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Attachment 1 to Appendix D

Statistical Analysis of Regional Land Use/Transportation Data for the Sacramento Region

This attachment to Appendix D provides additional detail regarding the travel and urban form analysis completed on the SACOG 2000 Household Travel Survey Dataset. The SACOG data was used as a pilot study for this project to help determine the best course of action for other regional data. Some approaches were unsuccessful and are not discussed within this document, although details are available in previous documentation. For instance, we built mode choice models using hierarchical linear modeling and binary logistic modeling. Tests were conducted on the full dataset as well as a subset deemed "transit competitive." However, the results were disappointing and the framework incorporating mode choice was determined to be inferior to the frameworks presented here. This attachment to Appendix D only includes the most promising models which were chosen as the best way to move forward with this project.

DATASET

The SACOG dataset provides information for 3,941 households and 28,630 trips. Additional demographic and travel statistics are shown in Table 1.

TABLE 1. SACOG DATASET STATISTICS

	Dataset
Households	3,941
Average Persons per Household	2.32
Average Workers per Household	1.14
Average Vehicles per Household	1.96
Trips	28,630
Average Household VMT	30.08
Average Household Trips	7.26
Average Household Vehicle Trips	4.99
Percentage of Households Making At Least One Vehicle Trip	80.0%

Source: SACOG, 2000.

The following variables were used in the analysis. Note that the prefixes H and NH were used on each D variable to denote whether the variable refers to the home-end or non-home-end of the trip, respectively. The natural logarithms of many of the D variables were also tested, and given the suffix "_log".

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TABLE 2. SACOG VARIABLES

Variable Name	Description
Household Level Variables	
OldAge	Head of household over 55 (1=yes, 0=no)
Nwork	Number of workers in the household
Hhsize	Number of persons in the household
NStud	Number of students in the household
Totveh	Number of vehicles in the household
Income	Household income (in thousands)
LogIncome	Natural logarithm of household income (in thousands)
Incat	Household income categories (1=<$15,000, 2=$15,000-$25,000, 3=$25,000-$45,000, 4=$45,000-$75,000, 5=>$75,000, 8=No Response)
Yeskids	Presence of children in the household (1=yes, 0=no)
Lowinc	Income less than $45,000 per year (1=yes, 0=no)
AgeHH	Age of the head of household
Trip Level Variables	
Senior55	Traveler over 55 (1=yes, 0=no)
Age	Age of traveler
Gender	Gender of traveler (1=female, 0=male)
Ratio	Transit travel time-private vehicle travel time ratio
Ratio_d	Splined transit ratios into two categories, broken at 3 (1=lower, 0=higher)
TripLength	Trip length
LogTripLength	Natural logarithm of trip length
HBWTrip	HBW trip purpose (1=yes, 0=no)
HBOTrip	HBO trip purpose (1=yes, 0=no)
NHBTrip	NHB trip purpose (1=yes, 0=no)
D Variables	
Parking	Presence of parking charges within TAZ
Nodes1h	Number of 1 link nodes within ½ mile
Nodes3&4h	Number of 3 and 4 link nodes within ½ mile
Dist_lrt	Distance to the nearest LRT stop
Dist_bus	Distance to the nearest bus stop
Emptot_h	Total employment within ½ mile
NetResJobDensity	Residential + Job Density within ½ mile
NetResJobDensity_h_log	Natural logarithm of Residential + Job Density within ½ mile
NetResDensity_h	Residential Density within ½ mile
NetJobDensity_h	Job Density within ½ mile
NetResDensity_h_log	Natural logarithm of Residential Density within ½ mile
NetJobDensity_h_log	Natural logarithm of Job Density within ½ mile

TABLE 2. SACOG VARIABLES	
Variable Name	**Description**
JobMix_h	Retail/Non-Retail Diversity Score within ½ mile
Hhtotalmix_h	Jobs/Housing Diversity Score within ½ mile
Intersection_density	Intersection Density within ½ mile
HH_End_HBW_ATTRs	Destination accessibility (HBW attractions) for household end
HH_End_All_ATTR	Destination accessibility (all attractions) for household end
Non_HH_End_PROD_HBW	Destination accessibility (HBW productions) for non-household end
NonHH_End_All_PROD	Destination accessibility (all productions) for non-household end
Source: SACOG, 2000; Fehr & Peers, 2011	

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 using a single linear regression model to estimate VMT after applying the initial trip making probability model. Framework 2 uses 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 Ds Analysis Module

The first step of this framework 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 0.252, 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

The D Analysis 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 SACOG household travel survey sample (3,941 total households). The best performing vehicle trip making model had a concordant statistic of 80.8 percent and correctly predicted 34.8 percent of the no auto travel households in the survey (20 percent of all the households in the SACOG travel survey did not have an auto trip).

