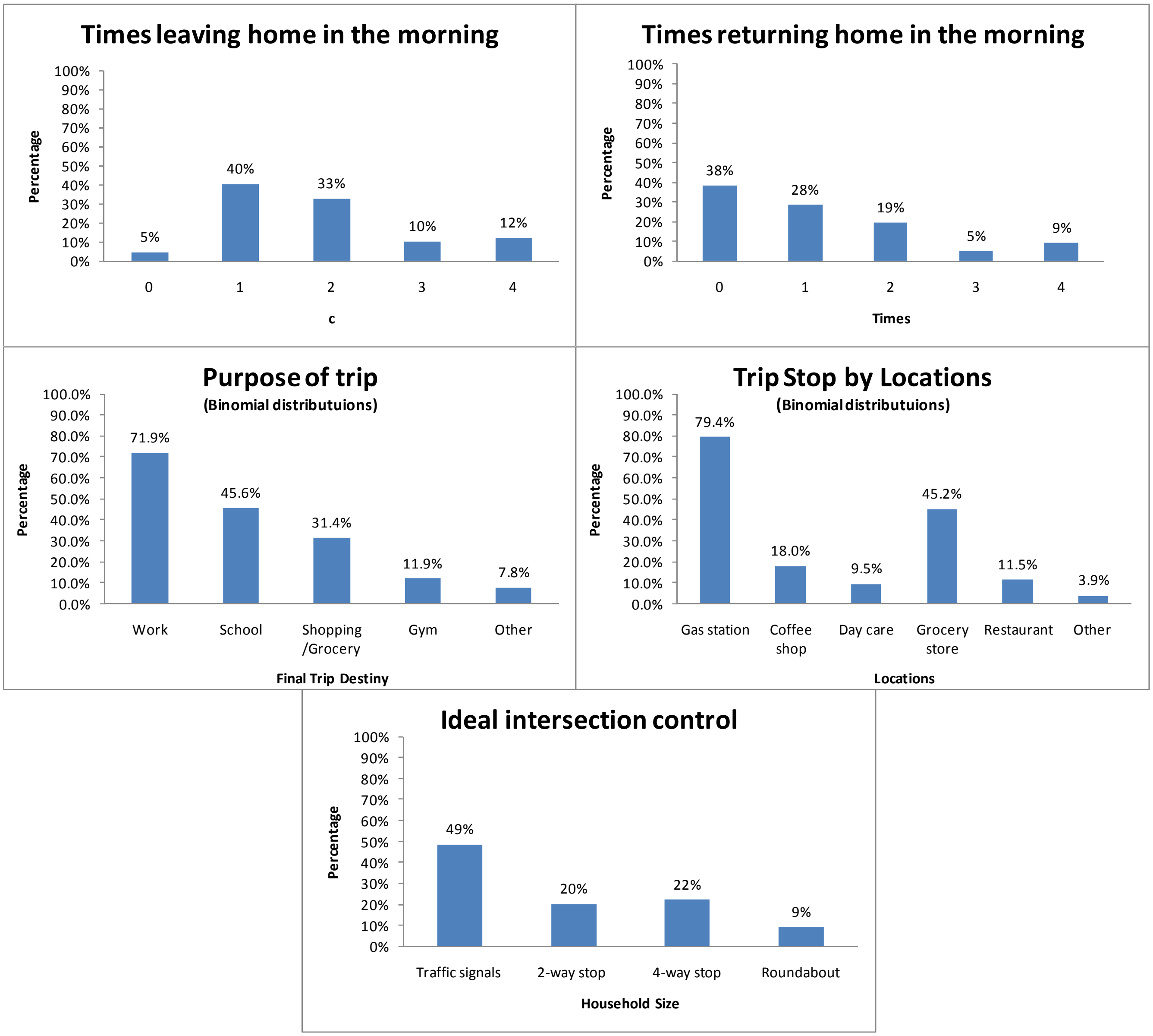

Figure 6.6 Discrete distributions of driver trip patterns

6.3.5 Assign route choice preference to parcel

Once the route choice preference of the driver at each parcel had been defined, the preference was entered through a joint attribute table into the parcel centroid's geospatial vector. The parcel centroid's geospatial vector was subsequently added to the network dataset. Figure 6.7 shows the geospatial vector including the route choice preference assigned to each parcel.

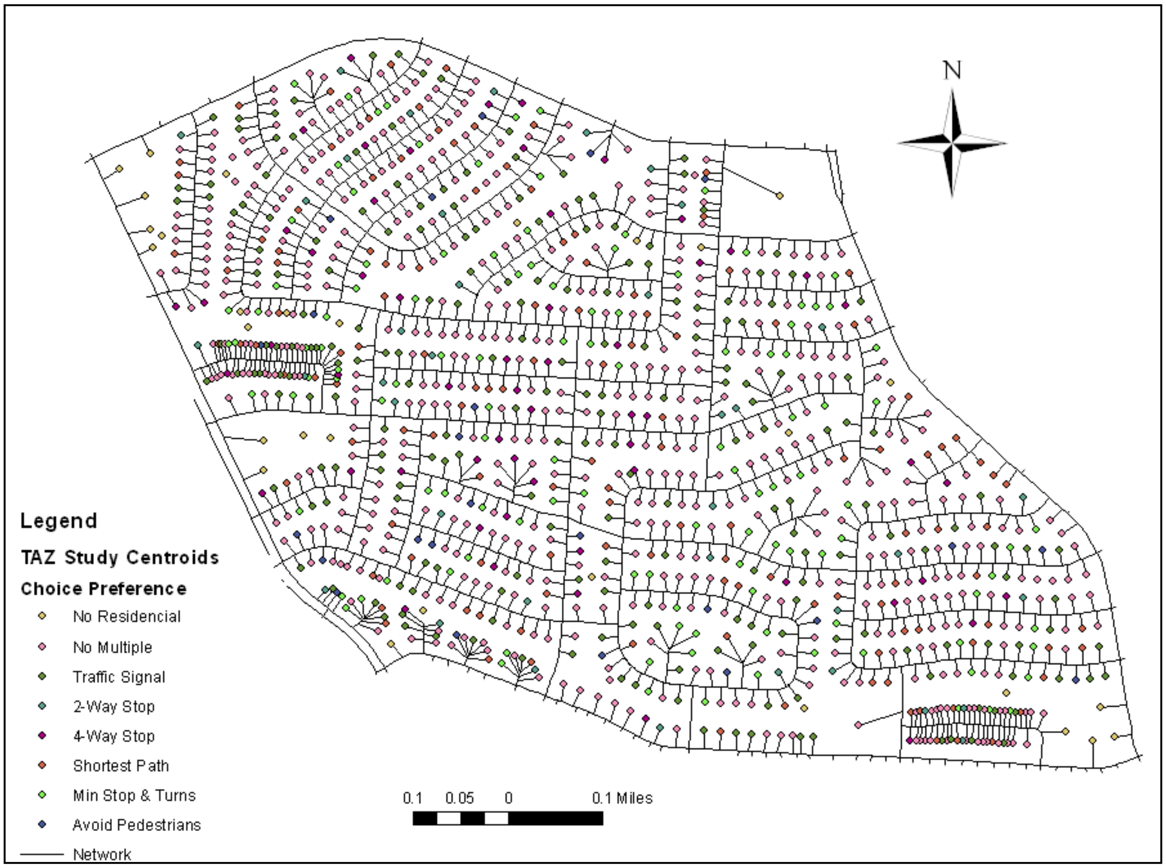

Figure 6.7 Parcel centroids including the driver route choice preference

6.3.6 Assign each parcel's access point

For each parcel, path analysis was carried to determine the access point the driver will use to access the main street. One access point along the main street was selected such that the path cost is minimized. Cost represents the impedance that the driver, according with his/her route choice preference, tries to avoid.

Prior to the execution of the path analysis, the candidate access points along the main streets were indentified and numbered. These 25 intersections are shown in Figure 6.8.

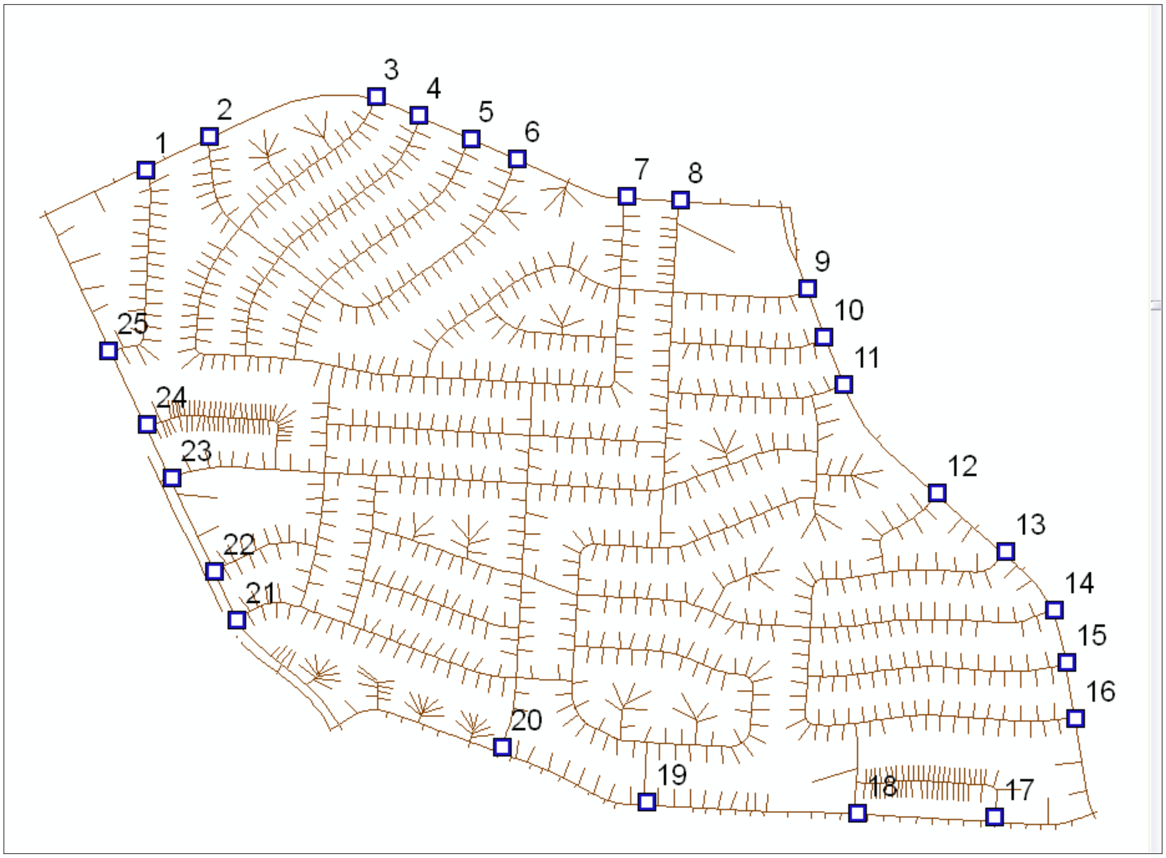

Figure 6.8 Access points to the TAZ

Since there are several route choice preferences, the path analysis based on the different criterion was performed in separate GIS layers. The first path analysis was for parcels that had no alternate route (*No Multiple*). The centroids of the parcels without an alternate route to the main street were selected as the trip origins. It is important to remark that during the survey, some participants chose this *No Multiple* option under his/her assumption that, even if there were multiple paths, he/she would not even consider other path for all the trips. This is why some parcels inside the TAZ have this route choice preference (based on the participants' answers). The path distance was used as the sole criteria to select the access point that is associated with the parcel in consideration. Figure 6.9 shows the trips connecting the parcels with *Not Multiple* route and the selected access points.

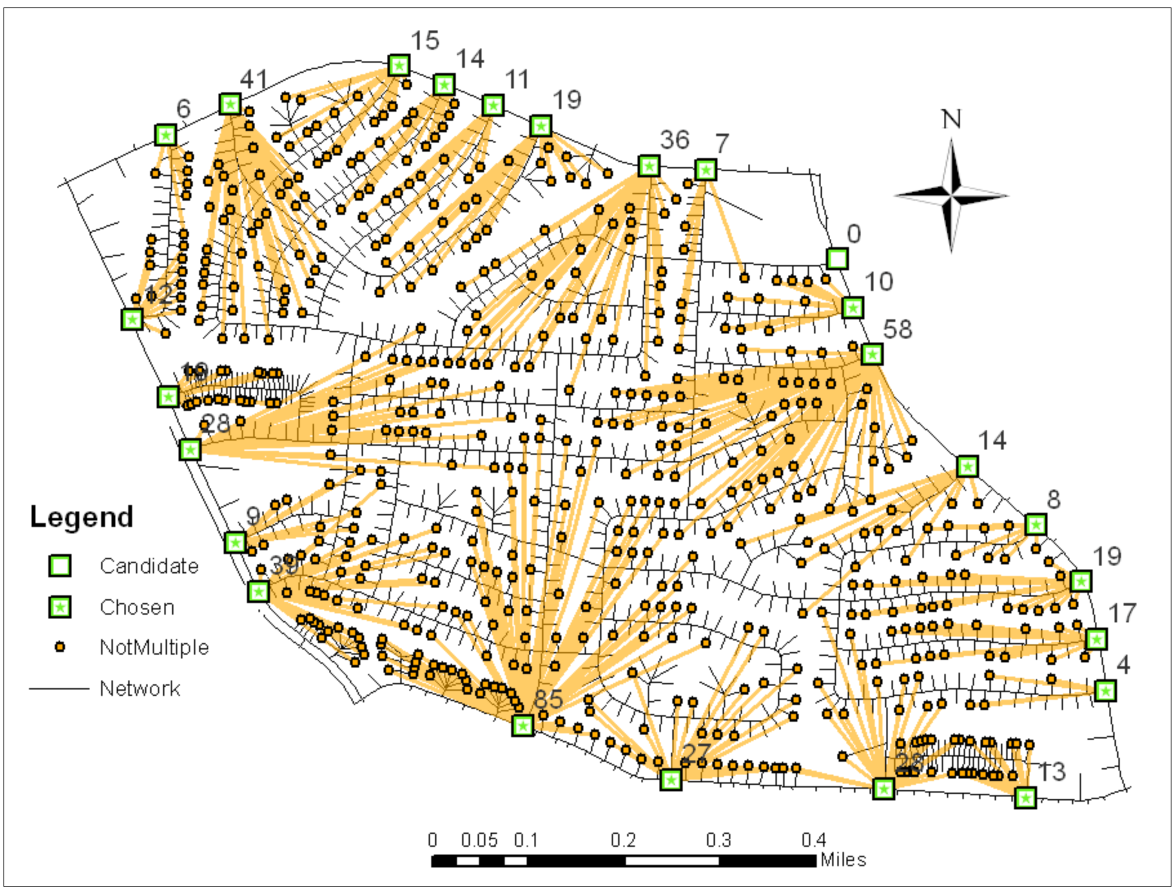

Figure 6.9 Access points for parcels with No Multiple choice

Figure 6.10 shows the parcels that have traffic signal as the route choice preference and the allocated signalized intersection as their access point. Note that, in this TAZ, there is only one available signalized intersection. If there are multiple signalized intersections, the intersection nearest (with the shortest path distance) to each parcel will be selected.

