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Exploring the relationship between urban transportation energy consumption and transition of settlement morphology: A case study on Xiamen Island, China ☆

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ABSTRACT

It is important to understand the settlement morphology and its transition process in the rapid urbanization cities of developing countries. It is equally important to learn about the relationships between transport energy consumption and the transition of settlement morphology and its underlying processes. Finally, if the existing transportation technologies are already adequately meeting the environmental challenges of that sector then urban policies can serve as a guide to the transition of settlement morphology, especially for developing countries. Through the application of an integrated land use and transportation modeling system, TRANUS, the paper demonstrates that this transition will bring great changes to the urban spatial distribution of population, jobs and land use, and to residents' travel patterns, thus resulting in different transportation energy consumption and CO_2 emission levels, but that these changes can be managed through appropriate public policies.

Introduction

Urban transport, especially passenger transport, forms a significant proportion of global energy consumption and is also a major contributor to greenhouse gas emissions. The transport sector has thus been identified as one in which energy saving should be encouraged. Commuting patterns and traffic modes will significantly influence energy consumption of the passenger transport sector. In reality, a number of principles, such as location of residences and employment districts, social and economical status and traffic infrastructure, work simultaneously in determining the commuting patterns and trip modal choice. These factors are also related to settlement morphology (Anderson, Kanaroglou, & Miller, 1996). Rapid urbanization and urban sprawl have not only consumed large amounts of natural resources, such as land and fossil-fuels, but have also resulted in the transition of settlement morphology through physical and social forms.

Politicians and researchers are now giving more attention to the discussion of the socioeconomic benefits and the environmental costs of rapidly expanding urban sprawl and believe that environmental sustainability in the megacities of developing countries has become one of the most critical elements of the Millennium Development Goal (MDG) (Zhao, 2010). The impact of this transition on settlement morphology due to urban expansion will therefore be the first focus of this paper.

Many scholars have studied the relationships between urban form and transport energy consumption as a basis for proposals about sustainable urban forms. Based on six case studies in the United Kingdom and the Netherlands, Banister, Watson, and Wood (1997) found that factors such as density, employment and car ownership would affect urban transportation energy use. An empirical study on three cities in the Netherlands (Dieleman, Dijst, & Burghouwt, 2002) found that dependency on private cars was related to the car ownership rate, household type, availability and convenience of public transportation and the urban form of the local residential environment. Many studies have shown that urban form plays an important role in determining mode choice and travel distance (Cervero, 2002; Cervero & Radisch, 1996). For

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example, Handy, Cao, and Mokhtarian (2005) found that population density, land use and mass transit were causally related to per capita passenger vehicle travel. Car dependence and transportation energy consumption per capita for low-density neighborhoods are greater than for compact ones (Kennedy & Van de Weghe, 2007; Kenworthy & Laube).

Urban form and urban design is seen as increasingly important in addressing climate change and has been examined by a number of researchers. Marshall (2008) studied the interrelation between urban population density and vehicle-kilometers traveled to build different urban sprawl scenarios to estimate potential carbon benefits. The results highlighted the potential significance of urban design for reducing transport CO_2 emissions and suggested that long term climate impacts could result from shifts which could be comparable to those from technological innovation. Previous studies on the relationship between urban form and transportation energy consumption have found a correlation with settlement morphology, especially the physical form of settlements. This relationship is the second focus of this paper.

