

Land-use/transport Interaction Models as Tools for Sustainability Impact Assessment of Transport Investments: Review and Research Perspectives

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Interest in the appraisal of the sustainability impacts of transport policies has grown the last few years, expressing the need for a balanced treatment of economic, environmental and social impacts. This paper represents a first step in creating a framework for Sustainability Impact Assessments; it will also review operational land-use/transport interaction models as assessment tools. An in-depth analysis of the potential impacts of land-use and transport policies, and scenarios, on the economy, society and the environment will present new challenges to land-use/transport interaction models. The first challenge is related to modelling behaviour: i.e. the model should estimate land-use, transport and accessibility impacts in a theoretically sound and consonant manner, and consistently link the full set of (long-term) land-use and (short-term) travel-behavioural responses to these policies. The second challenge is to improve methodologies to (better) include the wider (macro-)economic effects and the passive values. The third challenge is to generate more knowledge for understanding ecological and social impacts, and for the development of related indicators and methodologies to calculate them. A fourth, and final, challenge is related to the presentation and integration of the sustainability impacts, not only including the economic, ecological and social impacts, but also finding the 'right' balance between them. Although recent model developments facilitate a far more comprehensive analysis than is common

practice today, there is certainly a need for theoretical and practical research for conducting Sustainability Impact Assessments of land use and transport policies and scenarios.

Key words: sustainability impacts, transport policy appraisal, land-use/transport interaction model

1. Introduction

Research and policy issues are increasingly being addressed in an integrated approach to evaluating the sustainability impacts of policy plans, programmes or projects. The World Bank (Serageldin & Steer, 1994) was one of the first institutions to operationalise the concept of sustainable development for assessing the economic, ecological and social sustainability of specific funding proposals. In the United States, federal legislation issued in 1991 requires environmental justice assessments of transport investments, which, in turn, calls essentially for a broad evaluation of environmental, social and economic impacts (e.g. Forckenbrock & Schweitzer, 1997). In the UK, a series of studies on trunk/main road schemes have been conducted since 1998 using a broad evaluation framework, the Guidance on Methodology for Multi-Modal Studies (Dft, 2000), to meet sustainable transport objectives in the study areas. Recently, the European Commission announced its intention to launch a sustainability impact assessment for all new major policy proposals, including transport, as a tool to improving the quality and coherence of the policy development process. This would facilitate a more coherent implementation of the European strategy for Sustainable Development, incorporating in-depth analyses of potential impacts on the economy, society and the environment (EC, 2002). This new interest presents new challenges to land-use and transport modelling, and to evaluation methodologies. Many definitions of sustainability can be found in the literature. Most of these include (a) intergenerational aspects (for example, the report of the World Commission on Environment and Development – WCED, 1987), (b) a balance between economic, ecological and, sometimes, also social impacts or (c) both a and b. In this paper we will focus on the second approach, defining sustainability as a balance between economic, ecological and social impacts.

Here, a first step has been taken towards creating a framework for sustainability impact assessments of land-use and transport-system changes. The paper focuses on the assessment of transport-related impacts as the result of land-use changes, transport changes or the linkages between land use and transport. Land-use changes (policies, plans) with no expected effects on the transport system are not considered here, e.g. urban renewal or conservation of nature areas. Firstly, the paper presents a theoretical framework for the assessment of sustainability impacts for land-use/transport systems, and describes impact assessment methodologies (section 2). Secondly, a number of operational land-use/transport interaction models are reviewed as methods for assessing the sustainability impacts of land-use and transport changes such as land-use, transport, environmental, social and economic impacts (section 3). Here, we focus on land-use/transport interaction models, since this model type is, at present, the only available method that deals with an important range of impacts that may arise from planning decisions in land use and transport. Section 4 presents the conclusions.

2. A framework for Sustainability Impact Assessment

2.1 A conceptual model for the land-use/transport system

In the evaluation of land-use and transport changes, the indicators used for the measurement of impacts should, in general, give a representative, measurable and theoretically based picture of the interactions between the land-use/transport system and the ecological, economic and social systems. They should be responsive to changes in the land-use/transport system. Here, we present a conceptual model to describe simply the functioning and evaluation of the land-use/transport system (Figure 1) based on an extensive literature study. See also Van Wee & Dijst (2002) for an elaborate description of the different elements of the land-use/transport system and their impacts.

The central core of the conceptual model is formed by the land-use/transport system, which, in turn, comprises interdependent systems for land use and transport that interact bilaterally (see Wegener & Fürst, 1999) for an extensive overview of empirical and model studies on land-use and transport interaction). In short, the *land-use system* can comprise: (a) the distribution of the supply of land and buildings in space, i.e. locations for specific land-use functions (e.g. nature areas, houses, offices, schools, shops) and their characteristics, such as density, diversity and design; (b) the distribution of the demand for human activities, e.g. living, working, shopping, education or leisure locations, and (c) the confrontation between land-use demands and supply, resulting in the spatial structures expressed by people's interaction patterns. The land-use system co-determines the need for land use and creates the needs for travel and the movement of goods within the transport system to bridge the distance between the activities. Given the socio-economic population characteristics, people's *needs and opportunities* are further co-determined by people's preferences and attitudes. These, in turn, are influenced by both affective-reasoned factors (e.g. privacy, status) and instrumental-reasoned factors (perceived costs and benefits of travel) determined by the transport system (Steg et al., (2001). The volume and characteristics of travel, and movement of goods within the *transport system*, is the result of the confrontation of travel demand and infrastructure supply (i.e. the amount of time, costs and effort) and (accident) risks related to the use of infrastructure and vehicles. Finally, the transport system creates opportunities for spatial interactions that can be measured by accessibility. The distribution of accessibility in space co-determines decisions on locating households and enterprises, and leads to changes in the land-use system.