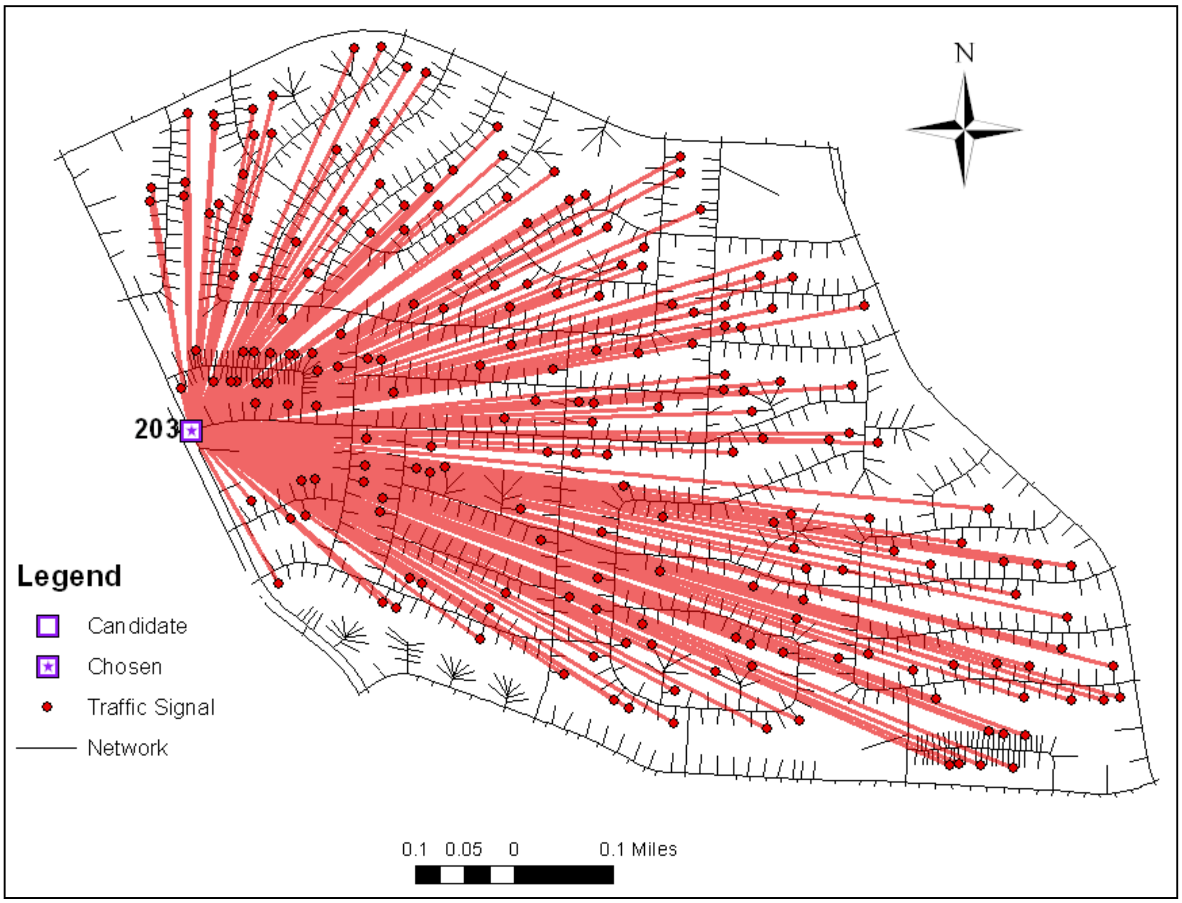

Figure 6.10 Access point for parcels with traffic signal as the route choice preference

The next route choice preference analyzed was two-way stop control intersections. The destinations (access points) were the intersections with this type of control and the origins were the parcels with two-way stops intersection assigned as the route choice criteria. Each parcel was linked to one of the available two-way stop control intersections by the shortest distance. The access point assignments are shown in Figure 6.11.

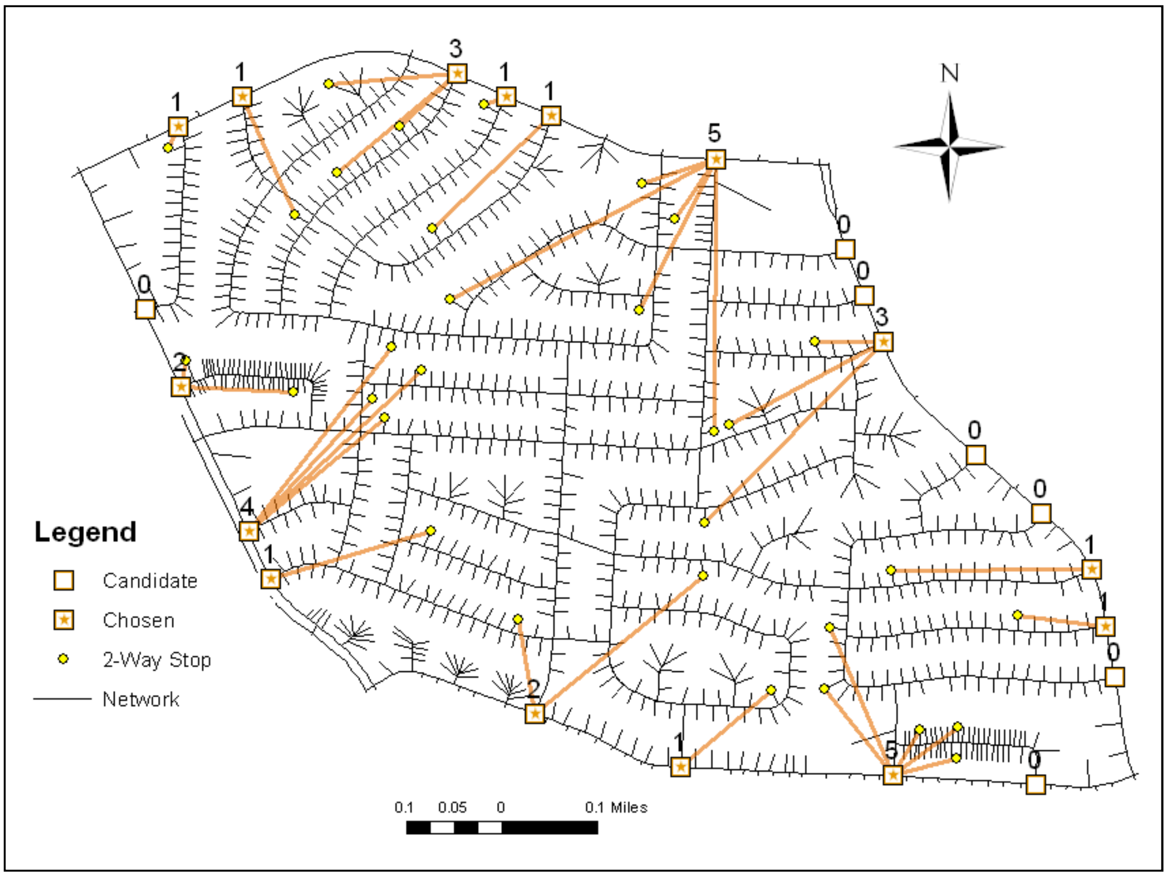

Figure 6.11 Access points for parcels with two-way stop control as the route choice preference

Figure 6.12 shows the allocation of parcels to the nearest four-way stop control access points by distance.

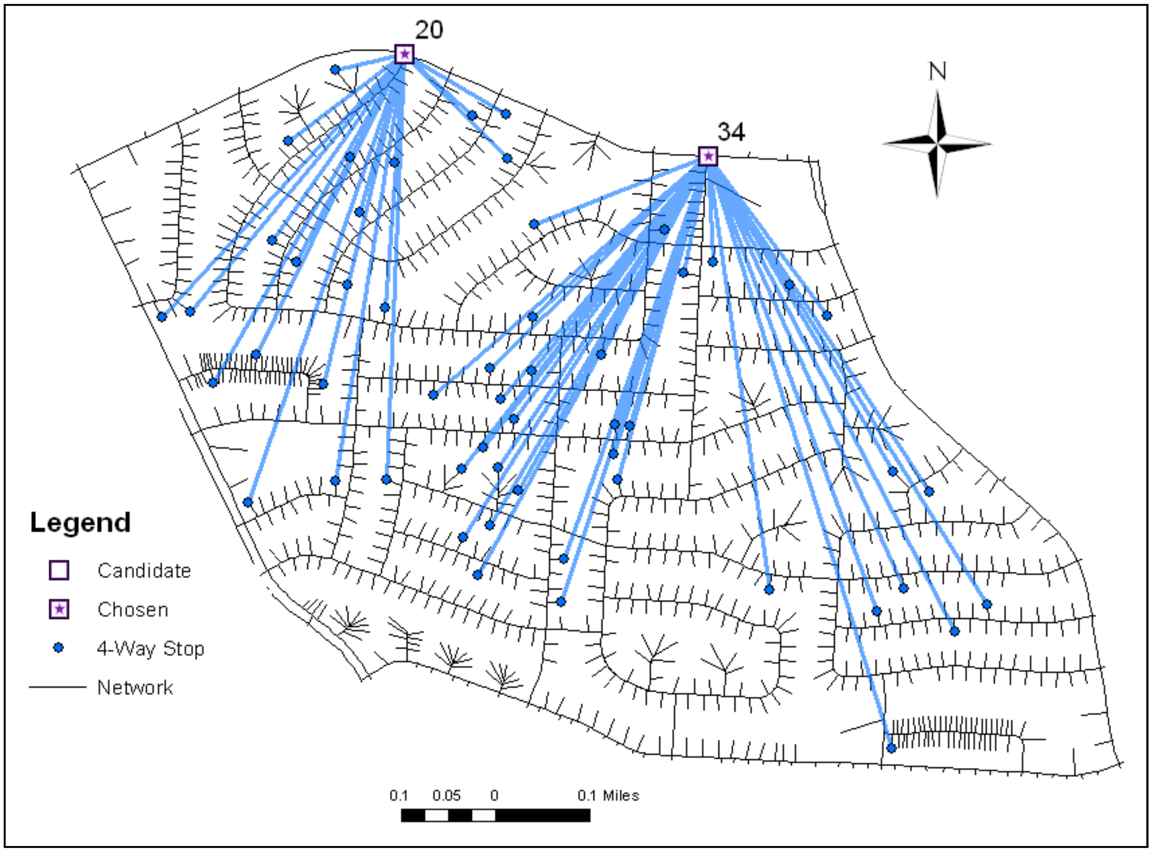

Figure 6.12 Access points for parcels with four-way stop control as the route choice preference

Figure 6.13 shows the parcels at which the drivers used shortest path as the route choice preference. All the 25 intersections were considered as access points. The distributions of the trips based on the shortest distance are shown in the figure.

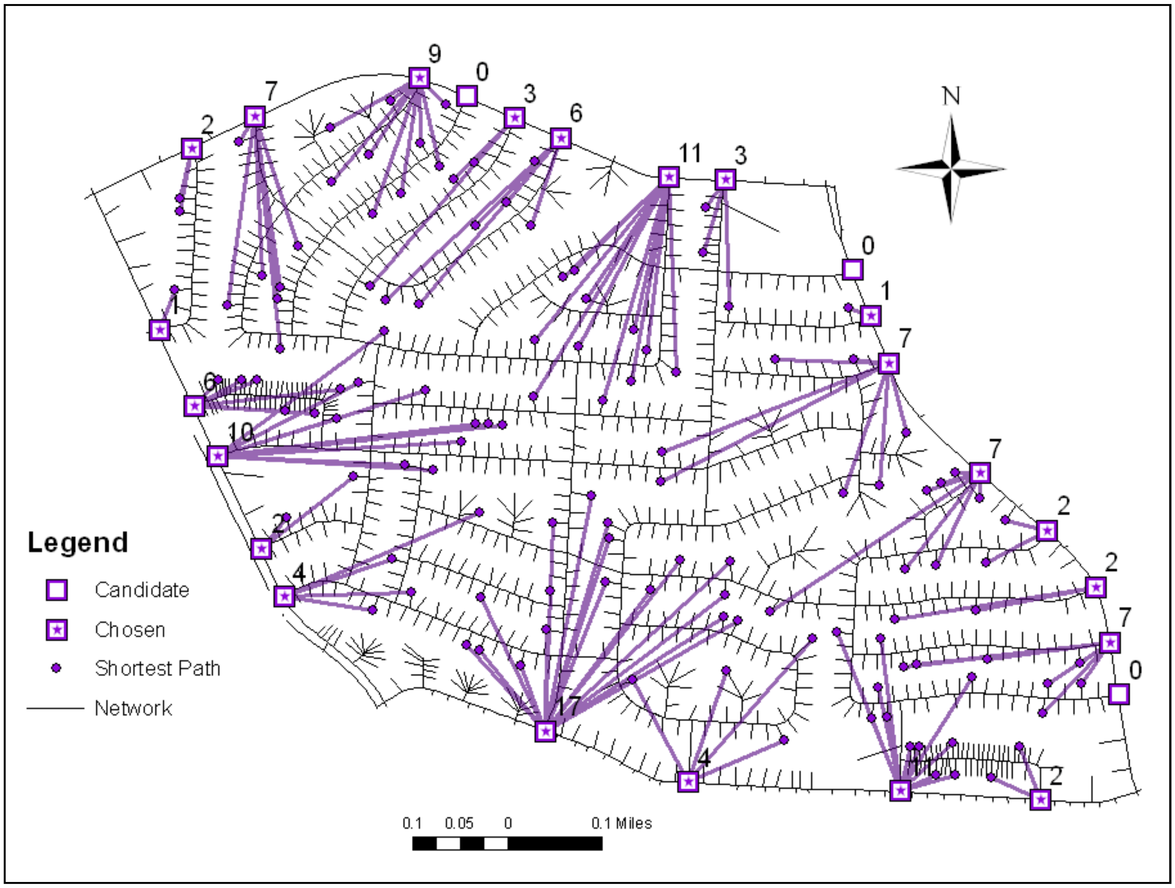

Figure 6.13 Access points for parcels with shortest path as the route choice preference

Other preferences not based on the type of intersection control was minimum number of stops and turns. The path cost that was used to evaluate this preference was the path travel time, which embedded street hierarchy to approximate intersection delay. Figure 6.14 shows the results obtained for this route choice preference.

