Household Travel, Household Characteristics, and Land Use: An Empirical Study from the 1994 Portland Travel Survey

By

Xiaoduan Sun[1]
Maruthi Emany[2]
Ram Pendyala[3]
Chester G. Wilmot[4]

[1]Assistant Professor, Civil Engineering Department, University of Southwestern Louisiana, Lafayette, LA, 70504, 318-482-6514, 318-482-6688 (F), xsun@usel.edu

[2]Graduate student, University of Southwestern Louisiana

[3]Assistant Professor, University of South Florida

[4]Research Associate Professor, Louisiana State University

INTRODUCTION

This paper presents an empirical investigation into the relationship between household travel patterns and influential factors based on the data from the 1994 Portland Activity-based Travel Survey. With the increasing concern about the environmental side effects of the use of vehicles, many transportation planners suggest that governments should promote balanced and mixed land use, and high density development. Since transportation demand derives from households' needs to participate in diverse activities, variations in land use development will influence travel patterns. Although the fundamental relationship between land use and transportation is complex, it has been long assumed that households in high density development areas will make fewer and shorter trips. While the validity of these assumptions is important, there have not been many empirical studies to support this assertion.

The need to understand how household travel behavior is affected by socioeconomic conditions and land use patterns makes great demands on transportation planning procedures. The ISTEA and CAA requirements have further stimulated the needs to improve the travel demand forecasting models. Various studies have been done in this field under the Travel Model Improvement Program (TMIP) initiated by the Federal Highway Administration, the Department of Transportation, the Environment Protection Agency, and the Department of Energy. The objectives of TMIP are to redesign the travel forecasting process to reflect today's traveler behavior under different settings, and to increase the policy sensitivity of existing travel models and their capacity to respond to emerging issues including environmental concerns, growth management, alternative land use development, and changes in personal and household activity patterns.

To fully understand today's household travel behavior and to develop practically operational travel forecasting models, it is essential to investigate the fundamental relationship between travel and its influential factors with real data. With the support from the Louisiana Education Quality Support Fund, we were able to obtain necessary travel data from the Metro, a Portland Metropolitan Service District. The travel information is from the 1994 Portland Household-based Activity Travel Survey, and the land use information is from Metro's GIS Data Resource Center. With these data, we set out to identify the significant household socioeconomic characteristics, and to investigate the effects of land use patterns on household travel. In this paper we present an initial analysis of the data, and discuss some preliminary results of the study. The continuing studies will be reported in subsequent papers.

HOUSEHOLD TRAVEL PROCESS

Generally, household needs are met through activities. Many activities are outside the home and these generate travel. Household travel patterns are driven by the spatial distribution of activities which, in turn, are determined by the socioeconomic characteristics of the household and land use development at both residence location and activity centers. Currently, land use is usually factored in terms of the spatial distribution of population and employment but, in recent years, increasing attention has been given to investigating travel behavior in terms of a more detailed description of land use [1, 2, 3, and 4]. The activity-based travel survey is becoming a powerful means to support the development of an improved travel modeling systems [5].

Household Socioeconomic Characteristics

The socioeconomic factors typically used in the trip generation models are household income, household size, and vehicle ownership. With the data used in this study, we were able to investigate additional variables which

provide, or are proxies for, a more expansive description of a household. They are the variables such as the number of separate phone lines in a household, presence of car phones, dwelling type, ownership of the home, and even the number of years in the current home of residence. These additional factors yield some very interesting results.

Land Use

Due to severe traffic congestion and consequent air pollution problems caused by mobile emissions, transportation planners have increasingly turned to land use policies as potential solutions. One of the major problems with current travel forecasting models is the absence of an effective means of studying the impact of alternative land use plans. To develop more realistic, policy sensitive travel demand forecasting models, a more effort at identifying the land use effect should be made. In doing so, the choice of land use measures is critical and the question of how to adequately define various land use patterns for the study of travel behavior is a subject of debate itself. Due to the lack of tangible data, some subjective measures have been used to describe the built neighborhood characteristics. Kockelman [6] has proposed some interesting land use measurements some of which are used below. Having reviewed the previous studies, we were able to examine the significance of land use patterns by the following measures with the available data.

Density:

The density of population or employment is widely used as a measure of land use largely because of its simplicity. It is commonly believed that residents in the high density area generate fewer auto trips and thus less VMT than the ones in the low density area. In this study, population density (population per acre), employment density (number of employees per acre of business area), and residential density (number of homes per acre of residential area) were used as independent variables. To investigate the possible link between a household's socioeconomic characteristics and the neighborhood that the household chooses to live in, we also examined the household's income at different densities.