Furthermore, contextual factors co-determine the functioning and impacts of the land-use/transport system. In brief, contextual factors include: (a) characteristics of the economy such as the level of economic growth, employment, and sectoral and regional structure of the economy; (b) the socio-demographic and socio-cultural characteristics of the population, such as the age and income distribution of the population; (c) characteristics of the ecology/environment, such as the quantity of such natural resources as fossil fuels, the ecological/environmental quality of an area and (d) the level of technological development, e.g. information and communication technology (ICT), and vehicle technology. Furthermore, governmental policies (e.g. investments in transport infrastructure, fuel taxes and location policies) also influence the land-use/transport system directly and indirectly (via the contextual factors).

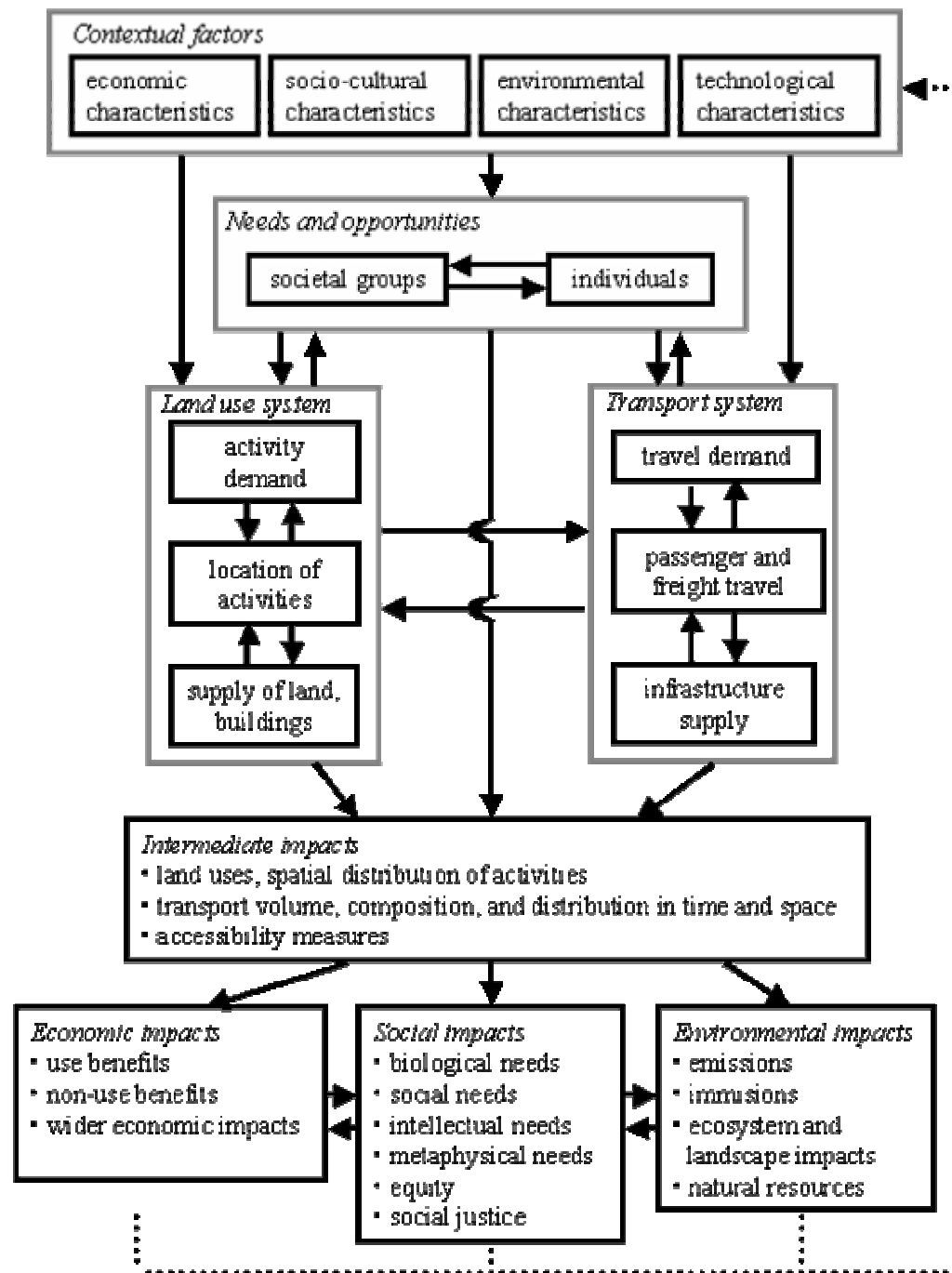


Figure 1. Conceptual model for the function and impacts of the land-use/transport systems.

Figure 1 shows the classification of these impacts, but omits policy influences to reduce the complexity. Changes in the functioning of the land-use/transport system (e.g. accessibility changes) are seen as ‘intermediate’ impacts (see section 2.2). These may, in turn, result in ‘final’ impacts outside the land-use/transport system, i.e. environmental, economic and social impacts (see sections 2.3 to 2.5). Note that some environmental, social and economic impacts are related; for example, air pollution may cause human health problems at immersion points, which, expressed in monetary terms, can be interpreted as economic effects. Thus, when

indicators are weighted to summarise the sustainability impacts we must be aware of double counting of impacts. Furthermore, Figure 1 shows the final impacts to interact to a certain extent with contextual factors, thus creating a feedback mechanism to the land-use/transport system; e.g. the environmental quality in an area may affect the location decisions made by households and firms. Lastly, final impacts also influence the development of policies aiming to mitigate or strengthen the economic, environmental or social impacts of the land-use/transport system.