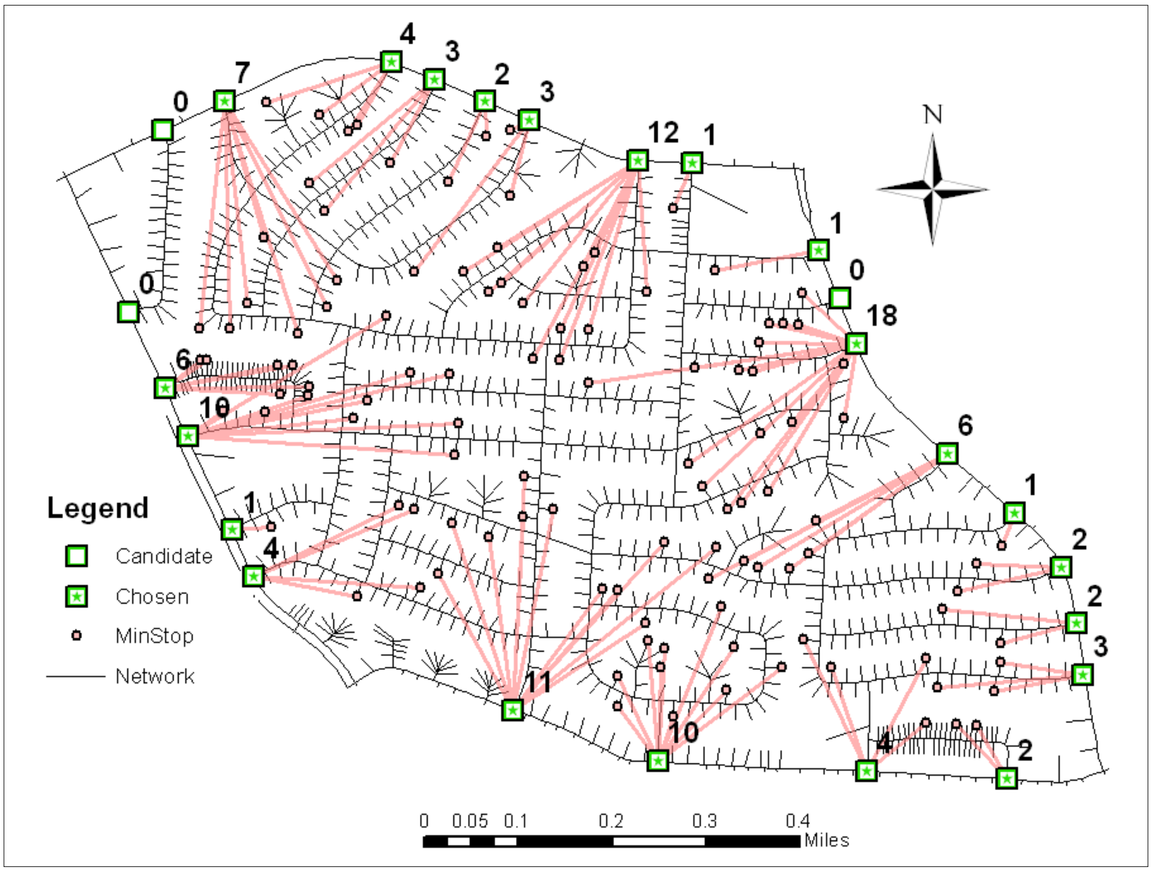

Figure 6.14 Access points for parcels with minimum stops and turns the route choice preference

The path analysis for avoid pedestrian preference was performed assuming all 25 intersections were access points. The neighborhood streets with pedestrian presence were assigned a lower speed limit of 15 mph to artificial increase the link cost. The path cost employed was the path travel time. Figure 6.15 shows the resulting parcel-access point pairs.

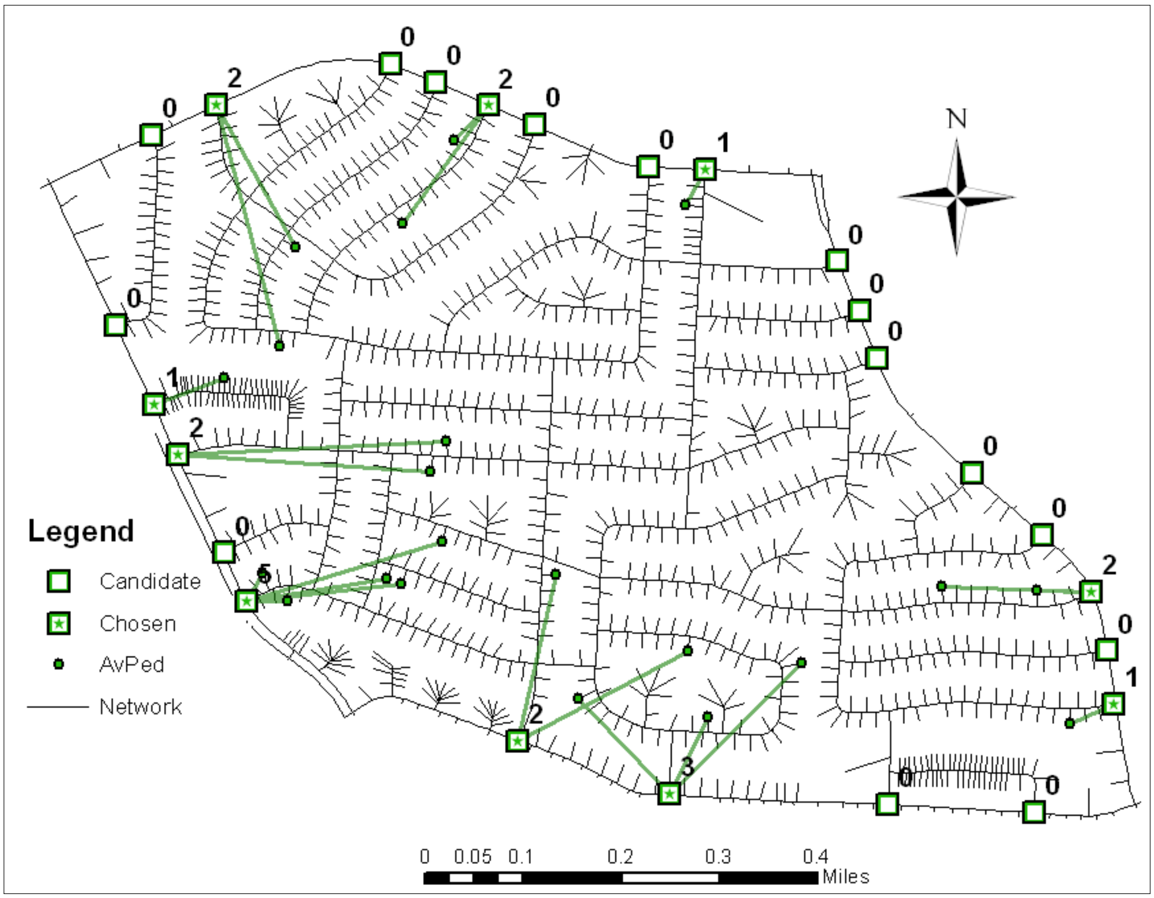

Figure 6.15 Access points for parcels with avoid pedestrians as the route choice preference

6.3.7 Obtain traffic volume for each access point

Table 6.2 shows the results of summing the total number of trips at each access points (from all the route choice preferences) and the corresponding volume splits in percent. Figure 6.16 shows the trips between all the parcels within the TAZ and their preferred access points.

Table 6.2 Total volume of each access point

Main Streets	Belvidere								Westwind								Escondido				Resler				
Intersection ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Intersection Type	2WS	2WS	4WS	2WS	2WS	2WS	2WS	4WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	TL	2WS	2WS
Traffic Light																							203		
2WS	1	1		3	1	1	5		0	0	3	0	0	1	1	0	0	5	1	2	1	4		2	0
4WS			20					34																	
Shorter Path	2	7	9	0	3	6	11	3	0	1	7	7	2	2	7	0	2	11	4	17	4	2	10	6	1
Minimize Stops and Turns	0	7	4	3	2	3	12	1	1	0	18	6	1	2	2	3	2	4	10	11	4	1	10	6	0
Avoid Pedestrians	0	2	0	0	2	0	0	1	0	0	0	0	0	2	0	1	0	0	3	2	5	0	2	1	0
No Multiple	6	41	15	14	11	19	36	7	0	10	58	14	8	19	17	4	13	28	27	85	39	9	28	19	12
Total Modeled Volume	9	58	48	20	19	29	64	46	1	11	86	27	11	26	27	8	17	48	45	117	53	16	253	34	13
Percentage	1%	5%	4%	2%	2%	3%	6%	4%	0.1%	1%	8%	2%	1%	2%	2%	1%	2%	4%	4%	11%	5%	1%	23%	3%	1%

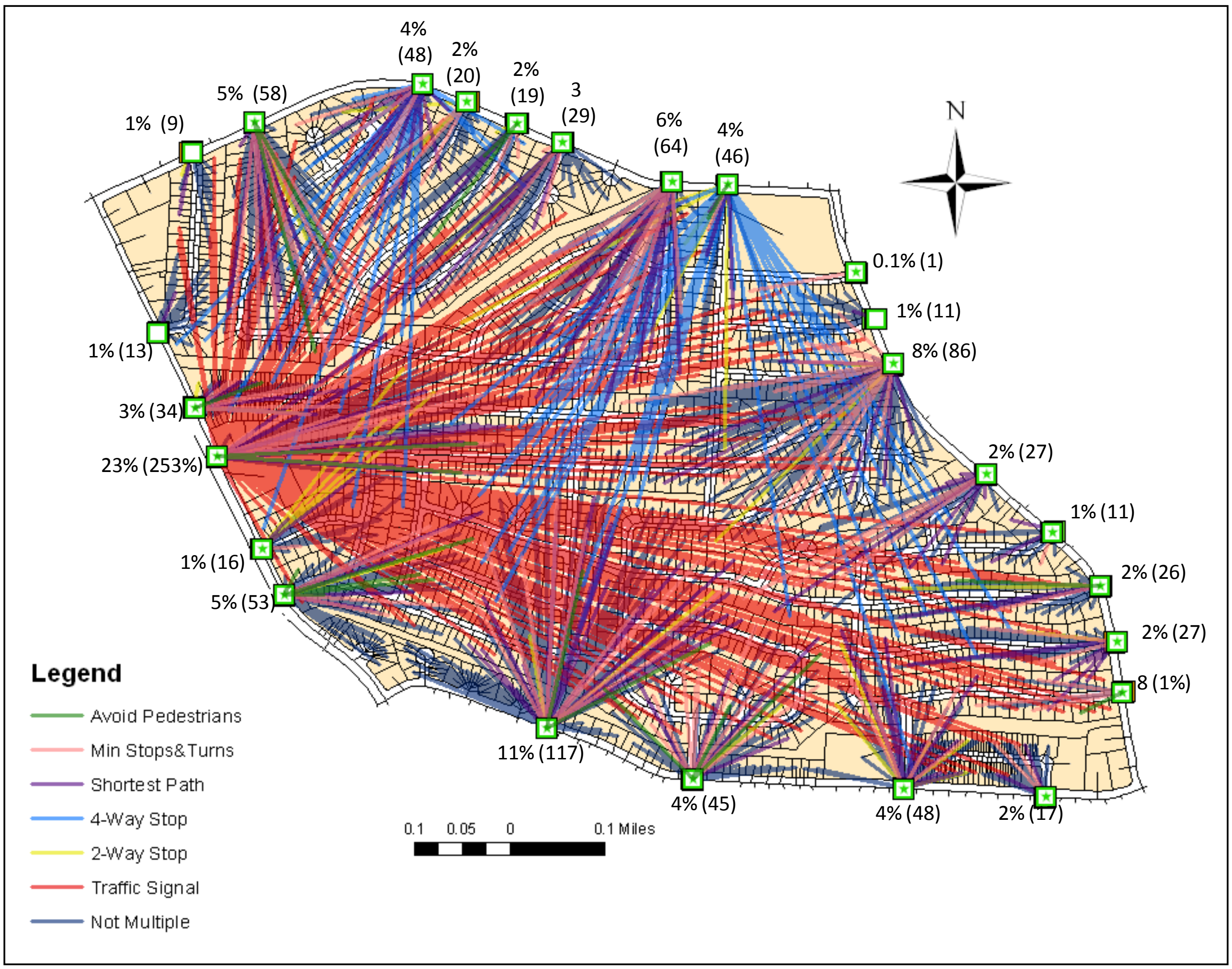

Figure 6.16 Access points of all the parcels

6.3.8 Validation

The validation of the access points and their volume splits consisted of comparing the allocated splits against field traffic counts of vehicles that are leaving the TAZ, along each main street.

Table 6.3 shows the volume splits that were assigned to the 25 access points and the splits obtained from the traffic counts. Figure 6.17 shows the correlation between both assigned and actual splits. The data provides an R-square value of 0.84 which indicates a high correlation between the estimated splits and the splits obtained from the field data.

Table 6.3 Validation of access point volume splits

Main Streets	Belvidere								Westwind								Escondido				Resler				
Intersection ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Intersection Type	2WS	2WS	4WS	2WS	2WS	2WS	2WS	4WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	TL	2WS	2WS
Total Modeled Volume	9	58	48	20	19	29	64	46	1	11	86	27	11	26	27	8	17	48	45	117	53	16	253	34	13
Percentage	1%	5%	4%	2%	2%	3%	6%	4%	0.1%	1%	8%	2%	1%	2%	2%	1%	2%	4%	4%	11%	5%	1%	23%	3%	1%
Modeled Vechicles Volume Connecting to The Main Street (%)	**27%**								**18%**								**21%**				**34%**				
Traffic Count Volumes																									
Total Traffic Count Volume	30	43	21	15	14	6	40	48	36	18	36	7	3	13	12	8	14	41	27	87	19	10	152	5	21
Percentage	4%	6%	3%	2%	2%	1%	6%	7%	5%	2%	5%	1%	0.4%	2%	2%	1%	2%	6%	4%	12%	3%	1%	21%	1%	3%
Traffic Count Vechicle Volume Connecting to The Main Street (%)	**30%**								**18%**								**23%**				**29%**				

During a MTS, it is important that the correct volume of vehicles be loaded from the TAZ to the surrounding main streets. Therefore, this validation also compares the percentage of the TAZ volume that was loaded to each of the main streets as in Figure 6.18. The bar chart shows a much closed match between the estimated volume split and the actual split that were loaded form the TAZ to each of the four main streets surrounding the TAZ.

