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Trends in Automobile Energy Use and GHG Emissions in Suburban and Inner City Neighborhoods: Lessons from Metropolitan Phoenix, USA

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Abstract

This paper compares the effects of long term suburban growth on travel behavior, energy consumption, and GHG emissions through a case study of neighborhoods in central Phoenix and the suburban city of Gilbert, in the Phoenix metropolitan region, USA. Motorized travel patterns in these study areas are estimated using 2001 and 2009 National Household Travel Survey data. Energy consumption and GHG emissions, including both Carbon Dioxide and Nitrous Oxide for each study area are estimated based on the corresponding trip distribution results. The final normalized outcomes are compared spatially between Phoenix and Gilbert within the same year, and temporally between year 2001 and 2009 to determine how the differential land use changes in those places influenced travel energy consumption and GHG emissions.

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Keywords: compact development; travel behaviour; energy consumption; GHG; suburban development

1. Introduction

Suburban growth in the U.S. urban regions has been defined by large subdivisions of single-family detached units. This growth is made possible by the mobility supported by automobiles and an extensive highway network. These dispersed, highly automobile-dependent developments have generated a large body of work examining the socioeconomic and environmental impacts of suburban growth on cities. The particular debate that this study addresses is whether suburban residents are more energy intensive in their

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travel behavior than central city residents. If indeed suburban residents have needs that are not satisfied by the amenities around them, they may be traveling farther to access such services. However, if suburbs are becoming like cities with a wide range of services and amenities, travel might be contained and no different from the travel behavior of residents in central areas. In this study explore this proposition by comparing the changes in travel behavior and associated energy use between 2001 and 2009 for inner city and suburban areas within metropolitan Phoenix.

2. Prior studies

A review by Anderson and collaborators [1] identified studies starting from the 1970's that explore how transport modes and distances vary with urban form. Most research examining the relationship among land use characteristics, socioeconomic attributes, and travel behavior seem to conclude that compact, high-density developments tend to reduce vehicle miles traveled by small to modest amounts (between 3 to 20 percent reduction in VMT from doubling density) (Table 3-1, p. 42, NRC 2009 [2]). The impact of the built environment on travel behavior is often captured in development patterns known as the 5 Ds [3]. These are: 1) Density; 2) Diversity; 3) Design; 4) Destination accessibility; and 5) Distance to transit. Density is the most common attribute examined in almost all studies. It is measured variously as population, employment, or housing units per unit area (e.g., per square mile, per acre). Early studies using aggregate cross-national or cross-US cities data have found significant and sizable inverse relationship between metropolitan residential densities and vehicle miles traveled [4, 5]. More recent studies using household, census tract, or zip code level data have shown more modest to marginal impact of density on travel behavior after controlling for socioeconomic characteristics and self-selection [6, 7].

Scholars agree that increasing diversity of land use types enhances the effect of density on travel behavior. Density also has a strong influence on the other Ds such as design, accessibility to destinations and to transit. For example, providing shopping and commercial establishments close to residences (i.e., increasing diversity and "mix" of land uses) allows origins and destinations to be close to each other, thereby encouraging non-motorized modes of travel. Higher density and higher diversity of neighborhoods also improve the viability of transit access to that neighborhood.

Boarnet and Crane [8] attempted to connect land use and travel behavior using travel cost variables. The most recent model proposed by Crane [9] is based on the demand of travelers, which is controlled by three factors: tastes, resources and prices. The results indicated that the compact development could indeed reduce travel speed or travel distance, which would possibly lead to reduced individual VMT. Another type of structural model was developed to control the "self-selection" effect, which was a concern in many early studies [10, 11]. The results from these studies revealed that by controlling the self-selection effect, higher residential density could still reduce household VMT generation. The national level study from Ewing's team also suggested that the density could have a positive effect on VMT reduction in urbanized areas [12].

3. Study areas and data sources

3.1. Study areas

We identified two study areas, one located within the Phoenix urban core and the other in the suburban city of Gilbert to determine the impact of compact development on motorized travel behavior in urban and suburban areas, respectively. The selection process was based on the development patterns and the size of the areas. The two specific study areas labeled as *Phoenix* and *Gilbert*, are comparable in size but have different land use patterns and growth trajectories, as tabulated in Table 1. *Gilbert* experienced

substantially more intensive development during the study period. However, by the end of 2009, the population and employment densities in *Phoenix* were still significantly higher. In 2009, the employment density in *Phoenix* was more than six times higher than that in *Gilbert*.