2.2 Land-use, transport and accessibility impacts

Several indicators can be used to describe the functioning of the land-use/transport system, and these can be categorised in several ways. Land-use and transport indicators can be grouped according to the rate at which they change. Wegener & Fürst (1999) identified four rates of change: (1) very slow changes, referring to transport networks and land use, the most permanent elements of the physical land-use structures; (2) slow changes, referring to residences and non-residential buildings, which may have a life-span up to 100 years and take several years to construct, from planning to completion; (3) fast changes, referring to the distribution of activities, which can change within one or more years and (4) immediate changes, referring to transport volumes (e.g. in terms of passenger and vehicle kilometres), and their composition (i.e. mode and vehicle choice) and distribution in time and space.

Accessibility measures can be used to describe the functioning of the transport system or the combined land-use/transport system. In general, four types of accessibility measures can be distinguished (see Geurs & Van Wee (2004) for a review of accessibility measures): (1) infrastructure-based accessibility measures, describing the level of service in transport infrastructure (e.g. 'level of congestion' and 'average travelling speed in the road network'); (2) location-based accessibility measures, describing the level of accessibility to spatially distributed activities, such as 'the number of jobs within 30 minutes travel time from origin locations', (3) person-based accessibility measures, describing accessibility at the individual level, e.g. 'activities in which an individual can participate at a given time, and (4) utility-based accessibility measures analysing the (economic) benefits people derive from access to the spatially distributed activities. Infrastructure-based accessibility measures describe the functioning of the transport system only, as this type of measure is only sensitive to transport changes, whereas the other types are sensitive to changes in both the land-use and transport systems. In other words, a change of accessibility may be the result of land-use changes, travel time or cost changes, or both.

Several methodologies and models are used in the literature to estimate the intermediate indicators described above. Since the 1960s, many land-use and transport models from different scientific fields have been developed to model and evaluate land-use or transport patterns and changes. See, for example, EPA (2000) and Hensher and Button (2000) for recent overviews of modelling approaches and underlying theories. This paper focuses on land-use/transport interaction models as evaluation tools, as these models are typically developed to simulate and evaluate land-use and transport-system changes and their interactions, incorporating the different rates of change. A great deal has already been written about differences in underlying theories and modelling techniques of operational land-use/transport models (e.g. In general, a land-use model's estimates of the spatial location of activities should be based on a behavioural representation of the different spatial processes

and actors involved. This would involve the modelling of the different land-use subsystems identified and a level of segmentation sufficient to assign the major observed differences to groups of homogeneous actors, and the strength of behavioural responses to be calibrated to match the real world's patterns. A second broad requirement is that the transport model's estimates of travel demand patterns should reflect a consistent outcome of the interplay between all the major behavioural responses to changes in costs and characteristics of transport supply. Thirdly, and finally, the model should consistently link the full set of (long-term) land-use and (short-term) travel behavioural responses. However, applying these criteria would imply a level of complexity and detail that can probably never be achieved in practice. DSC/ME&P (1999) conclude that none of the operational land-use/transport interaction models was, at the time of their review, able to meet the full set of criteria for a complete set of behavioural responses, even with the existing state-of-the-art modelling.

2.3 Economic impacts

Economic impacts of transport system changes are potentially diverse. Economic impacts can be categorised in many ways (e.g. Eijgenraam et al., 2000). Here, a first grouping is made between: (a) direct economic benefits—referring to the economic costs and benefits directly related to a project and (b) the wider economic benefits—referring to the economic effects not directly related to the project but causally linked to the direct impacts. Direct economic benefits can be further split up into (a) benefits of use, with travel cost savings typically being the most important category for infrastructure projects, and (b) passive-use benefits, a category covering a number of impacts, including option values, indirect benefits and existence values. A second grouping can be made by distinguishing: (a) economic effects for which 'market' prices are available, e.g. profits, fuel-cost reductions, and (b) effects for which no market prices are available, expressed in such monetary terms as travel time gains and ecological impacts. In the literature different methodologies are used to analyse the different categories of economic effects. A brief description is given below.

The measurement of the *direct user benefits* for households and firms is commonly based on micro-economic welfare theory using the classical concepts of 'willingness to pay' and 'consumer surplus'. This approach is typical in cost-benefit analyses (CBA) (see section 2.6 for a further discussion of CBA). In conventional transport project appraisals, the well-known rule-of-half measure is used as a consumer surplus measure, estimating the full benefit obtained by original travellers for origin-destination combinations and half the benefit obtained by new travellers or generated traffic. However, it has been repeatedly pointed out that this method of appraisal is incorrect if the patterns of land use are forecast to change as a result of the strategy (Neuburger 1971; DfT 2000, Simmonds, 2003). A conventional solution is to conduct a full appraisal of transport user benefits with land use held constant, and analyse other benefits with land use responding to transport strategies less formally. Some studies have singularly proposed less conventional methods to overcome this problem; these methods have been implemented in land-use/transport interaction models (Martínez & Araya 2000a,b).

Conventional economic appraisal methods of transport projects focus on the use benefits of transport, whereas *passive use benefits* receive little attention. In general, passive use benefits are a category of benefits not attributable to the actual use or consumption of a good or service and can be subdivided into three categories: option values, indirect benefits and

existence values (e.g. Bonsall et al., 1992). The last two categories are often grouped together under the term non-use values. Option values can be described as the valuation of choice options as a backup for other options or for future use. For example, individuals may be willing to pay to secure the option of visiting a nature reserve in future, and car-owners may value the ability to use a public transport service when for whatever reason they cannot drive or the car is unavailable. Indirect benefits are those that may be derived by individuals if services or goods are consumed by others, e.g. individuals may benefit from the use of public transport by others and in this way contribute to reduced congestion or environmental degradation. Existence benefits are based on altruism, and may be directed towards future generations (bequest values). Existence benefits may arise when people are willing to pay for services other people use. Passive use values may be an important reason for willingness-to-pay through public funds to subsidise public transport services (Roson, 2001). Note that passive use benefits can be seen as having a social or economic impact (when expressed in monetary terms), as they refer to individual valuations of available travel options or opportunities for themselves or for others. In environmental economics there is a large amount of literature on the measurement of option and existence values for natural environments and wildlife, although the particular estimates are often controversial (see, for example, Boardman et al., 2001 for an overview).