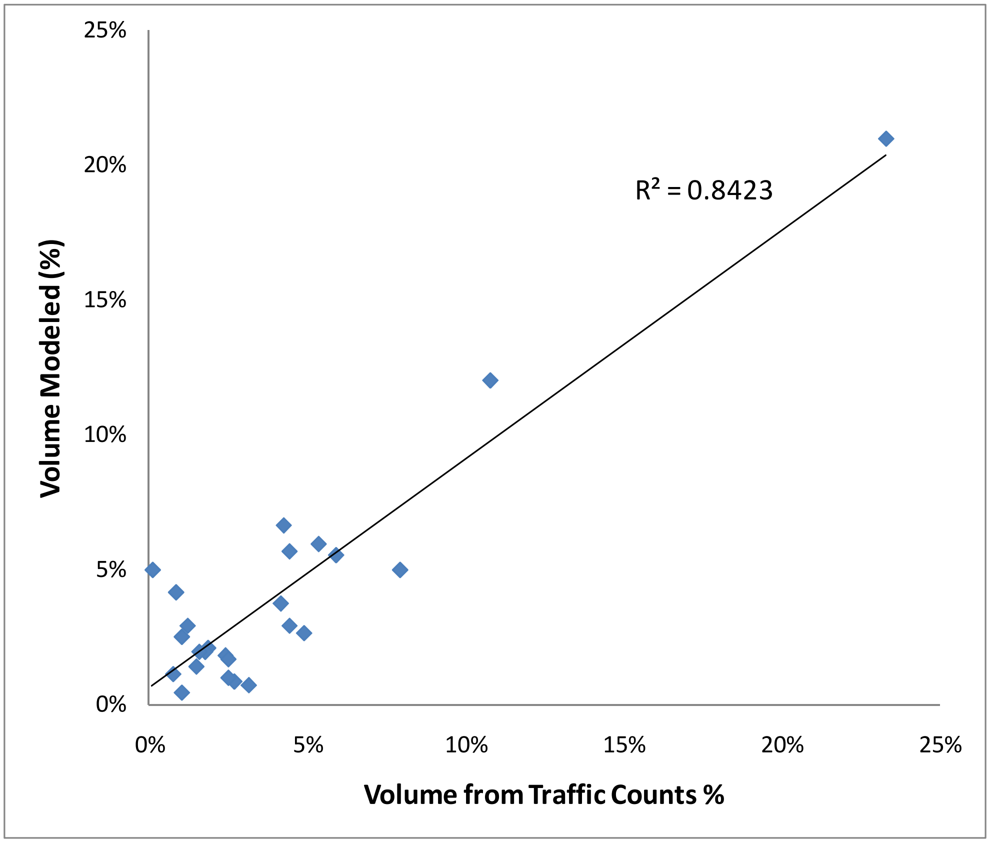

Figure 6.17 Correlation between the estimated access point splits with actual splits measured in traffic counts

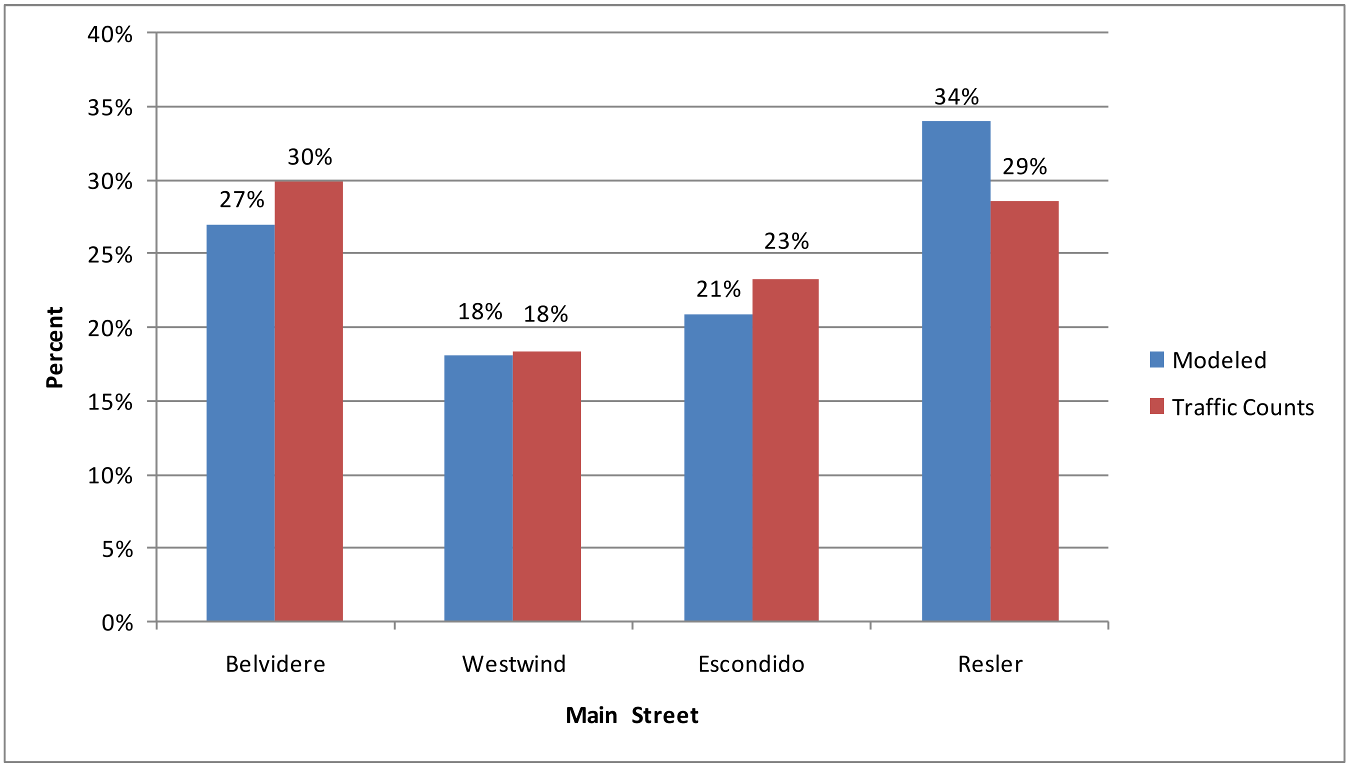

Figure 6.18 Comparison of volume splits loaded into the main streets

6.3.9 Propose minimum traffic connectors location

In this step, limited number of access points surrounding the TAZ was selected to build the traffic zone and zone connectors, based on the criteria mentioned in Section 6.2.9. The access points selected were intersections 4, 11, 20 and 23. They have percentage volume splits of 27%, 18%, 21% and 34% respectively. Figure 6.19 shows the selected access points to locate the traffic connectors and traffic zones to be used in MTS model.

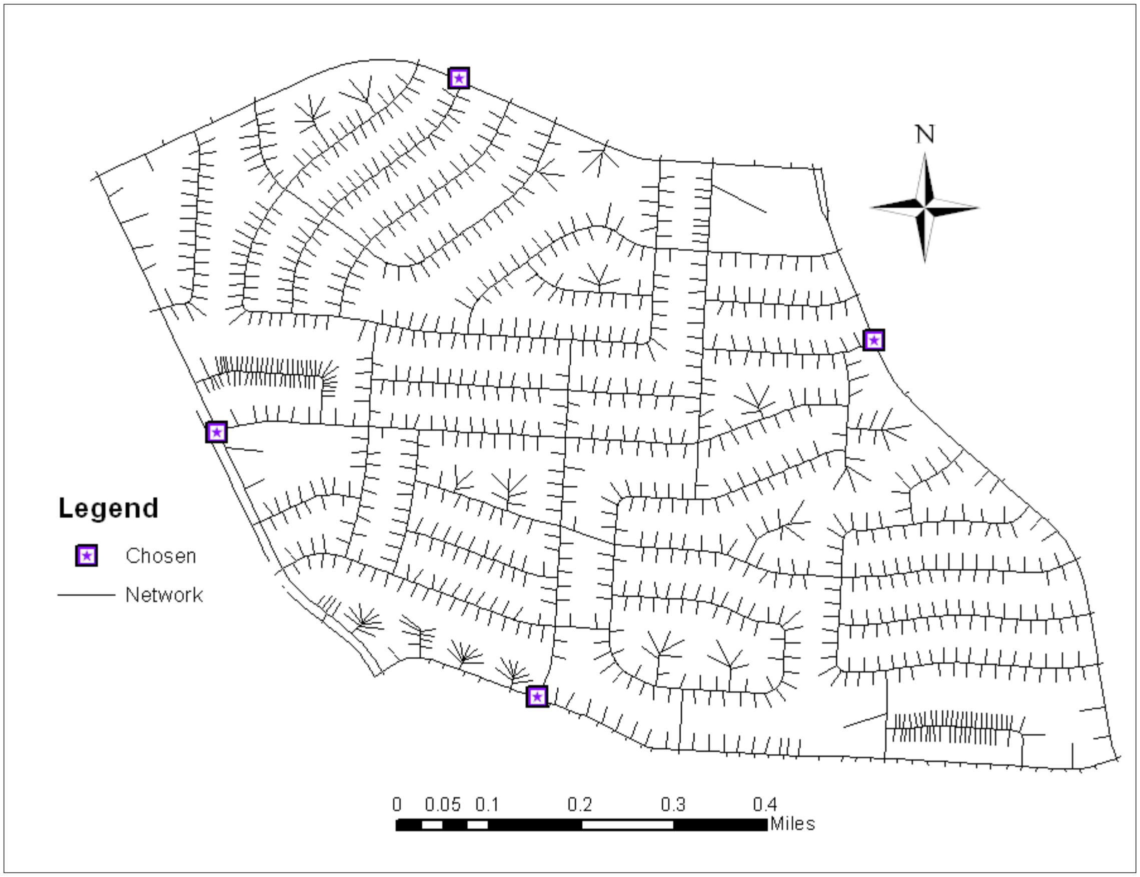

Figure 6.19 Selected access points to build traffic zones and zone connectors

6.4 Summary

In this chapter, a methodology combining driver's route choice preference and path analysis is presented as a new and systematic approach to define the location of traffic zones and zone connectors, and estimate the volume splits among the selected zones and connectors.

The methodology demonstrated in this chapter replies on the discrete choice approach to model driver's route choice preference (that was developed in Chapter 5). ArcGIS Network Analyst was used to processed data in the subsequent steps. The results show that, the volume splits that were assigned

to the assess points, as well as the main streets surrounding the TAZ, closely matched with the splits obtained from the field traffic counts.

Chapter 7: Estimation of Origin-Destination matrix for Microscopic Traffic Simulation

7.1 Introduction

This chapter describes the application of the methodology proposed in Chapter 6 to convert a **O-D$_p$** matrix into a **O-D$_m$** matrix. This is accomplished by a case study for a network consisting of five adjoining TAZs. It is assumed that a **O-D$_p$** matrix from a TPM, which consists of five TAZs, will be converted into a corresponding **O-D$_m$** matrix for MTS using PARAMICS.

7.2 Description of Area

The TAZs selected for this case study are located around the TAZ used in Chapter 6. Figure 7.1 shows the location of the TAZs and the main streets that form the boundaries between these TAZs. The TAZs are labeled TAZ Central, TAZ North, TAZ South, TAZ East and TAZ West respectively. These TAZ are part of the TAZs in the travel demand model used by the El Paso Metropolitan Planning Organization.

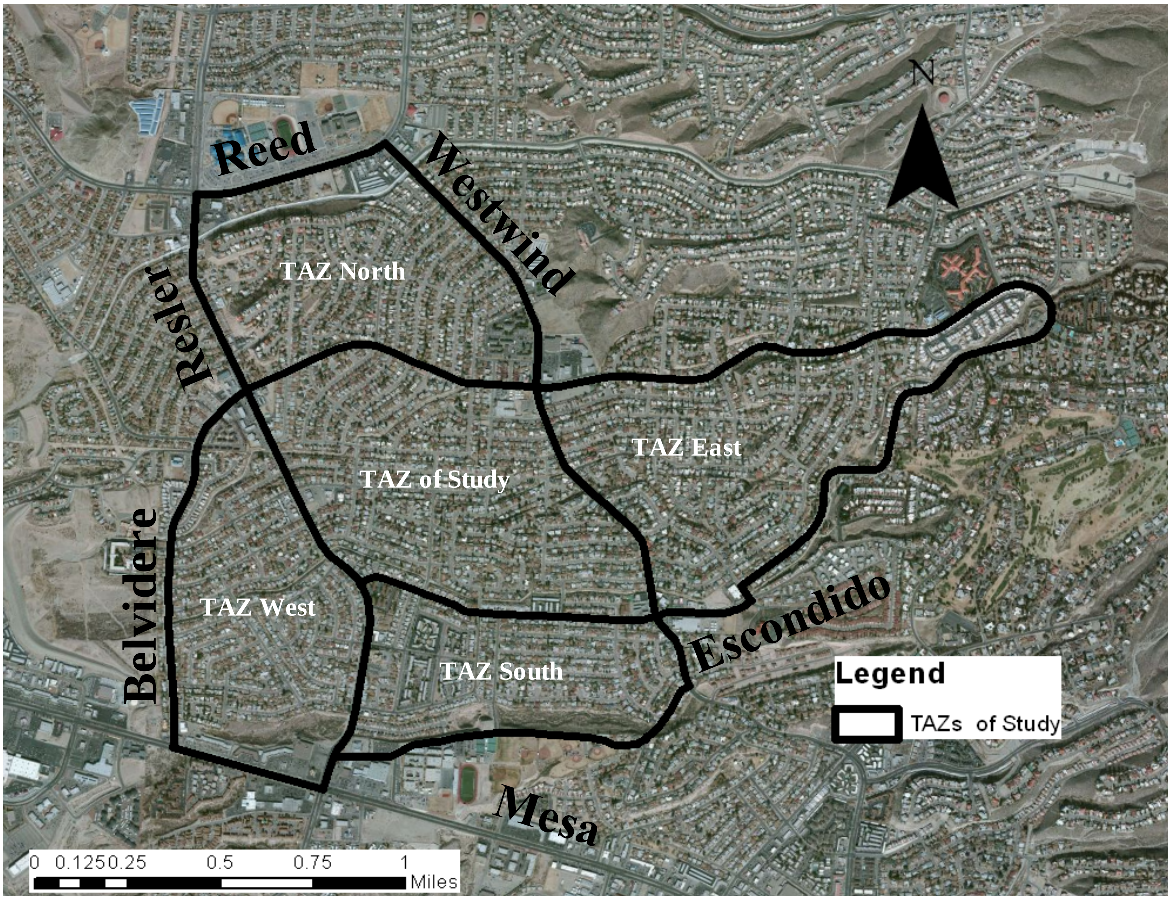

Figure 7.1 Location of area of study

7.3 Data Collection

Similar to what is described in Chapter 6, parcels and centerlines of the street network of the five TAZs were obtained in vector format. Parcel's land use classification was obtained in a vector file. Street hierarchies and types of intersection control were obtained from the field. Figure 7.2 shows the parcels and land use of the TAZs.

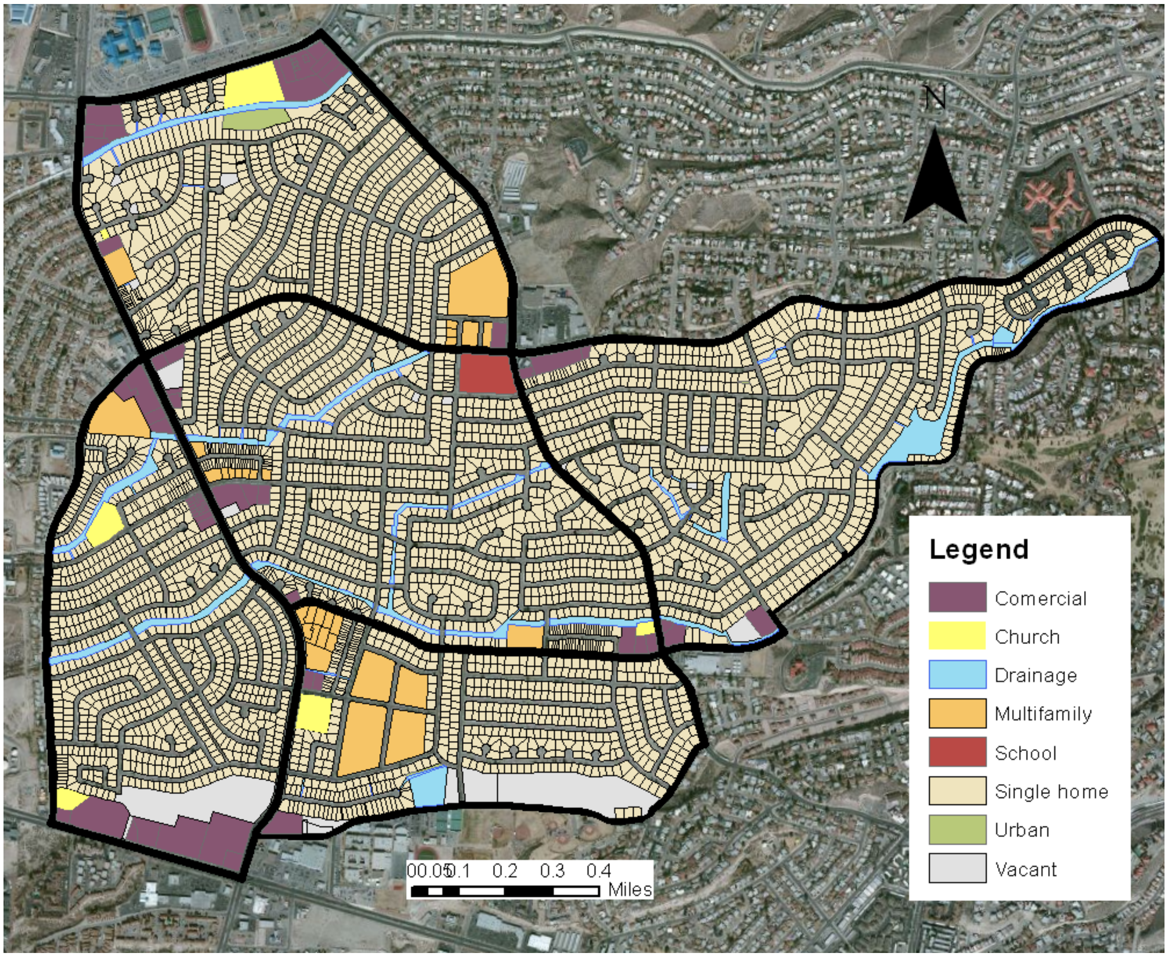

Figure 7.2 Parcels and land use in the area of study

The socioeconomic attributes of the population living in the area were extracted from Business Analyst. The attributes included gender, age, income, education, household size and vehicles per household. Figure 7.3 shows the discrete distributions of the attributes separated by each TAZ (TAZ North, TAZ South, TAZ East and TAZ West). The socioeconomic attributes of TAZ Central has already been shown in Figure 6.5.