Note that the dependent variable has a value of 1 if the household does not make a vehicle trip, and a value of 0 if the household does make a vehicle trip. Therefore, a positive coefficient correlates to a decrease in the probability of making a vehicle trip, and a negative coefficient correlates to an increase in the probability of making a vehicle trip. The results can be interpreted as follows:

- As the number of workers increases, the probability of an auto trip increases
- As number of vehicles available at the household increases, probability of an auto trip increases
- Higher income households are more likely to make an auto trip
- Households with children are more likely to make an auto trip
- As the residential density within a half-mile of the household increases, the probability of an auto trip decreases

A small sample of preliminary vehicle trip making models, along with the final model, is included at the conclusion of this attachment to Appendix D as Attachment A.

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TABLE 3. TWO-STEP DS ANALYSIS MODULE

Variables		Household Vehicle Trip Generation Probability Concordant=80.8%		Household VMT R^2=0.252	
		Coefficient	**Significance**	**Coefficient**	**Significance**
Constant		0.541	0.000	36.144	0.000
Demographics	Household Size			2.783	0.000
	Number of Workers	-0.391	0.000	7.980	0.000
	Low Income Household Flag			-5.306	0.000
	Number of Vehicles	-0.350	0.000	3.428	0.000
	Income (categorical)				
	2: $15,000 - <$25,000	-0.522	0.001		
	3: $25,000 - <$45,000	-0.819	0.000		
	4: $45,000 - <$75,000	-1.138	0.000		
	5: >$75,000	-1.253	0.000		
	8: No Response	-0.650	0.000		
	Children in Household Flag	-1.836	0.000		
Density	Residential Density at Home End	0.011	0.013		
	Log of Residential Density at Home End			-4.190	0.000
Diversity	Log of Households/ Employment Ratio at Home End			-0.980	0.203
Design	Intersection Density at Home End			-6.411	0.083
Destinations	Destinations Accessibility at Home End			-0.046	0.000

Fehr & Peers, 2012.

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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 (3,143 households). The best model with an adjusted R^2 of 0.252 is shown below.

The results can be interpreted as follows:

- As the number of workers in the household increases, household VMT increases
- As household size increases, household VMT increases
- As the numbers of vehicles available to the household increases, household VMT increases
- As income increases, household VMT increases
- As the residential population density (in relation to residential acres) within a half mile of the household end of the trip increases, household VMT decreases
- As the intersection density within a half mile of the household increases, household VMT decreases
- As the accessibility score of the household end of the trip in relation to all attractions increases, household VMT decreases
- As the ratio of households to all jobs within a half mile of the household end of the trip approaches the SACOG regional average, household VMT decreases

Overall, the results from the household VMT analysis are similar to what was found in earlier SACOG evaluations from 2002, namely that density and destination accessibility have a strong and substantial influence on household VMT. This result helps to clarify the results of a separate analysis conducted in 2008, which used a different formulation for destination accessibility and found a weak correlation with VMT. The 2008 analysis used a much simpler definition of destination accessibility (number of HBW attractions within a 20 minute auto drive time), which acts more like a binary variable (based on proximity to downtown Sacramento).

A small sample of preliminary Household VMT models, along with the final model, is included at the conclusion of this attachment to Appendix D as Attachment B.

Framework 2: Three-Step Ds Analysis Module

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 sub-model outcome is provided in the text following the table. Note that this framework begins with the same household vehicle trip generation probability sub-model as descried earlier.

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TABLE 4. THREE-STEP DS ANALYSIS MODULE

Variables		Household Vehicle Trip Generation Probability Concordant=80.8%		Household Vehicle Trip Generation R^2=0.227		Household Vehicle Trip Length R^2=0.187	
		Coefficient	Significance	Coefficient	Significance	Coefficient	Significance
Constant		0.541	0.000	1.154	0.002	9.746	0.000
Demographics	Household Size			1.046	0.000		
	Number of Workers	-0.391	0.000	0.572	0.000		
	Low Income Household Flag			-0.673	0.000	-0.432	0.000
	Number of Vehicles	-0.350	0.000	0.428	0.000	0.040	0.236
	Income (categorical)						
	2: $15,000 - <$25,000	-0.522	0.001				
	3: $25,000 - <$45,000	-0.819	0.000				
	4: $45,000 - <$75,000	-1.138	0.000				
	5: >$75,000	-1.253	0.000				
	8: No Response	-0.650	0.000				
	Age of Head of Household			0.022	0.000		
	Children in Household Flag	-1.836	0.000			-1.673	0.000
	Gender of Traveler					-0.727	0.000
	Senior Traveler Flag					-0.804	0.000
	Home-Based Work Trip Flag					5.116	0.000
Density	Residential Density at Home End	0.011	0.013	-0.020	0.027		
	Log of Residential Density at Home End					-0.505	0.000
	Log of Residential Density at Non-Home End					-0.104	0.012
Diversity	Households/Employment Diversity at Home End					-0.237	0.089
	Retail/Non-Retail Employment Diversity at Non-Home End					-0.801	0.000
	Households/Employment Diversity at Non-Home End					-1.598	0.000

