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16. Abstract

Metropolitan planning organizations (MPOs) have become increasingly interested in incorporating innovated land use planning and design into transportation plan-making. Many design ideas are recommended under the umbrella of the New Urbanism; yet in practice they hardly get fully implemented in the standard transportation planning procedures. The project includes two parts. Part one refines the analysis of trip generation as it relates to mixed use development (MXD), with a focus on trip-chaining behavior, an approach taken by CAMPO. Part two looks into the potential of and challenges facing land use intervention as an emission reduction tool. Through the Austin case study, it investigates the regional and local distributional effects of vehicle miles traveled (VMT) and Green House Gas (GHG) emission changes pertaining to recommended land use and design innovations.

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Identifying the Local and Regional Travel Effects of Activity Centers in the Austin, Texas Area

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Executive Summary

Metropolitan planning organizations (MPOs) have become increasingly interested in incorporating innovated land use planning and design into transportation plan-making. Many design ideas are recommended under the umbrella of the New Urbanism; yet in practice they hardly get fully implemented in the standard transportation planning procedures.

The project extends from a previous study, "Trip Internalization and Mixed-Use Development: A Case Study of Austin Texas" (Zhang, et al. 2009). The extended work includes two parts. Part one refines the analysis of trip generation as it relates to mixed use development (MXD). It focuses on trip-chaining behavior, an approach taken by CAMPO. Part two looks into the potential of and challenges facing land use intervention as an emission reduction tool. Through the Austin case study, it investigates the regional and local distributional effects of VMT and GHG changes pertaining to land use patterns.

MXD households make slightly more HBWD trips than non-MXD households, but much less HBWS trips. For HBWC, the average MXD trip chain rate is much higher than that for non-MXD. For HBNW, MXD residents make more retail trips than Non-MXD residents, while Non-MXD residents make more NHBO trips (1.66 person trips/household) than MXD residents (1.016 person trips/household). Travel for HBWC, HBNWR and NHBW appear more frequent in MXDs than in non-MXDs. The opposite was observed for HBWD, HBWS and NHBO. On average, the network trips distances in MXD areas are about 0.8 mile shorter than those in NON_MXD areas. For HBNWR, MXD trips are 3.2 miles shorter. For the internal rates of capture, 9.41% of MXD trips are internal, much higher than those in NON-MXD areas. Specifically, MXDs absorb much more trips inside for HBWD, HBNWR, HBNW2, NHBW and NHBO purposes. On average, a person living in MXDs travels 30 miles daily, about 1.2 miles less than those living outside MXDs. The difference between people living in MXDs and those in Non- MXDs, can be mainly attributed to shorter trips for HBNWR.

The study shows a rather complex picture on the relationship among built environment, VMT, and emissions. Region-wide, densification strategy potentially helps reduce regional VMT and consequently decrease regional emissions. Locally, higher population density is associated with higher emission density. This poses a challenge to the land use-based strategies for emission reduction—densification and mixed-use development function like a double-edged sword in terms of their effects on VMT and emissions. Supplemental policies are essential for land use intervention to succeed in achieving emission reduction goals.

1. Introduction

Transportation professionals have become increasingly interested in integrating innovative land use planning and urban design into transportation plan-making when seeking solutions to such enduring transportation problems as roadway congestion, vehicle emissions, and traffic accidents. Examples of the design ideas and land use patterns include transit oriented development (TOD), traditional neighborhood design, compact development, mixed use development, and pedestrian/cyclist friendly environmental design. Many planning organizations have created programs to incorporate urban design ideas and land use patterns. In Texas, for example, in the Dallas area, the North Central Texas Council of Governments (CTCOG) is expanding its program of Transit-Oriented Development (TOD) along with the expansion plan of the Dallas Area Rapid Transit (DART) network. In the greater Houston area, the Houston-Galveston Area Council (H-GAC) has been implementing a “Livable Centers” program that promotes clustering development of jobs, shopping, entertainment, and housing.

In Austin Metropolitan Statistical Area (MSA), Capital Metropolitan Planning Organization (CAMPO) has been active and rigorous in incorporating a regional growth concept of “Activity Centers” for its 2035 and 2040 Long Range Transportation Plans. Mixed land use is one important concern to evaluate these “Activity Centers”. The Activity Centers concept aims to preserve regional quality of life in the face of continued high growth rates. Through planning and financing future transportation improvements, the growth concept encourages an alternative pattern of land use across the region. Generally, city and neighborhood centers as well as important transportation nodes offer prime locations of activity centers.

However, when it comes to the making of long-range regional transportation plans, the urban design ideas hardly get fully implemented in the standard procedures, for a variety of reasons. First of all, there remain skepticisms on the role that the built environment could play to influence travel (Echenique, et al. 2012). The place-making initiatives such as those mentioned above may help improve livability in selected neighborhoods; whether they will generate significant transportation benefits at the regional scale are still unconvincing to many transportation engineers and to some urban planners as well. Furthermore, there are technical and institutional issues (Eash, 1997). As of today the majority of MPOs in the US apply the Four-Step modeling procedures (i.e., trip generation, trip distribution, modal split and traffic assignment) for demand analysis and forecasting. These modeling tools were first developed in the 1950s mainly for highway-based transportation planning. They are rather insensitive to changes in urban form at the site scale as the New Urbanists propose. Take the first step, trip generation modeling, as an example. Typically trip productions and attractions are estimated based on the trip rate tables recommended by national agencies such as NCHRP and ITE or developed by local regions (TRB/NRC, 1998). The tables provide trip rates varying along income, household size, vehicle ownership, and metropolitan populations. Urban design variables rarely enter into trip generation equations.

There have been efforts to better integrate urban design ideas into transportation planning practice. A variety of tools has been or is being developed (Moudon and Stewart, 2013). Generally speaking, the efforts fall into two categories. One is called the 'post-processing' approach (Cervero, 2002). The approach takes the output of the conventional four-step models as input and post-processes travel outcome by making empirical adjustments. For example, empirical studies have reported travel behavior elasticities of urban form attributes such as density, land use mixture, and intersection configuration (Ewing and Cervero, 2010). The post-processing approach applies the elasticities to adjust up or down the modeled trip volumes, modal splits and other aspects of trip making. While the approach offers a improved solution technically, it may not work due to policy or political constraints. In Austin, TX, for instance, the governing board of CAMPO does not approve plans that are made using borrowed data.

The second approach is what we call 'pre-processing', referring to the effort of developing large scale, integrated land use-transport models, for example, UrbanSim, PECAS, and region-specific models. The effort attempts to develop new modeling tools that eventually replace the conventional, highway focused four-step modeling procedures. Nevertheless, despite major progress achieved in the field, the integrated land use-transport models remain operational largely in academia. It may take years or even longer for them to become a common practice among MPOs due to known technical and institutional reasons.

This project sets a two-fold objective. First, it intends to contribute to the continuing debate on urban form-travel connection by adding further empirical evidence from the Austin, TX region. Differing from most existing empirical work in the area, the paper studies and reports evidence in metrics commonly used by transportation planners and engineers for travel demand analysis. Second, it presents what we call a 'present-processing' approach to integrating urban design ideas with transportation practice. The proposed approach lies between the pre-processing and the post-processing approach mentioned above. It incorporates urban design variables directly into the conventional demand analysis procedures. A number of MPOs throughout the country has made such efforts, for example, in Southern California (SANDAG, 2010). The case example of Austin, TX presented in the report adds to the efforts that help develop a practical solution to bridge the gap currently existing between the New Urbanist ideas and transportation planning practice.

The project extends from a previous study, "Trip Internalization and Mixed-Use Development: A Case Study of Austin Texas" (Zhang, et al. 2009). The extended work includes two parts. Part one refines the analysis of trip generation as it relates to mixed use development (MXD). In previous work, the trip generation study grouped trip purposes into four conventional categories, i.e., home-based work, Home based non-work, Non-home based work and Non-home based others. In this study, trip generation is analyzed focusing on trip-chaining behavior, an approach taken by CAMPO. Part two of the present work looks into the potential of and challenges facing land use intervention as an emission reduction tool. Through the Austin case study, it investigates the connection between the built-environment characteristics, Vehicle Miles Traveled (VMT), and transportation-related Green House Gas (GHG) emissions. In particular, the study examines the regional and local distributional effects of VMT and GHG changes pertaining to land use patterns.

This report is organized in two parts accordingly.

2. Trip Generation by Trip Chains (MXD vs Non-MXD)

In previous study, 42 MXDs were identified. See Zhang, et al, (2009) for details in MXD identification methods. For reference convenience, Table 1 below presents sample statistics of the households in and outside MXDs.

Table 1: Descriptive Statistics

Variable	HH Inside MXDs (n=65)				HH Outside MXDs (n=1,354)				t-test
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max	
# Persons in HH	2.29	1.2	1	5	2.82	1.54	1	13	-2.75
# Workers in HH	1.08	0.83	0	2	1.12	0.8	0	2	-0.44
Income/Person (2005 $1000s)	22.21	17.19	2.5	87.5	22.92	18.47	0.83	150	-0.3
Vehicles in HH	1.8	0.96	0	4	1.91	0.91	0	7	-0.93
Vehicles/Person	0.87	0.46	0	3	0.79	0.41	0	5	1.59
Vehicles/Worker	1.24	0.46	0	2	1.41	0.71	0	5	-1.54
Bikes in HH	0.85	1.39	0	7	1.67	7.2	0	99	-0.92
Years in Residence	3.8	1.73	0	5	3.98	1.58	0	5	-0.89

In this report we skip the literature review since prior work (Zhang, et al, 2009) reviewed related studies on urban form and trip generation. Instead we go straight to reporting the process and results of trip generation/trip chaining analyses from the Austin case study.

2.1 Study Approach

2.1.1 Classification of Trip Purposes

This study follows the trip chaining classification scheme adapted by CAMPO, which will include 12 trip purposes. The definitions for 12 trip purposes are listed below:

1) HBWD: Home Based Work Person Trips Direct.

HBWD trip is part of a trip "tour" that consists of both home-to-work and work-to-home trips as being direct. If either trip is not direct, then neither is considered to be direct. The exception to this rule has to do with "trip linking". In this study, if the distances of the intermediate stops and home or the intermediate stops and workplaces are less than 5 minutes (that what I use to define the trip purpose, CAMPO may use other way to define the "convenient point"), then these stops are called "convenient point" and are "linked out", and both the home-to-work and work-to-home trips remain Direct.

2) HBWS: Home Based Work Person Trips Strategic

HBWS trip contains an intermediate destination to either drop off or pick up a child at day-care, nursery school, baby sitter, pre-school, elementary or secondary school. If a traveler drops off their child at a day-care center in the morning yet proceeds directly home in the evening, then both trips are considered Strategic. This is the only case of serve passenger which is "linked out" to create a composite HBW Strategic trip.

3) HBWC: Home Based Work Person Trips Complex

HBWC trip is part of a trip "tour" that consists of one trip between home and work and another trip between home and work which involves an intermediate stop at any destination. In this case, the home-to-work leg of the trip chain would be coded as HBWC, the work-to other leg of the chain would be coded as NHB and the other-to-home leg of the chain would be coded as HBNW.

4) HBNWR: Home Based Non-work Retail Person Trips
5) HBNWO: Home Based Non-work Other Person Trips
6) HBNWE1: Home Based Non-work Primary Education Person Trips
7) HBNWE2: Home Based Non-work University/College Person Trips
8) NWAIR: Non-work Airport Person Trips
9) NHBW: Non-home Based Work-related Person Trips
10) NHBO: Non-home Based Other Person Trips
11) TRTX: Commercial Truck/Taxi Vehicle Trips

If trips do not fit into (1) ~ (2), and the trip purpose is not work nor home related, and the travel mode is truck or taxi, then they are defined as (11).

12) EXTER: If either the Origin point or End point is outside of the five counties in the metro region, that trip will be defined as (12).

2.1.2 Tabulation of Trip Rates Tables

In this research, trip rate tables are estimated in two scenarios: S0 and S1. The definition of the two approaches are as below:

1) Base scenario (S_0)

   It is assumed that there are no difference between MXDs and NON_MXDs. First the trip production rates are derived using the sample data for the entire region. Next, the generation tables are reported for MXD and NON-MXD households separately. The two tables have essentially the same trip rates.