To date, however, very few attempts have been made to measure passive use benefits of transport services; only a few empirical (stated preference) studies exist on option or passive use values of local public transport services (see Roson, 2001, Bristow et al., 1990, Painter et al., 2001). These studies show passive use values of transport services to be a relevant economic benefit category. Moreover, the UK Guidance on the Methodology for Multi-Modal Studies (GOMMMS) (DfT, 2000) includes increasing optional values as a sub-objective to the main national accessibility objective, although state-of-the-practice methodologies for measuring option values for transport services are lacking.

Several methodologies are used to analyse the *wider economic effects* of transport investments, these being the increase or decrease in economic activity arising from impacts in both intermediate and final output markets due to an intervention in an input market. Wider economic impacts may include distributional effects and productivity gains of firms. Assessment methods include highly aggregated production function-based models (see Banister and Berechman, 2000, for an overview; more detailed attempts to link transport or land-use transport interaction models to macroeconomic models (e.g. ME&P 2000), and the development of new model approaches like spatial general equilibrium models, focusing on imperfect competition and increasing returns to scale (e.g. Bröcker et al., 2002, Knaap et al., 2001).

The state of the art of the appraisal methods is not yet well-developed and lacks standardisation, and the position on double-counting with reference to transport benefits and total economic impacts, including the wider economic impacts, is opaque. The translation of direct transport benefits into productivity gains and economic growth is subject to rather complex mechanisms with positive and negative feedbacks, the net outcome of which is uncertain (see, for example, SACTRA, 1999). Results of these studies are often subject to heavy debate. CBA's experience of transport infrastructure investments in the Netherlands and elsewhere show that indirect benefits are generally expected to be small relative to the direct economic benefits and difficult to trace (CPB, 2002). As a result, the primary aim of recent appraisal guidelines for analysing wider economic impacts (e.g. the UK GOMMMS) is

to consider only the distribution effects, highlighting the fact that changes in transport infrastructure will often produce winners and losers, and to assume a zero-sum game for the total study area.

2.4 Environmental impacts

The environmental impacts of the land-use/transport system are diverse (see, for example, OECD, 1996) and can be grouped into four categories: (1) environmental pressures, (2) environmental quality, (3) ecosystem and landscape impacts, and (4) conservation of natural resources. These are shortly described below. *Environmental pressures* from transport include emissions of greenhouse gases, other air pollutants and noise emissions from transport. The increasing concentration of greenhouse gases in the atmosphere is the main cause of global warming, and transport is a significant source of carbon dioxide (CO₂) emissions. Air pollution from mobile sources includes hundreds of compounds with known harmful effects on the environment and human health. The most familiar polluting substances such as carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOC), and dust particles (PM) are directly emitted in large amounts in exhaust gases. Exposure to high levels of noise emissions from transport (road traffic, rail and aircraft) has an important impact on human health and ecosystems. *Environmental quality* focuses on air quality and noise levels, which are the result of the local effects of emissions from mobile sources occurring elsewhere and background concentration levels. *Ecosystem and landscape impacts* refer to the final ecosystem or landscape impacts, for example, as expressed in animal habitat quality or biodiversity. Ecosystem impacts are firstly affected by contamination of water, soil or biota, since compounds in the air (immersion levels) or their reaction products are deposited or absorbed (OECD, 1999). Secondly, transport infrastructure and built areas within nature areas will clearly have impacts on the environment in terms of loss of virgin land, green space, attractive landscapes, wildlife habitat, biodiversity and other locational values. Finally, the conservation of *natural resources* refers, firstly, to the consumption of mineral oil, which is a finite resource with many other uses. Secondly, land can also be seen as a natural resource, which can not be used for other purposes if it is taken for buildings, infrastructure or vehicles. This allocation may, indirectly, also result in land-use restrictions due, for example, to high noise levels.

Several countries, including Denmark, Finland, the Netherlands and Sweden, have an established history of conducting environmental impact assessments on transport projects, supported by legislation (ERM, 2000). Several methodologies and model types are available for analysing these environmental impacts, e.g. the *Manual on Strategic Environmental Assessment of Transport Infrastructure Plans* (EC, 2001). In general, existing environmental impact assessment methodologies for transport investments tend to focus on the calculation of energy use, emissions and noise from transport, for which models are often readily available. To compute the energy use and environmental impacts on global and continental levels, we simply base emissions on transport volumes and emission factors, whereas to calculate other pollutants, air dispersion models calculating immersions from emissions are used. Furthermore, standard methods to compute traffic noise as a function of traffic volume, composition and speed are readily available (e.g. Forckenbrock & Weisbrod, 2001; DfT, 2000). However, the impact of transport infrastructure, its use, noise and local air quality on ecosystems, for which micro-analytic methods are necessary, often receive less attention.

2.5 Social impacts

The social impacts of land-use/transport changes can take on many forms, some of which are particularly difficult to estimate with any precision. Perceptions as to the relative importance of different sorts of social impacts may also vary widely. Overviews of possible social impacts of transport are given by Finsterbusch (1980), Appleyard (1986), De Boer (1986), Forckenbrock *et al.* (2001) and Boon *et al.* (forthcoming). In general, relatively little work seems to have been done to develop methods, tools and techniques to rigorously estimate probable social effects of transport changes. To date, social impact assessments typically focus on accessibility impacts, traffic safety, noise and air quality, visual impacts and severance. However, manuals on assessment methodologies for transport investments have been developed recently in the UK (DfT, 2000) and the United States (Forckenbrock & Weisbrod, 2001), and are geared to facilitating a far more comprehensive analysis than is common practice today.

