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Investigating the impacts of built environment on vehicle miles traveled and energy consumption: Differences between commuting and non-commuting trips

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ABSTRACT

This research contributes to the understanding of the impacts of the built environment on vehicle miles traveled (VMT) and energy consumption by considering the mediating effects from vehicle type and travel speed. Meanwhile, whether the relationships among the built environment, VMT and energy consumption vary between commuting and non-commuting trip was examined by applying the multiple-group structural equation model (SEM). The primary travel data used in the research is drawn from the National Household Travel Survey (NHTS) Baltimore Add-on data. In this study, the built environment was measured for each residential location based on various external sources. By controlling for the socio-demographic factors, the model results show that the effects of the built environment on travel speed, VMT and vehicle energy consumption significantly vary between commuting and non-commuting trips. For the two different travel types, the direct, indirect, and total effects of the built environment measurements on VMT and vehicle energy consumption were discussed. The model results confirmed the important roles played by the built environment in influencing VMT and vehicle energy consumption. The results are expected to give urban planners and policy makers a better understanding on how the built environment factors can impact the VMT and energy consumption, and consequently develop more effective and targeted countermeasures.

1. Introduction

With the increasing automobile use and vehicle miles traveled (VMT), the shares of energy consumption and air pollution from transportation sectors are becoming significant (Xue et al., 2015). From 1970 to 2005, the average annual VMT per household grew by 50% (Bureau of Transportation Statistics, 2007). The transportation sector covers one third CO_2 emissions from fossil fuel combustion (EIA, 2007). In addition to the environmental damages, extensive automobile usage also causes problems in areas of public health and social equity (Yang & French, 2013). Fuel consumption and emission reduction from the transportation sector can be achieved by coordinating the "three-leg stool": fuel types, vehicle fuel efficiency, and vehicle miles traveled (Cervero & Murakami, 2010; Ewing, Bartholomew, Winkelman, Walters, & Chen, 2008; Litman, 2005). While policies such as alternative fuels and fuel-efficient vehicle aim to improve the first two "legs of the stool," many studies show that land use and urban design, such as transit-oriented development (TOD), smart growth, and new urbanism, could also induce less automobile travel and reduce corresponding transportation energy consumption and emissions (Ding, Liu, Lin, & Wang, 2014; Khan, Kockelman, & Xiong, 2014; Nahlik & Chester, 2014; Nasri & Zhang, 2014a; Van Acker & Witlox, 2010). It is critical to understand the underlying mechanism on how the built environment affects VMT and transportation energy consumption (Boarnet, 2011; Cervero & Murakami, 2010; Ewing & Cervero, 2001, 2010).

The aim of this study is to examine the effects of the built environment on VMT and energy consumption considering the mediating effects from vehicle type and travel speed. Meanwhile, whether the relationships among the built environment, VMT and energy consumption vary between the commuting trip and non-commuting trip was examined by employing the multiple-group structural equation model

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(SEM). The primary travel data used in the research is drawn from the National Household Travel Survey (NHTS) Baltimore Add-on data. We measured the built environment variables based on multiple dimensions, including density, diversity, and design. The direct, indirect and total effects of the built environment on VMT and energy consumption were calculated.

The remaining of this paper is organized as follows. The related previous studies were presented in Section 2. The third section introduced the data sources and the built environment measures. The modeling approach employed in this study is described in the following section. The model results are discussed in Section 5. The final section provides the conclusions and directions for future research.

2. Literature review

At the early stage of studies on revealing the influencing factors on VMT, correlation and linear regression analyses were extensively employed. Using data from major cities worldwide, Newman and Kenworthy (1989, 1999) examined how population density was related to vehicle energy consumption per capita. The results indicated that population density has a significantly negative relationship with energy consumption. However, the results neither revealed the in-depth effects of the built environment on vehicle energy consumption, nor did the results consider the differences among socioeconomic factors (Brownstone & Golob, 2009). One important deficiency of correlation and linear regression analyses is that it is not capable of modeling the complicated relationships among travelers' socioeconomic attributes, the built environment, VMT, and vehicle energy consumption simultaneously.