2) Scenario 1 (S_1)

   In this scenario it is assumed that trip production behavior differs for households living in MXDs vs. Non-MXDs. Trip rate tables are created for MXD and NON-MXD separately.

For both S_0 and S_1, three-way cross-classification was applied to estimate the HBW trip rate tables. The variables for three-way classification are:

1) Household size: “HHSIZE05” in TAZ geographic file,

2) Medium income group: “MEINCGRP05” in TAZ geographic file,

   “1” refers household income less than $20,000;

   “2” refers household income between $20,000 and $35,000;

   “3” refers household income between $35,000 and $50,000;

   “4” refers household income between $50,000 and $75,000;

   “5” refers household income more than $75,000

3) Employed population in household (EMP_HH):

Survey data was used to estimate "workers in household" by different income and household size. The estimates are shown in table below.

Table 2: Estimation of Employed Population in the Household

Household Size	Medium Income Group	EMP_HH
1	1	0.27
1	2	0.45
1	3	0.63
1	4	0.73
1	5	0.74
2	1	0.59
2	2	0.85
2	3	1.11
2	4	1.14
2	5	1.22
3	1	0.85
3	2	1.35
3	3	1.69
3	4	1.79
3	5	1.75
4	1	1.31
4	2	1.67
4	3	1.86
4	4	1.77
4	5	1.68
5	1	0.97
5	2	1.81
5	3	2.22
5	4	1.89
5	5	1.68

For tabulation of trip tables for other trip purposes, two-way classification is applied and "EMP_HH" was excluded.

2.1.3 Estimation of Missing Data

Due to limitation in the size of MXD sample, there are not enough observation points for all trip purposes for each income and household size category. It is obviously wrong to set zero for the missing vale cells. Three methods were tested to deal with the missing data in trip rates tables, marked as “REG”, “MEAN” and “REG_MIS”.

1) REG

Based on existing trip rates from Cross-Classification, this method uses multi-variable regression to build the relationship among trip rates and variables used in Cross-Classification (income, household size, and “workers in one family”), and then estimate all trip rates using the estimated equation to get new trip rates tables. It means that this method will not only fill the missing data, but also replace the previous trip rates from Cross-Classification.

Although, this way can fill most of missing data and data with extremely high value in trip rates tables, the data to build the regression is not enough to get the convincing result. Therefore the estimated rate looks, albeit nice, but may not represent the real situation.

2) MEAN

This method applied Cross-Classification first and then borrows the whole-area-wide average trip rate for specific trip purpose as the estimate for missing data.

In comparison with REG, this way is closer to the real situation because it uses the original survey data and Cross-Classification to obtain the trip rates. However, there are many odd values in trip rate tables because of the low volume of observation points. In addition, using average trip rates to fill the missing data ignores the trend.

3) REG_MIS

This method will use the method as REG to get the estimated equation, but just fill the missing value using the estimated trip rates.

This method is closer to the real situation, better than MEAN method, because this method considers the effect of trend. Also, it does not change too many trip rates from Cross-Classification. Although there are still some odd values in trip rates tables, the result is much better than MEAN.

2.2 Empirical Results Analysis

This study's major interests are the differences in people's travel behaviors between those who associate (living in, traveling from or to) with the MXDs and those who do not. Five aspects of travel behavior analyzed include trip production rates, frequency of produced trips, trip network length, internal rate of capture, and person miles traveled (PMT).

2.2.1 Trip Production Rates

As mentioned above, this study applied two approaches to estimate the trip rates tables: S_0 and S_1. For each approach, 12 trip tables are listed based on different trip purposes.

(1) Trip Rates under S_0

Different trip rates tables for different trip purposes are listed as below. The first row in the three-way cross-classification tables refers to the different household sizes.

Table 3: Trip Rates for HBWD under S_0

Trip Rates (HBW_D)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	0.99	1.07	1.16	1.25	1.34
	2	1.06	1.16	1.28	1.37	1.49
	3	1.14	1.25	1.37	1.48	1.58
	4	1.22	1.35	1.47	1.57	1.70
	5	1.31	1.46	1.61	1.73	1.83
Two+ Workers	1	0.00	1.52	1.64	1.78	1.94
	2	0.00	1.81	1.91	2.06	2.21
	3	0.00	2.01	2.13	2.24	2.40
	4	0.00	2.19	2.32	2.43	2.55
	5	0.00	2.29	2.42	2.54	2.64

Table 4: ***Trip Rates for HBWS under S_0***

Trip Rates (HBW_S)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	0.00	0.00	0.00	0.33	0.11
	2	0.00	0.00	0.13	0.00	0.00
	3	0.00	0.00	0.00	0.11	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.18	0.00
Two+ Workers	1	0.00	0.00	0.33	0.67	0.00
	2	0.00	0.00	0.19	0.33	0.10
	3	0.00	0.00	0.34	0.13	0.07
	4	0.00	0.00	0.27	0.21	0.00
	5	0.00	0.00	0.40	0.35	0.13

Table 5: ***Trip Rates for HBWC under S_0***

Trip Rates (HBW_C)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	0.00	0.00	0.00	0.33	0.11
	2	0.00	0.00	0.13	0.00	0.00
	3	0.00	0.00	0.00	0.11	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.18	0.00
Two+ Workers	1	0.00	0.00	0.33	0.67	0.00
	2	0.00	0.00	0.19	0.33	0.10
	3	0.00	0.00	0.34	0.13	0.07
	4	0.00	0.00	0.27	0.21	0.00
	5	0.00	0.00	0.40	0.35	0.13

Table 6: Trip Rates for HBNWR under S_0

Trip Rates (HBNW_R)					
Income	One	Two	Three	Four	Five+
1	1.12	2.05	2.60	0.92	1.56
2	0.90	1.53	1.21	1.20	1.16
3	1.04	1.28	1.69	1.33	2.18
4	1.22	1.75	2.02	2.02	2.11
5	1.06	1.66	1.32	2.10	1.52

Table 7: Trip Rates for HBNWO under S_0

Trip Rates (HBNW_O)					
Income	One	Two	Three	Four	Five+
1	1.08	1.97	2.47	3.85	5.31
2	0.92	1.75	2.15	3.46	6.09
3	0.71	1.75	1.76	3.69	5.91
4	0.61	1.46	2.29	3.45	7.42
5	0.76	1.20	2.54	5.01	7.44

Table 8: Trip Rates for HBNWE1 under S_0

Trip Rates (HBNW_E1)					
Income	One	Two	Three	Four	Five+
1	0.00	0.08	0.80	2.23	3.53
2	0.00	0.06	0.89	2.17	4.06
3	0.00	0.05	0.71	2.29	3.00
4	0.00	0.02	0.69	2.31	3.06
5	0.00	0.02	0.80	2.15	3.46

Table 9: Trip Rates for HBNWE2 under S_0

Trip Rates (HBNW_E2)					
Income	One	Two	Three	Four	Five+
1	0.05	0.13	0.27	0.08	0.31
2	0.00	0.01	0.11	0.00	0.06
3	0.05	0.04	0.16	0.02	0.12
4	0.00	0.09	0.02	0.12	0.11
5	0.00	0.02	0.12	0.17	0.13

Table 10: Trip Rates for NWAIR under S_0

Trip Rates (NW_AIR)					
Income	One	Two	Three	Four	Five+
1	0.00	0.04	0.00	0.00	0.00
2	0.00	0.01	0.00	0.10	0.00
3	0.04	0.03	0.02	0.00	0.00
4	0.04	0.04	0.00	0.05	0.06
5	0.12	0.04	0.13	0.12	0.00

Table 11: Trip Rates for NHBW under S_0

Trip Rates (NHB_W)					
Income	One	Two	Three	Four	Five+
1	0.08	0.16	0.33	0.77	0.38
2	0.32	0.59	0.51	0.51	0.63
3	0.38	0.59	0.61	1.21	0.94
4	0.52	0.59	1.16	1.29	1.58
5	1.06	1.05	1.53	1.38	2.19

Table 12: Trip Rates for NHBO under S_0

Trip Rates (NHB_O)					
Income	One	Two	Three	Four	Five+
1	0.96	1.05	2.13	1.85	2.38
2	0.82	1.23	0.91	1.07	2.22
3	0.73	1.05	1.00	1.52	3.42
4	0.83	1.34	1.27	1.95	4.58
5	0.76	1.14	1.75	3.14	4.71

Table 13: Trip Rates for TRTX under S_0

Trip Rates (TRTX)					
Income	One	Two	Three	Four	Five+
1	0.18	0.24	0.33	0.62	0.66
2	0.03	0.17	0.13	0.27	0.00
3	0.18	0.06	0.16	0.08	0.39
4	0.00	0.06	0.09	0.05	0.33
5	0.00	0.12	0.14	0.13	0.15

Table 14: Trip Rates for EXTER under S_0

Trip Rates (EXTER) Income	One	Two	Three	Four	Five+
1	0.00	0.03	0.00	0.00	0.00
2	0.08	0.16	0.04	0.15	0.00
3	0.11	0.26	0.04	0.19	0.15
4	0.13	0.11	0.04	0.26	0.11
5	0.12	0.26	0.07	0.02	0.06

(2) Trip Rates under S_1

In this section, MXD and Non-MXD are separated. Also three ways as mentioned before were used for estimation of missing data.

Table 15: Trip Rates for HBWD (Non-MXD) under S_1

Trip Rates (HBW_D) (Non-MXD)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	1.05	1.31	1.38	1.33	1.11
	2	1.57	1.73	1.70	1.50	1.67
	3	1.38	1.29	1.88	1.28	0.80
	4	0.87	1.11	1.57	1.07	1.00
	5	0.92	1.57	1.22	1.00	1.71
Two+ Workers	1	0.00	1.75	2.80	2.00	2.40
	2	0.00	3.05	3.24	2.64	3.21
	3	0.00	2.58	2.44	2.69	3.11
	4	0.00	2.87	3.31	1.68	2.88
	5	0.00	2.69	2.42	1.67	2.96

Table 16: Trip Rates for HBWD (MXD) under S_1 by using REG

Trip Rates (HBW_D) (MXD_REG)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	1.58	1.59	1.60	1.61	1.62
	2	1.50	1.51	1.52	1.53	1.54
	3	1.41	1.42	1.43	1.44	1.45
	4	1.33	1.33	1.34	1.35	1.36
	5	1.24	1.25	1.26	1.27	1.28
Two+ Workers	1	0.00	3.37	3.38	3.39	3.40
	2	0.00	3.29	3.30	3.30	3.31
	3	0.00	3.20	3.21	3.22	3.23
	4	0.00	3.11	3.12	3.13	3.14
	5	0.00	3.03	3.04	3.05	3.06

Table 17: Trip Rates for HBWD (MXD) under S_1 by using MEAN

Trip Rates (HBW_D) (MXD_MEAN)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	1.03	1.03	1.00	1.03	1.03
	2	2.00	2.00	2.00	1.03	1.03
	3	1.00	2.00	1.03	2.00	1.03
	4	0.00	1.03	1.03	1.03	1.03
	5	1.03	1.03	1.03	1.03	1.00
Two+ Workers	1	0.00	1.03	2.00	1.03	1.03
	2	0.00	8.00	1.03	3.00	2.00
	3	0.00	0.00	3.00	1.03	4.00
	4	0.00	1.60	4.00	1.03	1.03
	5	0.00	4.00	2.67	4.00	1.03

Table 18: Trip Rates for HBWD (MXD) under S_1 by using REG_MIS

Trip Rates (HBW_D) (MXD_ REG_MIS)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	1.58	1.59	1.00	1.61	1.62
	2	2.00	2.00	2.00	1.53	1.54
	3	1.00	2.00	1.43	2.00	1.45
	4	0.00	1.33	1.34	1.35	1.36
	5	1.24	1.25	1.26	1.27	1.00
Two+ Workers	1	0.00	3.37	2.00	3.39	3.40
	2	0.00	8.00	3.30	3.00	2.00
	3	0.00	0.00	3.00	3.22	4.00
	4	0.00	1.60	4.00	3.13	3.14
	5	0.00	4.00	2.67	4.00	3.06

