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A problem-structuring model for analyzing transportation–environment relationships

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ABSTRACT

This study discusses a decision support framework that guides policy makers in their strategic transportation related decisions by using multi-methodology. For this purpose, a methodology for analyzing the effects of transportation policies on environment, society, economy, and energy is proposed. In the proposed methodology, a three-stage problem structuring model is developed. Initially, experts' opinions are structured by using a cognitive map to determine the relationships between transportation and environmental concepts. Then a structural equation model (SEM) is constructed, based on the cognitive map, to quantify the relations among external transportation and environmental factors. Finally the results of the SEM model are used to evaluate the consequences of possible policies via scenario analysis. In this paper a pilot study that covers only one module of the whole framework, namely transportation–environment interaction module, is conducted to present the applicability and usefulness of the methodology. This pilot study also reveals the impacts of transportation policies on the environment. To achieve a sustainable transportation system, the extent of the relationships between transportation and the environment must be considered. The World Development Indicators developed by the World Bank are used for this purpose.

1. Introduction

In the new millennium, one of the greatest challenges to humanity is how to assess, build, and maintain a sustainable economy that will allow human society to enjoy a sufficiently high standard of living without destroying the natural and biological resources that sustain it. Sustainable development (SD) has become an essential component of international environmental policy, at least since the United Nations summit in Rio in 1992. The concept of sustainability combines the needs of present and future generations and takes the interdependencies of economic activities and ecological status into account (Phillis and Andriantiantsaholiniaina, 2001).

The rise in worldwide trade and the increasing interaction between countries previously separated by trade barriers have spurred a significant increase in transportation flows at all geographical scales. This has caused a wide variety of external environmental effects, ranging from ecological footprint problems to global pollution. The 1990s were characterized by a growing awareness of global environmental issues, particularly the impact of carbon dioxide emissions, referred to as the greenhouse effect. The World Bank expects that if current trends continue, CO_2 emissions caused by transportation will increase significantly by 2010 (Veen-Groot and Nijkamp, 1999). CO_2 emissions are already 1% higher than in 1990, and fossil fuels are the main source of emissions in both developed countries and emerging economies (World Bank, 2007). It is now generally agreed that a global climate change is occurring. It also appears that the poorer countries stand to suffer most as a consequence of this change, with estimated costs in the range of 5–9% of gross domestic product (GDP), especially for developing countries. It has also been estimated that the transport sector is responsible for about 25% of emissions of the gases contributing to global warming in industrial countries, but this percentage is lower by half in cities in developing countries (World Bank, 2002). In particular, road pollution contributes significantly to urban air pollution in many countries.

From the standpoint of the feasibility of providing growth in road capacity commensurate with the predicted growth in traffic, as well as from that of impact on the environment and society, current trends in transportation appear to be unsustainable. To resolve the problem, each country must work out its own transportation policies in accordance with its own geographical and political conditions.

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European Union (EU) countries have recently admitted that their transportation policies are unsustainable, and in fact their transport problems are even expected to worsen because worldwide automobile ownership tripled between 1970 and 2000 and the movement of goods is projected to increase by 50% by 2010. In the white paper, *European transport policy for 2010: time to decide* (ETP, 2000), EU countries have accepted the importance of having a balanced, sustainable, and integrated transportation system. In fact, until 1998, in many EU countries such as Germany and the United Kingdom, the basic transportation strategy was based on a "predict and provide" approach. However, such a strategy results in a disproportionate growth of road transportation and leads to an unsustainable and unbalanced transportation system. The white paper, *A New Deal for Transport: Better for Everyone* (Department of the Environment, Transport and the Regions (DETR, 1998) underlines the inadequacy of this approach and emphasizes the importance of a pragmatic multimodal plan.

Similar problems are apparent in an even more dramatic way in Turkey. The Turkish transportation network has not followed a planned growth strategy, mainly because of political factors. None of the transportation master plans developed so far in Turkey has succeeded in integrating the various transport modes into a balanced, multimodal system. As a result, currently, road transport accounts for 92% of freight shipments and 95% of passenger travel. Turkey's ninth development plan (2007–2013) underlines that even though considerable productivity increases have been obtained as a result of structural reforms implemented in many areas and the macroeconomic stability achieved in recent years, Turkey's competitiveness has not been sufficiently improved. One of the main reasons is acknowledged to be an inadequate transportation infrastructure (Ülengin et al., 2007).

