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Attachment 2 to Appendix D
Statistical Analysis of Data for the San Diego Region

This appendix provides additional detail regarding the travel and urban form analysis completed on the National Household Travel Survey results for San Diego County (SANDAG Region).

DATASET

The original dataset provides information for 6,002 households and 48,571 trips. However, some trips were not usable for this analysis. Specifically 4,242 trips did not have TAZs identified for at least one trip end. Another 51 trips were removed due to inter-city travel such as Amtrak or airplane or unreasonably high trip lengths.

TABLE 1. SANDAG DATASET STATISTICS

	Full Dataset	Usable Dataset
Households	6,002	
Average Persons per Household	2.45	
Average Workers per Household	0.96	
Average Vehicles per Household	2.10	
Trips	48,571	43,527
Home Based Work Trips	4,336	4,093
Home Based Other Trips	29,550	27,270
Non-Home Based Trips	14,601	12,112
Unclassified	84	52
Average Household VMT	42.7	33.2
Average Household Trips	8.1	7.4
Average Household Vehicle Trips	5.02	4.76
Percentage of Households Making At Least One Vehicle Trip	82.6%	79.7%

Source: NHTS, 2009.

The following variables were used in the analysis. Some were provided directly from the NHTS dataset, while others were calculated by Fehr & Peers as indicated in Table 2. The natural logarithms of many of the D variables were also tested.

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TABLE 2. INDEPENDENT VARIABLES

Variable Name	Description	Source
Household Level Variables		
Household Size	Number of persons in the household	NHTS
Number of Workers	Number of workers in the household	NHTS
Auto Ownership	Number of vehicles in the household	NHTS
Income	Household income classified into five categories or coded as unknown	NHTS/FP
Low Income	Binary variable indicating that the household income is less than $45,000 per year	NHTS/FP
Age of Head of Household	Age of the head of household	NHTS/FP
Senior Head of Household	Binary variable indicating that the head of household is older than 55	NHTS/FP
Children in Household	Binary variable indicating that the household has children	NHTS/FP
Household Members under 15	Number of household members under the age of 15	NHTS
Household Members between 16 and 21	Number of household members between the ages of 16 and 21	NHTS
Trip Level Variables		
HBW Trip	Binary variable indicating that trip purpose is home based work	NHTS/FP
HBO Trip	Binary variable indicating that trip purpose is home based other	NHTS/FP
NHB Trip	Binary variable indicating that trip purpose is non-home based	NHTS/FP
Gender of Tripmaker	Gender of tripmaker	NHTS/FP
Senior Traveler	Binary variable indicating that traveler is over 55	NHTS/FP
D Variables		
Residential Density	Household population per residential acre within half mile	FP
Employment Density	Employment per commercial acre within half mile	FP
Service Population Density	Household population and employment per developed acres within half mile	FP
Residential/Non-Retail Diversity	Residential/non-retail diversity score of area within half mile	FP
Retail/Non-Retail Diversity	Retail/non-retail diversity score of area within half mile	FP
Residential/Employment Diversity	Residential/employment diversity score of area within half mile	FP
Office & Service to Retail Diversity	Index between office and service employment over retail employment	FP
Employment/Household Diversity	Index between total employment and total households	FP
Households/School Diversity	Index between total households and school employment	FP
Roadway Density	Miles of roadway within half mile	FP
Intersection Density	Intersections within half mile	FP

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TABLE 2. INDEPENDENT VARIABLES		
Variable Name	**Description**	**Source**
Roadway Distance per Intersection	Ratio of roadway density to intersection density	FP
Walkability measure	Ratio of average block size to number of intersection within half mile	FP
Alternate intersection density measure	Natural log of product of number of blocks and number of intersections within half mile	FP
Nearest railroad station	Distance to nearest railroad stop in miles	NHTS
All Trips Destinations Score	Destinations access score for all trips	FP
Home-Based Trips Destinations Score	Destinations access score for home-based trips	FP
Parking Charges	Binary variable indicating that the TAZ has on-street or off-street parking charges	SANDAG
NHTS 2009, SANDAG 2012 and Fehr & Peers 2012.		

APPROACH

We took two approaches to estimating VMT at the household level, as shown below.