Table 19: Trip Rates for HBWS (Non-MXD) under S_1

Trip Rates (HBW_S) (Non-MXD)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	0.00	0.00	0.00	0.50	0.17
	2	0.00	0.00	0.22	0.00	0.00
	3	0.00	0.00	0.00	0.17	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.26	0.00
Two+ Workers	1	0.00	0.00	0.60	1.00	0.00
	2	0.00	0.00	0.29	0.55	0.16
	3	0.00	0.00	0.56	0.19	0.11
	4	0.00	0.00	0.46	0.32	0.00
	5	0.00	0.00	0.63	0.50	0.26

Table 20: Trip Rates for HBWS (MXD) under S_1 by using REG

Trip Rates (HBW_S) (MXD_REG)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	0.07	0.10	0.13	0.16	0.20
	2	0.00	0.03	0.06	0.09	0.13
	3	0.00	0.00	0.00	0.03	0.06
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
Two+ Workers	1	0.00	0.24	0.27	0.30	0.33
	2	0.00	0.17	0.20	0.23	0.26
	3	0.00	0.10	0.13	0.16	0.20
	4	0.00	0.03	0.06	0.10	0.13
	5	0.00	0.00	0.00	0.03	0.06

Table 21: Trip Rates for HBWS (MXD) under S_1 by using MEAN

Trip Rates (HBW_S) (MXD_MEAN)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	0.06	0.06	0.00	0.06	0.06
	2	0.00	0.00	0.00	0.06	0.06
	3	0.00	0.00	0.06	0.00	0.06
	4	0.00	0.06	0.06	0.06	0.06
	5	0.06	0.06	0.06	0.06	0.06
Two+ Workers	1	0.00	0.06	0.00	0.06	0.06
	2	0.00	0.00	0.06	1.50	0.00
	3	0.00	0.00	0.00	0.06	0.00
	4	0.00	0.00	0.00	0.06	0.06
	5	0.00	0.00	0.00	0.00	0.00

Table 22: Trip Rates for HBWS (MXD) under S_1 by using REG_MIS

Trip Rates (HBW_S) (MXD_REG_MIS)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	0.07	0.10	0.00	0.16	0.20
	2	0.00	0.00	0.00	0.09	0.13
	3	0.00	0.00	0.00	0.00	0.06
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
Two+ Workers	1	0.00	0.24	0.00	0.30	0.33
	2	0.00	0.00	0.20	1.50	0.00
	3	0.00	0.00	0.00	0.16	0.00
	4	0.00	0.00	0.00	0.10	0.13
	5	0.00	0.00	0.00	0.00	0.00

Table 23: Trip Rates for HBWC (Non-MXD) under S_1

Trip Rates (HBW_C) (Non-MXD)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	0.14	0.04	0.08	0.17	0.11
	2	0.26	0.17	0.07	0.00	0.00
	3	0.16	0.14	0.06	0.06	0.40
	4	0.33	0.07	0.21	0.21	0.08
	5	0.23	0.09	0.26	0.09	0.14
Two+ Workers	1	0.00	0.00	0.20	0.50	0.20
	2	0.00	0.27	0.19	0.14	0.11
	3	0.00	0.42	0.22	0.34	0.22
	4	0.00	0.45	0.23	0.43	0.13
	5	0.00	0.53	0.21	0.35	0.30

Table 24: Trip Rates for HBWC (MXD) under S_1 by using REG

Trip Rates (HBW_C) (MXD_REG)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	0.01	0.00	0.00	0.00	0.00
	2	0.19	0.02	0.00	0.00	0.00
	3	0.36	0.20	0.03	0.00	0.00
	4	0.54	0.37	0.21	0.04	0.00
	5	0.71	0.55	0.38	0.22	0.05
Two+ Workers	1	0.00	1.12	0.96	0.79	0.63
	2	0.00	1.30	1.13	0.97	0.80
	3	0.00	1.48	1.31	1.14	0.98
	4	0.00	1.65	1.49	1.32	1.15
	5	0.00	1.83	1.66	1.50	1.33

Table 25: Trip Rates for HBWC (MXD) under S_1 by using MEAN

Trip Rates (HBW_C) (MXD_MEAN)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	0.11	0.11	0.00	0.11	0.11
	2	0.25	0.00	0.00	0.11	0.11
	3	0.00	0.00	0.11	0.00	0.11
	4	0.00	0.11	0.11	0.11	0.11
	5	0.11	0.11	0.11	0.11	0.50
Two+ Workers	1	0.00	0.11	1.00	0.11	0.11
	2	0.00	0.50	0.11	1.00	1.00
	3	0.00	3.00	1.00	0.11	1.00
	4	0.00	1.00	0.75	0.11	0.11
	5	0.00	4.00	0.00	3.00	0.00

Table 26: Trip Rates for HBWC (MXD) under S_1 by using REG_MIS

Trip Rates (HBW_C) (MXD_REG_MIS)	Income	One	Two	Three	Four	Five+
Zero Worker	1	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	0.00
One Worker	1	0.01	0.00	0.00	0.00	0.00
	2	0.25	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.03	0.00	0.00
	4	0.00	0.37	0.21	0.04	0.00
	5	0.71	0.55	0.38	0.22	0.50
Two+ Workers	1	0.00	1.12	1.00	0.79	0.63
	2	0.00	0.50	1.13	1.00	1.00
	3	0.00	3.00	1.00	1.14	1.00
	4	0.00	1.00	0.75	1.32	1.15
	5	0.00	4.00	0.00	3.00	0.00

Table 27: Trip Rates for HBNWR (Non-MXD) under S_1

Trip Rates for HBNWR (Non-MXD)					
Income	One	Two	Three	Four	Five+
1	0.00	0.03	0.00	0.00	0.00
2	0.08	0.16	0.04	0.15	0.00
3	0.11	0.26	0.04	0.19	0.15
4	0.13	0.11	0.04	0.26	0.11
5	0.12	0.26	0.07	0.02	0.06

Table 28: Trip Rates for HBNWR (MXD) under S_1 by using REG

Trip Rates for HBNWR (MXD_REG)					
Income	One	Two	Three	Four	Five+
1	2.80	3.24	3.68	4.11	4.55
2	2.53	2.97	3.40	3.84	4.28
3	2.26	2.70	3.13	3.57	4.01
4	1.99	2.42	2.86	3.30	3.74
5	1.71	2.15	2.59	3.03	3.47

Table 29: Trip Rates for HBNWR (MXD) under S_1 by using MEAN

Trip Rates for HBNWR (MXD_MEAN)					
Income	One	Two	Three	Four	Five+
1	2.00	3.00	5.33	1.54	8.50
2	1.54	1.54	1.33	1.54	1.54
3	0.33	1.54	1.54	1.00	2.00
4	1.50	3.00	3.75	1.54	1.54
5	4.00	4.00	0.50	6.00	1.50

Table 30: Trip Rates for HBNWR (MXD) under S_1 by using REG_MIS

Trip Rates for HBNWR (MXD_REG_MIS)					
Income	One	Two	Three	Four	Five+
1	2.00	3.00	5.33	4.11	8.50
2	2.53	2.97	1.33	3.84	4.28
3	0.33	2.70	3.13	1.00	2.00
4	1.50	3.00	3.75	3.30	3.74
5	4.00	4.00	0.50	6.00	1.50

Table 31: Trip Rates for HBNWO (Non-MXD) under S_1

Trip Rates for HBNWO (Non-MXD)					
Income	One	Two	Three	Four	Five+
1	1.03	1.94	2.74	3.85	5.43
2	0.89	1.73	2.14	3.64	6.16
3	0.70	1.74	1.83	3.53	5.97
4	0.62	1.51	2.22	3.45	7.42
5	0.81	1.21	2.49	5.07	7.24

Table 32: Trip Rates for HBNWO (MXD) under S_1 by using REG

Trip Rates for HBNWO (MXD_REG)					
Income	One	Two	Three	Four	Five+
1	0.38	1.45	2.53	3.61	4.68
2	0.58	1.66	2.74	3.81	4.89
3	0.79	1.87	2.94	4.02	5.10
4	1.00	2.07	3.15	4.23	5.30
5	1.20	2.28	3.36	4.43	5.51

Table 33: Trip Rates for HBNWO (MXD) under S_1 by using MEAN

Trip Rates for HBNWO (MXD_MEAN)					
Income	One	Two	Three	Four	Five+
1	2.00	3.50	0.00	3.00	3.50
2	1.14	2.00	2.33	0.00	4.00
3	1.00	2.00	0.00	12.00	4.00
4	0.50	0.83	3.00	3.00	3.00
5	0.00	0.00	3.50	0.00	12.00

Table 34: Trip Rates for HBNWO (MXD) under S_1 by using REG_MIS

Trip Rates for HBNWO (MXD_REG_MIS)					
Income	One	Two	Three	Four	Five+
1	2.00	3.50	0.00	3.61	3.50
2	1.14	2.00	2.33	0.00	4.00
3	1.00	2.00	0.00	12.00	4.00
4	0.50	0.83	3.15	4.23	5.30
5	0.00	0.00	3.50	0.00	12.00

Table 35: Trip Rates for HBNWE1 (Non-MXD) under S_1

Trip Rates for HBNWE1 (Non-MXD)					
Income	One	Two	Three	Four	Five+
1	0.00	0.08	0.89	2.23	3.57
2	0.00	0.04	0.90	2.18	4.03
3	0.00	0.06	0.70	2.27	3.03
4	0.00	0.02	0.76	2.31	3.06
5	0.00	0.02	0.81	2.18	3.39

Table 36: Trip Rates for HBNWE1 (MXD) under S_1 by using REG

Trip Rates for HBNWE1 (MXD_REG)					
Income	One	Two	Three	Four	Five+
1	0.00	0.39	1.29	2.18	3.07
2	0.00	0.34	1.24	2.13	3.02
3	0.00	0.30	1.19	2.08	2.97
4	0.00	0.25	1.14	2.03	2.93
5	0.00	0.20	1.09	1.98	2.88

Table 37: Trip Rates for HBNWE1 (MXD) under S_1 by using MEAN

Trip Rates for HBNWE1 (MXD_MEAN)					
Income	One	Two	Three	Four	Five+
1	0.00	0.00	0.00	1.30	3.00
2	0.00	0.40	0.67	2.00	5.00
3	0.00	0.00	1.00	3.00	2.00
4	0.00	0.00	0.00	1.30	1.30
5	0.00	0.00	0.50	0.00	5.00

Table 38: Trip Rates for HBNWE1 (MXD) under S_1 by using REG_MIS

Trip Rates for HBNWE1 (MXD_REG_MIS)					
Income	One	Two	Three	Four	Five+
1	0.00	0.00	0.00	2.18	3.00
2	0.00	0.40	0.67	2.00	5.00
3	0.00	0.00	1.00	3.00	2.00
4	0.00	0.00	0.00	2.03	2.93
5	0.00	0.00	0.50	0.00	5.00

Table 39: Trip Rates for HBNWE2 (Non-MXD) under S_1

Trip Rates for HBNWE2 (Non-MXD)					
Income	One	Two	Three	Four	Five+
1	0.05	0.13	0.30	0.08	0.10
2	0.00	0.01	0.12	0.00	0.06
3	0.06	0.03	0.17	0.02	0.13
4	0.00	0.06	0.00	0.12	0.11
5	0.00	0.02	0.10	0.17	0.13

Table 40: Trip Rates for HBNWE2 (MXD) under S_1 by using REG

Trip Rates for HBNWE2 (MXD_REG)					
Income	One	Two	Three	Four	Five+
1	0.17	0.33	0.49	0.65	0.81
2	0.06	0.22	0.38	0.54	0.70
3	0.00	0.11	0.27	0.43	0.58
4	0.00	0.00	0.16	0.31	0.47
5	0.00	0.00	0.04	0.20	0.36

