Sustainable Urban Transportation: Performance Indicators and Some Analytical Approaches

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Abstract: Urban governments show considerable interest in formulating policies for a more sustainable transportation sector. In Australia, despite the Commonwealth Government Ecologically Sustainable Development (ESD) Transport Working Group making over 40 recommendations for more sustainable urban transportation a decade ago, a recent Institution of Engineers Australia, Transport Panel found little progress with transportation indicators of sustainability and appropriate analytical techniques. A review of the international literature is made to determine definitions of a sustainable urban transportation and land use system, and objectives that would form the basis for determining suitable indicators of performance. Drawing on hierarchical diagrams from decision theory, we show the link between higher-level policy objectives for sustainability and lower-order actions, measurable attributes, and performance indicators. The analytical framework for sustainable urban transportation analysis includes descriptive statistics—exploratory and graphical methods, spatial mapping, spatial statistics (to identify geographical patterns and to identify outliers in the data), regression analysis, travel preference functions based on Stouffer's intervening opportunity

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model, and linear programming. These analytical techniques are illustrated with examples of travel and urban form in Sydney using data from the Census of Population and Housing, 1961–1996. The need for geographically based indicators and transportation and land use policies is emphasized.

CE Database keywords: Urban areas; Public transportation; Australia; Statistics; Case reports.

Introduction

The Ecologically Sustainable Development Transport Working Group of the Commonwealth Government issued a report in 1991 full of recommendations for change in the transportation sector. When these recommendations were classified, most were either aimed at altering the value system, by specifying new goals and objectives for a more sustainable transportation sector, or were aimed at solutions to the perceived problem, such as higher density cities (Black 1996). Noticeably absent from the set of recommendations by the Working Group were suggestions on analytical tools, including appropriate "sustainability" indicators, and on targets to achieve them. A recent seminar convened by the Institution of Engineers Australia, New South Wales Transport Panel (see http://www.civeng.unsw.edu.au/IEAustTP/2001 Program/September Seminar/) confirmed that little progress had been made in Australia on analytical tools and performance indicators.

This paper redress these deficiencies by proposing a framework of performance indicators and analytical methods. The objectives are to review the literature on urban sustainable transportation, to classify it by geographical scale, to propose a general framework that links definitions and objectives for sustainability with appropriate performance indicators and analytical techniques, and to demonstrate their applicability with a case study. There are two parts to the framework. The first applies hierarchical diagrams to generate appropriate performance indicators given definitions of sustainable transportation and objectives (Keeney and Raiffa 1976). This approach is illustrated by examples of international practice that are drawn primarily from the most recent two World Conferences on Transport Research (Antwerp, 1998 and Seoul, 2001). These conferences are a fertile ground for discovering new research, practice, and policy: WCTR is the paramount international conference because it is multimodal and interdisciplinary, and aims at academics, practitioners, and policymakers. This search for relevant material is complemented by a summary of North American literature on car dependency and urban form that has been summarized by Suthanaya and Black (2001).

The second part of the framework are the supporting analytical techniques to examine urban sustainability issues. The analytical framework includes the importance of descriptive statistics—exploratory and graphical methods; spatial mapping, with an example of vehicle kilometers of travel (VKT) by automobile for local government areas (LGA) in Sydney; spatial statistics, especially to identify geographical patterns and to identify outliers in the data; regression analysis; travel preference functions based on Stouffer's intervening opportunity model and linear programming; and the recognition of the suitability of other modeling approaches that are beyond the scope of this paper, such as the four-step model and systems dynamics. These analytical techniques are illustrated with examples from our broader research into travel and urban form in Sydney. We believe that they have general applicability to any urban area where sustainable transportation targets are being proposed.

In the case of Sydney, Australia, the New South Wales Government has defined vehicle kilometers of travel (VKT) targets for 2010 so we did not need to apply, in this case, the hierarchical diagram; but in studies where the performance indicators are less clear such an exercise may prove invaluable. In the paper, we describe the essential features of the study area, the 44 local government areas on which the analysis is based, and the journey-to-work data sets from 1961 onward. As we are interested in long-term change we have used the Census data but are aware that other trip purpose are important in the overall consideration of a sustainable urban transportation sector. The selection of suitable predictive models based on time-series Census data with robust parameters to estimate future VKT by automobile is explained. The application of these models to scenarios for future (2010) land-use scenarios of population and workforce distributions in Sydney is outlined, and key results are presented.