- Framework 1: Two-Step Ds Analysis Module
  - Household Vehicle Trip Generation Probability
  - Household VMT Generation
- Framework 2: Three-Step Ds Analysis Module
  - Household Vehicle Trip Generation Probability
  - Household Vehicle Trip Generation
  - Vehicle Trip Length
  - Vehicle Miles Travelled calculated as product of Household Trip Generation and Vehicle Trip Length

The first step to both approaches uses a binary logistic model to estimate the probability of a household generating at least one vehicle trip. Framework 1 then directly estimates household VMT for those households that are likely to generate at least one vehicle trip. The application of Framework 2 is similar. After the vehicle trip generation probability sub-model, two linear regression models for those households that are predicted to generate vehicle trips: one to estimate household vehicle trip generation and the other to estimate vehicle trip length. VMT is then calculated as the product of those two values for each household predicted to make vehicle trips.

Framework 1: Two-Step VMT Ds Analysis Module

The first step of the Two-Step Ds Analysis Module is the vehicle trip making probability model, which is applied to estimate whether or not a household will make any vehicle trips. The second

step then provides a direct estimate of a trip-making household's VMT, using a linear regression model. The model has an R^2 of 0.221, which is typical for a model of this type. Table 3 presents the coefficients and statistical significance of each variable within the relevant models. Additional discussion is provided following the table.

Private Vehicle Trip Making Probability

Model Frameworks 1 and 2 rely on an estimate of the probability that a household will travel by private vehicle (auto) on any given weekday. To determine the likelihood of private vehicle trip generation, we used SPSS to estimate a binary logistic model based on the entire SANDAG household travel survey sample (6,002 total households). The best performing model had a concordant statistic of 82.3 percent and correctly predicted 41.2 percent of the no auto travel households in the survey (using a cut value of 0.65). Note that 20 percent of all the households in the SANDAG travel survey did not have an auto trip. Table 3 contains the model details.

The results can be interpreted as follows:

- As the number of workers increases, the probability of an auto trip increases
- A low income household is less likely to make an auto trip
- As the number of vehicles available at the household increases, the probability of an auto trip increases (note that the coefficients are nearly equal for households with 2 or 3+ vehicles)
- As the residential density within a half-mile of the household increases, the probability of an auto trip decreases
- As the ratio of households to school employment within a half-mile of the household increases, the probability of an auto trip increases

A small sample of preliminary vehicle trip making probability models, along with the final version of the model, is included at the conclusion of this appendix as Attachment A.

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TABLE 3. TWO-STEP DS ANALYSIS MODULE

Variables		Household Vehicle Trip Generation Probability Concordant=82.3%		Household VMT R^2=0.221	
		Coefficient	**Significance**	**Coefficient**	**Significance**
Constant		-2.712	0.000	58.784	0.019
Demographics	Household Size			2.570	0.000
	Number of Workers	0.811	0.000	11.840	0.000
	Low Income Household Flag	-0.320	0.000	-5.933	0.000
	Number of Vehicles			5.635	0.000
	One Vehicle	3.749	0.000		
	Two Vehicles	4.283	0.000		
	Three or More Vehicles	4.221	0.000		
Density	Residential Density at Home End	-0.009	0.000		
	Employment Density at Home End			-0.612	0.206
Diversity	Households/School Employment Ratio at Home End	-6.784E-7	0.011		
Design	Intersection Density at Home End[1]			-1.612	0.000
Destinations	Destinations Accessibility at Home End			-3.695	0.188
Distance to Transit	Distance to Transit at Home End			0.357	0.014

1. This variable is calculated as the natural log of the product of the number of blocks and the number of intersections within a half mile.

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Household VMT

This section summarizes the regression model developed for daily VMT at the household level. The data included the subset of households with at least one vehicle trip (4,784 households). The best model with an adjusted R^2 of 0.221 is summarized in Table 3.