Social impacts can be categorised in several ways. Here, a first grouping of impacts is made according to their interference with different levels of individual's needs. Theories of social needs typically distinguish four levels of social needs, i.e. biological, social, intellectual and metaphysical needs (e.g., Maslow, 1998). Table 1 shows a categorisation of impacts according to these four levels.

Table 1: Social impacts grouped according to four levels of human needs

Level	Hierarchy	Impacts
Biological	Physiological needs, safety	Traffic-related health impacts; physical exercise; traffic safety; psychosocial impacts; access to essential sources of human existence
Social	Love, belonging	Community cohesion; social exclusion; anonymity; severance; access to social opportunities by private & public transport and non-motorised modes
Intellectual/psychological	Self-esteem, trust, intelligence, self-fulfilment	Access to education, jobs & cultural facilities; travel opportunities, transportation choice; option values
Metaphysical	Cognitive, self-fulfilment, privacy	Visual quality; aesthetics of the built environment; liveability; availability of public spaces, quiet areas

Needs at the biological level are related to physiological needs, good health, a clean environment, availability of food and water, etc. Social impacts at this level include, firstly, transport-related *human health impacts*, expressed, for example, as mortality or morbidity effects. Health impacts may be diverse (see WHO, 2000; Dft, 2000 for overviews). These include long-term exposure to local air pollution (e.g. CO, NO₂, ozone and PM₁₀ emissions) and noise, traffic accidents, health-improvement impacts (walking and cycling) and psychosocial effects (e.g. stress, fear, aggression) due, for instance, to busy traffic or accidents. The assessment of health impacts of transport projects is often limited to traffic accidents, while other impacts receive little attention. To date, there has been a lack of knowledge on the health impacts of changes in traffic volumes or characteristics (EPCRPTT, 2002, WHO, 2000). Especially lacking are indicators and methodologies to assess psychosocial impacts (WHO, 2000). However, attention for traffic-related health impacts is

increasing and several studies are currently being undertaken to develop methodologies to evaluate these impacts, e.g. WHO (2003); Namdeo *et al.*, (2002). Secondly, social impacts at the biological needs level relate to *access to basic sources of human existence* such as food (supermarkets), clothing (retail services), health facilities and social services. These also include the distribution of these sources in space, and spatial or infrastructure barriers to reaching them due to severance of busy roads, for example. Several methods to analyse the accessibility impacts of transport projects (see previous section), and to a lesser extent to analyse barriers (severance) at the micro-level are often readily available (see De Boer, 2001 for an overview).

At the social level, impacts are related, first, to *community cohesion* or social exclusion, arising from the social interaction (or the lack of it) among members of a community. The literature, covering mainly community psychology, distinguishes among social cohesion (interaction between population groups such as minorities and the elderly), neighbourhood cohesion and place attachment (see Forckenbrock *et al.*, 2001, for an overview). However, few empirical studies have been conducted on the relationships between the characteristics of the physical environment, traffic levels and social interaction, cohesion and exclusion. Existing studies show ambiguous results and methodologies used are so far not very useful for transport evaluations, because changes in social cohesion, resulting from infrastructure projects, for example, have not been analysed. Secondly, the level of *access to social opportunities* is a relevant indicator at the social level, incorporating the distribution of opportunities in space and spatial or infrastructure barriers (severance) to reach them. For example, the number of friends or relatives who can be reached within a given travel time may be very low for elderly people living in rural areas without a car. As noted earlier in section 2.2, several methods to analyse the accessibility impacts are often readily available.

At the intellectual level, an individual's needs may include self-fulfilment, personal development and self-esteem. Social impacts at this level relate to the opportunities to participate in activities. This alludes in the first place to the spatial distribution of *access to jobs, education, cultural facilities* and, secondly, to the quantity and quality of *transportation choice options* to residents of particular areas, e.g. availability of walking, cycling, public transport and other transportation options as an alternative to using one's own car. Note that job accessibility also has economic impacts, but here, we are referring to the possibilities of fulfilling people's need for intellectual development. Choice of transportation also clearly relates to the previous levels of needs, as a lack of transportation choice in automobile-dependent communities limits the personal and economic opportunities available to people who are physically, economically or socially disadvantaged. Furthermore, the transportation choice is related to the concept of *option values* used in economic studies to value choice options as a backup to other options or for future use (see section 2.4). In general, land-use and travel data and/or models to evaluate accessibility levels and the actual use of transportation options is often readily available. An analysis of how people rate transportation choice, or option values, may be possible with (stated preference) surveys. However, to date, very few empirical studies have been conducted (see also section 2.3).

The final, metaphysical, level is the least tangible; it includes cognitive needs, perception, aesthetics, privacy, etc. Social impacts at this level include the effects of land use or transportation system changes on the *visual quality, aesthetics and liveability* of the physical environment (built and natural areas). Back in the 1960s, studies (Lynch, 1960) were carried out to define how people perceive cities and districts within them. Recent studies focus on

computer simulations, photomontage techniques and other visual experiments to visualise the impacts of transport projects in urban or natural areas, e.g. Burkart et al (1998), Vägverket (2001) and Forckenbrock et al (2001) for an overview. Liveability in urban areas can be interpreted as the cumulation of visual quality, including the presence of the transport system (infrastructure, the volume of moving and parked vehicles) and environmental impacts (noise, local air pollution) at the local level.