Land Use Balance:

Land use density alone cannot reflect the whole picture of land use development. The balance of land use, i.e., the relationship among job, housing, and service, is another important indicator describing the characteristics of land development. Intuitively, we would expect that residents in well-balanced neighborhoods travel less distance than those in other areas. However, the concept of a balance of land use is difficult to define. We used the entropy measure as suggested by Kockelman:.

$$ENTROPY = -\sum_i \frac{P_i \ln(P_i)}{\ln(I)} \qquad (1)$$

where, I is the number of different land use developments, and P_i is the proportion of land development i.

By definition, the value of entropy varies between one when different land use occurs in equal proportion (the "perfect" balance) and zero when the land use differs widely (the "worst" balance).

Accessibility:

In early years, accessibility measurement used in transportation was expressed by the travel distance or travel time between two points. This definition of accessibility directly reflects the connectivity of the street network. Today, it has been suggested and defined as a variable representing not only the connectivity but also the

intensity of opportunities at the analysis zone. The accessibility measures in this study are those used by the Metro [7]:

$$Accessibility = e^{\ln(Y) - .175T + 0.009T^2 - 0.000_{009}T^3} \qquad (2)$$

where, Y is the attraction for accessibility of household to job and attraction for job to household for a TAZ, which is computed by the Metro with the corresponding O-D matrix; and T is the travel time.

DATA

The data downloaded through the Metro FTP site consist of five files from the 1994 Portland Activity-based Travel Survey. They are the Household, Vehicle, Person, Activity, and Trip files. To facilitate our analysis, we reorganized the files in such a way that the household travel information is included in the household file, and individual activity and travel information is combined from Activity and Trip files into the person file. Because of limited land use information from original files, additional land use data were requested and obtained from Metro. These data, presented by Traffic Analysis Zone (TAZ), enable us to define the land use variables as described previously.

EMPIRICAL RESULTS

Analysis of Variance (ANOVA)

The ANOVA process was used to investigate the significance of selected variables on travel. Household travel is expressed in terms of the total number of trips and vehicle miles of travel (VMT) made during the two days of the survey. The significance of each variable is determined by a selected level of significance. Table 1 gives the results for the household socioeconomic characteristics.

For the magnitude of the difference in mean value, it can be seen that household income, number of vehicles, and household size are key factors in determining household travel. The difference in the number of trips between the two groups is 140% in household size, 82% in vehicle ownership, and 55% in income. The difference in VMT between the two groups is 150% in household size, 172% in vehicle ownership, an 38.6% in income. It is interesting to note that the dwelling type, the number of years in the current residence, home ownership, the number of separate phone lines, and the presence of car phones all make a significant difference in household travel based on the ANOVA test. The number of telephone lines or the presence of a car phone may reflect a measure of difference on household activity not captured by income or other included variables. On average, a household with a car phone generates 52% more VMT and 22.9% more trips than a household without a car phone. A household with more than one separate phone line makes 24% more daily trips and 29% more VMT than a household with only one phone line. A household living in a single family house travels 57% more in the number of daily trips and 120% more in VMT than a household living in other types of dwelling units, such as a condominium, apartment, or trailer home. A household owning or buying its home produces 40% more daily trips and 84% more VMT than a household renting its living quarters. Finally, a household with longer than five years of residency in the current home travels 11% more in VMT than a household with less than five years of residency in the current home.

TABLE 1. Significance of Household Socioeconomic Characteristics

Variable	Dividing Point	Number of Trips	VMT
Annual household income	$45k vs. >$45k	Significant 14.2 vs. 18	Significant 36.4 vs. 56.7
Household size	≤ 2 vs. >2	Significant 11.2 vs. 26.99	Significant 31.39 vs. 79.96
Dwelling type	Single Family House vs. Other	Significant 17.8 vs. 11.3	Significant 54.1 vs. 24.5
No. of separated phone lines	≤ 1 vs. > 1	Significant 15.7 vs. 19.5	Significant 45.3 vs. 58.6
Presence of a car phone	No vs. Yes	Significant 14.3 vs. 17.5	Significant 31.85 vs. 48.4
No. of vehicles	≤ 1 vs. > 1	Significant 10.8 vs. 19.8	Significant 23.0 vs. 63.1
Residence ownership	Own/buy vs. Rent	Significant 17.6 vs. 12.6	Significant 53.9 vs. 29.3
Years in current residence	≤ 5 vs. > 5	Not significant 15.9 vs. 16.2	Significant 43.7 vs. 48.7

It can be argued that the selection of dwelling type is greatly influenced by household income, thus the impact of dwelling type simply represents the impact of income. To investigate the possible correlation between these two factors, we further studied the significance of the dwelling type by two income groups: low (less than *$45,000)* and high (greater than *$45,000)* income groups. As shown in Table 2, the significance of the dwelling type is independent of the household income. The dwelling type does make a difference in the daily number of trips and VMT within both income groups. The only noticeable effect from income on the dwelling type is that the difference in travel between households in single family home and households in other type of living units is greater in the high income group than in the low income group.