The results can be interpreted as follows:

- As household size increases, household VMT increases
- As the number of workers living in the household increases, household VMT increases
- As income decreases, household VMT decreases
- As the numbers of vehicles available to the household increases, household VMT increases
- As the density of employment (in relation to commercial acres) within a half mile of the household increases, household VMT decreases
- As intersection density (measured as the natural log of the product of the number of blocks and the number of intersections) increases, household VMT decreases
- As the distance to the nearest railroad stop from the household increases, household VMT increases
- As the destinations accessibility score (relative to all trips) at the household end of the trip increases, household VMT decreases

The coefficient signs of all variables (including both demographic and urban form D variables) confirm expected results.

A small sample of preliminary household VMT models, along with the final version of the model, is included at the conclusion of this appendix as Attachment B.

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Framework 2: Three-Step Ds Analysis Module

This section describes the Three-Step Ds Analysis Module framework. This framework starts with the same vehicle trip making probability sub-model as was applied for the Two-Step Ds Analysis Module. After this step, two other sub-models are applied. Table 4 presents the coefficients and statistical significance for each variable in the Three-Step Ds Analysis Module. Additional detail and descriptive analysis of each variable's effect on the final outcome is provided in the text following the table.

Private Vehicle Trip Generation

Private vehicle trip generation is the second sub-model in Modeling Framework 1. To evaluate private vehicle trip generation, we used SPSS to evaluate linear regression models on the household dataset. Only households that made at least one vehicle trip were included (a total of 4,784 which is 79.7 percent of the full dataset). The best regression model resulted in an adjusted R^2 of 0.202.

The results can be interpreted as follows:

- As household size increases, the vehicle trip rate increases
- As number of workers in the household increases, the vehicle trip rate increases
- As age of the head of household increases, the vehicle trip rate increases
- As household income decreases, the vehicle trip rate decreases
- The presence of children in the household results in an increase in the vehicle trip rate
- As number of vehicles available at the household increases, the vehicle trip rate increases
- As the residential density within a half-mile of the household increases, the vehicle trip rate decreases
- As the ratio of total households to school employment within a half-mile of the household increases, the vehicle trip rate decreases

A small sample of preliminary private vehicle trip generation models, along with the final version of the model, is included at the conclusion of this appendix as Attachment C.

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TABLE 4. THREE-STEP DS ANALYSIS MODULE

Variables		Household Vehicle Trip Generation Probability		Household Vehicle Trip Generation		Household Vehicle Trip Length	
		Coefficient	Significanc	Coefficient	Significanc	Coefficient	Significanc
Constant		-2.712	0.000	1.299	0.000	32.258	0.000
Demographics	Household Size			0.477	0.000		
	Number of Workers	0.811	0.000	0.967	0.000	0.482	0.000
	Low Income Household Flag	-0.320	0.000	-0.559	0.000	-0.352	0.000
	Number of Vehicles			0.539	0.000		
	One Vehicle	3.749	0.000				
	Two Vehicles	4.283	0.000				
	Three or More Vehicles	4.221	0.000				
	Age of Head of Household			0.025	0.000		
	Children in Household Flag			0.682	0.000	-0.610	0.000
	Senior Traveler Flag					-0.486	0.000
	Home-Based Work Trip Flag					4.572	0.000
Density	Residential Density at Home End	-0.009	0.000	-0.007	0.000		
	Employment Density at Home End					-0.002	0.004
Diversity	Households/School Employment Ratio at Home End	-6.784E-7	0.011	-1.477E-6	0.000		
	Retail/Non-Retail Employment Diversity at Non-Home End					-4.243	0.000
	Households/Employment Diversity at Non-Home End					-2.619	0.000
	Households/School Employment Ratio at Non-Home End					-0.028	0.049
Design	Intersection Density at Home End					-0.526	0.000
	Walkability at Home End[1]					0.024	0.000
	Roadway Density at Non-Home End					-1.358	0.000
	Walkability at Non-Home End[1]					0.015	0.000
Destinations	Destinations Accessibility at Home End					-2.136	0.000
Distance to Transit	Distance to Transit at Home End					0.031	0.006
Parking Charges	Parking Charges at Non-Home End Flag					3.293	0.000

1. This variable is calculated as the ratio of average block size to number of intersections so a lower score represents a more walkable area.

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Private Vehicle Trip Length

The private vehicle trip length sub-model is the third component in Framework 2. Private vehicle trip length was also analyzed using linear regression in SPSS. The urban form D variables for both the household and non-household ends of the trips were evaluated. The best model has an adjusted R^2 of 0.119; full results are shown in Table 3.

