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Land-use planning: Implications for transport sustainability

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ABSTRACT

This research study explores three urban planning scenarios for Melbourne, Australia in 2030 and their implications for transport sustainability. As part of the analyses, a transport sustainability index, derived from 10 sustainability indicators, was developed and applied to compare the scenarios. A base-case scenario, an activity-centres scenario, and a fringe-focus scenario were used to consider compact to expanded urban development patterns. The activity-centres scenario, which favours compact development patterns, had the highest transport sustainability index. In contrast, the fringe-focus scenario that significantly expands urban development in the fringe resulted in a lower transport sustainability index. The results of scenario analysis would influence decisions regarding urban development in 2030.

1. Introduction

The transport sector is a major user of fossil energy, which causes air pollution and also contributes to global warming (Dobranskyte-Niskota et al., 2007). Negative environmental and social impacts of transport impose large costs on society. It is estimated that air pollution, noise and accident related costs are at least 5% of GDP for industrialised countries (Verhoef et al., 2001). Hence, the transport sector with its significant environmental, social and economic impacts, is an important element of urban sustainability (Haghshenas and Vaziri, 2012).

The 1987 Brundtland report (from the United Nations World Commission on Environment and Development) defined sustainable transport as "transport that meets the current transport and mobility needs without compromising the ability of future generations to meet these needs" (Balack, 2004). In recent years, many studies have worked on planning for sustainable transport systems. Due to uncertainty regarding the effects of particular policies on urban transport systems, considering their effects on transport sustainability is a challenging task for policy-makers (Shiftan et al., 2003).

There is a high level of interaction between transport activities and land-use planning decisions. For example, land-use patterns affect access to facilities and destinations, and consequently affect the amount and methods of travel. Therefore, understanding these interactions is important for urban planning (Litman, 2014b). Over the past 20 years, benefits of increased density in urban areas have been considered for regional planning. Bartholomew (2007) reviewed 80 urban planning scenarios in more than 50 US metropolitan areas and found that an 11% increase in density decreases the vehicle miles travelled (VMT) and NO_x emissions by 2.3% and 2.1%, respectively. Similarly, a study of future urban development scenarios for 11 metropolitan areas in the Midwestern US concluded that a 10% increase in density would reduce VMT and transport-related air emissions by 3.5% (Stone et al., 2007). In another study, Jakimavičius and Burinskiene (2009) assessed three urban development scenarios (compact development, extensive development, and decentralised concentrated development) in terms of fuel consumption, distance travelled, and driving time in a car during morning peak hours. The results indicated that compact and mixed land-use reduce fuel consumption.

Despite scenario analysis on the effect of land-use on distance travelled and related emissions, there is a lack of studies that consider the effects of urban planning scenarios on transport sustainability for Melbourne. This paper applied an indicator-based approach for sustainable transport modelling. The study considered the impacts of three urban planning scenarios on transport sustainability for Melbourne using various sustainable transport indicators. It provides insights into the future developments of the transport sector in 2030 resulting from the three urban planning strategies. First, a list of transport sustainability indicators was identified. In the next step, indicators were quantified using a land-use/transport interaction model, which were then normalised and integrated into a single index. In the final step, a transport sustainability index was quantified for three urban planning scenarios for Melbourne in 2030: a base-case scenario, an activity-centres sce-

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nario, and a fringe-focus scenario. Application of these scenarios is useful in assessing how the implementation of different policy measures may change transport sustainability in Melbourne.

2. Method

In the first step of this study, an indicator-based approach was undertaken to select and quantify transport sustainability indicators in environmental, social and economic dimensions. In the next step, selected indicators were normalised, weighted and integrated into a transportation environmental impact index (TEII), a transportation social impact index (TSII), and a transportation economic impact index (TCII). In the final step, selected indicators and consequently the environmental, social and economic indices were predicted for three urban planning scenarios in 2030. The details of each step are described in this section.

2.1. Indicator selection

The transport sector has a range of negative impacts. Therefore, to achieve a sustainable transport system, it is essential to assess the transport sector using indicators in decision-making when implementing solutions to these impacts. During the last two decades, measuring sustainability by indicators has been widely used by the scientific community and policy-makers (Dobranskyte-Niskota et al., 2007). Indicators as quantitative measures can be applied to simply illustrate complex phenomena (EEA, 2005). Indicator choice is a trade-off between available data sources and selection criteria (comprehensiveness, relevance, data availability, measurability, transparency) (Dur et al., 2010; Haghshenas and Vaziri, 2012; Li et al., 2009; Spiekermann and Wegener, 2004; Zito and Salvo, 2011). It should be balanced, reflecting a combination of environmental, social and economic objectives (Litman, 2005). A list of transport sustainability indicators is presented in Table 1. The selected spatial scale for this study [SLA (statistical local area) level] limited the number of indicators that can be quantified. As the objective of sustainable transport depends on the context (Castillo and Pitfield, 2010), the selected set of indicators represented Melbourne's trend towards transport sustainability and covered environmental, social and economic dimensions. Indicators such as vehicle kilometres travelled (VKT), passenger kilometres travelled (PKT), length of railways and main roads, and proportion of residents with public transit services within 500 m, are intermediate indicators rather than final indicators. Hence, they were used to quantify the final indicators such as depletion of non-renewable resources, emissions and accessibility.