Table 3 gives the results of land use parameters. In general, the impact of land use development on travel is very significant. Although the population density and land use balance makes little difference in the number of daily trips, they do play a significant role in household VMT. The households living in the high density areas generate 19% less VMT than the ones living in low density areas. The households living in better balanced land use development areas (higher value of entropy) contribute about 45% less VMT compared with those in other areas. Residential and employment densities make about 42% and 10% differences in average household VMT and daily trips, respectively. Both accessibilities (job to household and household to job) calculated from the O-D matrix exhibit considerable impact on household travel: The difference between two groups is about 64% in VMT and 13% in daily trips.

TABLE 2. Significance of Dwelling Type under Two Income Levels

	Number of Trips	VMT	Number of Non-auto Trips
Low income	Significant 15.9 vs. 11.8	Significant 43.6 vs. 22.9	Significant 7.38 vs. 6.65
High income	Significant 21.4 vs. 14.17	Significant 68.6 vs. 34.6	Significant 8.85 vs. 7.32

TABLE 3. Significance of Land Use Factors

Variable	Dividing Point	Number of Trips	VMT
Population Density	6 residents/ acre	Not Significant 16.3 vs. 16.1	Significant 66.4 vs. 47.3
Resident Density	5 houses/acre of residential area	Significant 16.89 vs. 15.42	Significant 67.3 vs. 47.3
Employment Density	3 employers/ acre of business area	Significant 16.98 vs. 15.38	Significant 67.2 vs. 48.2
Land Balance (entropy)	-0.5	Not Significant 16.8 vs. 16.1	Significant 76.7 vs. 53.7
Accessibility (household to job)	Low vs. High	Significant 17.3 vs. 15.2	Significant 72.3 vs. 44.5
Accessibility (job to household)	Low Vs. High	Significant 17.0 vs. 15.3	Significant 70.1 vs. 451
Neighborhood* Environment	Good PEF** and transit vs. Bad PEF and transit	Significant 14 vs. 17.7	Significant 27.6 vs. 50.9

* The analysis was done at household level (the rest is at TAZ level).

**PEF (Pedestrian Environment Factor).

The last variable, neighborhood environment in terms of PEF as listed in Table 3, is defined by the survey instrument. It is only applied to one of the five surveyed counties and covers about 15% of the total completed household surveys. Although this factor makes a huge difference in household travel, a 120% increase in VMT from good PEF and transit to bad PEF and transit, we could not use it in the linear regression analysis since we didn't have this type of information for the rest of households.

It has been speculated that, possibly, a household's socioeconomic characteristics determine the type of neighborhood in which the household chooses to live. To investigate the possible relationships between the household income and density, and between household income and land use balance (entropy), an analysis of

coefficient of correlation was conducted. The results are represented later in this paper.

Linear Regression Analysis

To study the complex relationship between household travel and the household's characteristics and land use factors with available data, we conducted multilinear regression analysis. The models tested here estimate a household's total number of trips and VMT as functions of socioeconomic characteristics and land use environment. To explore the maximum explanatory power of the independent variables, three models were developed for each travel indicator. The base model considers those independent variables available from the original household file. The intermediate model accommodates the land use variables from additional files. The final model considers only those significant variables identified by the base and intermediate models. The selection of independent variables for the base and intermediate models was based on the availability of the information from the survey and the ANOVA tests. The results from the base and final models are summarized in Tables 4 and 5.

TABLE 4. Household Daily Trips Models

	Base Mode		Final Model	
Variable	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
Constant	-2.481	0.487*	-4.147	0.502*
Household size	0.913	0.171*	0.978	0.178*
Income	0.189	0.028*	0.170	0.028*
Number of Vehicles	0.747	0.128*	1.088	0.136*
Home Ownership	0.616	0.325**		
Dwelling type	0.189	0.28***		
Number of Phone lines	0.597	0.258**	0.482	0.256**
Years in the residence	-1.107	0.224*	-1.293	0.217*
Number of activities	0.456	0.011*	0.457	0.011*
Half Mile to LR	-0.046	0.455***		
Employment Density			-0.005	0.003**
Accessibility (household to job)			2.286E-05	3.63E-06*
R^2	**0.661**		**0.671**	

* Significant at 1% level

** Significant at 10% level *** Not significant

The variables of home ownership, dwelling type, accessibility to the light rail, and the number of years in the current residence are modeled as binary variables. The value of zero is assigned to owning/buying home, single family house, light rail being within a half mile, and less than 5 years of residence in the current home. The value of one is assigned to the renting home, other living units, no light rail service within a half mile, and more than five years in the current residence.