Table 1: Average density for Phoenix and Gilbert in 2000 and 2009

Study Area	Area (Acres)	Population Density			Employment Density			Road Density (Mile/Acre)		
		2000	2009	Change	2000	2009	Change	2000	2009	Change
Phoenix	39934.4	8.54	8.68	2%	6.48	6.71	4%	0.029	0.029	1%
Gilbert	24684.3	4.81	6.52	36%	0.94	1.35	43%	0.013	0.024	82%

Data Source: Adapted based on American Community Survey (ACS) population data; employment and road data are obtained from MAG.

3.2. Data sources

National Household Travel Survey (NHTS) data was used to estimate trip generation rates by household categories for Home-based Work (HBW) and Home-based Shopping (HBSH) trips. For 2001, we used the 2001 NHTS transferability National files to generate trip production for the entire study region. In 2002, Maricopa Association of Governments (MAG) also conducted a travel survey. We didn't' apply this survey in trip production process, as the data collection and process procedures are different from NHTS. But the MAG survey result was used to estimate vehicle compositions for our study areas. We used the 2009 NHTS provided by Maricopa Association of Governments (MAG) for Phoenix Metropolitan area to estimate trip production rates for each type of households. We established the census tract level households distribution table based on 2009 ACS data (5-year estimates) and 2008 CTPP data, so that the result will be more comparable to the 2001 transferability NHTS data.

The trip attraction process mainly relied on the 2000 and 2010 Phoenix Metropolitan area disaggregated employment data from MAG. The employment from 2000 was classified with 2-digit Standard Industrial Classification (SIC) code, while the 2009 data was marked with 6-digit North American Industry Classification System (NAICS) code. To perform trip distribution process, we used 2010 Phoenix Metropolitan area road network data from MAG.

4. Results

4.1. Changes in commuting travel

Phoenix study area showed a very clear declining trend in proportion of Intra trips, due to the drop of local job opportunities (See Table 2). The decrease was also followed by an increase in inter-out commuting trips. Despite the fact that the regional population increased over time, the frequency of inter-in trips for Phoenix declined slightly from 1.73 million in 2001 to 1.70 million in 2009. In contrast, the proportion of Inter-in trips increased dramatically by 162% in Gilbert. The intensive development in *Gilbert* also helped the area to maintain the number of intra commuting trips, as the decrease was less significant compared with *Phoenix* study area. However, *Gilbert* residents also continued to generate more inter-out trips over study period.

Table 2: Changes in commuting travel patterns

Study Area	Year	Trip/Person	Avg. Trip Length	Ratio Inter-out/Intra	VMT/Person	Energy/Person	GHG/Person
Phoenix	2001	0.26	7.33	1.07	1.90	0.10	0.95
	2009	0.24	16.55	3.81	4.15	0.20	1.86
	% change	-9%	126%	257%	118%	95%	95%
Gilbert	2001	0.30	12.72	9.90	3.86	0.21	1.95
	2009	0.25	16.85	20.76	4.32	0.21	1.95
	% change	-16%	32%	110%	12%	0%	0%

The energy consumption and GHG emission difference between urban Phoenix and suburban Gilbert was almost eliminated between 2001 and 2009. Despite the fact the difference between Phoenix and Gilbert neighborhoods was significantly reduced over time, Gilbert residents remained to be more energy intensive with larger GHG footprint in 2009. By comparing the individual VMT change with the energy consumption change, we found that the advancement in vehicle technology was able to offset the increase of individual VMT in suburban *Gilbert*, as the individual energy consumption and GHG footprint remained stable, while the individual VMT increased from 3.86 to 4.32 miles during the period.

4.2. Variations in travel shopping patterns

The suburbanization of retail service in Phoenix Metropolitan area reversed the travel patterns for residents from Phoenix and Gilbert study areas (See Table 3). The average trip length in Phoenix increased from 3.97 miles in 2001 to 7.96 miles in 2009. Meanwhile, residents in Gilbert seemed to make shorter shopping trips, as the average trip length declined by 15% over study period. Although Gilbert residents continued to generate more inter-out trips, the total VMT merely increased by 6%, which is marginal compared with the 188% increase in Phoenix area. Such increase in VMT in Gilbert was offset by the vehicle technology advancement. The individual energy consumption and GHG emissions in Gilbert actually declined by 6% over study period. As a result, in 2009 Gilbert residents turned out to be less energy intensive in shopping travel compared with urban Phoenix residents.