The results can be interpreted as:

- As the number of vehicles available to the household increases, trip length increases
- Households with children present are more likely to make a shorter trip
- A low income household is more likely to make a shorter trip
- A traveler over 55 is more likely to make a shorter trip
- A home-based work trip is likely to be longer
- As the density of employment (in relation to commercial acres) within a half mile of the household end of the trip increases, trip length decreases
- As the intersection density within a half mile of the household end of the trip increases, trip length decreases
- As the ratio of average block size to number of intersections within a half mile of the household end of the trip increases, trip length increases
- As the distance to the nearest railroad stop from the household end of the trip increases, trip length increases
- As the destinations accessibility score (relative to all trips) at the household end of the trip increases, trip length decreases
- As the ratio of retail to non-retail jobs within a half mile of the non-home end of the trip approaches the SANDAG regional average, trip length decreases
- As the ratio of households to employment within a half mile of the non-home end of the trip approaches the SANDAG regional average, trip length decreases
- As the ratio of total households to school employment within a half mile of the non-household increases, trip length decreases
- As roadway density within a half mile of the non-household end of trip increases, trip length decreases
- As the ratio of average block size to number of intersections within a half mile of the non-household end of the trip increases, trip length increases
- Trips with non-home ends in a TAZ with parking charges tend to be longer

Some of the results above reflect the results of other national studies, including increased intersection density, increased diversity of land use, and shorter distances to transit from homes leading to shorter vehicle trips. However, other urban form characteristics showed less conventional results although they may still be reasonable.

As was the case with the SACOG results, the presence of parking charges at the non-home end of the trip was correlated with longer trips. This is reasonable given that transit, walking, and bicycling are more viable in areas with parking charges, so the remaining auto trips may be longer and potentially serve areas with poor transit service.

A small sample of preliminary trip length models, along with the final version of the model, is included at the conclusion of this appendix as Attachment D.

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Non-Home End Urban Form Variables

In addition to the above trip length regression, a model including only urban form variables for the non-home end of each trip was developed. All non-home end urban form variables that proved to be significant in predicting trip length are included. The model has an R^2 of 0.052. The dependent variable was the log of trip length.

TABLE 5. TRIP LENGTH MODEL USING ONLY NON-HOME END URBAN FORM VARIABLES

Variable	Coefficient	Significance
Constant	1.141	0.000
Residential Density at Non-Home End	0.001	0.000
Employment Density at Non-Home End	-0.001	0.000
Households/Non-Retail Employment Diversity at Non-Home End	0.387	0.000
Retail/Non-Retail Employment Diversity at Non-Home End	-0.250	0.008
Households/Employment Diversity at Non-Home End	-0.505	0.000
Employment/Households Ratio at Non-Home End	0.001	0.000
Roadway Density at Non-Home End	-0.023	0.000
Roadway Distance per Intersection at Non-Home End	1.152	0.000
Walkability at Non-Home End[1]	-0.011	0.000
Destinations Accessibility at Non-Home End Relative to All Trips	7.267E-5	0.000
Destinations Accessibility at Non-Home End Relative to Home-Based Trips	-1.373E-4	0.000
Parking Charges at Non-Home End Flag	0.239	0.000

1. This variable is calculated as the ratio of average block size to number of intersections so a lower score represents a more walkable area.

Source: Fehr & Peers, 2012.

All of the following results refer to the non-home end of the trip and consider a half mile buffer:

- As the density of residential population (in relation to residential acres) increases, the length of the trip increases
- As the density of employment (in relation to commercial acres) increases, the length of the trip decreases
- As the ratio of households to non-retail jobs approaches the SANDAG regional average, the trip length increases
- As the ratio of retail to nonretail jobs approaches the SANDAG regional average, the trip length decreases
- As the ratio of households to all jobs approaches the SANDAG regional average, the trip length decreases
- As the ratio of total employment to total households increases, trip length increases
- As roadway density increases, trip length decreases
- A the ratio of roadway density to intersection density increases, trip length increases
- As the ratio of block size to number of intersections within a half mile of the non-home end of the trip increases, trip length decreases

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- As the destination accessibility score (relative to all trips) increases, the average trip length increases
- As the destination accessibility score (relative to home-based work trips) increases, the average trip length decreases
- Trips with non-home ends in a TAZ with parking charges tend to be longer

Overall Module Performance

Table 6 summarizes the overall performance of the sub-models included in each framework. The estimates were calculated by using the dataset's average value for each variable within the model. Of all the models, the household trip probability model is least accurate, predicting 90 percent of households would make vehicle trips rather than 80 percent. However, all of the other model estimates are very accurate with the model predicting the actual dataset average within less than half a percent error.