A second grouping of social impacts is related to the distribution of land-use and transport system impacts, positive and negative, among members of a community. This is perhaps the most important and far-reaching category of social impacts. This introduces the concepts of equity and social justice. These concepts are often used interchangeably in the literature, but can be clearly distinguished. That is, *equity* is concerned with an empirical evaluation of the distribution of costs and benefits among the members of a community (e.g. Litman, 2002), whereas *social justice* is concerned with a normative evaluation relating to what people believe is fair (Khisty, 1996). Several theories or approaches of justice are documented in the literature, e.g. an equal shares approach, a utilitarian approach, and application of different social justice theories result in different valuations of the distribution of benefits to socio-economic groups and thus in different evaluations of the net benefits (Khisty, 1997, LT et al., 1998). Although equity and justice impacts are receiving increasing attention, especially in the United States, research on the distribution of positive and negative impacts in the land-use/transport system is, to date, fairly limited (Forckenbrock et al., 2001; Forckenbrock & Weisbrod, 2001).

2.6 Aggregation of impacts: CBA and MCA

Two approaches widely used for weighing impacts in policy appraisal are social cost-benefit analysis (SCBA) and multi-criteria analysis (MCA). These can, in principle, be used to summarise the sustainability impacts of transportation system changes. From an economic point of view, SCBA is generally the preferred and accepted method for evaluating all possible (economic, environmental and social) impacts of infrastructure investments in many countries, including the Netherlands. See Grant-Muller et al., 2001 and Hayashi & Morisugi, 2000) for an overview of transport infrastructure appraisal methodologies. Recent experience in the Netherlands has shown social cost-benefit analysis to lead to more systematic, realistic and complete evaluation. Although SCBA is a well-established methodology, it has been subject to severe criticism. This ranges from its ethical and philosophical underpinnings, the lack of treatment of equity impacts, to its heavy reliance on monetary valuations, and the alleged omission of factors for which money valuations are difficult or impossible, such as nature and landscape intrusion, severance and social cohesion (e.g. see Beuthe (2002) for more elaborate criticisms). Alternatively, MCA can be used to weight criteria (see Nijkamp et al. (1990) for an overview of different weighting techniques). MCA requires weighting of criteria that appropriately represent the relative importance given to the criteria by decision-makers to the criteria. MCA is therefore capable of handling equity and non-utilitarian social justice evaluations. This will not always lead to a unique final value or solutions, but the structure and consequences of conflicts among decision-makers can be made explicit, and the range of politically feasible alternatives can be analysed in greater detail. In practical transport infrastructure evaluations, a mixture of SCBA and multi-criteria analysis is often used (Bristow & Nellthorp, 2000), where monetary valuations of items are employed for which

consumer preferences are suitable, and non-monetary valuations of policy-makers are used for items for which consumer preferences are not suitable. Furthermore, social cost-benefit analysis has been extended to take the distributions of the costs and benefits of impacts of policy strategies amongst the various sectors of the community into account (e.g. Lichfield, 1996).

3. Characterisation of Land-use/Transport Interaction models

3.1 Introduction

Since the 1960s, many land-use/transport interaction (LUTI) models from different scientific fields have been developed to model and evaluate land-use and transport patterns, and changes. Several existent literature reviews on operational land-use/transport interaction models focus on modelling techniques, along with the underlying theories and the type of policies that can be analysed (DSC/ME&P, 1999; Wegener & Fürst, 1999; EPA, 2000). This section does not provide an extensive overview of operational models but a selection of models aiming to describe the current state-of-the-practice of LUTI models as tools for sustainability impact assessments of land-use and transport policies. Here, we describe two Dutch models, and three other well-known LUTI models recently applied in integrated and sustainable transport policy appraisal studies. The review focuses on the intermediate, economic, environmental and social indicators estimated. The models are included in this overview are described below:

- The Environment Explorer (EE) (Engelen et al., 2003), a dynamic GIS-based land-use/transport interaction model for the Netherlands, developed to design, explore and evaluate the economic, social and environmental impacts of long-term spatial policies. The model simulates land use, land cover and activities for the entire territory of the Netherlands, linking spatial processes and interactions between land use and transport at different spatial levels (i.e. national, regional, subregional and local) The model is entropy-based to model land-use interactions at regional level (40 administrative regions). The model uses the theory of Cellular Automata to simulate spatial processes at a detailed spatial level (25 ha cells) on a yearly basis. Cellular Automata are objects associated with surface-area units or cells, which follow simple stimulus–response rules to change or not to change their state based on the state of adjacent or nearby cells. By adding random noise to the rules, surprisingly complex land-use patterns can be generated. The model has recently been elaborated with a transport demand model for private and public transport, and has been used in several case studies in the Netherlands;
- TIGRIS (Erasmus et al., 2002), a model also applicable to the whole territory of the Netherlands, simulates land-use activities at the spatial level of 345 zones on the basis of entropy-maximisation pioneered by Wilson in the 1970s. This model has, so far, been applied in four (regional) case studies in the Netherlands, and is included here as an alternative modelling approach for the Netherlands (see also Van der Hoorn & Schoemakers elsewhere in this volume);
- The LOIS Strategic Policy Model (WSP, 2002) is a land-use and transport model set up originally for use in the London to Ipswich multi-modal study (Jin et al., 2002; LOIS, 2003). It uses a redefined zoning system of the LASER3.0 based on the MEPLAN

principles for land-use and transport interaction and evaluation (Echenique et al., 1990). The model can be characterised as a spatial-economic model in which land-use and transport are fully integrated, i.e. interactions between economic sectors, determined by input-output tables, are used to derive passenger and goods travel. The evaluation framework applied in the LOIS study is consistent with the UK Guidance On the Methodology for Multi-Model Studies (GOMMMS) (DfT, 2000), addressing environmental, traffic safety, economy, accessibility and integration (of transport policies into land use and other policy) impacts. See for a more elaborate description Devereux et al. in this volume.