TABLE 5. Household VMT Model

Base Mode			Final Mode	
Coefficient	**Variable**	**Standard Error**	**Coefficient**	**Standard Error**
-15,890	**Constant**	3.56*	17.022	4.214*
3.004	**Household size**	1.244*	3.077	1.208*
1.179	**Income**	0.204*	0.740	0.190*
12.213	**Number of Vehicles**	0.932*	12.015	0.918*
0.274	**Home Ownership**	2.369		
-3.432	**Dwelling type**	2.429**		
0.932	**Number of activities**	0.081*	1.024	0.078*
-0.489	**Number of Phone Lines**	1.888		
-0.0037	**Half Mile to LR**	3.32		
	Employment Density			
	Land Use Balance (entropy		-7.04	4.73**
	Accessibility (household to job)		-0.00014	2.96E--5*
	Accessibility (job to household)		-0.00053	9E-5*
R^2	**0.2255**		**0.3660**	

*Significant at 1% level

** Significant at 15% level

The results from the linear regression analysis demonstrate the significance of land use variables in household travel estimation. With the VMT model, the inclusion of accessibility and entropy leads to a 62% increase in R^2. Most variables in the final model are significant at least at the 1% level of significance with a few at the 10% or 15% level. Some of the variables that are proved to be significant in ANOVA process, such as home ownership and dwelling type, are not included in the final regression model because their significance level is more than 5%.

From the household daily trip model, we see that on average, one trip occurs for about every two activities

(coefficient of 0.457 for the number of activities). The activity was defined by the survey as how a household member spends his or her time such as work, shopping, meals, household business, entertaining, etc. The very small standard error confirms the importance of activity in trip generation. However, the activity's influence on VMT is not as large as on the number of daily trips. The coefficient of 1.02 for the number of activities indicates that one additional activity generates about one VMT if everything else remains the same.

ANALYSIS OF RESULTS

Although the empirical results presented here is just the first step of the study, many interesting household travel behaviors have been observed and they are apparently different from the household travel behavior of decades ago when the conventional travel forecasting models were first developed. Most importantly, land use has been proved to be very important in determining the household travel patterns. In light of this, we offer the following discussions.

Impact of Land Use

Solutions for severe urban traffic congestion and consequent air pollution problems have to come from both the supply and demand sides of highway transportation systems. Looking for alternative land use strategies to curb travel demand has prompted land use studies from the transportation point of view. Our preliminary results have shown the explanatory power of land use in travel demand models. It is interesting to note that the number of daily trips is not affected a much by the land use variables defined in this paper as VMT. Some land use variables such as population density and land use balance do not appear to affect the number of household daily trips. However, they are quite influential in the amount of household VMT. In other words alternative land use policy may not reduce the number of household daily trips, but it does appear to affect total vehicle miles of travel. VMT is the main indicator for traffic congestion and air pollution, and therefore, it would appear that promoting well-balanced land use development would be an effective way of reducing congestion and mobile emission.

Residential Location Choice

As interests in land use studies grow, a question has been raised about the possible link between a household's characteristics and the type of neighborhoods in which the household chooses to live. The answer to this question is important in developing the effective land use policies which intend to reduce travel demand. With the Portland data, we conducted the coefficient of correlation analysis to examine the possible links between household income and choice of the residential location. The results are listed in Table 6.

The very small absolute values of coefficients in Table 6 indicate the lack of apparent association between household income and the residential location. We realize that income is only a partial indication of the wealthiness of a household and these results may not represent the complete picture.

TABLE 6. Coefficient of Correlation

Land Use Variable	Income
Dwelling type	-0.041
Employment Density	-0.077
Population Density	-0.052
Residential Density	-0.019
Accessibility (HH-Job)	-0.14
Accessibility (Job-HH)	-0.0004

Although the household income seems insensitive to the location of households, vehicle ownership does vary between high and low density/entropy areas. The average number of vehicles is 1.87 in the low density area comparing with 1.41 in the high density area. The reason for the difference in vehicle ownership could be from the difference in the household size. The average household size is 2.19 in the high density area comparing with 2.52 in the low density area; and 1.70 in the high entropy area versus 2.40 in the low entropy area. This implies that high density/entropy areas attract smaller families with fewer children or being childless. This observation supports the belief that the life stage or life style of a household is one of the underlying factors in the selection of the neighborhood and subsequently in the determination of household travel patterns.