Table 41: Trip Rates for HBNWE2 (MXD) under S_1 by using MEAN

Trip Rates for HBNWE2 (MXD_MEAN)					
Income	One	Two	Three	Four	Five+
1	0.00	0.00	0.00	0.09	3.50
2	0.00	0.00	0.00	0.00	0.00
3	0.00	0.33	0.00	0.00	0.00
4	0.00	0.67	0.25	0.09	0.09
5	0.00	0.00	0.50	0.00	0.00

Table 42: Trip Rates for HBNWE2 (MXD) under S_1 by using REG_MIS

Trip Rates for HBNWE2 (MXD_REG_MIS)					
Income	One	Two	Three	Four	Five+
1	0.00	0.00	0.00	0.65	3.50
2	0.00	0.00	0.00	0.00	0.00
3	0.00	0.33	0.00	0.00	0.00
4	0.00	0.67	0.25	0.31	0.47
5	0.00	0.00	0.50	0.00	0.00

Table 43: Trip Rates for NWAIR (Non-MXD) under S_1

Trip Rates for NWAIR (Non-MXD)					
Income	One	Two	Three	Four	Five+
1	0.00	0.04	0.00	0.00	0.00
2	0.00	0.01	0.00	0.10	0.00
3	0.04	0.00	0.02	0.00	0.00
4	0.05	0.00	0.00	0.05	0.06
5	0.00	0.04	0.11	0.12	0.00

Table 44: Trip Rates for NWAIR (MXD) under S_1 by using REG

Trip Rates for NWAIR (MXD_REG)					
Income	One	Two	Three	Four	Five+
1	0.14	0.03	0.00	0.00	0.00
2	0.26	0.15	0.04	0.00	0.00
3	0.39	0.28	0.17	0.06	0.00
4	0.52	0.41	0.30	0.19	0.07
5	0.64	0.53	0.42	0.31	0.20

Table 45: Trip Rates for NWAIR (MXD) under S_1 by using MEAN

Trip Rates for NWAIR (MXD_MEAN)					
Income	One	Two	Three	Four	Five+
1	0.00	0.00	0.00	0.03	0.00
2	0.00	0.00	0.00	0.00	0.00
3	0.00	1.00	0.00	0.00	0.00
4	0.00	0.67	0.00	0.03	0.03
5	2.00	0.00	0.50	0.00	0.00

Table 46: Trip Rates for NWAIR (MXD) under S_1 by using REG_MIS

Trip Rates for NWAIR (MXD_REG_MIS)					
Income	One	Two	Three	Four	Five+
1	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00
3	0.00	1.00	0.00	0.00	0.00
4	0.00	0.67	0.00	0.19	0.07
5	2.00	0.00	0.50	0.00	0.00

Table 47: Trip Rates for NHBW (Non-MXD) under S_1

Trip Rates for NHBW (Non-MXD)					
Income	One	Two	Three	Four	Five+
1	0.09	0.17	0.30	0.77	0.40
2	0.27	0.54	0.50	0.44	0.55
3	0.38	0.60	0.64	1.24	0.97
4	0.57	0.61	1.07	1.29	1.58
5	1.13	1.04	1.51	1.37	2.22

Table 48: Trip Rates for NHBW (MXD) under S_1 by using REG

Trip Rates for NHBW (MXD_REG)					
Income	One	Two	Three	Four	Five+
1	0.06	0.30	0.54	0.78	1.02
2	0.25	0.49	0.73	0.96	1.20
3	0.44	0.67	0.91	1.15	1.39
4	0.62	0.86	1.10	1.34	1.58
5	0.81	1.05	1.29	1.53	1.77

Table 49: Trip Rates for NHBW (MXD) under S_1 by using MEAN

Trip Rates for NHBW (MXD_MEAN)					
Income	One	Two	Three	Four	Five+
1	0.00	0.00	0.67	0.81	0.00
2	0.71	1.60	0.67	2.00	3.00
3	0.33	0.33	0.00	0.00	0.00
4	0.00	0.33	2.00	0.81	0.81
5	0.00	2.00	2.00	2.00	1.50

Table 50: Trip Rates for NHBW (MXD) under S_1 by using REG_MIS

Trip Rates for NHBW (MXD_REG_MIS)					
Income	One	Two	Three	Four	Five+
1	0.00	0.00	0.67	0.78	0.00
2	0.71	1.60	0.67	2.00	3.00
3	0.33	0.33	0.00	0.00	0.00
4	0.00	0.33	2.00	1.34	1.58
5	0.00	2.00	2.00	2.00	1.50

Table 51: Trip Rates for NHBO (Non-MXD) under S_1

Trip Rates for NHBO (Non-MXD)					
Income	One	Two	Three	Four	Five+
1	1.00	1.05	2.37	1.85	1.93
2	0.91	1.27	0.96	1.13	2.29
3	0.72	1.09	1.04	1.41	3.41
4	0.86	1.36	1.20	1.95	4.58
5	0.75	1.15	1.81	3.18	4.83

Table 52: Trip Rates for NHBO (MXD) under S_1 by using REG

Trip Rates for NHBO (MXD_REG)					
Income	One	Two	Three	Four	Five+
1	0.43	1.20	1.98	2.75	3.53
2	0.19	0.97	1.74	2.52	3.30
3	0.00	0.74	1.51	2.29	3.06
4	0.00	0.50	1.28	2.05	2.83
5	0.00	0.27	1.04	1.82	2.60

Table 53: Trip Rates for NHBO (MXD) under S_1 by using MEAN

Trip Rates for NHBO (MXD_MEAN)					
Income	One	Two	Three	Four	Five+
1	0.40	1.00	0.00	1.75	9.00
2	0.14	0.60	0.00	0.00	0.00
3	1.00	0.00	0.00	7.00	4.00
4	0.50	1.00	2.00	1.75	1.75
5	1.00	0.00	0.50	0.00	2.00

Table 54: Trip Rates for NHBO (MXD) under S_1 by using REG_MIS

Trip Rates for NHBO (MXD_REG_MIS)					
Income	One	Two	Three	Four	Five+
1	0.40	1.00	0.00	2.75	9.00
2	0.14	0.60	0.00	0.00	0.00
3	1.00	0.00	0.00	7.00	4.00
4	0.50	1.00	2.00	2.05	2.83
5	1.00	0.00	0.50	0.00	2.00

Table 55: Trip Rates for TRTX (Non-MXD) under S_1

Trip Rates for TRTX (Non-MXD)					
Income	One	Two	Three	Four	Five+
1	0.16	0.23	0.30	0.62	0.70
2	0.04	0.17	0.08	0.28	0.00
3	0.19	0.07	0.17	0.08	0.41
4	0.00	0.07	0.05	0.05	0.33
5	0.00	0.12	0.14	0.13	0.15

Table 56: Trip Rates for TRTX (MXD) under S_1 by using REG

Trip Rates for TRTX (MXD_REG)					
Income	One	Two	Three	Four	Five+
1	0.33	0.31	0.29	0.27	0.26
2	0.25	0.24	0.22	0.20	0.18
3	0.18	0.17	0.15	0.13	0.11
4	0.11	0.09	0.08	0.06	0.04
5	0.04	0.02	0.00	0.00	0.00

Table 57: Trip Rates for TRTX (MXD) under S_1 by using MEAN

Trip Rates for TRTX (MXD_MEAN)					
Income	One	Two	Three	Four	Five+
1	0.40	0.50	0.67	0.18	0.00
2	0.00	0.00	1.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.50	0.18	0.18
5	0.00	0.00	0.25	0.00	0.00

Table 58: Trip Rates for TRTX (MXD) under S_1 by using REG_MIS

Trip Rates for TRTX (MXD_REG_MIS)					
Income	One	Two	Three	Four	Five+
1	0.40	0.50	0.67	0.27	0.00
2	0.00	0.00	1.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.50	0.06	0.04
5	0.00	0.00	0.25	0.00	0.00

Table 59: Trip Rates for EXTER (Non-MXD) under S_1

Trip Rates for EXTER (Non-MXD)					
Income	One	Two	Three	Four	Five+
1	0.00	0.03	0.00	0.00	0.00
2	0.09	0.16	0.04	0.15	0.00
3	0.11	0.27	0.04	0.20	0.16
4	0.14	0.11	0.05	0.26	0.11
5	0.13	0.26	0.07	0.02	0.07

Table 60: Trip Rates for EXTER (MXD) under S_1

Trip Rates for EXTER (MXD)					
Income	One	Two	Three	Four	Five+
1	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00

(3) Trip Rates Summary

Despite limitation in sample size, the cross-tabulation shows interesting trip chaining patterns: MXD households make slightly more HBWD trips (average 1.507 person trips/household) than Non-MXD households (average 1.415 person trips/household), but much less HBWS trips (in average, 0.043 and 0.080 person trips/household in MXDs and non-MXDs, respectively). For HBWC, the average MXD trip chain rate (0.464 person trips/household) is much higher than that for Non-MXD (0.14 person trips/household). The variations may be attributed to the siting of schools and locations of community services. In MXDs, schools are relatively close to homes. School-age children are more likely to go to schools by themselves than those in non-MXDs. Similarly, stores, hospitals and other services tend to be more conveniently located in MXD neighborhoods than in non-MXDs. MXD residents thus are more likely to chain these activities with their commuting than non-MXD residents.

For HBNW, MXD residents make more retail trips than Non-MXD residents, likely due to more convenient access to retail shops that induce more trip making. In contrast, Non-MXD residents make more NHBO trips (1.66 person trips/household) than MXD residents (1.016 person trips/household). To understanding this difference, we may speculate that the Non-MXD residents live relatively farther away from service destinations and are thus more likely to perform NHB activities once they are away from homes.

2.2.2 Frequency of Produced Trips

Once all trip rates were calculated, we applied those tables to the first step of 4-step travel demand modeling and calculated trip productions as shown below. First, we compared the pros and cons of the three methods for filling missing information in trip tables. Then we select the best-fit method and report the result at the end of this section.

Table 61: Frequency of Produced Trips by using REG

Frequency of Produced Trips (REG)						
Trip purposes	Trip frequency for MXDs			Trip frequency for Non-MXDs		
	S_0	S_1	Difference (%)	S_0	S_1	Difference (%)
TOTAL	1134588	1621365	43%	4975183	190357	4%
HBWD	230213	332432	44%	1114689	155674	16%
HBWS	17408	11620	-33%	172530	64331	59%
HBWC	30099	127742	324%	116668	5763	5%
HBNWR	189542	360441	90%	708922	-15956	-2%
HBNWO	272632	327504	20%	1142320	-7970	-1%
HBNWE1	98203	124116	26%	482378	9490	2%
HBNWE2	9747	29309	201%	32155	-4397	-12%
NHBW	92333	103417	12%	444564	-10727	-2%
NHBO	160002	163823	2%	659983	588	0%

The REG method results in too many trip rates. This may be attributed to trip rates since there are not significant differences in trip rates among different social-demographic groups. One may challenge the reliability of this methods because too much information are manually set rather arbitrarily.

Table 62: Frequency of Produced Trips by using MEAN

Frequency of Produced Trips (MEAN)						
Trip purposes	Trip frequency for MXDs			Trip frequency for Non-MXDs		
	S_0	S_1	Difference (%)	S_0	S_1	Difference (%)
TOTAL	1134588	1205129	6%	4975183	190357	4%
HBWD	230213	224761	-2%	1114689	155674	16%
HBWS	17408	13140	-25%	172530	64331	59%
HBWC	30099	97882	225%	116668	5763	5%
HBNWR	189542	257167	36%	708922	-15956	-2%
HBNWO	272632	250388	-8%	1142320	-7970	-1%
HBNWE1	98203	73707	-25%	482378	9490	2%
HBNWE2	9747	16845	73%	32155	-4397	-12%
NHBW	92333	125606	36%	444564	-10727	-2%
NHBO	160002	92248	-42%	659983	588	0%

Different from REG, the MEAN method only estimated the trip rates for missing data (Table above). However, using regional average as the estimate for missing information ignores the variance among different social-demographic conditions.