Build upon this research, Bagley and Mokhtarian (2002) used SEM approach for the first time to investigate the direct and indirect effects of various factors on travel behavior. Since SEM is a powerful tool to handle complicated relationships among multiple dependent variables (Golob, 2003), it has become a hotspot to study the relationship between the built environment and VMT (Wang, Grengs, & Kostynuik, 2014, Wang, Liu, Kostynuik, Shen, & Bao, 2014; McIntosh, Trubka, Kenworth, & Newman, 2014; Nasri & Zhang, 2014b; Wang, 2013; e Silva, Morency, & Goulias, 2012; Liu & Shen, 2011; Cervero & Murakami, 2010; Van Acker & Witlox, 2010). With the data from 370 U.S. urbanized areas and using SEM, Cervero and Murakami (2010) studied the influences of the built environments on annual VMT. The results found both significant direct and indirect effects of density on VMT. Using SEM and aggregated data of Traffic Analysis Zones (TAZ) from Taipei in Taiwan, Lin and Yang (2009) empirically examined the relationships between density/design and trip generation/mode split. Due to the lack of valid data of vehicle energy consumption and emissions at the individual level, the research on the built environment and vehicle energy consumption is rare. In previous literature, the assumption was that vehicle energy consumption and emissions were positively related to VMT. Therefore, VMT is usually used as the proxy of vehicle energy consumption and emissions, as shown in Fig. 1.

In recent years, with the improvement in modeling of vehicle energy consumption and emissions, scholars began to work on the vehicle energy consumption data that were derived from travel behavior data (Brownstone & Golob, 2009; Marique, Dujardin, Teller, & Reiter, 2013; Susilo & Stead, 2009). For example, on the basis of the Dutch National Travel survey data, Susilo and Stead (2009) revealed the relationship of urban form on transport emissions and energy consumption, with a concentration on commuting trips. The results showed that living more urbanized environments with higher density was significantly related to lower CO_2 emissions and less energy consumption. Furthermore, they found that compared to the built environment, the socioeconomic factors are more important on affecting CO_2 emissions and energy consumption. Brownstone and Golob (2009) used the California subsample of the 2001 U.S. NHTS to investigate the associations between residential density and auto use and fuel consumption on the household level. After controlling for the socioeconomics, the results revealed that a 40% reduction of residence density implies 5% increase in VMT and energy consumption.

However, in addition to the energy consumption and emission data, other travel outcome variables such as travel mode, travel speed, vehicle type and fuel type should also be incorporated. Recently, the connections between the built environment and household vehicle type choice have gained more attention. Using the 2000 travel survey data of Bay Area in San Francisco, Bhat and Sen (2006) examined the factors that influenced household vehicle type based on a nested model structure. The results revealed that household in high density environments have lower propensity to own medium-to-large vehicles. In a more in-depth analysis of the built environment variables, Bhat, Sen, and Eluru (2009) investigated the effects of the built environment on household vehicle type, considering household socio-demographics, vehicle type characteristics and fuel cost. Similar to their study in 2006 (Bhat & Sen, 2006), they found out that living in denser environments is significantly related to lower probability to own medium-to-large vehicles. Vehicle energy consumption and emissions are directly related to travel speed. In general, vehicle energy consumption per mile declines with the increase in travel speed. However, the association between travel speed and energy consumption is not linear. In other words, traveling at a speed that is extremely high or low will lead to more vehicle energy consumption and emissions. Using Baltimore metropolitan area as a study area, Liu and Shen (2011) empirically explored the impacts of urban land use on household travel and transportation energy consumption, considering the influences of vehicle type, mode choice, and travel speed as intermediate factors. Their findings showed that travel speed have significant effects on VMT and vehicle energy consumption with positive signs.

There are limited studies that focus on the energy consumption at the individual level of travelers when investigating the connection between the built environment and energy consumption. In previous literature, the general assumption is that VMT is positively related with vehicle energy consumption. Consequently, VMT is used as the proxy of vehicle energy consumption, which makes it impossible to explore the influence of VMT on vehicle energy consumption. Meanwhile, the research on the connections between vehicle type and vehicle energy consumption is rare. Therefore, the influence of the built environment on vehicle energy consumption through affecting vehicle types also deserves further study. Some researches indicated that the vehicle

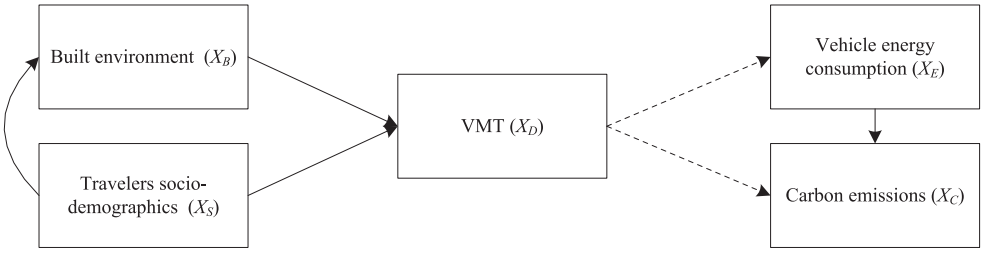

Fig. 1. Conceptual framework describing the relationships between the built environment and travel emissions.