Framework for Literature Review

An extensive review of the literature suggests that national governments are concerned with sustainability issues at the national or global scale (for example, global climate change). The framework of Table 1 is a simple device for classifying the literature on targets and performance indicators for any scale. Elsewhere, we have considered all geographical scales, merely noting here the dominance in the literature of indicators at the global and transnational scales. In a search—primarily from the most recent two World Conferences on Transport Research (Antwerp, 1998 and Seoul, 2001)—for indicators at the urban scale (and the local government areas that make up metropolitan regions), we have not found very much previous work. The relevant literature is classified in Table 1 and the bibliographic references are cited at the end of this paper.

"Sustainability" Indicators for Urban Areas

The context for much of this urban research is "sustainability," and this requires a working definition before any subobjectives and indicators can be determined. A research study, (PROSPECTS), supported by the European Commission under its Framework 5 Environment and Sustainable Development Program (May et al., unpublished, 2001), has provided a working definition of sustainability of the urban land-use and transport system and, furthermore, has sought decision makers' acceptance of such a definition. Based on considerations espoused by Minken (1999) and others, "a sustainable urban transport and land use system

- Provides access to goods and services in an efficient way for all inhabitants of the urban area;

Table 1. Classification of Sustainable Transportation Practice by Urban Scale

Geographical scale	Examples from the literature
Cities	Kim (unpublished, 2001)—comparison of Canadian and Korean Cities; Lee (1999)—sustainable spatial development for Kanji, Korea; Latus and Tisane—policy scenarios for Helsinki tested by MEPLAN/GIS model; Lu and Zhang (unpublished, 2001)—sustainability and environmental capacity; May et al., unpublished, (2001)—survey of decision makers in 109 European cities; Zeitgeist et al.
Suburban/local government areas	Páez, et al. (unpublished, 2001)—spatial statistics to identify differing journey to work travel behavior in 44 Lags of Sydney; Suthanaya and Black (2001) reviews U.S. literature on urban form and travel behavior
Organizations/developers	Black et al. (1999)—UNSW Transport Program; James and Greensmith (unpublished, 2001) TAPESTRY framework for mobility management plans (“green transport plans”) in Europe; NSW Department of Transport and RTA (2000)—Transport Management Accessibility Plans.

- Protects the environment, cultural heritage and ecosystems for the present generation; and
- Does not endanger the opportunities of future generations to reach at least the same welfare level as those living now, including the welfare they derive from their natural environment and cultural heritage.”

(May et al., 2001, unpublished, p. 12)

Decision makers in 54 European cities were asked to consider how appropriate the above definition of sustainability was to their circumstances (the definition had been previously agreed upon among the six “core cities” working in close collaboration with the research team—Edinburgh, Helsinki, Madrid, Oslo, Stockholm, and Vienna). Only a quarter of the responses considered the definition to be “very appropriate”; the majority (61%) thought the definition to be “quite appropriate” (May et al., 2001, unpublished, p. 12). The research team concluded that there could be scope for identifying a definition of sustainability that is more appropriate to the circumstances of European cities.

Assuming the definition of sustainability for the urban land use and transportation system is accepted, the literature reviewed fails to link indicators with higher-level goals for the system. The majority of the practice reviewed applies indicators to help assess the economic, social, and environmental implications of alternative scenarios or policy packages (for example, Lautso and Toivanen 1999). Some of this practice is directed as specific elements of sustainability—for example, sustainable accessibility and mobility (Zuidgeest et al., unpublished, 2001) or environmental capacity (Lu and Zhang, unpublished, 2001). There is a large stream of literature at the suburban (zonal) scale—much of it of North American origin—as reviewed by Suthanaya and Black (2001). The general characteristics of this work are investigating whether planned urban developments have different travel characteristics than that of neotraditional neighborhoods (where density is higher and land uses mixed), or determining whether zones close to railways or light-rail systems generate less car travel than zones more distant from public transport. None of the North American literature reviewed was aimed at targets or performance indicators.