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TABLE 4. THREE-STEP DS ANALYSIS MODULE

Variables		Household Vehicle Trip Generation Probability Concordant=80.8%		Household Vehicle Trip Generation R^2=0.227		Household Vehicle Trip Length R^2=0.187	
		Coefficient	**Significance**	**Coefficient**	**Significance**	**Coefficient**	**Significance**
Design	Intersection Density at Non-Home End					-0.003	0.000
Destinations	Destinations Accessibility at Home End					-0.004	0.000
Distance to Transit	Distance to Transit at Home End			0.006	0.007		
	Transit Travel Time Competitive Trip Flag					-2.001	0.000

Fehr & Peers, 2012.

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Private Vehicle Trip Generation

Private vehicle trip generation is the second sub-model in Modeling Framework 1. Tests were done on a subset of the household data including only those households with at least one private vehicle trip (3,143 households of 3,941 total households) with the average number of daily vehicle trips per household used as the dependent variable. The best regression model resulted in an adjusted R^2 of 0.227.

The results can be interpreted as follows:

- As the number of workers in the household increases, the vehicle trip rate increases
- As household size increases, the vehicle trip rate increases
- As number of vehicles available at the household increases, the vehicle trip rate increases
- As household income decreases, the vehicle trip rate decreases
- As age of the head of household increases, the vehicle trip rate increases
- As the population density (in relation to residential acres) within a half mile of the household increases, the vehicle trip rate decreases
- As the distance from the household to the nearest bus stop increases, the vehicle trip rate increases

In addition to the variables tested above, a wide variety of diversity, pedestrian design, regional destination accessibility, and parking cost variables were reviewed; however these variables were not significant or had very marginal effects on vehicle trip generation. This result came as somewhat of a surprise given the earlier SACOG work and the results of similar analyses conducted around the country.

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

Private Vehicle Trip Length

The private vehicle trip length sub-model is the third and final component in Framework 1. Private vehicle trip length was also analyzed using linear regression in SPSS. The full dataset of vehicle trips (25,893 trips) was considered.

This analysis is different than many other types of trip length analyses in that the urban form D variables for both the household and non-household end of the trip were evaluated. Using this formulation, we were able to evaluate the relative importance of urban form at both ends of the trip, as opposed to the more common forms of analysis which focus only on the household end.

The results can be interpreted as:

- As the number of vehicles available in the household increases, trip length increases
- A trip made by a household with children is likely to be shorter
- A trip made by a low income household (less than $45,000) is likely to be shorter
- A trip made by a female is likely to be shorter (1=female, 0=male)
- A trip made by an older person (over age 55) is likely to be shorter
- A transit competitive trip (relatively low transit travel time to vehicle travel time) is likely to be shorter

- A HBW trip is likely to be longer
- As the density of residential population (in relation to residential acres) within a half mile of the household end of the trip increases, the length of the trip decreases
- As the ratio of households to all jobs within a half-mile of the household end of the trip approaches the SACOG regional average ratio (better jobs/housing balance), the trip length decreases
- As the destination accessibility score (all attractions) increases on the household end of the trip, the average trip length decreases
- As the density of the residential population (in relation to residential acres) within a half-mile of the non-home-end of the trip increases, the trip length decreases
- A higher number of 3 and 4 leg intersections within a half mile of the non-household end of the trip is likely to result in a shorter trip
- As the ratio of retail to nonretail jobs within a half-mile of the non-home end of the trip approaches the SACOG regional average, the trip length decreases
- As the ratio of households to all jobs within a half-mile of the non-home end of the trip approaches the SACOG regional average, the trip length decreases

The results above generally reflect the results of other national studies, namely that higher density, better diversity of land use, and more access to regional destinations leads to shorter vehicle trips. However, because we had urban form characteristics at both trip ends, we were also able to confirm that the land use diversity and pedestrian design at the non-home end of the trip also were significantly correlated with shorter trips.

A small sample of preliminary private vehicle trip length models, along with the final model, is included at the conclusion of this attachment to Appendix D as Attachment D.

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Overall Performance

Table 5 summarizes the overall performance of the Ds analysis modules included in each framework. The predictions were calculated by using the dataset's average value for each variable within the model. As shown, all the components perform quite well.