TABLE 6. MODEL PERFORMANCE

Model	Dataset Average	Model Prediction
Household Trip Probability[1]	0.80	0.90
Vehicle Trip Generation[2]	5.98	5.96
Vehicle Trip Length[2]	6.52	6.51
Product of Trip Generation and Trip Length: VMT Estimate (Three-Step Model Framework)	38.96	38.79
Household VMT[3] (Two-Step Model Framework)	41.59	41.60

Notes:
[1] Element of Two-Step and Three-Step Ds Analysis Module
[2] Element of Three-Step Ds Analysis Module
[3] Element of Two-Step Ds Analysis Module
Source: Fehr & Peers, 2012.

ELASTICITIES

The two VMT calculation approaches were analyzed to determine individual elasticities for each D variable, as shown in Table 7. Each elasticity was calculated at the 5 percent, 10 percent, and 20 percent level and the average elasticity is reported (there is very little variation between each level). This provides a simple way to compare the relative strength of the D variables against each other, as well as previously published results from a national analysis of many VMT/built environment studies. The national averages shown below come from Ewing and Cervero's 2010 publication, *Travel and the Built Environment: A Meta-Analysis*.

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TABLE 7. INDIVIDUAL ELASTICITIES OF D VARIABLES

Variable Name	Elasticity		
	National Average for Home End of Trip	Framework 1: Two-Step Ds Analysis Module	Framework 2: Three-Step Ds Analysis Module
Density Variables			
Residential Density at Home End	-0.04	-0.02	-0.05
Employment Density at Home End	-0.04	-0.01	-0.01
Diversity Variables			
Households/School Diversity at Home End	-0.09	-0.01	-0.02
Households/School Diversity at Non-Home End	-0.09	N/A	0
Residential/Non-Retail Diversity at Non-Home End	-0.09	N/A	-0.03
Employment/Household Diversity at Non-Home End	-0.09	N/A	-0.22
Design Variables			
Alternate intersection density measure (product of intersections and blocks) at Home End	-0.12	-0.31	N/A
Intersection Density at Home End	-0.12	N/A	-0.08
Walkability Measure at Home End	-0.12	N/A	0
Roadway Density at Non-Home End	-0.12	N/A	-0.2
Walkability Measure at Non-Home End	-0.12	N/A	0
Destinations Variables			
Household destination accessibility relative to distance and number of attraction trip ends	-0.20	-0.08	-0.31
Distance to Transit			
Distance from Home End to Nearest Railroad Station	-0.05	-0.08	-0.02
Parking Cost			
Parking Charges at Non-Home End	N/A	N/A	0.04

Fehr & Peers, 2012.

Note that the national elasticities only relate to the home-end of a trip and are generic in their classifications. To emulate this approach, we also combined multiple variables that relate to the same D category as noted in Table 8. For instance, the density elasticity was calculated by varying both residential and employment density simultaneously. Note that this approach has an additive effect on elasticity in a linear regression model.

Since the national averages did not control for the non-home-end of each trip, it is likely that some of the effects of both trip ends are reflected in the overall national elasticity values. Therefore, evaluating the home-end and non-home-end elasticities separately reveals more polarized values with the national average falling somewhere in between the values for each trip end.