Table 1 identifies a scale where the responsibilities for action are explicit—an individual organization [in Australia, the best-known example is that of the corporate transportation plan of the University of New South Wales and its travel demand management framework, as described by Black et al. (1999)]. Mobility management is an innovative approach to tackling local transport problems, in which key new players (potential players include local/regional authorities; site owners or managers; public transportation companies; event organizers; commercial interest groups; trade unions, employers organizations; environmental organizations; pedestrian, cyclist, or other specific road-user groups; and community groups) work together, often with local government, to develop appropriate transportation solutions. The emphasis is on information, communication, organization, and coordination. Part of the European Union's 4th Framework Program for Research, Technological Development, and Demonstration Activities supported MOMENTUM (Mobility Management for the Urban Environment) and MOSAIC (Mobility Strategy Applications in the Community). Early in 1999, a European Platform on Mobility, Management, established with the support of European Commission DG VII, aims to promote and further develop mobility management plans. James and Greensmith (unpublished, 2001) describe recent initiatives with mobility management plans.

Moving from general objectives to more specific objectives is essential in the search for appropriate indicators. In consultation with the Core Cities, (May et al., unpublished, 2001, pp. 12, 13) have developed a list of six subobjectives for sustainability:

- economic efficiency
- livable streets and neighborhoods
- protection of the environment
- equity and social inclusion
- safety
- contribution to economic growth

Over 90% of decision makers in 54 European cities considered these subobjectives of some importance (economic growth received the highest scores; equity and social inclusion the lowest). Twenty percent of the cities in Europe had no indicators; 80% use indicators of some type—quantified in monetary terms, quantified in nonmonetary terms, or qualitative. One quarter of the cities use all three types of indicators. Only 35% use indicators, which are quantified in monetary values (May et al., unpublished, 2001, pp. 13, 14). ''Indicators are of three types with this structured approach being welcomed by our core cities,'' and reflecting practice in the cities surveyed (May et al., unpublished, 2001, pp. 13, 14):

- Level 1 indicators—comprehensive measures of all aspects of a subobjective where the impacts are both quantified and monetarily valued (for example, cost benefit analysis produces a comprehensive measure of economic efficiency
- Level 2 indicators—quantifiable measures of aspects relating to the achievement of a subobjective
- Level 3 indicators—qualitative assessments of the level of goal achievement

As of mid-2002, PROSPECTS has not published a list of indicators fully acceptable to the core cities, but correspondence with the project team suggests that such a list may be soon forthcoming.

In the absence of this information on indicators, we have searched to find some logic to translate broad goals into specific and measurable indicators. Almost everyone who has seriously thought about objectives in a complex system has come up with a hierarchy (Keeney and Raiffa 1976, p. 41). Black et al. (1983, Fig. 4, p. 100) have imposed structure on the issue of planning objectives, and the appropriate policy instruments to achieve them, by introducing a hierarchy diagram with the broadest goal at the top (for example, ''sustainability''), where different layers of detail cascade down through lower levels of the hierarchical tree until the most precisely defined objectives are at the bottom (lower-level objectives). Measurable attributes (targets) are attached to each subobjective and a specific policy instrument (action) is proposed to meet the target. This approach owes inspiration to, but is substantially different in context from, the work of Manheim and Hall (1967).

Different levels in the hierarchy move from a general statement of the problem (''unsustainable transportation''), to objectives based on social theory, to a conceptual clarification of each objective, to the identification of an appropriate attribute that measures achievement of that policy objective (target), and to the identification of a particular instrument. To clarify the objectives of sustainable transportation, hierarchical diagrams describing both unsustainable transportation and sustainable transportation have been constructed (Figs. 1 and 2), based on the literature reviewed. Some researchers argue that emissions and other impacts resulting in climate change and loss of soil and biodiversity can be put in the strongly unsustainable category, while air pollution, and other concerns, can be put into the weakly unsustainable category. Noise and accidents might also be considered weakly unsustainable, as they might never have an obvious intergenerational impact (OECD 1996). Another factor, congestion, has traditionally been viewed in the U.S. transport sector as a problem of inadequate capacity for which the solution has been to build additional capacity (i.e., lanes, or airport runways, or applied ITS technology). Additional capacity no longer seems to be a sensible solution. Some cities are approaching gridlock, making these systems unsustainable.