Table 63: Frequency of Produced Trips by using REG_MIS

Frequency of Produced Trips (REG_MIS)						
Trip purposes	Trip frequency for MXDs			Trip frequency for Non-MXDs		
	S_0	S_1	Difference (%)	S_0	S_1	Difference (%)
TOTAL	1134588	1205129	6%	4975183	190357	4%
HBWD	230213	224761	-2%	1114689	155674	16%
HBWS	17408	13140	-25%	172530	64331	59%
HBWC	30099	97882	225%	116668	5763	5%
HBNWR	189542	257167	36%	708922	-15956	-2%
HBNWO	272632	250388	-8%	1142320	-7970	-1%
HBNWE1	98203	73707	-25%	482378	9490	2%
HBNWE2	9747	16845	73%	32155	-4397	-12%
NHBW	92333	125606	36%	444564	-10727	-2%
NHBO	160002	92248	-42%	659983	588	0%

REG_MIS recalculates the trip rates for missing data, but used the regression method which is different from MEAN. This method took the advantage of the other two methods. Therefore it is the best-fit method applied in estimating missing trip rates. For the final analysis, the results by applying this method were utilized.

Note that in scenario S_1 trip rates for MXDs and Non-MXDs differ. Comparing results of S_1 with those of S_0, it shows that more trips are generated in MXDs than those in Non-MXDs. Specifically, frequencies of trips for HBWC, HBNWR and NHBW appear much higher in MXDs than in Non-MXDs, while the frequencies for HBWD, HBWS and NHBO are lower.

2.2.3 Trip Network Distance

The following table shows the trip network distances for people living in MXDs and those living in Non-MXDs:

Table 64: Trip Network Distance for People in MXDs and Non-MXDs

Trip Purposes	Home in MXDs				Home in Non-MXDs			
	Number	Distance (Miles)			Number	Distance (Miles)		
		Mean	Max	Std. Dev		Mean	Max	Std. Dev
Total	518	7.46	21.81	4.44	12405	8.25	28.55	5.34
HBWD	104	7.38	21.64	4.89	1826	7.99	27.13	5.16
HBWS	3	0.04	0.08	0.04	156	0.06	0.47	0.08
HBWC	6	8.47	15.08	4.88	204	7.70	23.26	5.28
HBNWR	101	5.69	16.71	3.98	1968	8.89	28.55	5.61
HBNWO	131	8.05	18.25	4.04	3451	8.38	28.31	5.28
HBNWE1	34	7.69	13.25	3.03	1285	8.48	25.74	5.31
HBNWE2	8	10.13	17.77	4.01	96	8.88	23.09	5.46
NWAIR	11	6.48	15.41	4.10	39	5.53	13.76	3.68
NHBW	51	8.57	21.81	5.54	1031	8.00	25.91	5.16
NHBO	59	8.14	19.58	3.65	2145	8.34	28.24	5.15
TRTX	10	8.72	17.59	6.08	204	8.72	26.39	5.21

On average, the network trips distances in MXD areas are about 0.8 miles shorter than those in NON_MXD areas. Especially, we can find this gap is enlarged for HBNWR (3.2 miles shorter). The possible reason is that people living in MXDs have more convenient access to retail uses. It accords with our expectation.

2.2.4 Internal Rate of Capture

The table below reports internal rates of capture for each of the 42 MXDs in the study area.

Table 65: Internal Rate of Capital for Trips in MXDs and Non-MXDs

Variables	Trips in MXDs (n=1318)	Trips in Non-MXDs (n=11605)
Total Trips	1318	11605
Internal Trips	124	818
% Internal	9.41%	7.05%
By Purpose (% Internal)		
HBWD	8.91%	3.76%
HBWS	0.00%	2.67%
HBWC	0.00%	0.00%
HBNWR	6.25%	1.95%
HBNWO	5.46%	10.82%
HBNWE1	0.00%	11.81%
HBNWE2	13.33%	2.25%
NWAIR	0.00%	0.00%
NHBW	10.38%	3.67%
NHBO	17.46%	8.31%
TRTX	11.11%	8.02%

On average, 9.41% of MXD trips are internal, with both trip origins and destinations falling within identical MXD boundaries. This number is much higher than those in NON-MXD areas (7.05%). Specifically, the table also shows that MXDs absorb much more trips inside in terms of HBWD, HBNWR, HBNW2, NHBW and NHBO. It is demonstrated that more jobs, retail uses, schools, and services within MXDs make the need for external trips decreased a lot.

2.2.5 Person Miles Traveled

On average, a person living in MXDs travels 30 miles daily, about 1.2 miles less than those living outside MXDs. The difference between people living in MXDs and those in Non- MXDs, can be mainly attributed to shorter trips for HBNWR.

Table 66: Person Miles Traveled for People in MXDs and Non-MXDs

Trip Purposes	Home in MXDs				Home in Non-MXDs			
	Number	PMT (Miles)			Number	PMT (Miles)		
		Mean	Max	Std. Dev		Mean	Max	Std. Dev
Total	128	30.20	193.1	28.96	3258	31.43	378.9	30.36
HBWD	46	16.68	106.6	17.66	851	17.15	146.6	12.17
HBWS	1	0.12	NA	NA	52	0.18	0.6	0.18
HBWC	6	8.47	15.08	4.88	204	7.70	23.3	5.28
HBNWR	50	11.50	39.42	8.45	1117	15.62	95.9	12.90
HBNWO	52	20.28	93.99	16.31	1536	18.84	166.2	17.97
HBNWE1	19	13.76	26.42	6.44	719	15.16	47.9	10.20
HBNWE2	5	16.20	23.26	7.50	50	17.05	70.5	12.85
NWAIR	6	11.89	24.31	8.30	22	9.81	26.2	6.77
NHBW	24	18.22	54.69	13.62	472	17.42	359.2	24.32
NHBO	32	15.00	42.00	11.29	1069	16.67	131.6	16.38
TRTX	6	14.54	47.18	16.32	119	14.14	66.5	11.92

3. Analysis of VMT and Emissions from MXD vs Non-MXD Travel

3.1 RELATED STUDIES

There is a large volume of literature on the land use-travel connection. This review focuses on the relationship between built environmental characteristics and VMT, which in turn links to GHG emissions.

VMT is a function of trip distance, trip frequency, and share of motorized travel. Hence, strategies that modify one or all of these elements will affect the VMT outcome. Transit-oriented development (TOD) is an example of such strategies. Studies have estimated that one transit passenger-mile represents 1.4 to 9.0 miles of reduction in vehicle miles (Holtzcaw et al. 2002). VMT generated from TOD residents is half that of typical suburban communities (Holtzclaw 1999). A recent study by Zhang (2010) for the Austin, TX region estimated a VMT reduction of 21 – 27 percent associated with the region's TOD scenarios. Job and household relocations in the TOD scenarios attribute to the simulated VMT reductions as average trip length shortens. In the Portland, Oregon area, the regional land use-transportation model, namely LUTRAQ predicts that transit-oriented development likely reduces vehicle trips by 77 percent and VMT by 13.6 percent.

Mixed-use development brings trip destinations (e.g., stores, jobs, schools, et al.) close to trip origins (e.g., homes, work sites). From the transportation service perspective, improved urban design with a more pedestrian- or bicyclist-friendly environment means improved quality for walkers or cyclists (Moudon et. al., 1997). It is thus expected that more mixed-use development and a better pedestrian/biking environment lead to fewer and/or shorter driving and more walking/biking. Empirical evidence reported from the San Francisco Bay Area has confirmed these hypotheses (Kockelman 1997; Cervero and Kockelman 1997). They found that mixed use development pattern also helped reduce VMT; for every one percent increase in land use mix VMT declined by 5~11 percent. A most recently released Transportation Research

Board (TRB) Special Report #298 (TRB, 2009) reviews extensively existing studies and summarizes that: 1) Developing more compactly, that is, at higher residential and employment densities, is likely to reduce VMT; 2) More compact, mixed-use development can produce reductions in energy consumption and CO2 emissions both directly and indirectly; 3) Significant increases in more compact, mixed-use development will result in modest short-term reductions in energy consumption and CO2 emissions), but these reductions will grow over time.

Scholars however have been cautious in generalizing the relationship between land use and VMT. Changes in the built environment (or specific features of it) may influence various aspects of travel in different directions, which suggests unclear net effect on travel outcome. For example, when density increases or land use mix improves (i.e., more balanced job-housing distribution), the average trip distance may decrease, all else being held equal. The decrease in average trip distance, however, suggests a fall in the price of travel, which may induce additional travel, for instance, by way of increased trip frequency (Crane 1996, Crane and Crepeau 1998, and Handy 1996). The final outcome of the combined shorter trip distance and higher trip frequency is thus determined empirically. Rodriguez, et al. (2006) found that at the metropolitan level, urban containment policies were associated with higher population densities but more per capita miles traveled.

The study by Frank, et al (2000) is among the few early efforts that relate directly the attributes of the built environment to vehicle emissions of nitrogen oxides (NOx), carbon monoxide (CO), and volatile organic compounds (VOC). Utilizing panel travel survey and census data from the Puget Sound, Washington area and the base emission rates from MOBILE5a, the authors estimate total vehicle emissions as a function of the built environmental features in addition to fleet characteristics and household socioeconomic characteristics. The study findings suggest a significant inverse relationship between household/employment density and vehicle emissions. Street connectivity matters to nitrogen oxides emissions. Accordingly the authors recommend policies to reducing vehicle emissions through the configuration and siting of future development and transportation network improvement within the Puget Sound region. Nonetheless, the authors are ambiguous on how higher densities relate to local emissions.

A recent study raised such a concern and investigated at the disaggregate level the connection between the built environment and vehicle emissions. Utilizing detailed GPS second-by-second travel recordings, Wang (2010) found that more per mile vehicle emissions were associated with higher development densities in the Greater Detroit area; The recorded travel speeds were lower and there were more stop-and-go movements relative to less dense places. It should be pointed out that the study is limited in sample size with a group of 85 sampled drivers. Hence the study findings should be interpreted with caution.

This study aims at contributing to the knowledge base of the relationship among urban form, VMT, GHG emission by offering empirical evidence from the Austin, TX area.

3.2 Study Approach

A critical part of the study method concerns emission estimation. Emission rates vary significantly along with such factors as vehicle types, vehicle age, operating speed, temperature and others. In estimating emissions the study follows the approach suggested by Frank, et al. (2000) and considers these factors in a multi-stage of engine operating mode (cold start, hot start and stable running). Instead of estimating emissions with MOBILE5a, this study relies on emission information published by secondary sources. Specifically, it borrows emission rates estimated with MOBILE5a by Environmental Science Activities for the 21st Century, a project supported by the U.S. National Science Foundation (ESA21, 2010). Table 67 shows the base emission rates for NOx, CO and VOC used for this study.

Table 67: Base Emission Rates

	Running Average (gram/mile)	Cold Start (gram/start)	Total (gram/mile)
NOx	1.34	2.1	3.34
CO	6.4	19.7	26.1
VOC	1.3	2.5	3.8
Source: ESA21 (2010)			

A person's daily driving emissions is the sum of cold-start emissions and running emissions over the distance driven. In this study, cold-start refers to the vehicle start after a 2-hour or longer soak time (Shafizadeh, et al 2007). Specifically,

$$Emission_i = \#Cold\_Start \times Cold\_Start\_Emission\_Rate_i + Running\_Aerage\_Emission\_Rate_i \times Miles\_Driven$$

Where i denotes NOx, CO, and VOC, respectively.

Summing NOx, CO and VOC emissions for each person gives personal total emissions in a day.

Additional adjustments are made considering vehicle age and operating speed. The 2005 Austin travel survey reports household vehicle information, including make, model year, fuel type, odometer reading (incomplete), and identifier linking the vehicle to the specific trip made by an household individual in the survey day. Vehicle age adjustment is made based on the relationship between emission rates and vehicle model years shown in ESA21 (2010). Vehicle speeds are derived from the reported trip times and distances in the travel survey. Figure 1 shows the relationship between vehicle speed and emission rates of three major pollutants; based on the relationship travel emissions are adjusted.