Household Characteristics

Other than income, vehicle ownership, and household size, the household lifestyle has been proved to be relevant in determining the household travel patterns through the choice of residence location. While further study on household ownership, the number of separate phone lines, and dwelling type may be needed, the presence of car phones seems to increase automobile dependency since it makes driving more productive though not safer. Travelers become accessible to the outside world for some kind of activities even when they are traveling along the road. As the technology advances and the prices decrease, car phones will become more affordable to the average household. It will no long be seen as a luxury but an accessary. Although its impact on trip generation remains to be investigated, its potential influence on VMT should not be ignored.

FUTURE WORK

The results presented here have certainly encouraged us to continually pursue the work in the following areas.
1. Utilizing the GIS capability to continually explore the fundamental relationship between household travel and land use with additional land use data from Metro's GIS Data Recourse Center. The land use information for the current study is aggregated at the TAZ level (density and entropy). To adequately describe the characteristics of land use at aggregate level, we need information not only on land use balance but also on how the different types of land use development are integrated within the area of spatial analysis. Having additional land use variables such as land use mix, accessibility to highway network (miles of major highway per unit

area), and accessibility to public transportation (number of bus stops per unit area and number of bus lines per unit area), the explanatory power of the regression models will be improved.

2. Investigating the impact of land use on individual travel journeys and trips. A journey consists of at least two trips. Conceivably, the number of daily journeys, and mode choice and travel distance of each trip within a journey can be affected by land use patterns at both residence and key activity locations (work). By revealing the impact of land use on individual travel behavior through different types of journeys, we want to qualitatively evaluate the effectiveness of alternative land use policies.

ACKNOWLEDGMENT

This research is supported by the Louisiana Education Quality Support Fund (LEQSF). The authors would like to express their gratitude to Metro, especially to Mr. Steve Perone for his valuable and timely assistance.

REFERENCES

[1] Susan Handy, "Understanding the Link between Urban Forum and Travel Behavior," Transportation Research Board 74th Annual Meeting, 1995.

[2] Ryuichi Kitamura, Patricia Mokhtarian, and Laura Laidet, "A Micro-Analysis of Land Use and Travel in Five Neighborhoods in the San Francisco Bay Area," University of California, Davis, UCD-ITS-RR-94-28, 1994.

[3] Roger Mackett, "Land Use Transportation Models for Policy Analysis," Transportation Research Record 1466.

[4] "Transit and Urban Form," Transit Cooperative Research Program Report TCD16, Volumes 1 & 2, 1996.

[5] Cambridge Systematics, Inc.,"Data Collection in the Portland, Oregon Metropolitan Area Case Study," TMIP Document, June 1996.

[6] Kara Maria Kockelman, "Travel Behavior as Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidence from the San Francisco Bay Area," Transportation Research Board 76th Annual Meeting, 1997.

[7] Correspondence From Steve Perone, Metro, Portland, Oregon, 1997.

Interactions among Land Use, Area Type, Congestion Mitigation Strategies, and Air Quality

John N. Ivan, M. ASCE[1]
and
Markus R. Kusuma[2]

Abstract

The study performs a microscopic analysis of the impacts of individual projects on air quality. The rationale is that even though the overall impact of a state-wide or regional-wide transportation improvement programs is needed for the final conformity analysis, it is also important to learn the contributions of individual projects to assist in selecting among projects competing for funding. This study examines four types of projects commonly encountered in air quality analysis, here referred to as "congestion mitigation strategies." These strategies are studied in the context of different types of land use, development density and traffic control to see how these variations affect the resulting air quality and traffic operations.

Introduction

It is widely known that traffic congestion has negative impacts on air pollution. Lyons *et al.* [1] found that as vehicle congestion and, thus, acceleration-deceleration cycles increase, harmful gas production exceeds that of normal operating levels. Mitigating congestion, however, does not reduce air pollution if it enables motorists to drive at high speeds, because tail pipe emissions of most air pollutants are the lowest at intermediate speeds.

[1]Assoc. Director, Connecticut Transportation Institute, Asst. Professor, Civil and Environmental Engineering, University of Connecticut, 261 Glenbrook Road, U-37, Storrs, CT 06269-2037.
[2]Transportation Engineer, URSGreiner, 1400 Union Meeting Road, Suite 202, Blue Bell, PA 19422-1972