It is noted that considering air pollutants and mortality effects of air pollutants in two separate indicators may risk double counting the effect. However, along with harming human health, air pollutants can cause a variety of environmental effects such as acid rain, eutrophication, and ozone depletion. Therefore, considering air pollutants as well as the mortality effects of air pollutants, attempts to consider all these impacts.

2.2. Indicator quantification

Statistical local areas (SLAs) in Melbourne were selected as the study areas in this paper. Using the 2006 Australian Bureau of Statistics (ABS) database and the 2007 Victorian Integrated Survey of Travel and Activity (VISTA07) conducted by DOT (2007), the selected indicators were quantified, which is presented in the following sections in detail.

2.2.1. Transportation environmental indicators

Selected environmental indicators were quantified as follows:

- Depletion of non-renewable resources: the inclusion of depletion of non-renewable resources is justified by the definition of a sustainable transport system as a system that minimises non-renewable resources consumption. In this study, the amount of primary fuel (crude oil) consumed is a measure for resource depletion. To calculate the primary fuel consumed, first transport energy consumption was estimated by multiplying VKT for private transport and PKT for public transport by energy factors estimated by Rickwood (2009). To convert MJ of energy consumption in transport to litres of primary fuel, the petroleum refinery efficiency must be applied. By knowing transport energy consumption and petroleum refinery efficiency in Melbourne (90%) (Australian Government, 2010 BREE, 2010), the amount of primary fuel consumed was calculated.
- Transport emissions: according to the definition of a sustainable transport system as a system that produces emissions only within the planet's ability to absorb them, selection of greenhouse gas (GHG) emissions as one of the transport environmental indicators is justifiable. Emissions of pollutants other than GHGs from transport into the air are major sources of poor air quality. The justification for including them is the same as including GHG emissions. In this study, GHG emissions were estimated by multiplying VKT for private transport and PKT for public transport by emission factors estimated by Rickwood (2009). CO, PM_{10}, and NO_2 were also quantified using emissions factors presented by the Australian National Pollutant Inventory (NPi, 2008).

Hence, estimates of total VKT and percentage of trips by cars (modal split) in each SLA are required. According to the literature, spatial and land-use planning, economic, social, and behavioural factors are the main factors influencing transport development (Corpuz et al., 2006; Dargay and Hanly, 2003; Giuliano and Dargay, 2006; Lindsey et al., 2011; Næss, 2009; Shiftan et al., 2003). Distance from the CBD, area of SLAs, access to public transport, walkability, proportion of couples with children to other households, household annual income, and car ownership, were selected for estimating VKT; while population density, area of SLAs, access to public transport, walkability, proportion of couples with children to other households, household annual income, and car ownership, were selected for estimating modal split (Corpuz et al., 2006; Dargay and Hanly, 2003; Giuliano and Dargay, 2006; Haque et al., 2013; Kitamura et al., 1997; Kobos et al., 2003; Lindsey et al., 2011; Litman, 2012; Miller and Ibrahim, 1998; Newman and Kenworthy, 1991; Paravantis and Georgakellos, 2007; Pongthanaisawan and Sorapipatana, 2010; Soltani and Somenahalli, 2005; Whelan et al., 2010; Zhang et al., 2012). VKT and percentage of trips by cars (modal split) were quantified as functions of the above selected land-use and socio-economic factors, using an artificial neural network (ANN) model.

A feed-forward neural network model is the most popular type of ANN in transport modelling studies. "This network consists of an input layer, an output layer, and one or more hidden layers between the input and output. The number of nodes in the input layer is usually identical to the number of independent variables, while the number of nodes in the output layer is the same as the number of dependent variables" (Limanond et al., 2011). A neural network model is applied to map between a set of inputs and a set of outputs, and provides appropriate responses. The process of adopting an appropriate network to the data is known as neural network training (Limanond et al., 2011). The ANN was implemented for Melbourne data in MATLAB. VKT and modal split were introduced to the MATLAB neural network fitting tool as outputs, and selected socio-economic and land-use factors were introduced as inputs. Seventy per cent of data was used for training, 15% for validation, and 15% for testing, which are the default settings in MATLAB. When training data is fed as inputs to the model, the neu-