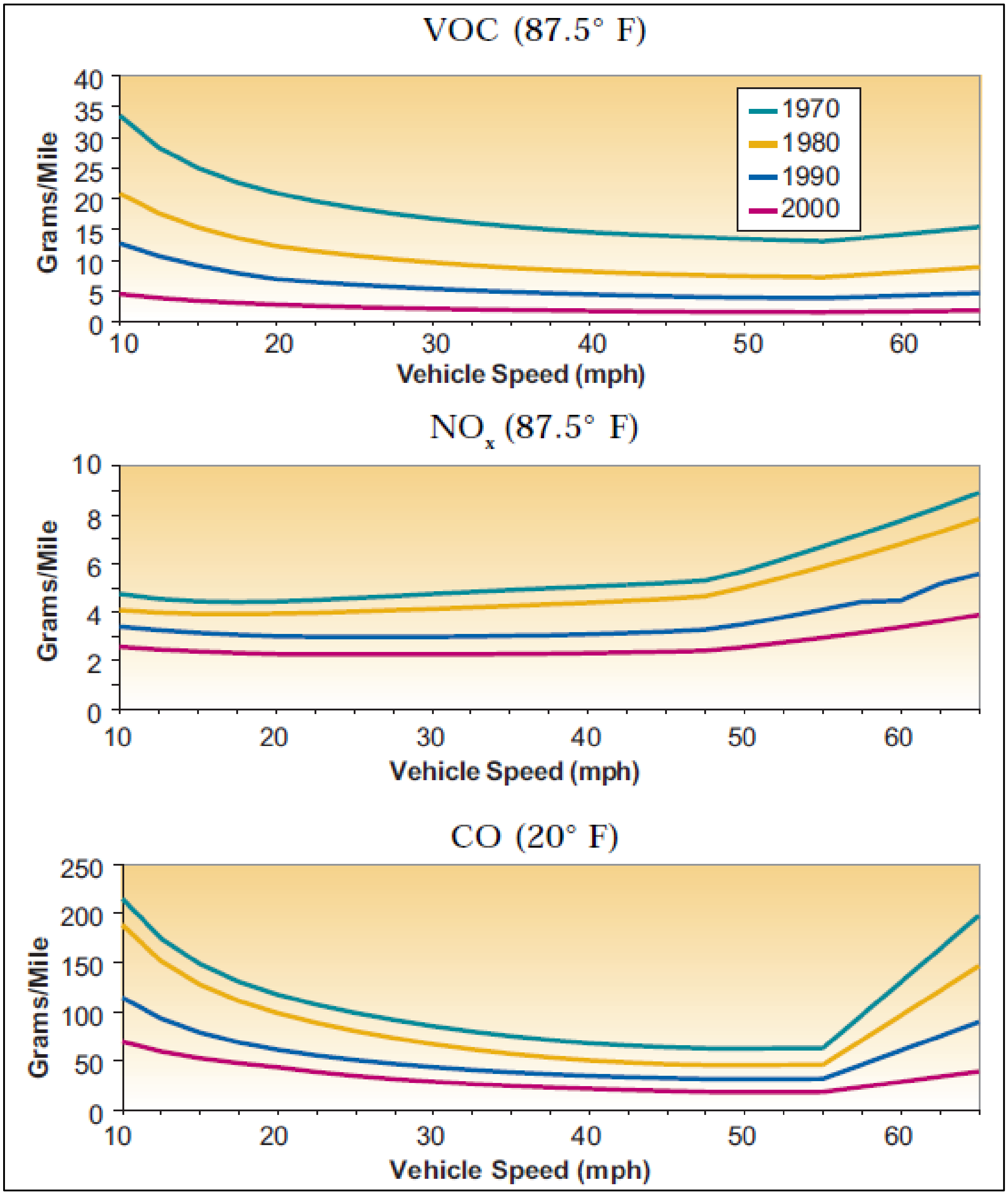

Figure 1: ***Vehicle Speed and Emission Relationship***

Source: ESA21 (2010)

3.3 ANALYSIS AND RESULTS

Table 3 portrays a general picture of personal travel by all means of transportation in the Austin, TX area. On average, a person living in MXDs travels 17 miles daily, about six miles less than those living outside MXDs. The difference may be attributed to shorter travel distances for HBNW and NHBO purposes (Table 68).

Table 68: Average Person-Miles of Travel by Households In- and Out-of-MXDs

	Home Inside MXDs (n=123)				Home Outside MXDs (n=3,264)				
Variable	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max	t-test
PMT/Day	17.0	16.5	0.3	84.0	23.2	22.6	0.0	276.0	-3.00
By Purpose									
HBW	5.8	11.5	0.0	71.7	5.9	13.1	0.0	100.7	-0.14
HBNW	8.3	10.2	0.0	61.9	12.2	15.3	0.0	120.7	-2.81
NHBW	1.3	4.9	0.0	33.2	1.9	7.5	0.0	214.9	-0.77
NHBO	1.7	5.1	0.0	36.2	3.2	8.9	0.0	92.4	-1.94
By Travel Mode									
Walk/Bike	0.4	1.8	0.0	16.4	0.7	3.2	0.0	56.3	-1.21
Drive Alone	10.1	14.5	0.0	67.0	11.8	18.4	0.0	143.0	-1.02
Carpool	6.4	10.5	0.0	71.7	10.4	16.8	0.0	123.0	-2.63
Transit	0.1	0.9	0.0	9.7	0.2	5.1	0.0	276.0	-0.17
Other	0.0	0.2	0.0	1.8	0.1	1.2	0.0	50.9	-0.27

Table 69 reports results of estimated daily emissions at the individual level. In this table, only those who drove as the driver in the survey day are included. Data records with individuals choosing driving modes as passengers are excluded. Therefore the reported person miles traveled (PMT) equate the vehicle miles traveled (VMT) of the sampled individual. The top section is for those living in the MXDs, whereas the mid-section for residents living in the rest of the region. On average, a driver living in the MXD emitted daily 42.88, 241.13, and 28.87 grams of NOx, CO, and VOC, respectively. Notably, the emitted amount is lower in each of the three items than an average suburban counterpart who emitted daily 68.34, 366.24, and 40.64 grams, respectively. Compared to the suburban residents, the MXD residents tend to own slightly older vehicles at an average vehicle age of 7.17 in 1999-2000 model years vs. 6.98 in 2000-2001 model years. Furthermore, they operate at a lower average speed (19.15 mph vs. 24.53 mph). It suggests that on a per mile basis, the MXD driver likely emits more than the suburban driver. Nevertheless, the suburban driver's long daily driving (28.45 miles on average) wipes out the benefit of driving a newer vehicle at a higher speed; an MXD driver drives 9.52 fewer miles a day and hence emits 162.3 gram less or 34% lower than his/her suburban counterpart.

The bottom section of Table 69 reports emissions by a driver who does not live in MXDs and is neither a typical suburban resident; the person lives in non-MXD TAZs that are adjacent to MXDs and mostly are urban residents. They are thus labeled as Urban non-MXDs. To eliminate possible distortions caused by downtown residents, the subsample excludes those sampled individuals living in Austin downtown (no MXDs are located in the downtown). It is interesting (and surprising) to see that the MXD resident out-emitted the urban non-MXD residents in NOx, CO, and VOC. Possible explanations to the results are MXD residents' more frequent trip-making (indicated by more cold-starts) coupling with a slower average driving speed. Higher development density and more mixed uses in MXDs likely contribute to higher trip frequencies and lower driving speeds of MXD residents than others.

Table 69: Emission Characteristics of MXD vs. Non-MXD Residents in Austin, TX

MXD (n=97)				
Variable	Mean	Std. Dev.	Min	Max
NOx Emission (g/day)	44.16	39.45	1.86	178.20
CO Emission (g/day)	253.11	197.86	16.48	860.01
VOC Emission (g/day)	30.39	25.93	1.38	128.78
Total Emission (g/day)	327.67	261.21	19.72	1152.35
Emission Density (g/mile)	29.47	22.37	9.14	139.72
Vehicle Speed (mph)	19.15	11.41	2.88	51.14
Vehicle Age (years)	7.17	5.81	0.00	37.00
Cold Start (times)	1.55	0.71	0.00	4.00
All Trip Frequency	3.78	2.51	1.00	15.00
Vehicle Miles Driven	18.93	19.32	0.53	97.14
Region Wide Non-MXD (n=2227)				
Variable	Mean	Std. Dev.	Min	Max
NOx Emission (g/day)	69.43	65.26	0.09	706.02
CO Emission (g/day)	376.45	328.87	0.93	3595.79
VOC Emission (g/day)	41.93	34.25	0.05	447.76
Total Emission (g/day)	487.81	424.78	1.07	4749.57
Emission Density (g/mile)	23.22	20.20	9.14	631.41
Vehicle Speed (mph)	24.53	12.95	0.05	70.00
Vehicle Age (years)	6.98	4.93	0.00	45.00
Cold Start (times)	1.47	0.76	0.00	5.00
All Trip Frequency	3.89	2.51	1.00	31.00
Vehicle Miles Driven	28.45	26.07	0.02	342.51
Urban Non-MXD (not including CBD) (n=1,412)				
Variable	Mean	Std. Dev.	Min	Max
NOx Emission (g/day)	33.06	32.42	0.15	284.55
CO Emission (g/day)	181.65	164.90	1.52	1372.80
VOC Emission (g/day)	19.87	16.23	0.18	130.74
Total Emission (g/day)	234.58	211.60	1.86	1711.17
Emission Density (g/mile)	22.57	15.08	9.14	182.54
Vehicle Speed (mph)	23.76	14.22	0.70	70.00
Vehicle Age (years)	7.00	4.95	0.00	45.00
Cold Start (times)	0.72	0.76	0.00	4.00
All Trip Frequency	2.17	1.58	1.00	14.00
Vehicle Miles Driven	13.26	12.13	0.07	100.57

To understand factors explaining the shorter VMT of MXD travelers, a regression model was estimated (Table 70). Notably, aside from individual and household socioeconomic factors, urban form factors contribute additional explanatory power to the VMT variance. Specifically, living one mile farther from the city center is associated with 0.235 more daily VMT. On the other hand, an increase in density by one additional person per acre likely reduces personal daily VMT by 0.435 miles. Roadway supply also matters; one more linear feet of street length per acre is associated with 0.08 less VMT. The result makes intuitive sense: when street density is high, the driver can readily find direct path between origin and destination. The coefficients for job density and share of cul-de-sac intersections display expected signs; yet they do not carry statistical significance at the 10% level.

Table 70: Regression Analysis of Average Vehicle Miles of Travel

	Coef.	Std. Err.	t-Stat.	
Age (years)	-0.0614	0.0403	-1.52	
Gender (1: Female; 0: Male)	-4.7859	1.0069	-4.75	**
Employed (1: Yes; 0: No)	8.0547	1.2070	6.67	**
Student (1: Yes; 0: No)	-2.3412	2.1992	-1.06	
With Passengers in Vehicle	3.7179	0.2658	13.99	**
Household Size (Persons)	2.1821	0.7203	3.03	**
Income Per Capita (2005 $)	0.1492	0.0325	4.60	**
Vehicles Per Capita	6.9779	1.5215	4.59	**
Years in Residence	0.1839	0.3210	0.57	
Distance to Downtown (Miles)	0.2350	0.0528	4.45	**
Population Density (Persons/Acre)	-0.4353	0.1788	-2.43	**
Job Density (Jobs/Acre)	-0.0890	0.1241	-0.72	
% Cul de sac Intersections	0.6356	5.0268	0.13	
Street Density (Feet/Acre)	-0.0764	0.0155	-4.93	**
Constant	15.4725	4.1365	3.74	**
Number of obs: 2,227				
R-squared: 0.200				
Adj R-squared: 0.195				

*Note: * Significant at 0.01 level; ** Significant at 0.05 level.*

Additional regression models are estimated to explain personal total emissions (Table 71) and emission density or total emission per mile distance driven (Table 72). VMT is undoubtedly a strong predictor of total emissions; results reported in Table 6 indicate nearly 15 grams more emissions associated with one additional VMT. Female drivers tend to emit less than male drivers while larger household size and higher per capita vehicle ownership are associated with more daily emissions. Interestingly, total daily emissions correlate negatively with higher income, presumably due to newer vehicles (lower emission rates) owned by the higher income

(The model specification did not include vehicle age explicitly for the consideration that the emission rates were not observed but derived from vehicle age and other variables. Including vehicle age in the emission model would then cause endogeneity problems.) Population density turns out significant at the 10% level in explaining total emissions after the effects of VMT and driver socioeconomic characteristics are controlled. If the average density increases by one person per acre, daily personal emissions likely rise by 1.64 grams.