Incorporation of environmental issues within an urban transport strategy requires the identification of the main factors that contribute to environmental pollution in a transportation system. Therefore, it does not make sense to study transport issues separately. There is a widespread acceptance that integration of decisions across transport, land use planning, and environmental policy is crucial for sustainable development.

This study proposes a decision support framework that guides transportation policy makers in their future strategic decisions by using a multi-methodology approach. The proposed methodology includes the specification of the factors in transportation, environment, society, and energy relationship as well as the interactions among those factors using cognitive map analysis. Subsequently those relationships are hypothesized and quantified using structural equation modeling (SEM). Finally scenario analysis and multi attribute decision making are employed to forecast the implications of some policies and to select the best one. This paper also provides a pilot study that focuses only on the relationships between transportation and the environment as well as their effect on the health of the society is conducted to validate the appropriateness of proposed framework. In the second section of this paper, a literature survey of existing research in sustainable transportation models is provided. The proposed methodology is presented in the third section. The fourth section explains the details of the pilot study, which focuses on transportation and environment relationship. Finally, conclusions and further suggestions are given.

2. Literature survey

The report of the joint project of the European Conference of Ministers of Transport (ECMT) and the Office for Economic Cooperation and Development (OECD) on *Implementing Sustainable Urban Travel Policies* (ECMT, 2001) underlines that planning for transport, land use, and environment can no longer be conducted separately in isolation. Geerlings and Stead (2003) provide a review of European policy documents and research activities and underline that relatively little European research has been carried out on the issue of policy integration, particularly in relation to transport, land-use planning, and environmental policies. The European Transport White Paper (Commission of the European Communities (CEC, 2001) highlights the need to integrate environmental considerations into transport policies, although how to achieve this integration remains unclear.

Gilbert and Tanguay (2000), Gudmundsson (2001), and Gilbert et al. (2003) reveal sustainable transportation indicators in order to set sustainable transport goals and to monitor whether the current transport system is moving towards sustainability. Steg and Gifford (2005) analyze the social impact of sustainable transportation from quality of life perspective and describe several quality of life indicators for this purpose. Richardson (2005) provides frameworks illustrating the interaction of factors that influence indicators of transport sustainability. However, these studies do not suggest any method for quantification of the relationships among the variables/indicators and they also do not include any policy making method for transportation.

Fiksel (2006) provides an overview of current approaches for modeling and management of complex economic, ecological, and social systems and underlines the lack of modeling and decision-making approaches that will help in understanding the full implications of alternative choices and their relative attractiveness in terms of enhancing system resilience to achieve sustainable systems. The STEEDS project, which is a computer-based decision support system (DSS) focusing on transport–energy–environment interactions, has recently been developed and validated (Brand et al., 2002). This DSS was developed to evaluate policy and technology options for the European transport system. However, the DSS also includes a transport demand model, vehicle stock model, energy emissions model, lifecycle analysis model, and environmental impact model. In essence, it is several domain-specific models linked together. The causal relations among all the variables of the system are not considered.

Ülengin et al. (2007) provides an integrated decision support system designed to allow formulation of aggregate long-term scenarios (national, regional, or global). Using a systems approach, it analyzes the interrelations among transportation, socioeconomic, and demographic variables using a causal map approach and then uses a neural network and the Bayesian causal map to analyze the impact of different scenarios on passenger and freight transportation demand in the future. The model is used to guide transportation policymakers in their future strategic decisions; to facilitate analysis of the possible consequences of a specific policy for changing the share of transportation modes for both passenger and freight transportation; to highlight in detail the causal relationships among relevant variables in the transportation system under study; and finally, to show the impact of a change in any variable on the whole system. Ülengin et al. (2007), conducted interviews with the transportation domain experts and encouraged them to identify the concepts that might be relevant to the transportation system of Turkey and influencing the passenger and freight transportation demand of different modes. The list of variables finally obtained to develop the structural model of the transportation system of Turkey is much more detailed when compared to the ones used in similar studies conducted in EU countries (Shaw et al., 2003). However, the developed model does not take into account the interactions between transportation systems and the environment.

Tsamboulas and Mikroudis (2006) have proposed a DSS, TRANSPOL, specifically developed for the transport policy sector, to provide policy support information which can be generated