Table 3: Changes in shopping travel patterns

Study Area	Year	Trip/Person	Avg. Trip Length	Ratio Inter-out/Intra	VMT/Person	Energy/Person	GHG/Person
Phoenix	2001	0.36	3.97	0.40	1.44	0.08	0.73
	2009	0.52	7.96	3.66	4.16	0.20	1.87
	% change	44%	100%	818%	188%	157%	157%
Gilbert	2001	0.44	8.13	3.63	3.50	0.19	1.77
	2009	0.54	6.81	5.83	3.70	0.18	1.67
	% change	25%	-15%	61%	6%	-6%	-6%

The suburbanization of retail service in Phoenix Metropolitan area reversed the travel patterns for residents from *Phoenix* and *Gilbert* study areas. The average trip length in *Phoenix* increased from 3.97 miles in 2001 to 7.96 miles in 2009. Meanwhile, residents in *Gilbert* seemed to make shorter shopping

trips, as the average trip length declined by 15% over study period. Although *Gilbert* residents continued to generate more inter-out trips, the total VMT merely increased by 6%, which is marginal compared with the 188% increase in *Phoenix* area. Such increase in VMT in *Gilbert* was offset by the vehicle technology advancement. The individual energy consumption and GHG emissions in *Gilbert* actually declined by 6% over study period. As a result, in 2009 *Gilbert* residents turned out to be less energy intensive compared with urban *Phoenix* residents.

5. Conclusions

We found that as suburbs grew and diversified, the difference in travel behavior between people living in suburban and urban areas became smaller. In the case of commute trips, the individual VMT, energy consumption and GHG emissions converged between 2001 and 2009. In 2001, Gilbert residents with higher individual commuting VMT was more energy intensive. While, in 2009 suburban Gilbert residents surpassed urban residents by only 0.01 Gallon per day. In the case of shopping trips, suburbanization of retail service reversed the travel patterns for residents from urban and suburban areas. In 2009, suburban Gilbert residents with shorter shopping trips turned out to be less energy intensive than urban Phoenix residents. Gilbert residents used to consume approximately 200% more energy in 2001, when the retail services were less accessible.

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Reference

[1] Anderson, W. P., P. S. Kanaroglou, and E. J. Miller. Urban form, energy and the environment: a review of issues, evidence and policy. *Urban studies* 1996; 33(1): 7-35.

[2] National Research Council (NRC). *Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO_2 Emissions, Special Report 298*. Committee for the Study on the Relationships among Development Patterns, Vehicle Miles Travelled, and Energy Consumption, 2009.

[3] Cervero, R., & K. Kockelman. Travel Demand and the 3Ds: Density, Diversity and Design. *Transportation Research D* 1997; 2 (3): 199–219.

[4] Newman, P. W., & J. R. Kenworthy. *Sustainability and Cities: Overcoming Automobile Dependence.* Washington, DC: Island Press; 1999.

[5] Holtzclaw, J., R. Clear, H. Dittmar, D. Goldstein. & P. Haas. Location Efficiency: Neighborhood and Socioeconomic Characteristics Determine Auto Ownership and Use — Studies in Chicago, Los Angeles, and San Francisco. *Transportation Planning and Technology* 2002; 25 (1): 1-27.

[6] Handy, S., X. Cao, & P. L. Mokhtarian. Self-selection in the relationship between the built environment and walking: Empirical evidence from Northern California. *Journal of the American Planning Association* 2006; *72*(1): 55-74.

[7] Cao, X., Mokhtarian, P. L., & Handy, S. L. Examining the impacts of residential self-selection on travel behavior: a focus on empirical findings. *Transport Reviews* 2009; 29(3): 359-395.

[8] Boarnet, M. G., & Crane, R. *Travel by design the influence of urban form on travel*. Oxford University Press; 2001.

[9] Crane, R. D., & Z. Guo. Toward a Second Generation of Land Use/Travel Models. *Oxford Handbook of Urban Economics and Planning*. Oxford University Press; 2011.

[10] Bhat, C. R., & J. Y. Guo. A comprehensive analysis of built environment characteristics on household residential choice and auto ownership levels. *Transportation Research Part B: Methodological* 2007; 41(5): 506-526.

[11] Brownstone, D., & T. F. Golob. The impact of residential density on vehicle usage and energy consumption. *Journal of Urban Economics* 2009; 65(1): 91-98.

[12] Ewing, R., S. Hamidi, F. Gallivan, A. Nelson, & J. Grace. Combined Effects of Compact Development, Transportation Investments, and Road User Pricing on Vehicle Miles Traveled in Urbanized Areas. *Transportation Research Record: Journal of the Transportation Research Board* 2013; 2397: 117-124.

Biography

Subhrajit Guhathakurta is Director of the Center for Geographic Information Systems (CGIS) and Professor in the School of City and Regional Planning at the Georgia Institute of Technology. His research interests and publications include issues of urban sustainability, urban modeling, and geographic information systems. He is the co-editor of the Journal of Planning Education and Research and a visiting high-end expert for UNEP-Tongji Institute of Environmental Sustainability at Tongji University, Shanghai, China.