Transportation Research Part C 43 (2014) 267–279

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

# Trade-offs between mobility and equity maximization under environmental capacity constraints: A case study of an integrated multi-objective model

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ARTICLE INFO

*Article history:*
Received 10 July 2013
Received in revised form 20 March 2014
Accepted 21 March 2014

*Keywords:*
Policy decision making
Environmental capacity
Mobility
Accessibility-based equity
Car ownership

ABSTRACT

This paper investigates the performance of a policy decision tool proposed for multi-objective decision under different policy interventions. This tool deals with the trade-off between mobility and equity maximization under environmental capacity constraints. Two system objectives, maximization of mobility and equity, are formulated in terms of the sum of total car ownership and number of trips, and the differences in accessibility between zones. Environmental capacities are based on production efficiency theory in which the frontier emission under maximum system efficiency is taken as environmental capacity. To examine the performance of the proposed model, three types of hypothetical policies (network improvement, population increase and urban sprawl) are formulated. Effects are simulated using data pertaining to Dalian City, China. Results show that the proposed model is capable of representing the trade-offs between mobility and equity based on different policy interventions. Compared with two extreme cases with the single objective of mobility maximization or equity maximization, the Pareto-optimal solutions provide more interesting practical options for decision makers. Taking the solution based on the maximum equity as an example, the policy of urban sprawl yields the most significant improvement in both emission and accessibility of the three scenarios.



## 1. Introduction: Policy context

The rapid expansion of car ownership and the increase of car dependency have been main reasons for worldwide urban problems such as congestion, accidents, and emissions. In most developed and developing cities, automobiles have become the most important source of urban pollution (e.g. Cai and Xie, 2007; Gao and Niemeier, 2008). In spite of the progress in developing environmental friendly vehicles (i.e., electric vehicles, new type of fuel resource, automatic driving), technology alone does not provide a sufficient solution. A more integrated approach is needed, especially in developing cities where people will continue pursuing the ideal of motorized convenience when their economic situation improves (Schafer, 1998). Urban planning and mobility management should therefore consider the interrelationships between urban development, land use and transport demand generation.

Especially the situation in large metropolitan areas in developing countries such as China has become increasingly more problematic. These cities have attracted many new people from the countryside seeking job opportunities. This has resulted

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http://dx.doi.org/10.1016/j.trc.2014.03.012
0968-090X/

in a rapid growth of population, firms and infrastructure. Although investments in public transport and high density neighborhoods have been important planning ingredients, nevertheless the changing land use requirements have resulted in substantial urban sprawl. In turn, urban sprawl implies longer distances and this in turn has triggered reliance on cars and the road network, with congestion and adverse environmental impacts as negative externalities. Obviously, improved economic conditions have meant that an increasing share of the population can afford cars.

Urban sprawl, increased car ownership and use, and the resulting environmental impact are however not the only policy issue in this context. Substantial differences in welfare and significant spatial difference in these metropolitan cities in terms of service and transport provision imply that policy makers also face a distributional problem of the impacts of the policies. This is the issue of equity (or inequality). Equity is commonly understood as fairness or justice of the distribution of the impacts (both benefits and costs) of an action on two or more subgroups (Litman, 2002). In the field of urban and transportation planning, equity can be examined from either a social or a spatial perspective. Social equity basically refers to differences in income or social welfare between individuals. Spatial equity indicates differences in the *spatial* distribution of transportation services (e.g., travel time, cost, distance, and number of transfers) or other services. Different from social equity, spatial equity represents the differences which could be affected by zonal/regional mobility levels, transport network conditions, inter-zonal mode choice, land use topology, etc. This paper is concerned with spatial equity which is defined using a formal indicator based on zonal accessibility.

Recognizing the importance of motorized mobility and spatial equity, a vast literature has contributed to this topic area. The relationship between urban development and mobility has been discussed from different perspectives, such as car ownership (Kitamura, 1987; Meurs, 1993), and car use (Steg et al., 2001; Gardner and Abraham, 2008). Spatial equity has been mainly discussed in the context of the network design problem where equity has been generally used as one of the constraint conditions (Meng and Yang, 2002; Santos et al., 2008). To position the present paper, it should be emphasized that these different literatures have been isolated; there is a paucity of research which evaluates the dynamic interactions between urban development, mobility, environmental impact and equity in a comprehensive manner. Arguing that mobility levels should be at their maximum while keeping inequitable influences at their minimum, policy development may be assisted by developing an integrated modeling framework, which incorporates evaluations of both mobility and equity and their trade-offs.

To that end, we have formulated a policy decision support tool that allows decision makers to identify maximum mobility levels under environmental capacity constraints (Feng et al., 2008). The applicability of the model has been verified in a case study using real network data. Moreover, model performance under different policy interventions has been examined (Feng et al., 2010). Previous publications have verified the effectiveness of the modeling framework as a policy decision tool, however, the model has not been tested when dealing with multiple policy concerns. The purpose of this study therefore is to investigate the performance of an enhanced integrated model proposed for multi-objective policy decision making. The model addresses the trade-offs between mobility and equity maximization under environmental capacity constraints. The idea behind the multi-criteria formulation is to identify the maximum mobility level while keeping the maximum equity of accessibilities. Specifically, it deals with two strategic targets, maximization of (i) motorized mobility and (ii) accessibility-based equity, which are respectively formulated in terms of total car ownership and number of trips, and differences between zonal accessibility. Based on efficiency theory, environmental capacity is derived from frontier emissions under the most environmentally efficient system.

To investigate the performance of the proposed model, three types of hypothetical policies, network improvement (NI), population increase (PI) and urban sprawl (URS), are designed and the effects of these policy scenarios are simulated using data of Dalian City, China.

The remainder of this paper is organized as follows: Section 2 presents the integrated model and details of its components. A genetic algorithm designed for the multi-objective optimization problem is developed. A case study and the relevant designed policy scenarios are introduced in Section 3. Results of analyses are discussed in Section 4. The paper is completed with a summary and discussion in Section 5.

## 2. The integrated model

### 2.1. Scope

The integrated model proposed here serves two optimization objectives: maximization of mobility which is measured in terms of total car ownership (i.e. the number of cars) and total number of trips, and maximization of spatial equity which is defined and measured using a zonal accessibility measure. The modeling process is based on a bi-level programming method which follows an iterated process to obtain the optimal solutions under the constraint that the environmental load does not exceed environmental capacity. The Pareto-optimal solutions which relate to a vector of zonal car ownerships are obtained at the upper level of the bi-level programming problem, subject to the constraint that the environmental load should not be larger than the corresponding environmental capacity. Zonal car ownership is used to calculate inter-zonal transport mode choice probabilities which in turn are used to calculate the origin–destination (O–D) trip matrix. The resultant O–D matrix is then assigned to the road network in the lower level problem, resulting in a distribution of traffic flows and associated emission levels which provide the inputs for the upper level problem. A flowchart of the whole modeling process is depicted in Fig. 1.