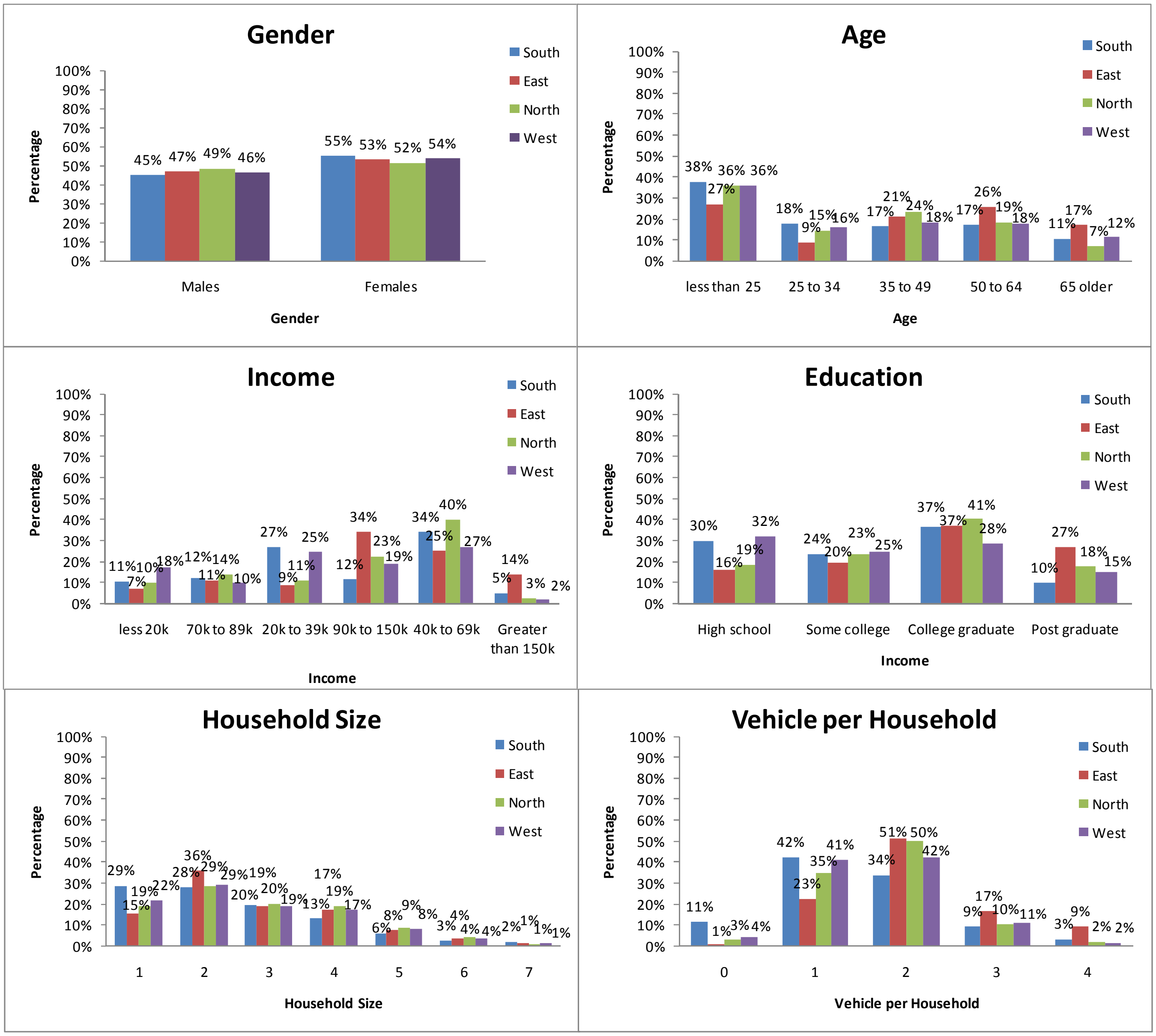

Figure 7.3 Discrete distributions of socioeconomic attributes of TAZ North, TAZ South, TAZ East and TAZ West

The **O-D$_\mathbf{p}$** matrix for the weekday morning peak hour (7:00 a.m. to 8:00 a.m.) was obtained from the Texas Transportation Institute El Paso Office.

7.4 Network Coding

Attributes were added to the geospatial vectors of the TAZs. The attributes added were related to link and parcel information, such parcel centroid, link speed, link travel time, link length and link hierarchy.

7.5 Calculation and Assignment of Route Choice Preference

The discrete choice model estimated in Chapter 5 was applied to all the parcels in TAZ North, TAZ South, TAZ East and TAZ West, similar to the manner described in Chapter 6. Each parcel is linked to a preferred access point at the boundary of its TAZ. Assuming that each residential parcel generated one trip in the morning, the total traffic volume at each access point was obtained, followed by the volume splits between the access points that belong to a TAZ.

7.6 Selection of Zone Connectors

For each TAZ, traffic zones and zone connectors were selected according to the guidelines and steps mentioned Sections 6.3.6 to 6.3.9.

7.6.1 TAZ Central

The location of traffic zones and zone connectors and portion of volume of this TAZ had been determined in Section 6.3.9. However, in order to create the $\mathbf{O\text{-}D_m}$. the identification and total trips produced and attracted were established. Table 7.1 shows the analysis of the layers, the access points

selected to allocate the traffic zones and zone connectors, the volume splits and trips to be loaded from this TAZ into the main streets. The traffic zones were identified as C1, C2, C3 and C4 respectively, in Figure 7.4.

Table 7.1 Access point volume for TAZ Central

	Main Streets	Belvidere								Westwind								Escondido				Resler				
	Intersection ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Intersection Type	2WS	2WS	4WS	2WS	2WS	2WS	2WS	4WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	TL	2WS	2WS
LAYER	Traffic Light																							203		
	2WS	1	1		3	1	1	5		0	0	3	0	0	1	1	0	0	5	1	2	1	4		2	0
	4WS			20					34																	
	Shorter Path	2	7	9	0	3	6	11	3	0	1	7	7	2	2	7	0	2	11	4	17	4	2	10	6	1
	Minimize Stops and Turns	0	7	4	3	2	3	12	1	1	0	18	6	1	2	2	3	2	4	10	11	4	1	10	6	0
	Avoid Pedestrians	0	2	0	0	2	0	0	1	0	0	0	0	0	2	0	1	0	0	3	2	5	0	2	1	0
	No Multiple	6	41	15	14	11	19	36	7	0	10	58	14	8	19	17	4	13	28	27	85	39	9	28	19	12
	Modeled Volumes																									
	Total Modeled Volume	9	58	48	20	19	29	64	46	1	11	86	27	11	26	27	8	17	48	45	117	53	16	253	34	13
	Percentage	1%	5%	4%	2%	2%	3%	6%	4%	0.1%	1%	8%	2%	1%	2%	2%	1%	2%	4%	4%	11%	5%	1%	23%	3%	1%
	Modeled Vechicles Volume Connecting to The Main Street	**27%**								**18%**								**21%**				**34%**				
	Vehicles Produced (47 TPM)	23								16								18				30				
	Total vehicles per traffic zone	**23**								**16**								**18**				**30**				
	Vehicles Attracted (47 TPM)	23								16								18				30				
	Total vehicles per traffic zone	**23**								**16**								**18**				**30**				
	Traffic Zone ID	C4								C1								C2				C3				

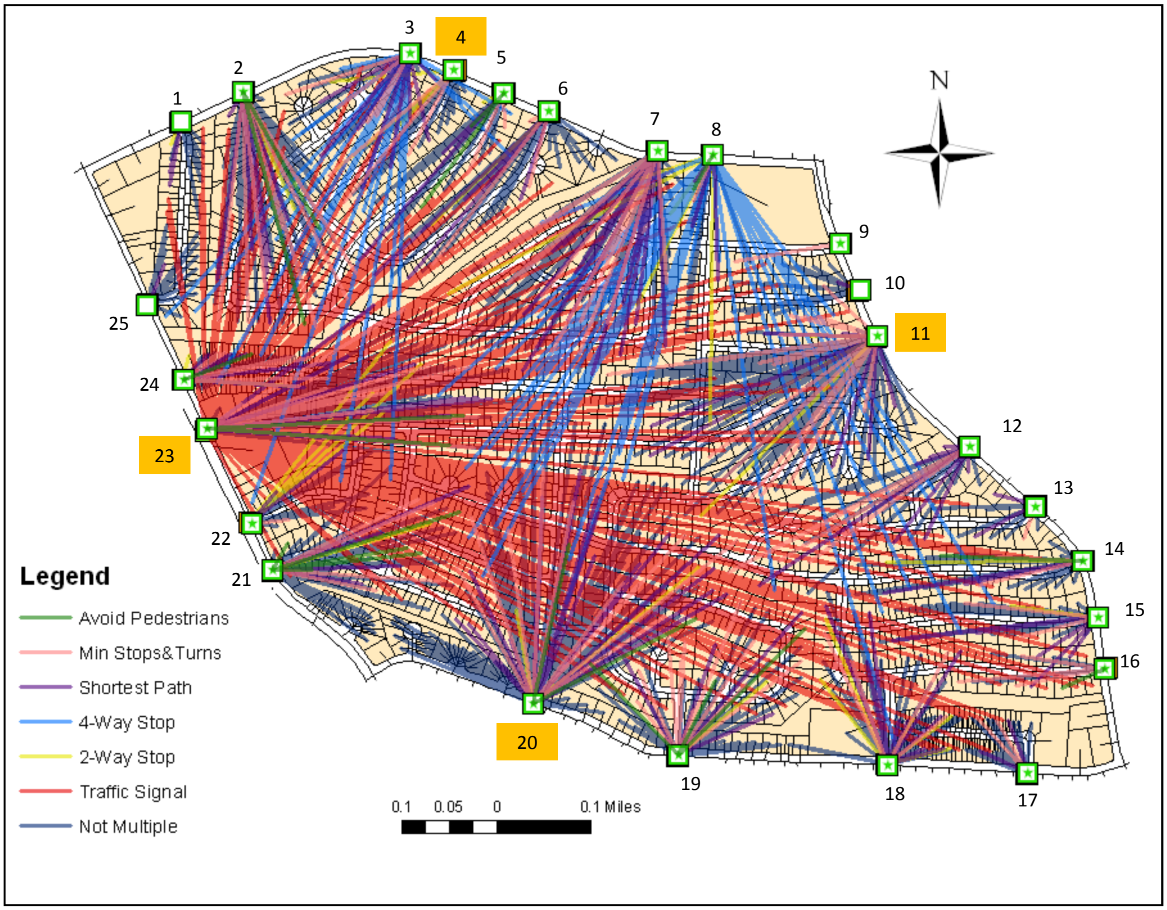

Figure 7.4 Locations of traffic zones and traffic connectors for TAZ Central

7.6.2 TAZ North

TAZ North, delimited by the main streets Westwind, Belvidere, Resler and Redd, had a total of 26 access points. Five traffic zones and zone connectors (access points 2, 16, 17, 20 and 24) were chosen and identified as N1, N2, N3, N4 and N5 to form the **O-D$_{\mathbf{m}}$** matrix. Table 7.2 shows the access points, traffic zones and zone connector selected. It also shows the volume splits, and trips produced by each traffic zone. Figure 7.5 shows the locations of access points, traffic zones and zone connectors for this TAZ.

Table 7.2 Access point volume for TAZ North

Street	Westwind								Belvidere											Resler			Reed			
Intersection ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Intersection Type	2WS	4WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	4WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS
LAYER: Traffic Light																										
2WS	10		42	11	15	13	9	0	0	4	8	22	10	29	34		48	35	10	37	0	0	0	0	0	0
4WS		20														23										
Shorter Path	4	12	2	2	5	7	2	0	1	1	1	0	2	2	2	6	8	8	4	11	0	0	0	2	0	1
Minimize Stops and Turns	5	11	2	6	4	4	0	0	0	0	4	5	0	5	3	9	7	10	7	9	0	0	2	0	0	0
Avoid Pedestrians	1	2	0	0	0	2	0	0	0	0	3	0	0	4	2	5	2	0	0	3	0	0	0	0	0	0
No Multiple	13	35	14	11	9	14	10	0	0	1	6	12	12	8	10	37	33	23	28	28	9	9	9	10	4	8
TOTAL	33	80	60	30	33	40	21	0	1	6	22	39	24	48	51	80	98	76	49	88	9	9	11	12	4	9
Percentage	4%	9%	6%	3%	4%	4%	2%	0%	0%	1%	2%	4%	3%	5%	5%	9%	11%	8%	5%	9%	1%	1%	1%	1%	0.4%	1%
% Vehicles connecting to Main Street	32%								53%											11%			4%			
Vehicles Produced (47TDM)	**15**								**25**											**5**			**2**			
Volume per link selected	32%								29%							24%				11%			4%			
Total vehicles per traffic zone	**15**								**14**							**11**				**5**			**2**			
Vehicles Attracted (47 TDM)	15								25											5			2			
Volume per link selected	32%								29%							24%				11%			4%			
Total vehicles per traffic zone	**15**								**14**							**11**				**5**			**2**			
Traffic Zone ID	N1								N2							N3				N4			N5			