TABLE 5. DS ANALYSIS MODULE PERFORMANCE

Model	Dataset Average	Model Prediction
Household Trip Probability[1]	0.80	0.83
Vehicle Trip Generation[2]	6.26	6.27
Vehicle Trip Length[2]	4.59	4.58
Product of Trip Generation and Trip Length: VMT Estimate (Three-Step Framework)	28.70	28.72
Household VMT[3] (Two-Step Framework)	37.69	37.69

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

ELASTICITIES

The two Ds analysis frameworks were analyzed to determine individual elasticities for each D variable, as shown in Table 6. 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 6. 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	-0.11	-0.14
Residential Density at Non-Home End	-0.04	N/A	-0.02
Diversity Variables			
Households/Employment Diversity at Home End	-0.09	-0.02	-0.03
Households/Employment Diversity at Non-Home End	-0.09	N/A	-0.20
Retail/Non-Retail Diversity at Non-Home End	-0.09	N/A	-0.12
Design Variables			
Intersection Density at Home End	-0.12	-0.13	N/A
Number of 3 and 4 Node Intersections at Non-Home End	-0.12	N/A	-0.07
Destinations Variables			
Household destination accessibility relative to all attraction trip ends	-0.20	-0.26	-0.33
Distance to Transit			
Distance from Home End to Nearest Bus Stop	-0.05	N/A	-.02

Fehr & Peers, 2012.

Note that these elasticities only relate to the home-end of a trip and are generic in their classifications. To emulate this approach, we combined multiple variables that relate to the same D category as noted in Table 7. 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 7. COMBINED ELASTICITIES OF D VARIABLES

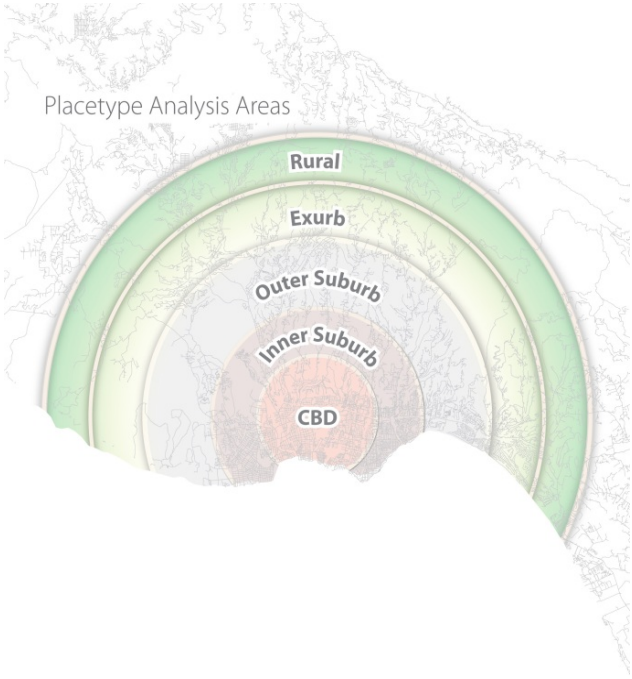
Variable Name	National Average for Home End of Trip	Two-Step Ds Analysis Module		Three-Step Ds Analysis Module	
		Home End	Non-Home End	Home End	Non-Home End
Density	-0.04	-0.11	N/A	-0.14	-0.02
Diversity[1]	-0.09	-0.02	N/A	-0.03	-0.32
Design	-0.12	-0.13	N/A	N/A	-0.07
Destinations	-0.20	-0.26	N/A	-0.33	N/A
Distance to Transit	-0.05	N/A	N/A	-0.02	N/A

Notes:
1. At the non-home end, diversity elasticity was calculated by varying the retail/non-retail diversity score and the households/employment diversity score.

Fehr & Peers, 2012.

AREA-TYPES

We developed a "area-types" analysis to help judge how well each Ds Analysis Module 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 tests consisted of choosing five areas within the Sacramento region with varying urban form characteristics. The areas include:

- Midtown (Central Business District)
- Citrus Heights (Inner Suburb)
- Elk Grove (Outer Suburb)
- El Dorado Hills (Exurb)
- Yuba City (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 8. AREA-TYPE ANALYSIS			
Area-Type	**Actual VMT from SACOG Survey**	**Two-Step Ds Analysis Module Estimate**	**Three-Step Ds Analysis Module Estimate**
Central Business District	16.56	4.46	12.26
Inner Suburb	26.03	34.25	24.39
Outer Suburb	55.11	50.62	37.55
Exurb	92.55	57.39	47.83
Rural	12.03	31.13	27.99
Fehr & Peers, 2012.			

Both the Three-Step and Two-Step Ds Analysis Modules performed fairly well at predicting the relative household VMTs for the area-types. In general, the magnitudes of the predicted VMT were below the actual data. Therefore, the SACOG Ds Modules may be better suited to pivoting from a reliable baseline VMT as opposed to directly estimating VMT. In general, the Two-Step Ds Analysis Module did a better job of predicting the high VMT areas while the Three-Step Ds Analysis Module was better at the low VMT areas. Neither module performed particularly well at the predicting the VMT of the rural area.