- The DELTA/START package, a land-use/economic model (DELTA) linked with a transport model (START) was developed in the UK and used in several case studies in the UK. The model can be characterised as an ‘activity-based’ model, founded primarily on representation of the different processes affecting the different types of activities considered. It has a relatively detailed segmentation of activities, elaborately treating both the decision to move and location choice. Other well-known examples of this model type include the IRPUD model (Wegener, 1998b) and URBANSIM (Waddell, 2001). The model description in this paper is based on the south and west Yorkshire Strategic Model version (SWYSM) used in the south and west Yorkshire multi-modal study (Coombe & Skinner 2002). The model also follows the UK appraisal methodology, GOMMMS. See also Simmonds elsewhere in this volume.
- PROPOLIS, a strategic urban planning system developed for the EU project Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability (PROPOLIS, 2003). PROPOLIS is not a model but a model system which links three existing LUTI models (MEPLAN, TRANUS, IRPUD) with additional urban sustainability indicators, a GIS-based Raster module, a database and presentation module and a decision-support tool to evaluate the results of policy options. The model system is applied to seven European regions. See also Spiekerman & Wegener elsewhere in this volume.

3.2 Land-use, transport and accessibility indicators

Although all models included in this paper simulate land-use, transport and accessibility impacts as indicators of the function of the land-use/transport systems, the comprehensiveness and the level of detail differ. Table 2 overviews the intermediate indicators used in the different models, while the categories used are taken from the conceptual framework described in Section 2. The table shows PROPOLIS, LOIS-LASER and DELTA-START to be the most comprehensive in the evaluation of land-use and transport indicators, estimating all components of the land-use and transport systems. Specifically, these models focus explicitly on the modelling of physical stock for housing and non-residential buildings, and the modelling of activities. Behaviour of householders and companies is based on micro-economic theories, simulating endogenous land, floor space or housing prices and market clearings in each period. In contrast, the Environment Explorer and TIGRIS do not model land or housing prices endogenously to reach an equilibrium state, and the market-based approach is not suitable for the strongly regulated land and housing markets in the Netherlands (Erasmus et al., 2002). Furthermore, the transport models used in PROPOLIS, LOIS and START are relatively desegregated and comprehensive multi-modal

transport models. The LOIS and SWYMS studies also involved the use of detailed transport models using congested assignment procedures with junction simulation. The Environment Explorer simulates land use, activities and accessibility at a relatively high level of spatial detail (25 ha bases); it is also comprehensive in accessibility evaluations, simulating several infrastructure-based, location-based and utility-based measures. The location-based measures are measured both at the meso (traffic analysis zones) and local level (25 ha grid cells) using information on land use, travel costs and distances to road infrastructure, road access, and exit points and railway stations. To date, there is still no operational land-use/transport interaction model, including the models described here, which is able to analyse person-based accessibility measures, since this requires state-of-the-art activity-based transport modelling.

Table 2: Overview of intermediate indicators in selected LUTI models

Category		Environment Explorer	TIGRIS	LOIS-LASER	DELTA-START	PROPOLIS
Land use	Land uses	++		●	●	●
	Physical stock		+	+	+	+
	Activities	++	+	+	+	+
	Land prices, rents			+	+	+
Transport	Car	+	+	+/(++)	+/(++)	+
	Public transport	+	+	+	+	+
	Non-motorised			+	+	+
	Freight travel			+	+	+
Accessibility	Infrastructure-based	+	+	+	+	+
	Location-based	+ / ++	+	+	+	+
	Person-based					
	Utility-based	+				

+ = operational at the meso level (zones)

++ = operational at a high spatial resolution

● = operational, but not all categories included

(++) = detailed analysis conducted using output from the model, using additional methods or models

3.3 Economic, environmental and social indicators

Table 3 overviews the final indicators used in the different land-use/transport interaction models. The economic impacts are grouped into the following four categories as described in section 2.3: (a) use benefits, (b) passive use values (option and non-use values), (c) wider economic impacts, and (d) net economic effects, including the monetary valuation of social and environmental impacts. The environmental indicators are grouped into five categories, as described in section 2.4: (a) emissions, including greenhouse gases and other pollutants, (b) noise, (c) air quality, (d) ecosystem and landscape impacts, and (e) the use of natural resources. The social indicators are grouped into the categories described in section 2.5, i.e.: (a) biological needs, including traffic related health impacts, (b) social needs, including access to social opportunities and community cohesion, (c) intellectual needs, including

access to jobs, (d) metaphysical needs, including visual quality and open spaces, and (e) equity, including spatial, economic and social, and (f) social justice.

Table 3 shows all models included here so as to estimate indicators from all components of sustainability (economic, environmental and social). The PROPOLIS model system clearly provides the most comprehensive sustainability impact assessment, comprising a total of 35 key indicators to measure the three dimensions of sustainability, and some at a very high spatial resolution. The Environment Explorer also estimates a comprehensive list of indicators from all components.

Table 3: Overview of final indicator categories in selected LUTI models

Category	Sub-category	Environment Explorer	TIGRIS	LOIS-LASER	DELTA-START	PROPOLIS	
Economic	(Active) user benefits	●		(+)	+	+	
	Passive use benefits						
	Wider economic impacts	●	●	●	●	●	
	Net economic benefits			(+)	(+)	+	
Ecological	Emissions	+		+	+	+	
	Noise (road traffic)	++		(●)	+	++	
	Environmental quality	●		●	+	++	
	Nature and landscape	++		●		●	
Social	Natural resources (oil consumption, land coverage)	+		●		+	
	Biological needs	Traffic safety			+	+	+
		Other health impacts			(●)	(●)	●
	Social needs	Access to transport	+	+	+	+	+
		Community cohesion			(●)	(●)	●
	Intellectual needs	Access to opportunities	+	+	+	+	+
		Transport option values			(●)	(●)	
	Metaphysical needs	Noise, quiet areas	+				+
	Equity	Distribution of costs			+	+	+
		Distribution of benefits (accessibility)	++	+	+	+	+
Social justice	Exposure to noise & air pollution					++	