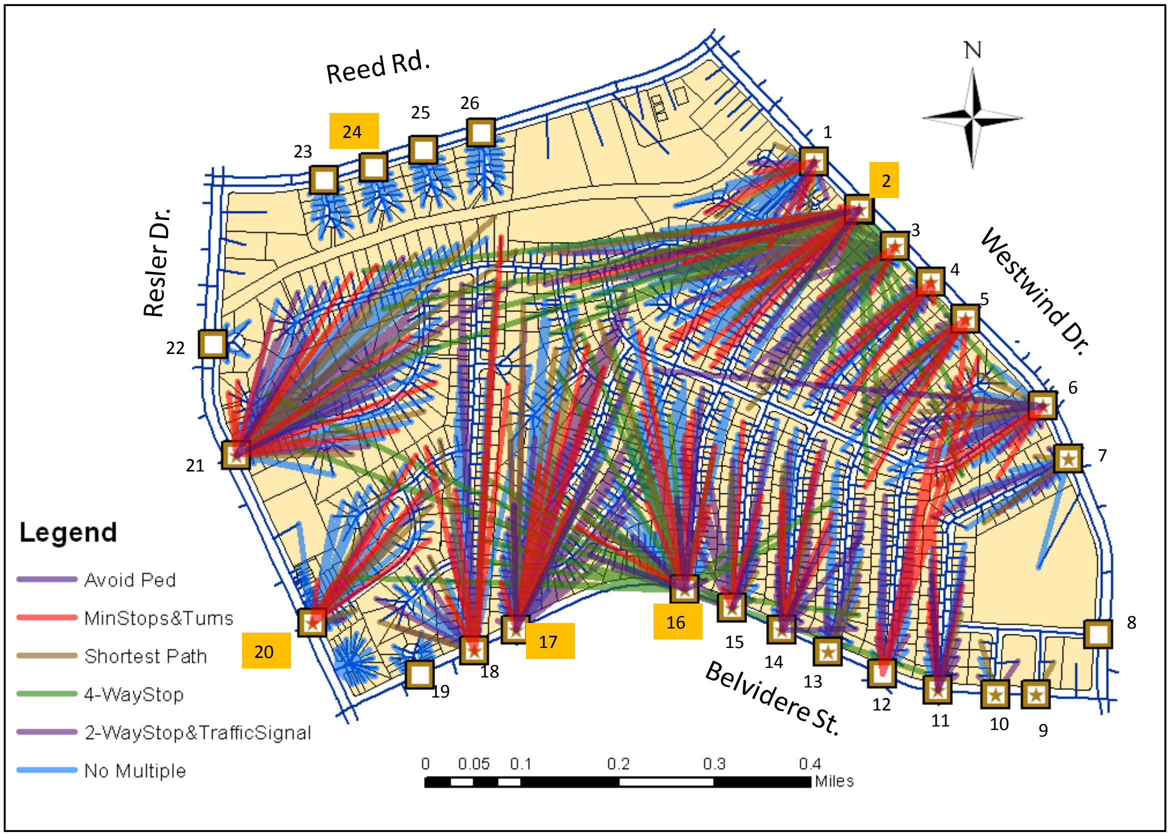

Figure 7.5 Locations of traffic zones and traffic connectors of TAZ North

7.6.3 TAZ South

This TAZ had 13 access points with Escondido, Westwind, Cloudview and Resler as the main streets. Due the lack of 4-way stops access point, drivers with this preference were assigned to the two-way stop access points during path analysis step. A total of four traffic zones and four traffic connectors (access points 5, 8, 10 and 12) were chosen. The four traffic zones were identified as S1, S2, S3 and S4, respectively to form the **O-D$_{\mathbf{m}}$** matrix later. Table 7.3 shows the access points selected to allocate the traffic zones and traffic connectors, the volume splits and trips produced at the traffic zones. Figure 7.6 shows the access points of all the parcels within TAZ South.

Table 7.3 Access point volume for TAZ South

	Main Street	Escondido						Westwind			Cloudview	Resler		
	Intersection ID	1	2	3	4	5	6	7	8	9	10	11	12	13
	Intersection Type	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	TL	2WS
	Traffic Light												89	
	2WS	0	1	3	6	1	6	4	5	6	9	2		0
LAYER	4WS													
	Shorter Path	5	1	5	2	6	4	2	3	4	6	4	2	8
	Minimize Stops and Turns	3	0	3	6	5	4	0	2	7	6	4	3	3
	Avoid Pedestrians	0	1	0	0	2	0	0	2	1	0	1	1	2
	No Multiple	21	6	14	19	40	9	14	26	20	23	18	14	35
	TOTAL	29	9	25	33	54	23	20	38	38	44	29	109	48
	Percentage	6%	2%	5%	7%	11%	5%	4%	8%	8%	9%	6%	22%	10%
	% Vehicles connecting to the link Main stret	**35%**						**19%**			**9%**	**37%**		
	Vehicles Produced (47 TPM)	16						9			4	18		
	Total vehicles per traffic zone	**16**						**9**			**4**	**18**		
	Vehicles Attracted (47 TPM)	16						9			4	18		
	Total vehicles per traffic zone	**16**						**9**			**4**	**18**		
	Traffic Zone ID	S4						S1			S2	S3		

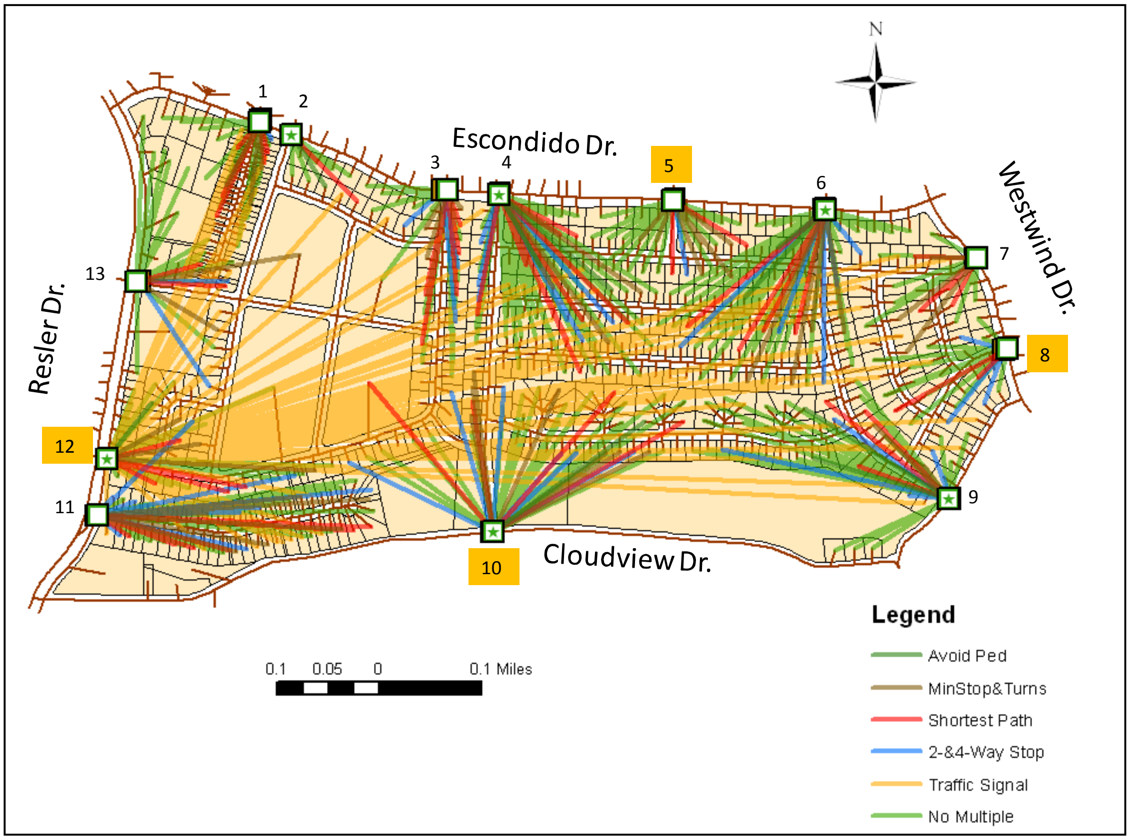

Figure 7.6 Access points of all the parcels for TAZ South

7.6.4 TAZ East

TAZ East has 15 access points. The main streets surrounding this TAZ are Belvidere/Bandolero and Westwind. Three access points (intersections 3, 7 and 12) were selected to build traffic zones and traffic connectors. The traffic zones were identified as E1, E2 and E3 respectively. Table 7.4 shows the volume splits and access points selected to allocate the traffic zones and zone connectors. Figure 7.7 shows the locations of the access points, the parcels that are attracted to each access point, traffic zones and zone connectors for TAZ East.

Table 7.4 Access point volume for TAZ East

	Main Street	Belvidere/Bandolero						Escondido	Westwind							
	Intersection ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Intersection Type	2WS	4WS	2WS	4WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS
LAYER	Traffic Light												97			
	2WS	27		51		13	17	28	4	5	9	2	14	3	8	7
	4WS		21		22											
	Shorter Path	11	17	11	12	5	6	16	2	3	11	4	5	4	1	3
	Minimize Stops and Turns	8	4	10	7	6	7	6	2	0	12	1	4	4	1	3
	Avoid Pedestrians	6	0	4	2	0	0	2	1	0	1	0	1	0	0	0
	No Multiple	53	50	61	62	19	60	77	8	13	24	6	27	14	10	14
	TOTAL	105	92	137	105	43	90	129	17	21	57	13	148	25	20	27
	Percentage	10%	9%	13%	10%	4%	9%	13%	2%	2%	6%	1%	14%	2%	2%	3%
	% Vehicles connecting to Main Street	56%						13%	32%							
	Vehicles Produced (42TPM)	23						5	13							
	Total vehicles per traffic zone	**23**						**5**	**13**							
	Vehicles Attracted(42 TpM)	23						5	13							
	Total vehicles per traffic zone	**23**						**5**	**13**							
	Traffic Zone ID	E1						E2	E3							

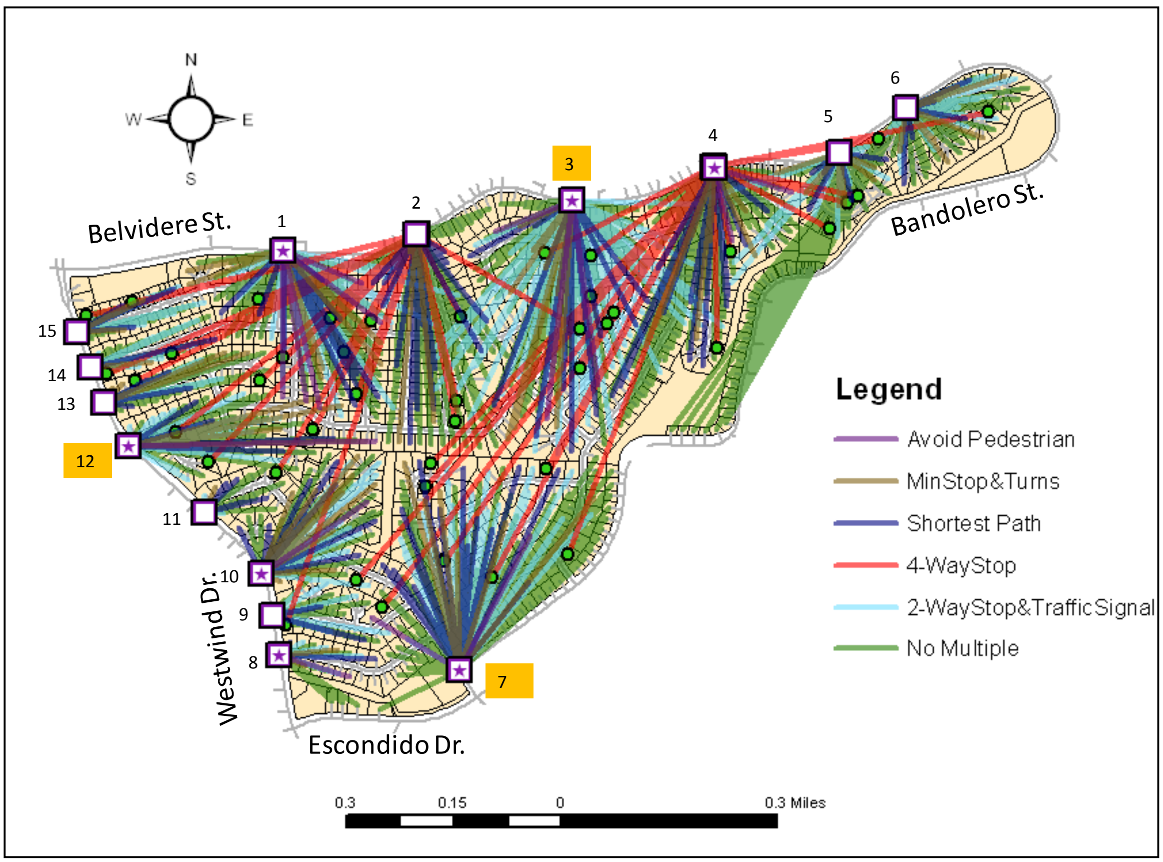

Figure 7.7 Location of traffic zones and traffic connectors of TAZ East

7.6.5 TAZ West

This TAZ had 15 access points along with the main streets named Belvidere, Resler and Mesa. The access point to Mesa was discarded as the residential parcels have no direct connection to this main street. Four access points were selected along Belvidere and Resler as traffic zones and connectors. The locations of the selected access points 2, 7, 13 and 8 are shown in Figure 7.8. These access points were labeled as W1, W2, W3 and W4 respectively (see Figure 7.8). Table 7.5 shows the calculation of volume splits before and after the traffic zone selection.

Table 7.5 Access point volume for TAZ West

	Street	Resler							Belvidere							
	Intersection ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Intersection Type	2WS	TL	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	2WS	4WS	2WS	2WS
LAYER	Traffic Light		150													
	2WS	10		4	6	10	2	11	18	6	1	3	8		0	0
	4WS													41		
	Shorter Path	1	2	7	5	12	9	8	9	4	4	4	3	2	3	2
	Minimize Stops and Turns	6	2	6	1	13	7	17	11	11	4	5	4	0	1	5
	Avoid Pedestrians	2	0	0	1	2	3	1	4	1	3	1	1	2	0	0
	No Multiple	16	12	16	15	29	31	42	85	20	17	14	18	13	17	20
	TOTAL	35	166	33	28	66	52	79	127	42	29	27	34	58	21	27
	Percentage	4%	20%	4%	3%	8%	6%	10%	15%	5%	4%	3%	4%	7%	3%	3%
	Street	56%							44%							
	Vehicles Produced (112 TDM)	62							50							
	Volume per link selected	32%			24%				27%				17%			
	Total vehicles per traffic zone	**36**			**27**				**31**				**19**			
	Vehicles Attracted (112 TDM)	62							50							
	Volume per link selected	32%			24%				27%				17%			
	Total vehicles per traffic zone	**36**			**27**				**31**				**19**			
	Traffic Zone ID	W1			W2				W3				W4			