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TABLE 8. COMBINED ELASTICITIES OF D VARIABLES

Variable Name	National Average for Home End of Trip	Two-Step Ds Analysis Module		Three-Step Ds Analysis Module	
		Home End	Non-Home End	Home End	Non-Home End
Density[1]	-0.04	-0.04	N/A	-0.05	N/A
Diversity[2]	-0.09	-0.01	N/A	-0.02	-0.25
Design[3]	-0.12	-0.31	N/A	-0.07	-0.2
Destinations	-0.20	-0.08	N/A	-0.31	N/A
Distance to Transit	-0.05	-0.04	N/A	-0.02	N/A
Parking Cost	N/A	N/A	N/A	N/A	0.04

Notes:

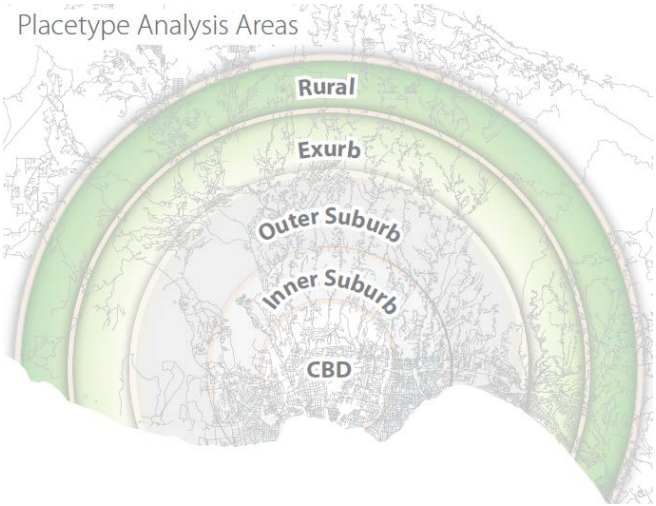
1. Density elasticity was calculated by varying both residential and employment density.
2. Diversity elasticity was calculated by varying the households/school employment ratio, retail/non-retail diversity score and households/employment diversity score.
3. Home end design elasticity was calculated by varying the intersection density and walkability scores. Non-home-end design elasticity was calculated by varying the roadway density and walkability scores.

AREA-TYPES

We developed a "area-types" analysis to help judge how well each Ds Analysis Module framework operates under demographic and built environment situations that are more representative of real-world conditions. This analysis is designed to complement the elasticity tests shown above. While the elasticity tests confirmed that the Ds Analysis Modules respond well to individual variables, the area-type tests are designed to determine how well the modules respond to many D variables changing simultaneously.

The area-type test consisted of choosing five areas within San Diego County with varying urban form characteristics. The areas include:

- Downtown San Diego (Central Business District)
- National City (Inner Suburb)
- Santee (Outer Suburb)
- Escondido (Exurb)
- Ramona (Rural)



Within each of those area-types, clusters of five households were identified and both the Two-Step and Three-Step Ds Analysis Modules were applied. The results are shown below.

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TABLE 9. AREA-TYPE ANALYSIS			
Area-Type	**Actual VMT From NHTS Survey**	**Two-Step Ds Analysis Module Estimate**	**Three-Step Ds Analysis Module Estimate**
Central Business District	28.1	41.5	24.5
Inner Suburb	1.6	4.6	1.9
Outer Suburb	45.0	39.9	41.3
Exurb	35.6	38.7	31.2
Rural	33.5	26.6	23.2
Fehr & Peers, 2012.			

In general, we feel that the Three-Step Ds Analysis Module performed better in the area-type tests. The module did well in matching the observed data from the NHTS model for all cases, although the Three-Step Ds Analysis Module did under-predict the VMT of the rural households. The Two-Step Ds Analysis Module matched general trends; however the module substantially overestimated the VMT of the more dense and diverse Central Business District neighborhood.

One area-type stands out as an outlier – the Inner Suburb. The reason the VMT is so low for the inner suburb is that only two of the five households made vehicle trips. Moreover, the vehicle trip making probability model only predicted that one of the households would make a vehicle trip so VMT was only calculated for a single household, but averaged over all five. This area-type was significant since it demonstrated that the vehicle trip making probability model can reasonably predict households with no vehicle travel. Another issue worth noting is that the observed and estimated VMT in the CBD is higher than we initially expected. A closer look at the demographics of the selected households in the CBD indicates that all five sampled households have fairly high incomes and at least two of which have three or more cars, and one of which has four workers. This resulted in relatively high VMT estimates from the Ds Analysis Modules.