Because of the serious impacts of the transportation sector on both energy use and environmental quality, various methods have been implemented in an attempt to reduce the transportation energy consumption and mitigate the environmental effects of vehicle emissions. Most of these efforts, however, have focused only on efficiency improvements to vehicle and fuel technologies, and the results of these improvements have been largely offset by increasing car ownership and use (Cui, Niu, & Wang, 2010; Sandy Thomas, 2009; Zhao & Melaina, 2006). Simultaneously, a general consensus has emerged that prompt development and implementation of new green individual transportation technologies is unlikely, especially in the fast-growing cities of developing countries, where increased consumption has been caused mainly by the affordability of these 'new' cars (Assmann & Sieber, 2005; Pridmore & Bristow, 2002; Zegras, 2007). The framework of ASIF (emissions are the product of activity [A], modal share [S], modal energy intensity [I], and fuel type [F]) is the widely recognized methodology for describing the environmental impacts of transportation energy consumption (Schipper, Celine, & Gorham, 2000). Therefore, particularly because of the failure of [I] and [F] to address the problem, it appears that urban authorities of developing countries should make [A] and [S] the urgent priorities for mitigating the environmental impacts of the transportation sector. Benoit Lefevre (2009) built a transportation-land-use model to demonstrate that an emerging city like Bangalore can significantly curb the trajectories of transportation energy consumption with existing technologies from urban public policies such as land use, transportation and economic development. Hence, the third focus of this paper is to look for suitable urban policies to guide the transition of settlement morphology for reducing transportation energy consumption and CO_2 emissions, using existing transportation technologies.

According to the three focuses described above, this paper concludes that it is urgent, first, to understand the settlement morphology and its transition process in the rapid development in the cities of developing countries; second, to determine the relationships between transportation energy consumption and the transition of settlement morphology and its underlying processes; and third, to propose that the existing transportation technologies are already adequate to take up the environmental challenges of the transportation sector, if there are suitable urban policies to guide the transitions of settlement morphology. The paper addresses these issues through a case study of Xiamen Island, which is the main urban area of Xiamen City, China.

Methodology

TRANUS, an integrated land use and transport modeling system

TRANUS is an integrated transport-land use model, which de la Barra and Perez have been developing since 1982 (De la Barra, 2005; De la Barra, Prez, & Vera, 1984). This model uses the relationships of dynamic equilibrium between urban transportation and land use to simulate the evolutionary process of cities. It has been implemented in many cities such as Baltimore, Sacramento, Osaka, Caracas and Bangalore and has been shown to have good applicability and operability (Lefevre, 2009; Modelistica, 2007).

The general structure of TRANUS is shown in Fig. 1. There are two main subsystems in TRANUS: activities and transportation. A distinction is made between demand and supply elements that interact to generate a state of equilibrium within each subsystem. The demand side in the activities subsystem is the location of and interaction between activities, showing that activities such as industries and households locate in specific places and interact with other activities. The real-estate market provides activities

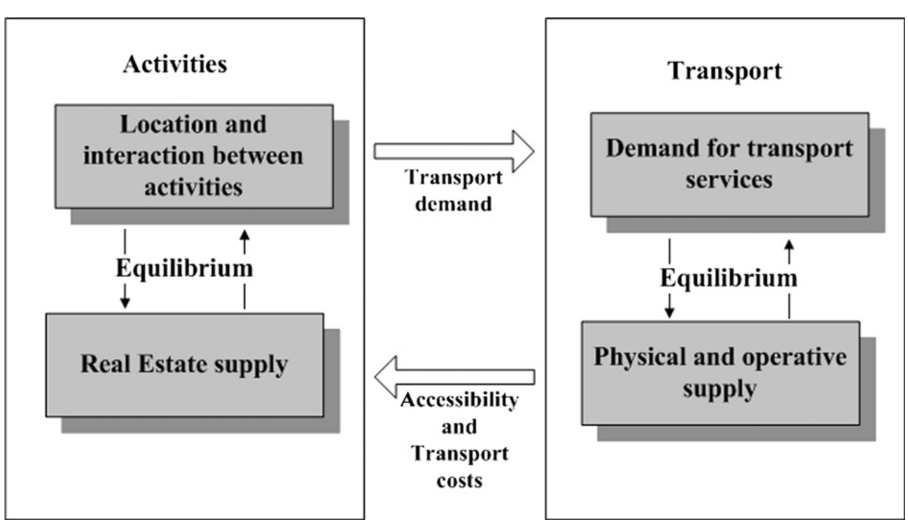

Fig. 1. Model structure of TRANUS (Modelistica, 2007).