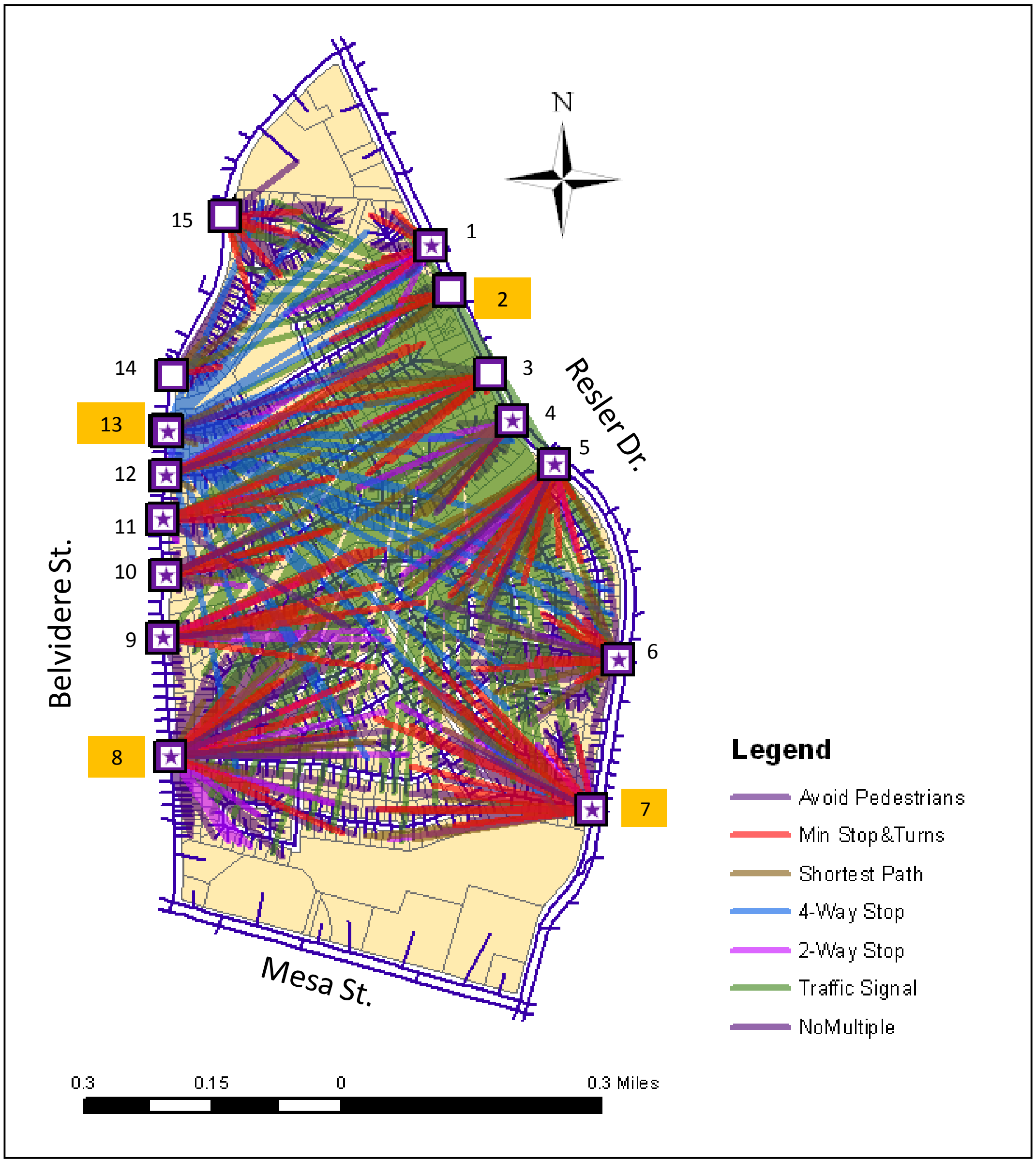

Figure 7.8 Location of traffic zones and traffic connectors of TAZ West

7.7 Estimation of Origin-Destination Matrix for Microscopic Traffic Simulation

The area of study has a total of 20 traffic zones. Therefore, the **O-D$_m$** is a 20x20 matrix. Figure 7.9 shows the traffic zones, zone connectors and main streets as coded in the PARAMICS MTS model.

Figure 7.9 Traffic zones and traffic connectors in the area of study

As mentioned, the total trips produced by each TAZ (O_{ij}^{p}) and attracted to each TAZ (D_{ij}^{p}) during the morning peak hour have been provided by Texas Transportation Institute El Paso Office. The

traffic generated by and attracted to each traffic zone, $o_{i_a}^m$ and $d_{i_a}^m$ respectively, are calculated based on the volume splits as determined in Tables 7.1 to 7.4. After obtaining the $o_{i_a}^m$ and $d_{i_a}^m$ for all traffic zones, the gravity mode (Equation [2.1]) was applied to perform trip distribution analysis to solve for $t_{i_a j_b}^m$. The travel times between traffic zones were obtained along the shortest paths, using the assumed free-flow speeds and intersection turning delays. Then, the friction factors among the different traffic zones were calculated and finally the **O-D$_{\mathbf{m}}$** matrix was obtained. The estimated **O-D$_{\mathbf{m}}$** matrix is shown in Table 7.6. Note that there is no trip between traffic zones that belong to the same TAZ.

Table 7.6 Estimated **O-D$_{\mathbf{m}}$** matrix for the area of study

		Destination																				
		W1	**W2**	**W3**	**W4**	**C1**	**C2**	**C3**	**C4**	**S1**	**S2**	**S3**	**S4**	**E1**	**E2**	**E3**	**N1**	**N2**	**N3**	**N4**	**N5**	**Total**
Origin	**W1**	0	0	0	0	2	3	6	4	1	1	3	3	2	1	2	2	2	2	1	0	35
	W2	0	0	0	0	2	3	4	3	1	1	3	3	0	1	2	1	1	1	1	0	27
	W3	0	0	0	0	2	3	5	4	1	1	3	2	2	1	2	2	2	2	1	0	33
	W4	0	0	0	0	1	2	3	2	1	0	2	1	1	0	1	1	1	1	1	0	18
	C1	2	1	1	1	0	0	0	0	1	0	1	1	2	0	1	1	1	1	0	0	14
	C2	3	2	2	1	0	0	0	0	1	0	1	2	1	0	1	1	1	1	0	0	17
	C3	6	3	4	2	0	0	0	0	1	0	2	2	2	0	1	1	2	1	1	0	28
	C4	4	2	3	2	0	0	0	0	1	0	1	1	2	0	1	2	2	1	1	0	23
	S1	1	1	1	1	1	1	1	1	0	0	0	0	1	0	1	0	0	0	0	0	10
	S2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	S3	3	2	2	1	1	1	2	1	0	0	0	0	1	0	1	1	1	1	0	0	18
	S4	2	2	1	1	1	1	2	1	0	0	0	0	1	0	1	1	1	1	0	0	16
	E1	3	2	2	1	2	1	3	2	1	0	1	1	0	0	0	1	1	1	0	0	22
	E2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	E3	1	1	1	1	1	1	1	1	0	0	1	1	0	0	0	1	1	1	0	0	13
	N1	2	1	1	1	1	1	2	2	1	0	1	1	1	0	1	0	0	0	0	0	16
	N2	2	1	2	1	1	1	2	2	0	0	1	1	1	0	1	0	0	0	0	0	16
	N3	2	1	1	1	1	1	1	1	0	0	1	1	1	0	0	0	0	0	0	0	12
	N4	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	N5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	34	19	22	14	16	19	33	24	10	3	21	20	18	3	16	15	16	14	6	0	

7.8 Summary

In this chapter, the application of the methodology proposed to convert a **O-D**$_p$ matrix into a **O-D**$_m$ matrix has been applied to an area which consists of five TAZs. The method consists of (1) discomposing each TAZ's trip production and trip attraction into the traffic zones' trip production and trip attraction, respectively; and (2) applying the gravity model to solve for the trip interchanges between traffic zones. The estimated **O-D**$_m$ matrix is ready to be used as an input into a MTS model.

CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

This research has developed a methodology and demonstrated the feasibility the proposed methodology to convert a transportation planning origin-destination matrix (**O-D$_p$**) into a microscopic traffic simulation origin-destination matrix (**O-D$_m$**). This was the objective of this dissertation.

The methodology consists of estimating a discrete choice model to predict drivers' route choice preferences from residential parcels to the main street surrounding the TAZ. The discrete choice model uses a driver's socioeconomic and trip characteristics as inputs, so as to predict the route choice criteria. By combining the route choice criteria with a path analysis in GIS, the volume splits (percent distribution) of trips from the all residential parcels in a TAZ to the access points along the main streets surrounding the TAZ can be estimated. A set of guidelines have been proposed to select the limited number of traffic zones (each is connected to a main street by a zone connector) from among the access points, based on the volume splits and network geometry. The home based trips that are generated in a TAZ is then split among the selected traffic zones such that the total number of trips is conserved. The above procedure has selected traffic zones, zone connectors and estimated the number of trips produced by each traffic zone. A similar procedure may be developed to estimate the number trips attracted to each traffic zone. Finally, this dissertation has demonstrated that, with the trip productions and trip attractions of all the traffic zones, the gravity model may be applied to perform trip distribution analysis to obtain the **O-D$_m$**.

The discrete choice model was estimated using the data gathered from a questionnaire survey. The survey collected demographic profiles, factors in route choices and trip characteristics of drivers when they travel from their homes to the main street at the boundary of the TAZ. From the data gathered in the City of El Paso, the discrete choice model consists of three sub-models: one MLM and two NLMs. The questionnaire developed in this dissertation may be applied to other metropolitan areas, from which the data gathered may be developed into discrete choice models of different or structures or structure sub-models. The estimated discrete choice model can then be combined with the socioeconomic data of the TAZ (readily available in the GIS Business Analyst) to predict the route choice preferences of drivers.

Based on the three logit sub-models that have been fitted to the data collected in the City of El Paso, the following observations may be concluded concerning drivers' route choices from their homes to the mains streets:

- Females, drivers older than 64 years old and drivers stopping at gas stations and coffee stores prefer to select their routes by the type of intersection control. This is probably due to safety concerns and store locations.
    - Traffic signal control is preferred by drivers older than 64 years old and also by females.
    - Two-way stop control is only preferred by drivers who stop at restaurants and return two times during the morning.
    - Four way stop intersection is attractive only by driver who go to grocery stores in the morning. Drivers leaving home four times in the morning, with high school level, or older than 65 years old are less likely to use this type of intersection.
- Shortest route is preferred by males or drivers with three vehicles in the household.

- Drivers with graduate degrees or drivers stopping at gas stations tend not to avoid pedestrians. Middle income drivers are more likely take a route to avoid encountering pedestrians.

The path analysis in GIS Network Analyst employs a network dataset of geospatial vectors maps (parcels, land use, center street lines). This method of analysis is also transferable across different metropolitan areas.

8.2 Recommended Methodology

The methodology developed in this dissertation is summarized in the following 11 steps. Flow chart of the methodology is shown in Figure 8.1. The description of each step is described below:

1. Selection of area to be modeled in MTS.

   The area is TAZ based, which may consist of a few to hundreds of TAZ.

2. Data collection.
   - Conduct questionnaire surveys.
   - Collect GIS parcel, land use and network center line layers of the area to be modeled by MTS.
   - Obtain field traffic count data in selected TAZs.

3. Development of a discrete choice model.

   Estimate the discrete choice model from the data gathered in the questionnaire survey.

4. Prediction of route choice preference.

   Apply the discrete choice model estimated in Step 3 to each residential parcel within the modeled area. The output of this step is the route choice preference of all the drivers within the area (assuming one driver-trip per residential parcel).

5. GIS network coding.

    - Create the street network using the street centerline geospatial vectors and edit the driveways.
    - Add street hierarchy, free-flow speed and free-flow travel time to each link.
    - Identify access points for each TAZ.

6. Location of parcel's access point.

    For each parcel in the area, perform path analysis to identify the access points using the route choice preference predicted in Step 4 and access points identified in Step 5.

7. Estimation of access point volume.

    Obtain the total traffic volume of each access point and convert it into the percent split of the TAZ's volume.

8. Selection of traffic zones and zone connectors.

    For each TAZ, select traffic zones and zone connectors based on the volume splits obtained in Step 7 and the TAZ's network geometry. Each traffic zone is connected by one zone connector to a main street.

9. Estimation of volume splits among traffic zones.

    - Reallocate the traffic from the access points to the selected traffic zone.
    - Recalculate the volume splits among the traffic zones.

10. Proportion of trip productions and trip attractions.

    Divide each TAZ's trip production (O_i^p) and trip attraction (D_j^p) into its traffic zones' trip production ($o_{i_a}^m$) and trip attraction ($d_{j_b}^m$), using the volume splits estimated in Step 9.

11. Trip distribution estimation to obtain **O-D$_{\mathbf{m}}$**.

    - Estimate the travel times between all traffic zones in the modeled area.

- Apply the gravity model to calculate trips between traffic zones ($t^m_{i_a j_b}$).

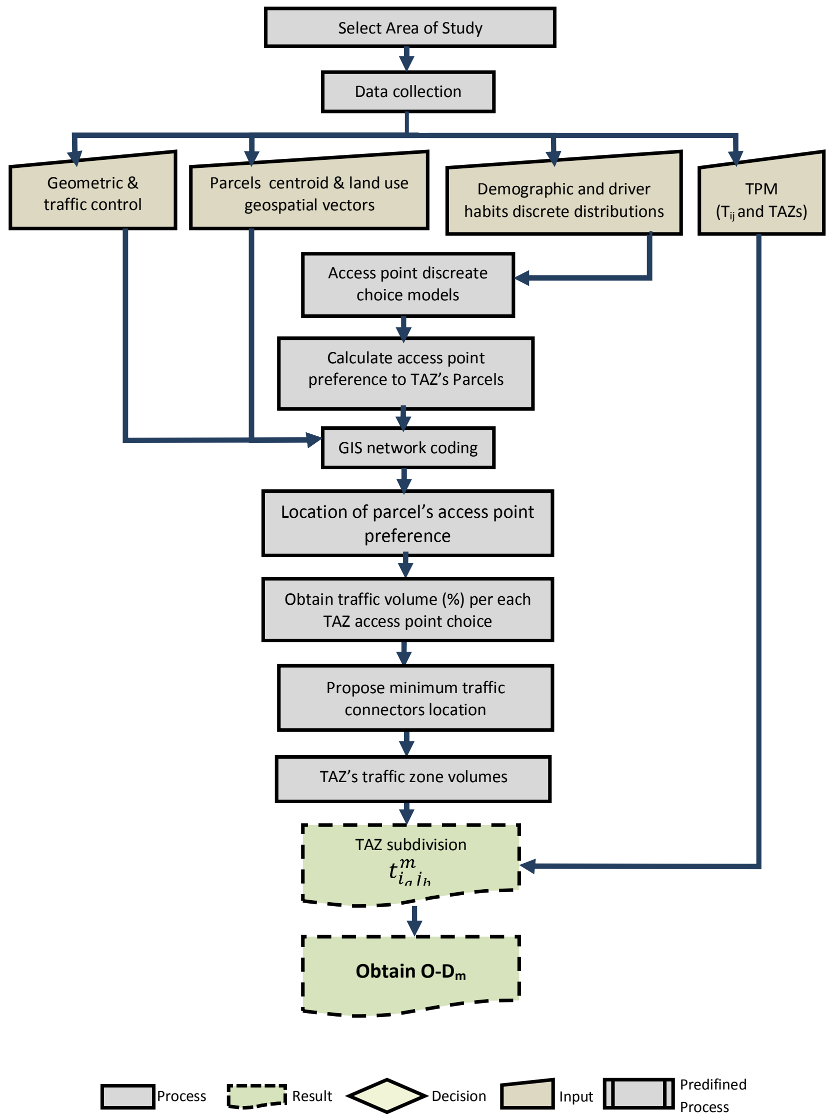

Figure 8.1 Flow chart of methodology

8.3 Contributions

The methodology developed in this research enables MTS to be applied to large networks. This will enable planners in transportation agencies (departments of transportation, metropolitan planning organizations) and consultants to perform microscopic analysis of large networks with future traffic

scenarios or with intelligent transportation system implementations. This methodology will save the analysts significant amount of time to construct a $\mathbf{O\text{-}D_m}$ matrix from scratch, e.g. conduction household survey or estimate it from traffic count data. Another advantage of creating the $\mathbf{O\text{-}D_m}$ matrix based on the TPM is that future traffic demand may be estimated from land use, demographic and economic forecasts.

