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Evaluation of sustainable policy in urban transportation using system dynamics and world cities data: A case study in Isfahan

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ABSTRACT

Study of transportation infrastructure of various cities and its environmental, economic and social impacts could shed some light on identifying successful policies for sustainable transportation. Few studies have addressed sustainability covering various cities of the world. The aim of current study was to analyze impacts of various transportation policies using system dynamics model based on pertinent data of world cities. The study database was developed based on few comprehensive databases covering numerous cities over 4 decades. Based on the study database, 9 urban sustainable transportation indicators were selected, 3 indicators presenting each key group of environmental, economic and social sustainability. Furthermore, a composite index was applied for combining the selected indicators. In order to analyze transportation sustainability in historic city of Isfahan, a system dynamics model was developed. Urban transportation causal loops were conceptualized and the dynamic relations among urban transportation variables were created to develop the pertinent urban dynamics model. Trip generation, modal share, transportation supply and equilibrium between supply and demand were the key modules of the developed model. Moreover, economic, social and environmental indicators were the key outputs of the model. The model inputs were urban characteristics pertinent to transportation. To validate the results, time-series data were used and model estimation was satisfactory. By monitoring Isfahan sustainable transportation indicators using future scenarios, efficacious transportation policies were identified. The model results reflected that transit network development is the most important policy for Isfahan sustainability.

Introduction

Excess of automobile usage and its environmental, economic and social impacts on urban life, has been a major global issue. Continuing growth of urbanization and car dependency will intensify the issues in the future (Haghshenas & Vaziri, 2012). Based on World Bank's reports, about 25% and 50% of pollutants affecting global warming in developed and developing countries are emitted by transportation sector (Gwilliam, 2002). Due to growing urban pressures, interest in sustainability among all aspects of urban planning and development including transportation has considerably increased. Academics and practitioners alike are interested in studying new policies, programs and projects with taking account of sustainability (Marsden & Stead, 2011; Vojnovic, 2014). The CST, Centre for Sustainable Transportation, developed a definition of sustainable transportation system (Gilbert et al., 2003):

- Allows the basic needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health.
- Is affordable, operates efficiently, offers choice of various transportation modes, and supports a booming economy.
- Limits emissions and waste so that plants are able to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable level, reuses and recycles its components, and minimizes noise pollution and use of land.

Even though many transportation agencies have adopted sustainability within their mission statements (Mihyeon & Amekudzi, 2005), few studies have addressed policy development based on sustainable transportation indicators. A fundamental issue

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for sustainable policy development in urban transportation is measurement of sustainability by developing and applying appropriate indicators. The assessment of policies outcomes with respect to sustainability enables policy makers and planners to compare and analyze various scenarios more precisely. Nevertheless, due to complexity of urban transportation systems, few studies have analyzed overall index of transportation sustainability on an urban scale, and most of decision-making processes are proposed only to solve specific problems based on limited number of indicators and under local circumstances (Emberger, Pfaffenbichler, Jaensirisak, & Timms, 2008; Li, Liu, Hu, Wang, & Yang, 2009; May et al., 2005; Zhao, 2009). Talebian et al. conducted a study to find the most effective policies to enhance the transportation sustainability index of one city using experience of other similar successful cities around the world. Authors introduced 12 characteristics affecting similarity among cities and employed two international data banks to recognize successful cities worldwide (Talebian, Haghshenas, & Gholamialam, 2014). Macário and Marques introduced a general framework explaining how transferability of a measure from a particular city to another city could be investigated. To screen measures, authors believe that the key transportation practitioners at the city level are the most appropriate choices to do it, based on their local knowledge of the local setting (Macário & Marques, 2008). The weaknesses of conventional transportation modeling on the one hand, and complexity of urban transportation and its multiple variables on the other hand, has raised the use of system dynamics models to simulate urban transportation (Armah, Yawson, & Pappoe, 2010; Shen, Chen, Tang, & Yeung, 2009). The system dynamics approach was invented by Forrester in 1950s in order to the analysis of complicated socioeconomics systems. This method involves feedback loops, variables and equations as the key components of the model.

The identification of important factors and policies affecting urban sustainable transportation is the idea of current study. Proposing a method to establish relations among important factors so that its result could be utilized by all cities for policy development was the main concern to accomplish the idea. The relationships between sustainable transportation and cities' characteristics including transportation supply and demand features were modeled based on world cities data to quantitatively predict outcomes of various policies with respect to sustainability for every city with its assuming characteristics. In other words, the model has been developed based on past trends and variables of cities and its result is used to evaluate and predict outcomes of future policies.