Fig. 1 shows a diagram for unsustainable transportation. The actors involved include governments, private sectors, and individuals. Given limitation of resource availability, such as fossil fuel and land, government policies and market forces will drive the behavioral response of the individual. Car-dependent urban form, spatial mismatch, socioeconomic and demographic factors, nonoptimal

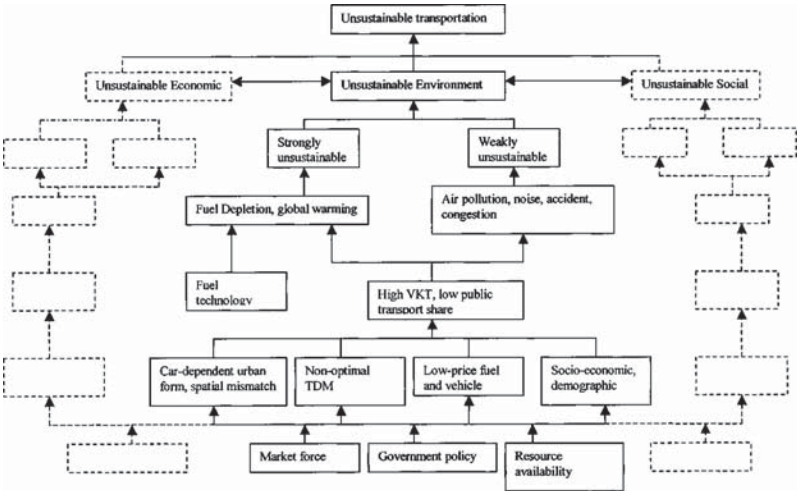

Fig. 1. Hierarchical diagram for unsustainable transportation based on literature reviewed

travel demand management (TDM), and low price of fuel and vehicle will lead to the worsening performance of travel patterns, such as increasing trip length, VKT, and decreasing public transportation share. Worsening travel-pattern performance, together with slow progress in technology development, will contribute to the fuel depletion and global warming—outcomes regarded as strong unsustainability as they strongly influence the ability of the future generation to meet their needs. Other environmental impacts are local pollution, noise, accidents, and congestion, all of which affect local populations, and intragenerational equity issues.

Fig. 2 shows the hierarchical diagram for sustainable transportation, starting from a global objective of sustainable transportation to several subobjectives and attributes. Sustainable transportation objectives consider three issues: environmental sustainability, economic efficiency, and social equity. Emphasis here is given to environmental sustainability. Within this environmental sustainability, the objectives can be divided into global as well as local and regional objectives. This distinction is important, as the policy taken at the local scale is mainly directed to achieve local objectives and may not be related to the achievement of broader global objectives. The global objective consists of two subobjectives: reduction of fuel depletion by minimizing fuel consumption measured in barrels per year (for example, through technology improvement) and global pollution by minimizing CO_2 and CFC emissions measured in grams per capita. The local/regional objectives consist of local pollution subobjectives (minimizing NO_x, CO, VOC, and PM_{10} measured in grams per capita) and other environmental subobjectives, such as minimizing noise, accidents, and congestion.

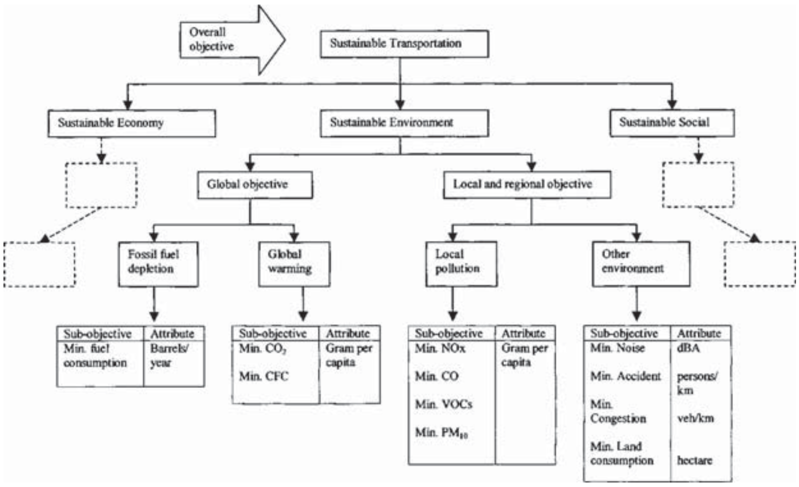

Fig. 2. Hierarchical diagram for sustainable transportation based on literature reviewed