8.4 Limitations

This research has only considered TAZs which consist of primarily residential parcels. The trips generated from or attracted to commercial land use have not been considered.

In GIS land use layer, parcels with single-family and multifamily residents have only one centroid. In this research, it has been assumed that each single-family parcel generated one person-trip. Although the number of multifamily parcels in the TAZ of study is small, it has been assumed that each multifamily parcel generated only one person-trip.

The discrete choice model is based on the driver's answers on his/her morning weekday trips. The model validation was performed for the morning peak hour (7:00 a.m. to 8:00 a.m.). Therefore the methodology applies to the morning peak hour with "home based work" and "home based others" trips.

Finally, it is assumed that the $\mathbf{O\text{-}D_p}$ matrix for the morning peak hour. Most of the TPMs have $\mathbf{O\text{-}D_p}$ matrix for 24-hour traffic demand. The 24-hour $\mathbf{O\text{-}D_p}$ matrix must be converted to morning peak hour $\mathbf{O\text{-}D_p}$ matrix before this methodology can be applied.

8.5 Further Research

Based on the limitations and difficulties encountered in this research, some directions of future research to improve and complement the methodology are listed here.

A potential area of future research is to define the way to reflect multiple person-trips generated by a multifamily parcel. This will be important if a TAZ has significant number of multifamily family parcels. A possible way to implement this idea is to subdivide a multifamily parcel into the corresponding units of single-family parcels.

Another important direction of future research is to consider multiple person-trips per single-family parcel. The survey questionnaire and discrete choice model may be modified to estimate the number of morning person-trips generated by each household based on number of vehicles per household, house size, and etc.

An improvement of the geocoding process could be the automatic process of editing driveways that connect the parcel centroids with the neighborhood street's centerline. This task, needed to provide the correct parcel-access point path through the network, was initially edited by address management tool. However the location of the driveways was not precise at all and required considerable manual editing work. The development of a more precise automatic editing tool will save considerable amount of time for a large network.

Finally, a non-residential TAZ (such as TAZ with primarily industrial, commercial, schools etc.) would provide the possibility of complementing the current residential-based methodology developed in this research.

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Glossary

Access point	An intersection along a main street at the boundary of a TAZ from which a vehicle from a particular parcel within the TAZ will use it to leave the TAZ.
Intersection	The factor a driver used to decide his/her routes between his/her parcel to the main street(s). The available factors are related to the type of intersection control: traffic signals, two-way stop control, or four-way stop control.
Main street	The street that forms part of the boundary of a TAZ.
Multiple	A scenario in which a driver has more than one route to choose from when traveling between his/her parcel to the main street(s).
No Multiple	A scenario in which a driver has only one route when traveling between his/her parcel to the main street.
Not Intersection	The factor a driver used to decide his/her routes between his/her parcel to the main street(s). The available factors are shortest distance, minimize stops and turns, avoid pedestrians, or wider street. They not related to the type of intersection control.
Route choice preference	The criteria a driver uses to select the route to travel from his/her parcel to the access point when leaving the TAZ.
Traffic Analysis Zone (TAZ)	A term used in transportation planning models to describe an area, bounded by main streets, in which the land use is homogeneous. A city is usually divided into many TAZs.
Traffic connector	Also known as traffic zone connector. A term used in microscopic traffic simulations to describe a local road that connects a traffic zone with an access point. Usually a connector is used to load and/or receive traffic between a traffic zone and an access point.
Traffic zone connector	See traffic connector.
Traffic zone	A term used in microscopic traffic simulations to describe an area that generate and/or attract traffic from the network. Usually a TAZ in a transportation planning model is divided into several traffic zones.
Volume split	The percent of the total traffic volume from a TAZ that will use a traffic connector.

Appendix

Section A: About yourself

1. Please indicate your gender: ☐ Male ☐ Female

2. Please indicate your age range:

   ☐ <25 yrs ☐ 25 to 34 yrs ☐ 35 to 49 yrs ☐ 50 to 64 yrs ☐ 65 & older

3. What is your approximate annual household income?

   ☐ Under $20,000 ☐ $20,000 - $39,999 ☐ $40,000 - $69,999
   ☐ $70,000 - $89,000 ☐ $90,000 - $150,000 ☐ over $150,000

4. Please indicate your highest education completed:

   ☐ High school ☐ Community college/ associate degree ☐ Undergraduate/ bachelor degree ☐ Graduate/ PhD degree

5 ZIP Code 799 ______	6. What is your household (family) size? _______	7. Number of household vehicles? ☐ 1 ☐ 2 ☐ 3 ☐ 4 or more

Section B: Your route choice habits in the **MORNING (6 a.m. to 10 a.m.)**

8. How many times do you **leave** home in a typical weekday in the morning?

   ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 or more

9. How many times do you **return** home in a typical weekday in the morning?

   ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 or more

10. What is(are) the **purpose**(s) of your morning trips in an average weekday? (You may select more than one answer)

    ☐ Work ☐ School ☐ Shopping/ grocery ☐ Gym ☐ Others:___________

11. Do you **stop by** any location **in your neighborhood** on the way from/to home?

    ☐ No. Please proceed to Question 12.

    ☐ Yes. Please proceed to Question 11a.

    11a. I regularly stop at the following locations: (You may select more than one answer)

    ☐ Gas station ☐ Coffee shop ☐ Day care ☐ Grocery store
    ☐ Restaurant ☐ Others:_______________________________________

12. When driving from home to the main street (for examples, Mesa, Resler, Belvidere, Escondido, Westwind), do you have multiple routes to choose from?

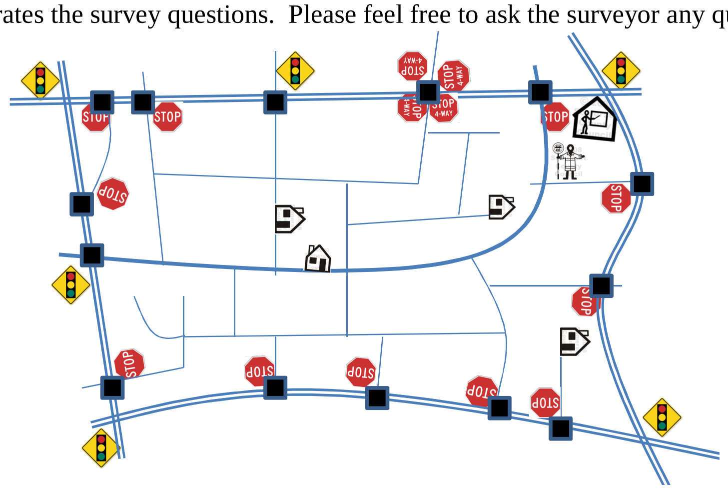
    ☐ I have **no choice** – there is only one access point from my home to the main street. Please proceed to Question 15.

    ☐ Yes, I have multiple routes to choose from, and I decide the route based on the **type of intersection** to the main street. Please proceed to Question 14.

    ☐ Yes, I have multiple routes to choose from, and I decide the route **NOT based on the type of intersection** to the main street BUT on other factors. Please proceed to Question 13.

13.	When choosing your route in the neighborhood streets between your home and the main street, which of the following **best** describe your route choice criteria? (Please select **only one** answer). Please proceed to question 15. ☐ I choose the shortest route by distance; that is, I drive to the nearest intersection that allows me to turn into the main street. ☐ I minimize the number of stops and turns. ☐ I avoid school zone, park or area with pedestrians. ☐ I drive through wider streets. ☐ Others:____
14.	When choosing your route in the neighborhood streets between your home and the main street, which of the following **best** describe your route choice criteria? (Please select **only one** answer). Please proceed to question 15. ☐ I drive to the intersection that has **traffic lights** to turn into the main street. ☐ I drive to the intersection that has Stop signs in all the directions (**4-way sto**p control) ☐ I drive to the intersection that has Stop sign at the minor street, no stop sign at the main street (**2-way stop** control) ☐ Others ____
15.	Which are the **streets** that comprise the **intersection** that you use more frequently in weekdays to connect to the main street driving from your house in the morning? _____________________________ and _________________________________
16.	What kind of intersection control **would** you prefer in your neighborhood? (Please select **only one** answer) ☐ Traffic signals or traffic lights ☐ Stop sign at the minor street, no stop sign at the main street (2-way stop control) ☐ Stop signs in all the directions (4-way stop control) ☐ Roundabout
	Thank you!

The figure below illustrates the survey questions. Please feel free to ask the surveyor any questions you may have.



Sección A: Acerca de Usted		
1. Género: ☐ Masculino ☐ Femenino		
2. Edad: ☐ <25 yrs ☐ 25 to 34 yrs ☐ 35 to 49 yrs ☐ 50 to 64 yrs ☐ 65 & older		
3. Ingresos anuales aproximados en su hogar: ☐ Under $20,000 ☐ $20,000 - $39,999 ☐ $40,000 - $69,999 ☐ $70,000 - $89,000 ☐ $90,000 - $150,000 ☐ over $150,000		
4. Máximo grado de estudios: ☐ High school ☐ Escuela Tecnica/ Community college ☐ Licenciatura/ bachelor degree ☐ Postgrado/ Graduate		
5. CódigoPostal (ZIP) 799 ______	6. ¿Cuántos miembros hay en su hogar? ____________	7. ¿Cuántos vehículos hay en su hogar? ☐ 1 ☐ 2 ☐ 3 ☐ 4 o mas

Sección B: Sus hábitos para escoger su ruta por la **MAÑANA (6 a.m. a 10 a.m.)**
8. ¿Cuántas veces **sale** de su casa por las **mañanas** en un día ente semana? ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 o más
9. ¿Cuántas veces **regresa** a su casa por la **mañana** en un día entresemana? ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 o más
10. ¿Cuál es el propósito de su viaje en la **mañana** en un día normal entre semana? (seleccione una o más opciones) ☐ Trabajo ☐ Escuela ☐ Shopping/ grocery ☐ Gimnasio ☐ Otros:___________
11. ¿Se detiene en algún lugar **dentro de su vecindario** cuando sale o regresa a su casa? ☐ No. Por favor proceda a la pregunta 12. ☐ Si. Por favor proceda a la pregunta 11a. 11a. regularmente me detengo en las siguientes lugares (Puede seleccionar una o más) ☐ Gasolinera ☐ Coffee shop ☐ Guarderia ☐ Grocery store ☐ Restaurant ☐ Others:____
12 ¿Cuándo maneja saliendo de su casa usted cuenta con **varias rutas** para tomar las avenidas principales? (Por ejemplo: Mesa, Resler, Belvidere, Escondido, Westwind) ☐ No tengo opción- solo hay una ruta de mi casa a la calle principal. Proceda con la pregunta 15. ☐ Si, tengo múltiples rutas para escoger y decido la ruta para llegar a la calle principal de acuerdo con el tipo de intersección. Proceda con la pregunta 14. ☐ Si, tengo múltiples rutas para escoger y decido la ruta para llegar a la calle principal tomando en cuenta las calles del vecindario. Proceda con la pregunta 13.

13. Cuando escoge su ruta entre las calles de su vecindario para moverse de su casa a la calle principal, ¿Cuál de las siguientes opciones es la que mas toma en cuenta? (Seleccione solo una opción). Proceda con la pregunta 15.

☐ Selecciono la ruta más corta, esto es, manejo a la intersección con la calle principal más cercana desde mi casa.

☐ Selecciono la ruta con menos altos y vueltas.

☐ Evito zonas escolares, parques o zonas donde puede haber gente caminando.

☐ Selecciono la ruta a través de calles amplias.

☐ Otro:____

14. Cuando maneja entre las calles de su vecindario para llegar a la calle principal, ¿Cuál de las siguientes opciones es la que mas toma en cuenta? (Seleccione solo una opción). Proceda con la pregunta 15.

☐ Manejo a la intersección que tiene semáforo para incorporarme a la calle principal.

☐ Manejo a la intersección que tiene solo alto en la calle menor y la calle principal no tiene alto

☐ Manejo a la intersección que tiene cuatro altos

☐ Otros:____

15. ¿Qué tipo de señalamiento **preferiría** en su vecindario? (Seleccione solo una opción).

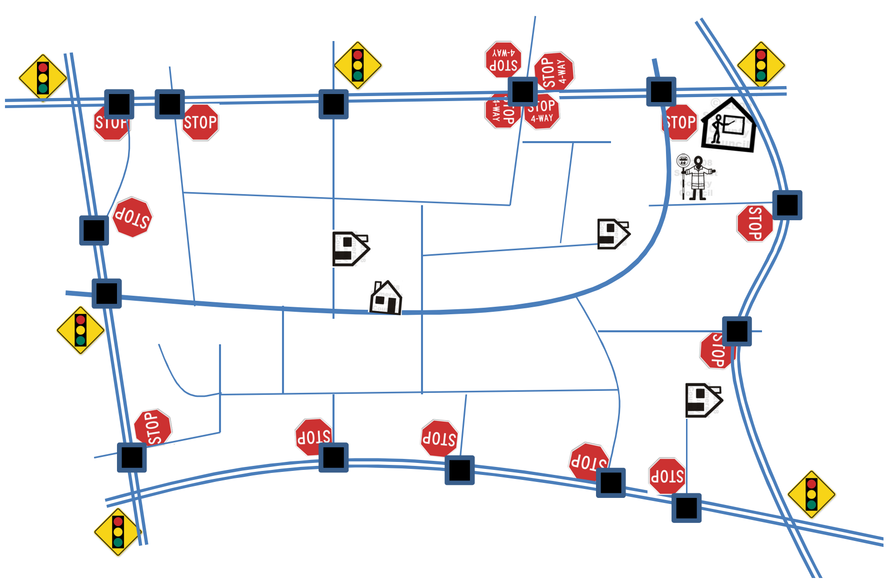
☐ Semáforos

☐ Un alto, carros de la calle principal no se detiene y solo se detiene los de la calle menor (alto de 2-vias)

☐ Cuatro altos

☐ Glorieta

Gracias!



Vita

Jose Osiris Vidaña Bencomo, son of Armida Eloisa Bencomo Balbuena and Hector Vidaña Flores, was born in Chihuahua, Mexico in 1973, Osiris attended the University Autonomous of Chihuahua where he received his Bachelor diploma in Civil Engineering and his Master degree in Transportation. Osiris collaborated in the private sector in the international construction company Ingenieros Civiles y Asociados (ICA) as a geotechnical and construction engineer. Also, Osiris has experience as Assistant Professor at the University Autonomous of Ciudad Juarez, Mexico in the Civil Engineering program. While pursuing his Ph.D. degree, Osiris worked as Research Graduate Assistant at Texas Transportation Institute (TTI) where he participated in microscopic traffic simulation and travel planning projects.

He has a certified recognition as a Professional Engineer in infrastructure systems by El Colegio de Ingenieros Civiles de Mexico. Most recently, Osiris received the Executive Leadership Fellowship from the International Road Federation in Washington D.C. in 2010. He also received the Eisenhower Fellowship by the Federal Highway Administration in 2010.

He has participated in different conference presentations such as: 13th TRB National Transportation Planning Applications Conference, Reno, Nevada, May 2011; TexITE Spring Meeting, Fort Worth, Texas, March 2011; TRB 90th Annual Meeting Innovative Doctoral Research from Dwight David Eisenhower Transportation Fellowship Program, Washington D.C, January 2011.

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