Table 71: Explaining Total Emissions (g/day)

	Coef.	Std. Err.	t-Stat.	
Vehicle Miles Traveled	14.8625	0.1476	100.66	**
Age (years)	-0.3923	0.2549	-1.54	
Gender (1: Female; 0: Male)	-24.1092	7.4021	-3.26	**
Household Size (Persons)	10.0004	3.1662	3.16	**
Vehicles Per Capita	72.4459	12.0175	6.03	**
Income Per Capita (2005 $)	-0.0017	0.0002	-6.80	**
Population Density (Persons/Acre)	1.6381	0.8871	1.85	*
Constant	35.4009	25.0440	1.41	
Number of obs: 2,227				
R-squared: 0.834				
Adj R-squared: 0.833				

*Note: * Significant at 0.01 level; ** Significant at 0.05 level.*

The emission density model performs fairly poor, with an adjusted R-squared value of 0.018. Two variables appearing significant at the 1% level are income per capita and population density. Their coefficients have consistent signs with those in the total daily emission model (Table 71): higher income predicts lower emission density, whereas higher population density is associated with higher per mile emission. This is again attributable to lower traffic speed in denser area. For the same reason as above, the model specification did not speed variable. To confirm, a traffic speed model was estimated as a function of density along with others (Table 73). The results suggest that increasing population density by one person per acre would likely decrease traffic speed by 0.63 miles per hour, all else being equal.

Table 72: Explaining Emission Density (g/mile)

	Coef.	Std. Err.	t-Stat.	
Age (years)	0.0309	0.0294	1.05	
Gender (1: Female; 0: Male)	0.3620	0.8507	0.43	
Household Size (Persons)	0.0203	0.3645	0.06	
Vehicles Per Capita	0.8361	1.3841	0.60	
Income Per Capita (2005 $)	-0.0001	0.0000	-4.25	**
Population Density (Persons/Acre)	0.4771	0.0995	4.80	**
Constant	21.1448	2.8514	7.42	**
Number of obs: 2,227				
R-squared: 0.021				
Adj R-squared: 0.018				

*Note: * Significant at 0.01 level; ** Significant at 0.05 level.*

Table 73: Explaining Driving Speed (miles/hour)

	Coef.	Std. Err.	t-Stat.	
Age (years)	-0.0623	0.0182	-3.43	**
Gender (1: Female; 0: Male)	-1.5410	0.5278	-2.92	**
Household Size (Persons)	0.1287	0.2272	0.57	
Vehicles Per Capita	3.1850	0.8586	3.71	**
Income Per Capita (2005 $)	0.0000	0.0000	1.08	
Vehicle Age (years)	-0.1767	0.0547	-3.23	**
Population Density (Persons/Acre)	-0.6253	0.0662	-9.45	**
% Cul-de-Sac Intersection	10.1647	2.3374	4.35	**
Constant	26.8282	1.8843	14.24	**
Number of obs: 2,227				
R-squared: 0.021				
Adj R-squared: 0.018				

*Note: * Significant at 0.01 level; ** Significant at 0.05 level.*

4. Summary of Findings and Conclusions

4.1 On Trip Generation and MXD

Land use planner, urban designer and transportation professions have had converging interest in the potential of altering urban form to alter travel outcome. Yet, when it comes to the implementation stage, there are a lot of barriers coming from both technical and non-technical aspects. This study focuses on the technical side and intend to integrate transportation planning and land use patterns. The research incorporated land use patterns and design metrics directly in the first three steps of the 4-step travel demand modeling procedures. The approach is illustrated through the Austin MSA, TX.

The study first identified MXD sites in the Austin, TX area and then analyzed travel characteristics associated with the MXDs vs. non-MXDs. Main results are summarized below:

1) Per CAMPO HBW classification, MXD households make slightly more HBWD trips than non-MXD households, but much less HBWS trips. For HBWC, the average MXD trip chain rate is much higher than that for non-MXD. For HBNW, MXD residents make more retail trips than Non-MXD residents, while Non-MXD residents make more NHBO trips (1.66 person trips/household) than MXD residents (1.016 person trips/household);
2) For frequency of produced trips, generally, more trips are generated in MXDs. Specifically, frequency of trips for HBWC, HBNWR and NHBW increase a lot in MXDs, while that for HBWD, HBWS and NHBO decrease a little bit;
3) On average, the network trips distances in MXD areas are about 0.8 mile shorter than those in NON_MXD areas. Especially, we can find this gap is enlarged for HBNWR (3.2 miles shorter);
4) For the internal rates of capture, 9.41% of MXD trips are internal, with both trip origins and destinations falling within identical MXD boundaries. This number is much higher than those in NON-MXD areas. Specifically, MXDs absorb much more trips inside in terms of HBWD, HBNWR, HBNW2, NHBW and NHBO.

5) On average, a person living in MXDs travels 30 miles daily, about 1.2 miles less than those living outside MXDs. The difference between people living in MXDs and those in Non- MXDs, can be mainly attributed to shorter trips for HBNWR.

The results suggest areas in which CAMPO models can be modified or refined to capture the potential effects of the Activity Centers growth strategy on regional travel, for instance, revising trip rates for trip production and attraction modeling and improving estimation of internal trip making by including land use pattern indicators. Also, differences between MXD and Non-MXD in travel as reported above could have significant implications region wide.

Yet it should also be pointed out that fully incorporating the results in CAMPO planning process still requires additional efforts. For example, supplemental surveys of travel in the MXDs will be needed in order to apply this spatial grouping method. It is non-trivial task to accomplish what are suggested so far.

4.2 ON VMT AND GHG RELATING TO MXD

The study of Austin, TX region shows a rather complex picture on the relationship among built environment, VMT, and GHG emissions. Region-wide, densification strategy potentially helps reduce regional VMT (indicated by the results shown in Table 69) and consequently decrease regional emissions. Locally, however, higher population density is associated with higher emission density. While an MXD driver living in dense, mixed use neighborhoods emits less than a suburban driver, a non-MXD urban resident likely emits even lesser! This poses a challenge to the land use-based strategies for GHG reduction—densification and mixed-use development function like a double-edged sword in terms of their effects on VMT and GHG emissions.

One implication of the study results is that densification strategies alone may not work well in achieving the goal of reducing transportation emissions. Restricting vehicle travel in dense, mixed use area is critical to minimize emissions due to frequent stops and low speed, which happen mostly in dense, mixed use areas. Furthermore, densification should be coupled with promoting green travel by non-motorized modes and low-emission transit. While it is practically infeasible to eliminate vehicle travel entirely throughout the city, it is worth asking whether there exists an optimal level of development density and land use mix for a given level of vehicle travel. The question certainly warrants further investigation both theoretically and empirically.

This exercise utilizes activity travel survey data to explore the relationship among urban form, VMT and transportation emissions. The findings show consistency with existing studies that use GPS recordings (e.g., Wang, 2010) or involve sophisticated MOBILE6 or MOVES modeling. As activity travel survey data are readily available in many metropolitan areas, the study demonstrates a relatively low-cost approach to investigate the urban form-emission connection. Further exploration is worthwhile along this line of inquiries.

There exist a number of limitations in this study. First, trip times are based on the self-reported travel durations of the surveyed individuals. Any reporting errors, which are highly likely, will affect speed estimate. Second, the trip distance is estimated based on the assumption that the traveler took the shortest route. This may not be the case in reality and therefore the estimate may introduce inaccuracies in PMT and VMP estimates. Lastly, the study did not consider all categories of GHG emissions. The estimates can be fine-tuned with further consideration of vehicle age, model, and speed as well as other contextual factors such as temperature variations throughout the day.

To conclude, the project contributes to transportation planning and policy making in Central Texas by providing local empirical evidence on land use pattern-travel indicator connection. The study's method and process can be of interest to a broad audience in academia and practice.