Fig. 3 shows a diagram describing the link between urban form and sustainable transportation. The first step before using urban form as a tool to achieve sustainable transportation is to understand how urban form influences travel patterns, as travel patterns can be used as a proxy for energy consumption and transport emissions. Travel patterns at the regional scale need urban-form solutions at the regional scale. Similarly, solving travel patterns at the local scale needs a local solution. Suitable urban-form solutions to the local travel patterns problem might not contribute to the solution at the regional scale as every local

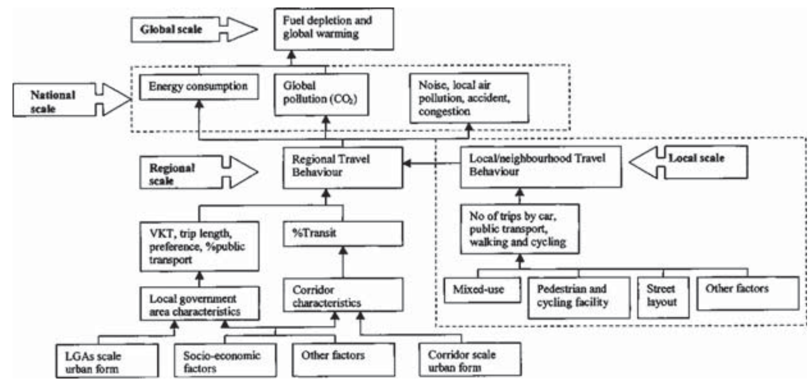

Fig. 3. Urban form and sustainable transportation based on literature reviewed

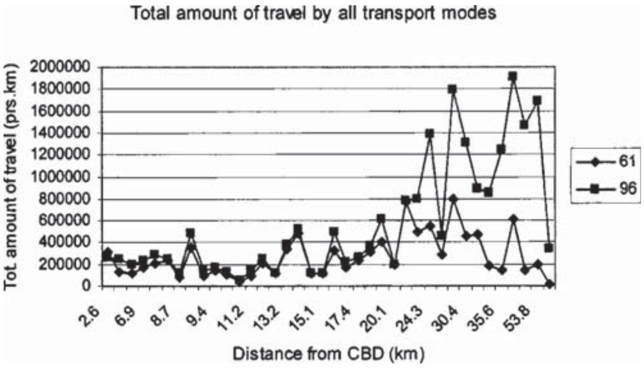

Fig. 4. Total amount of LGA journey-to-work travel by all transportation modes and LGA distance from CBD in Sydney, based on 1961 and 1996 census data

area has its own unique characteristics. Urban-form solutions at the local scale usually include mixed-use design, more jobs-housing balance, pedestrian-friendly design, and street layout improvement (neotraditional neighborhood design or transit-oriented developments). At the regional level, the scale of the analysis can be divided into macro level [local government area (LGA)] and microlevel (rail corridor). The travel patterns at the LGA level are influenced by the characteristics of local or neighborhood level. The travel patterns at the local/neighborhood level are influenced by the individual behavior.

Careful inspection of Figs. 1–3 will reveal that travel patterns are a component of environmentally sustainable transportation (EST) indicators. Aspects of travel such as VKT, trip length, and mode choice can be used as a proxy for energy consumption and transport emissions. Before demonstrating applications of these travel indicators to a case study city, we will describe the analytical approaches available.

Transportation Sustainability: Analytical Approaches

The previous section has shown how to identify indicators of performance; this section shows how the indicators may be quantified. Our approach is to draw upon a raft of suitable analytical techniques to help understand the relationship between urban form (land use) and travel, and then to apply these to scenarios to examine the degree to which specified policy targets might be met in the future. The analytical framework includes

1. Descriptive statistics—exploratory and graphical methods
2. Spatial mapping
3. Spatial statistics
4. Travel preference functions (Stouffer's intervening opportunity model and linear programming)
5. Regression analysis