The approach to achieve mentioned goals is applying urban sustainable transportation indicators and creating system dynamics model based on world cities data. To evaluate each part of environmental, social and economic aspects of urban transportation, relevant indicators were applied. Moreover, system dynamics model as the key instrument to analyze and evaluate urban transportation was employed. The system dynamics model was developed, using pertinent data of world cities over a period of 4 decades. To develop model, urban transportation causal loops were conceptualized and the dynamic relations among variables were created. The model that has been made to examine and analyze transportation system of a city, calculates sustainable transportation indicators based on geographical, demographic, economic and transportation features of city. In an attempt to validate results, six cities from Asia, Europe and North America were selected and their sustainability indices were calculated with and without using the model, and the error prediction of the model was found satisfactory. As a case study, the model was applied to predict sustainability index of the historic city of Isfahan. All the variables required to run the model were collected and entered into the model. Then, 14 developed scenarios were considered to observe how different policies would affect sustainable transportation index of Isfahan.

Database development

From an international perspective, most of databanks in the field of urban transportation are limited to cities' reports and are rarely gathered in an integrated package. However, there are some transportation databanks, covering various locations of the world, at country level and not urban level. In some studies, urban data have been collected for a specific country or region of the world (Haghshenas & Vaziri, 2012). International organizations such as the EPOMM and UN-Habitat have covered world cities with limited quantitative data of urban transportation (Posch & Karl-Heinz, 2011; United Nations Habitat, 2004). Kenworthy et al. have collected three comprehensive and reliable urban transportation databanks. The first one is an international sourcebook of automobile dependence in cities, ISADC, which contains selected transportation indicators for 4 years in the period of 1960–1990, including 47 world cities (Kenworthy, Laube, & Newman, 1999). Two others have been prepared in cooperation with International Association of Public Transport, UITP: MCDST, Millennium Cities Database for Sustainable Mobility and MCD, Mobility in Cities Database (UITP, 2001, 2006). The MCDST has more than 230 indicators including 100 world cities. The MCD consists of transportation data for 50 cities worldwide. The study database was developed based on the above-mentioned 3 homogeneous and accessible global databases, covering relevant data including 100 cities in 6 years over 4 decades. In the year 1995, many cities and variables are covered. The study database pertinent to urban transportation covered 87 variables and these variables are listed in Appendix A. Data for city of Isfahan were obtained from the Isfahan Municipality (ICTTS, 1995–2010).

Indicator selection

Sustainable transportation indicators are used to monitor transportation sustainability. Chapter 40 of Agenda 21 states that "indicators of sustainable development need to be developed to provide solid bases for decision-making at all levels and to contribute to a self-regulatory sustainability of integrated environment and development systems" (United Nations, 1992). Some attempts have been made to develop sustainable transportation indicators listed as STI (Newman & Kenworthy, 1999; Litman, 2008, 2009; Zegras, 2006). Haghshenas and Vaziri developed 9 STI's for urban studies, 3 indicators for key dimensions of environmental, economic and social. These indicators greatly cover key aspects of urban transportation sustainability and are calculable using study database. Hence, these indicators were applied to measure and compare the effects of different policies, and the model was developed such that these indicators were outputs of the model. Table 1 presents indicators used in the current study that were suggested by Haghshenas and Vaziri (2012).

A composite index reflecting all the key dimensions was suggested. The method used was the additive weighted method. Firstly, *Z*-score of all indicators was calculated as Eq. (1). *Z*-score is frequently used to normalize the indicators for algebraic computations (Joumard & Gudmundsson, 2010). Then for each group, a composite index is built by adding normalized indicators, assuming herein equal importance weight as shown in Eqs. (2)–(5). Negative sign "−" is used for an indicator when the smaller amount is more desirable for sustainable transportation, such as emission, and positive sign "+" is used for an indicator when larger amount is more desirable, like access. The I_{TE}, I_{TC} and I_{TS} are environmental, economic and social composite indices, respectively. Overall index of sustainable transportation, I_{OST}, was built by adding the result of normalized composite indices, Z_{ITE}, Z_{ITC} and Z_{ITS} based on Eq. (5), assuming equal weights.