Appendix

SQL Coding for Classification of Trip Purposes:

```
SELECT * INTO Trip_D
FROM aussurvey06
WHERE Not ACTNUM=0
ORDER BY N_ID;
SELECT aussurvey06.* INTO Trip_O
FROM aussurvey06, Trip_D
WHERE aussurvey06.N_ID=Trip_D.N_ID-1;
SELECT * INTO Trip_Exter
FROM Trip_Total
WHERE O_LOCATION_1>5 OR D_LOCATION_1>5
ORDER BY TRIP_ID;
FROM Trip_Total
WHERE O_LOCATION_1<6 AND D_LOCATION_1<6
ORDER BY TRIP_ID;
SELECT DISTINCT PERSONID INTO People
FROM Trip_Inter
ORDER BY PERSONID;
SELECT * INTO People_HBW
FROM People
WHERE PERSONID IN
                          ( SELECT PERSONID
                            FROM Trip_Inter
                            WHERE O_PURPOSE=1 AND (D_PURPOSE=3 OR
D_PURPOSE=4)
                            OR
                            (O_PURPOSE=3 OR O_PURPOSE=4) AND
D_PURPOSE=1)
ORDER BY PERSONID;
SELECT Trip_Inter.* INTO Trip_HBW_Related
FROM Trip_Inter, People_HBW
WHERE Trip_Inter.PERSONID=People_HBW.PERSONID
ORDER BY TRIP_ID;
SELECT DISTINCT PERSONID INTO HBW_D1_1
```

```
FROM Trip_HBW_Related
WHERE O_PURPOSE=1 AND (D_PURPOSE=3 OR D_PURPOSE=4);
SELECT DISTINCT PERSONID INTO HBW_D1_2
FROM Trip_HBW_Related
WHERE (O_PURPOSE=3 OR O_PURPOSE=4) AND (D_PURPOSE=1);
SELECT DISTINCT v.PERSONID INTO HBW_D1
FROM HBW_D1_1 AS i INNER JOIN HBW_D1_2 AS v ON i.PERSONID=v.PERSONID;
SELECT Trip_HBW_Related.* INTO Trip_HBW_D1
FROM Trip_HBW_Related, HBW_D1
WHERE (Trip_HBW_Related.PERSONID = HBW_D1.PERSONID)
        AND
        ((Trip_HBW_Related.O_PURPOSE=1 AND (Trip_HBW_Related.D_PURPOSE=3 OR
Trip_HBW_Related.D_PURPOSE=4)) OR ((Trip_HBW_Related.O_PURPOSE=3 OR
Trip_HBW_Related.O_PURPOSE=4) AND (Trip_HBW_Related.D_PURPOSE=1)))
ORDER BY TRIP_ID;
SELECT TRIP_ID, D_PURPOSE INTO HBW_D2_1A
FROM Trip_HBW_Related
WHERE TRIP_ID IN (SELECT TRIP_ID+1
FROM Trip_HBW_Related
                                                        WHERE
(O_PURPOSE=1) AND (LESS5MIN_TR=1));
SELECT DISTINCT TRIP_ID, PERSONID INTO HBW_D2_1
FROM Trip_HBW_Related
WHERE TRIP_ID IN (SELECT TRIP_ID
                        FROM HBW_D2_1A
                        WHERE D_PURPOSE=3 OR D_PURPOSE=4);
SELECT DISTINCT PERSONID INTO HBW_D2_2
FROM Trip_HBW_Related
WHERE (O_PURPOSE=3 OR O_PURPOSE=4) AND (D_PURPOSE=1);
SELECT DISTINCT v.PERSONID INTO HBW_D2
FROM HBW_D2_1 AS i INNER JOIN HBW_D2_2 AS v ON i.PERSONID=v.PERSONID;
SELECT DISTINCT Trip_HBW_Related.* INTO Trip_HBW_D2
FROM Trip_HBW_Related, HBW_D2, HBW_D2_1
WHERE (Trip_HBW_Related.PERSONID = HBW_D2.PERSONID)
        AND
        (((Trip_HBW_Related.O_PURPOSE=3 OR Trip_HBW_Related.O_PURPOSE=4) AND
(Trip_HBW_Related.D_PURPOSE=1))
```

```
                                        OR
                              Trip_HBW_Related.TRIP_ID=HBW_D2_1.TRIP_ID
                                        OR
                               Trip_HBW_Related.TRIP_ID=HBW_D2_1.TRIP_ID-1)
                             AND
                              (NOT (Trip_HBW_Related.O_PURPOSE=4 AND Trip_HBW_Related.D_PURPOSE=4
));
        SELECT TRIP_ID, D_PURPOSE INTO HBW_D3_1A
        FROM Trip_HBW_Related
        WHERE TRIP_ID IN (SELECT TRIP_ID+1
                                                                             FROM
Trip_HBW_Related
                                                                             WHERE
(O_PURPOSE=3 OR O_PURPOSE=4) AND (LESS5MIN_TR=1));
        SELECT DISTINCT TRIP_ID, PERSONID INTO HBW_D3_1
        FROM Trip_HBW_Related
        WHERE TRIP_ID IN (SELECT TRIP_ID
                                           FROM HBW_D3_1A
                                           WHERE D_PURPOSE=1);
        SELECT DISTINCT PERSONID INTO HBW_D3_2
        FROM Trip_HBW_Related
        WHERE (D_PURPOSE=3 OR D_PURPOSE=4) AND (O_PURPOSE=1);

        SELECT DISTINCT v.PERSONID INTO HBW_D3
        FROM HBW_D3_1 AS i INNER JOIN HBW_D3_2 AS v ON i.PERSONID=v.PERSONID;
        SELECT DISTINCT t3.* INTO Trip_HBW_D3
        FROM Trip_HBW_Related AS t3, HBW_D3 AS h3, HBW_D3_1 AS g3
        WHERE (t3.PERSONID = h3.PERSONID)
                             AND
                              (((t3.D_PURPOSE=3 OR t3.D_PURPOSE=4) AND (t3.O_PURPOSE=1))
                                        OR
                               t3.TRIP_ID=g3.TRIP_ID
                                        OR
                               t3.TRIP_ID=g3.TRIP_ID-1)
                             AND
                             (NOT ((t3.O_PURPOSE=4 AND t3.D_PURPOSE=4 ) OR (t3.O_PURPOSE=3 AND
t3.D_PURPOSE=4 ) OR (t3.O_PURPOSE=4 AND t3.D_PURPOSE=3 )) )
```

```
ORDER BY t3.TRIP_ID;
DELETE *
FROM Trip_HBW_D1
WHERE TRIP_ID IN (SELECT d1.TRIP_ID
                  FROM Trip_HBW_D1 d1, Trip_HBW_D2 d2, Trip_HBW_D3 d3
                  WHERE d1.TRIP_ID=d2.TRIP_ID OR
d1.TRIP_ID=d3.TRIP_ID);

DELETE *
FROM Trip_HBW_D2
WHERE TRIP_ID IN (SELECT d2.TRIP_ID
                  FROM Trip_HBW_D2 d2, Trip_HBW_D3 d3
                  WHERE d2.TRIP_ID=d3.TRIP_ID);
SELECT DISTINCT * INTO Trip_HBW_D
FROM Trip_HBW_Related
WHERE TRIP_ID IN (SELECT DISTINCT TRIP_ID
                  FROM Trip_HBW_D1)
      OR
      TRIP_ID IN (SELECT DISTINCT TRIP_ID
                  FROM Trip_HBW_D2)
      OR
      TRIP_ID IN (SELECT DISTINCT TRIP_ID
                  FROM Trip_HBW_D3);
SELECT DISTINCT * INTO Trip_HBW_ND
FROM Trip_HBW_Related
WHERE TRIP_ID NOT IN (SELECT DISTINCT TRIP_ID
                      FROM Trip_HBW_D);
SELECT TRIP_ID, D_PURPOSE INTO HBW_S1_1A
FROM Trip_HBW_ND
WHERE TRIP_ID IN (SELECT TRIP_ID+1
                                          FROM
Trip_HBW_ND
                                          WHERE
(O_PURPOSE=1) AND (D_PURPOSE=10));
SELECT DISTINCT TRIP_ID, PERSONID INTO HBW_S1_1
FROM Trip_HBW_ND
WHERE TRIP_ID IN (SELECT TRIP_ID
```

```
                                        FROM HBW_S1_1A
                                        WHERE D_PURPOSE=3 OR D_PURPOSE=4);
        SELECT DISTINCT PERSONID INTO HBW_S1_2
        FROM Trip_HBW_ND
        WHERE (O_PURPOSE=3 OR O_PURPOSE=4) AND (D_PURPOSE=1);
        SELECT DISTINCT TRIP_ID, PERSONID INTO HBW_S1_1
        FROM Trip_HBW_ND
        WHERE TRIP_ID IN (SELECT TRIP_ID
                                        FROM HBW_S1_1A
                                        WHERE D_PURPOSE=3 OR D_PURPOSE=4);
        SELECT DISTINCT Trip_HBW_ND.* INTO Trip_HBW_S1
        FROM Trip_HBW_ND, HBW_S1, HBW_S1_1
        WHERE (Trip_HBW_ND.PERSONID = HBW_S1.PERSONID)
                  AND
                   (((Trip_HBW_ND.O_PURPOSE=3    OR    Trip_HBW_ND.O_PURPOSE=4)    AND
(Trip_HBW_ND.D_PURPOSE=1))
                          OR
                   Trip_HBW_ND.TRIP_ID=HBW_S1_1.TRIP_ID
                          OR
                    Trip_HBW_ND.TRIP_ID=HBW_S1_1.TRIP_ID-1);

        SELECT TRIP_ID, D_PURPOSE INTO HBW_S2_1A
        FROM Trip_HBW_ND
        WHERE TRIP_ID IN (SELECT TRIP_ID+1
                                                                    FROM
Trip_HBW_ND
                                                                    WHERE
(O_PURPOSE=3 OR O_PURPOSE=4) AND (D_PURPOSE=10));
        SELECT DISTINCT TRIP_ID, PERSONID INTO HBW_S2_1
        FROM Trip_HBW_ND
        WHERE TRIP_ID IN (SELECT TRIP_ID
                                        FROM HBW_S2_1A
                                        WHERE D_PURPOSE=1);
        SELECT DISTINCT PERSONID INTO HBW_S2_2
        FROM Trip_HBW_ND
        WHERE (D_PURPOSE=3 OR D_PURPOSE=4) AND (O_PURPOSE=1)
        SELECT DISTINCT v.PERSONID INTO HBW_S2
```

```
FROM HBW_S2_1 AS i INNER JOIN HBW_S2_2 AS v ON i.PERSONID=v.PERSONID;
SELECT DISTINCT t3.* INTO Trip_HBW_S2
FROM Trip_HBW_ND AS t3, HBW_S2 AS h3, HBW_S2_1 AS g3
WHERE (t3.PERSONID = h3.PERSONID)
                AND
                 (((t3.D_PURPOSE=3 OR t3.D_PURPOSE=4) AND (t3.O_PURPOSE=1))
                          OR
                  t3.TRIP_ID=g3.TRIP_ID
                          OR
                  t3.TRIP_ID=g3.TRIP_ID-1)
ORDER BY t3.TRIP_ID;
SELECT DISTINCT * INTO Trip_HBW_S
FROM Trip_HBW_ND
WHERE TRIP_ID IN (SELECT DISTINCT TRIP_ID
                                    FROM Trip_HBW_S1)
                 OR
                 TRIP_ID IN (SELECT DISTINCT TRIP_ID
                                    FROM Trip_HBW_S2);
SELECT DISTINCT * INTO Trip_HBW_NDS
FROM Trip_HBW_ND
WHERE TRIP_ID NOT IN (SELECT DISTINCT TRIP_ID
                                          FROM Trip_HBW_S);
SELECT * INTO Trip_HBW_C
FROM Trip_HBW_NDS
WHERE (O_PURPOSE=1 AND (D_PURPOSE=3 OR D_PURPOSE=4 )) OR (D_PURPOSE=1 AND
(O_PURPOSE=3 OR O_PURPOSE=4 ));
SELECT DISTINCT * INTO Trip_N_HBW
FROM Trip_Inter
WHERE TRIP_ID NOT IN (SELECT DISTINCT TRIP_ID
                                          FROM Trip_HBW_D)
                 AND
                 TRIP_ID NOT IN (SELECT DISTINCT TRIP_ID
                                          FROM Trip_HBW_S)
                 AND
                 TRIP_ID NOT IN (SELECT DISTINCT TRIP_ID
                                          FROM Trip_HBW_C);
SELECT DISTINCT * INTO Trip_HBNW_R
```

```
FROM Trip_N_HBW
WHERE (O_PURPOSE=1 AND D_PURPOSE=7) OR (O_PURPOSE=7 AND D_PURPOSE=1);
SELECT DISTINCT * INTO Trip_NHBW_NR
FROM Trip_N_HBW
WHERE TRIP_ID NOT IN (SELECT TRIP_ID
                      FROM Trip_HBNW_R);
SELECT DISTINCT * INTO Trip_HBNW_E1
FROM Trip_NHBW_NR
WHERE (O_PURPOSE=1 AND D_PURPOSE=5) OR (O_PURPOSE=5 AND D_PURPOSE=1);
SELECT DISTINCT * INTO Trip_NHBW_NRE1
FROM Trip_NHBW_NR
WHERE TRIP_ID NOT IN (SELECT TRIP_ID
                      FROM Trip_HBNW_E1);
SELECT DISTINCT * INTO Trip_HBNW_E2
FROM Trip_NHBW_NRE1
WHERE (O_PURPOSE=1 AND D_PURPOSE=6) OR (O_PURPOSE=6 AND D_PURPOSE=1);

SELECT DISTINCT * INTO Trip_NHBW_NRE
FROM Trip_NHBW_NRE1
WHERE TRIP_ID NOT IN (SELECT TRIP_ID
                      FROM Trip_HBNW_E2);
SELECT DISTINCT * INTO Trip_NW_AIR
FROM Trip_NHBW_NRE
WHERE (O_TYPE_OF_PL=21 OR D_TYPE_OF_PL=21) AND (NOT O_PURPOSE=3) AND (NOT
O_PURPOSE=4) AND (NOT D_PURPOSE=3) AND (NOT D_PURPOSE=4);
SELECT DISTINCT * INTO Trip_NHBW_NREA
FROM Trip_NHBW_NRE
WHERE TRIP_ID NOT IN (SELECT TRIP_ID
                      FROM Trip_NW_AIR);
SELECT DISTINCT * INTO Trip_HBNW_O
FROM Trip_NHBW_NREA
WHERE O_PURPOSE=1 OR D_PURPOSE=1;
SELECT DISTINCT * INTO Trip_NHB
FROM Trip_NHBW_NREA
WHERE TRIP_ID NOT IN (SELECT TRIP_ID
                      FROM Trip_HBNW_O);
SELECT DISTINCT * INTO Trip_NHB_W
```

```
FROM Trip_NHB
WHERE O_PURPOSE=3 OR D_PURPOSE=3 OR D_PURPOSE=4 OR O_PURPOSE=4;

SELECT DISTINCT * INTO Trip_NHB_NW
FROM Trip_NHB
WHERE TRIP_ID NOT IN (SELECT TRIP_ID
                      FROM Trip_NHB_W);
SELECT DISTINCT * INTO Trip_TRTX
FROM Trip_NHB_NW
WHERE O_MODE=8 OR O_MODE=9 OR O_MODE=12 OR D_MODE=8 OR D_MODE=9 OR
D_MODE=12;
SELECT DISTINCT * INTO Trip_NHB_O
FROM Trip_NHB_NW
WHERE TRIP_ID NOT IN (SELECT TRIP_ID
                      FROM Trip_TRTX);
```

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