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Measuring the impact of urban policies on transportation energy saving using a land use-transport model

Masanobu Kii [a,*], Keigo Akimoto [b], Kenji Doi [c]

[a] Faculty of Engineering, Kagawa University, 2217-20 Hayashi-cho, Takamatsu, Kagawa, Japan
[b] Research Institute of Innovative Technology for the Earth (RITE), 9-2 Kizugawadai, Kizugawa-shi, Kyoto 619-0292, Japan
[c] Department of Global Architecture, Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka, Japan

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ABSTRACT

Various projects all over the world are attempting to build smart cities in hopes of achieving energy-efficient and livable communities, but most of them are aiming to fulfill their goals technologically. However, the energy efficiency and livability of a city are affected by not only these technological factors but also urban structures that encompass residential areas, offices, transportation networks, and other facilities. Urban policies intervene in transportation and land-use conditions and thereby change how citizens consume energy and go about their daily lives as the actors in the urban system alter their behavior. This means that energy efficiency and quality of life share close ties. Assessments of urban policies thus need to consider the reactions of actors to the intervention.

This study demonstrates the applicability of a land-use transport model to the assessment of urban policies for building smart communities. First, we outline a model that explicitly formulates the actors' location-related decisions and travel behavior. Second, we apply this model to two urban policies – road pricing and land-use regulation – to assess their long-term impact on energy saving and sustainability using the case of a simplified synthetic city. Our study verifies that, under assumed conditions, the model has the capacity to assess urban policies on energy use and sustainability in a consistent fashion.

1. Introduction

Urban policies aimed at compaction and modal shift are considered important measures for saving energy from the transportation sector. Cities can become more compact or public transportation-oriented by prompting the actors in the urban system to modify their behavior; changing household locations, moving company office locations, and expanding transportation modes for a wider range of travel purposes are three examples of this mode of modified behavior. Urban policies, including the development of public facilities or infrastructure, transportation or land-use regulations, and taxes or subsidies, change the conditions of an urban system and induce behavioral changes among the actors in the system. As a result, urban policies affect energy use in urban activities as well as the happiness or quality of life of people in the city, which can serve as a representative index of sustainability.

Policies that decrease city residents' quality of life are not sustainable because they thwart the satisfaction of the needs of current or future generations. When we evaluate urban policies as energy-saving measures, we should recognize not only their impact on energy saving but also their effects on people's lives as indices of sustainability.

A land-use transport (LUT) model is an analytical tool for assessing the impact of urban policies on people's activities and quality of life. This approach assumes the behavioral principles of people and firms with regard to their location choices and travel in the urban system, analyzing the impact of policies on these urban activities. As a result, it is possible to calculate their energy consumption. In addition, it is possible to link the estimated spatial distribution of populations and urban activities to the requirements of infrastructure investments that consume both energy and public budget funds. With this analytical tool, one can estimate how policies affect people's happiness or quality of life and influence transportation-related energy consumption levels in light of the people's behavior.

The objective of this study is to demonstrate the applicability of a LUT model to the assessment of energy-saving measures in urban transportation systems. We have developed a LUT model that explicitly describes people's behavior in order to assess the effectiveness of urban

* Corresponding author at: Faculty of Engineering, Kagawa University, 2217-20 Hayashi-cho, Takamatsu, Kagawa 761-0396, Japan. Tel.: +81 87 864 2140.
E-mail addresses: kii@eng.kagawa-u.ac.jp (M. Kii), aki@rite.or.jp (K. Akimoto), doi@civil.eng.osaka-u.ac.jp (K. Doi).

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policies in saving transportation-related energy use and evaluate the impact of urban policies on urban sustainability. Using this model, we analyze the repercussions of modal shift among passengers and urban compaction in an assumed virtual city. In Section 2, we review urban policies as mitigation measures and studies for urban modeling. Section 3 covers our LUT model, and Section 4 discusses the simulation results for a modal shift policy and an urban compaction policy.

2. Urban policies and analytical models

2.1. Urban policies as transport-related energy-saving measures

Given the inextricable links between CO_2 emissions and energy consumption in urban transportation, policies to reduce CO_2 emissions contribute directly to energy saving in urban transportation. Here, we review the literature pertaining to energy saving and CO_2 emission reduction in urban policy.

Some studies have shown that urban policies can have a substantial impact in reducing CO_2 emissions. The National Institute for Environmental Studies in Japan discussed policy measures to realize its vision of the urban lifestyle of the future and future reductions in CO_2 emissions [1]. It concluded that by 2050, emissions could be reduced by 70% from their 1990 level. Urban policies are responsible for part of the emission reductions in its model, which the institute analyzes to argue that it is possible to slash CO_2 emissions from building, heating/cooling, and transportation [2]. The Intergovernmental Panel on Climate Change (IPCC) compiled a wide range of mitigation measures in the field of land use and transportation policy, including urban compaction and modal shift [3]. In order to promote mitigation through urban policies, the Japanese government selected 13 “eco-model” cities to implement policies for a low-carbon society [4]. In this program, the government helps the selected local governments achieve their emission reduction targets through urban policies. The following section summarizes the features of urban compaction and modal shift in passenger transportation from the literature.

2.1.1. Urban compaction

Urban compaction is a policy that aims to reduce CO_2 emissions and energy consumption without undermining resident welfare by limiting the urban sphere and leading to higher population density. Measures that support this policy include land-use regulations like zoning and development controls, strategic investments in urban infrastructure at the city center, and property/land value tax systems that give preference to location and development at the city center.

This policy is designed to have the following positive effects: reduced total trip length, a modal shift from private cars to public or non-motorized transportation, fewer expenses tied to infrastructure and buildings in suburbs, and improved efficiency of area heating/cooling because of higher city-center density. At the same time, the potential negative effects of the policy include worse traffic congestion, increased land prices, increased construction costs, less residence/office space per person, a risk of concentrated hazards from air pollution, and increased energy consumption from building maintenance and operations due to intensive vertical development.

Many studies highlight the effects of urban form on CO_2 emissions and energy consumption in commuting [5–9]. These studies provide empirical evidence of reduced CO_2 emissions and energy consumption in compact cities because of the shorter average commuting length. However, the findings hold only when the distributions of the activities are given. Gaigné et al. [10] explained that policies targeting higher density affect prices, wages, and land rents, which lead firms and households to relocate. Using a simple economic model, the authors demonstrated that such policies might actually increase emissions and energy consumption under certain conditions. Their results underline the need to consider the indirect effects of compaction policies through the relocation of the actors involved.

Some cities are facing the problems of urban shrinkage due to economic decline, depopulation, and aging. Despite the shrinking environments, these cities rarely develop a more compact urban form naturally in the market. Researchers have shown that this urban shrinkage causes problems in land use and the oversupply and underuse of housing stocks [11–15], making urban compaction a potentially productive solution in these cases. Compact cities require less infrastructure and tend to be cost-effective [16]. Infrastructure requires a substantial amount of energy and monetary input that needs to factor into policy assessment [17].

2.1.2. Modal shift of passenger transportation

A modal shift policy aims to induce a modal shift from private cars to public transportation or non-motorized transport, which can help alleviate road congestion and reduce energy consumption and CO_2 emissions. The following policy measures are considered effective: the development of a public transportation infrastructure, subsidies for public transportation operations, fare controls, traffic regulations and pricing schemes for private cars, fuel taxes, and parking fee controls [18].

By establishing these policies, cities hope to create social benefits through improved services and reduced public transportation costs, curb CO_2 emissions, and cut down on road congestion. However, these policies can also lead to increased fiscal expenditures on public transportation and a decline in social welfare due to restrictions on or increased costs of car usage.

Pigou [19] and Knight [20] took extensive looks at road pricing. Many studies have focused on finding socially optimum prices under various situations [21–24] but limited the assessment scope to within road networks and given little concern to the impact of policies on land use or competition among cities. Some studies have tried to capture the impact on land use using the land-use transport models which are described in the next section.

2.2. Urban models and land-use transport models

Although these two policies may reduce energy consumption and CO_2 emissions from the transportation sector, they have both positive and negative effects on social benefit. Assessments of the impact of these policies should thus evaluate not only reductions in CO_2 emissions but also social sustainability. Because the path of the impact of urban policies on social sustainability is too complicated to be readily intuitive, we need an analytical tool to determine the ways in which urban policies might affect society.

There are various studies of urban models based on different theoretical frameworks, including the optimization model of residential location [25], the life-cycle assessment model for estimating lifetime environmental burden from buildings and transportation [26], and the urban economics model for assessing the impacts of policies on the spatial patterns of economic activities and on social welfare [27]. Of these studies, only the urban economics models explicitly describe people's behavior in a city and are able to quantify the social sustainability indices, including benefit based on behavioral principles.

LUT models, which integrate urban economics models and transportation behavior theory, provide a comprehensive analytical framework for the assessment of urban policies (see review papers by Wegener [28] and Miyamoto et al. [29]). For example, Anas and Xu [30] developed a general equilibrium model of the urban activities of households and firms in a city, based on discrete choice theory, to assess urban policies such as road pricing and the provision of public housing. The authors divided the urban space into discrete zones and used their model to evaluate policy impact through two methods: first, they compared the equilibrium states with and without the policy. Second, they examined where in each zone the equilibrium state represents the simultaneous equilibrium of markets, including the commodity, labor, land, and transportation markets.