+ = operational at the meso level (transport zones)

++ = operational at a high spatial resolution

●/●● = operational at a low/high spatial resolution, but simplified analysis

(+) = estimated using output from the model, using additional methods or models

(●) = qualitatively addressed, using output from the model and expert judgement

Economic impacts

DELTA/START and PROPOLIS offer economic evaluation modules to assess the user benefits of alternative land-use and transport policies based on the principles of consumer surplus and to simulate the distribution of benefits among the different groups affected, including households, firms, government and operators. The Environment Explorer estimates transport user benefits only, using utility-based accessibility measures developed by Martínez

& Araya (2000a). All models compute wider economic impacts in a limited form; distributive effects of economic activities are estimated, assuming a zero-sum game at the total study area level. In other words, the models only model a possible relocation of activities; total quantities are either fixed for each point in time in each scenario, or vary only by marginal locational change.

Furthermore, none of the economic evaluation methodologies explicitly addresses the passive benefits of land-use and transport policies as an economic benefit category. However, option values of transport services are included as an accessibility indicator in the UK multi-modal transport studies. For instance the LOIS study includes a simplified method for analysing option values as a social impact by estimating the number of residents within an 8-km catchment area of railway stations. Furthermore, several environmental indicators can be qualified as non-use benefit indicators (i.e. land coverage, quality of open space), but do not have a price tag. The lack of attention for passive use benefits in economic evaluation is, however, not surprising as very little empirical efforts have been made to value them.

Ecological impacts

The PROPOLIS model system and the Environment Explorer are the only two models taken up in this paper that use indicators in all ecological indicator categories, including the use of natural resources like energy use and land-take. TIGRIS does not explicitly model ecological indicators. In general, the spatial resolution of operational land-use/transport interaction models is based on transport zones and often too coarse to model land-use and travel behaviour on the level necessary for modelling ecological (and human health) impacts. Most models incorporate environmental submodels that simulate transport emissions; however, for ecological impact assessments and immision modelling, relatively advanced environmental submodels of air quality, traffic noise and ecosystems are needed (Wegener, 1998a). Models with a relatively high spatial resolution of environmental modelling are PROPOLIS and the Environment Explorer. The PROPOLIS model system incorporates a raster module to simulate air quality, noise, fragmentation and quality of open space at the 100-m grid level. Note, however, that land-use processes are modelled at the meso level. The Environment Explorer models land use, activities, noise immisions, air quality and fragmentation of nature areas at the resolution of 500-m grid cells. This spatial resolution is, given the data availability, considered appropriate for modelling land-use processes. It is also sufficient for analysing developments and impacts of land-use and transport policies, and scenarios, but still seems too coarse for exact measurements of ecosystem and health impacts at the local level.

Social impacts

Clearly, the evaluation of social impacts of land-use and transport policies, and scenarios, is a challenging task. Given the wide range of impacts, the number of social impacts quantitatively or qualitatively analysed with land-use/transport interaction models is rather limited. However, this is not surprising, as it is already clear from section 2.5 that many social impacts are particularly difficult to estimate with much precision. Furthermore, relatively little work has been done to develop methods, tools and techniques to rigorously estimate their probable effects. Land-use/transport interaction models are typically used to estimate location-based accessibility measures (mainly for car travel) as indicators for assessing social

impacts at the social needs level (potential access to housing, population), intellectual level (potential access to jobs) and level of spatial equity.

However, the models are typically not able to analyse access to opportunities at the local (neighbourhood) level, such as basic services, health and social services, and green areas; these would require a higher spatial resolution. Furthermore, health impact analyses are often not included in land-use/transport interaction models, or are limited to traffic accidents (PROPOLIS, DELTA/START, LOIS-LASER) and exposure to noise and air pollution (Environment Explorer, PROPOLIS). This is likely due to the current lack of knowledge and methodologies to measure the impacts of transport system changes and travel behaviour changes, and to the high spatial resolution needed for computations. This is also the case for analysing such social impacts as community cohesion and severance. In the LOIS study, a number of social indicators were analysed in qualitative terms using the model output and expert judgement. Furthermore, equity and social justice impacts receive little explicit attention, except for the PROPOLIS study in which equity and justice of exposure to noise and air pollutants is analysed using different theories of justice; spatial segregation is also estimated.

Integration of impacts

PROPOLIS and DELTA/START provide cost-benefit analysis tools to estimate the net economic effect including impacts on transport costs and external costs. These, in turn, include noise, air pollution and accident costs, calculated using unit prices. In the London to Ipswich South and West Yorkshire multi-modal studies, a common UK appraisal tool (Mott MacDonald, 2003) was used to conduct economic cost-benefit analysis (excluding external costs), based on the LOIS-LASER and DELTA/START model output. To date, the PROPOLIS model system, at least to the authors' knowledge, is the only one in which CBA and MCA are used to integrate the social, environmental and economic impacts. CBA is used to derive the economic component of sustainability, expressed as the total net economic benefits of the evaluated land-use and transport projects, and MCA is used to aggregate the different indicators to the social and environmental components of sustainability.

4. Conclusions and discussion

This paper presents a framework for sustainability impact assessments of land-use and transport system changes, focusing on transport-related impacts. Furthermore, several operational land-use/transport interaction models were reviewed as appraisal tools. We limited ourselves to land-use/transport interaction models as this model type is, at present, the only available method considering the substantial range of impacts that may arise from planning decisions in land use and transport. Clearly, an in-depth analysis of the potential impacts of land-use and transport policies and scenarios on the economy, society and the environment would present new challenges for land-use/transport interaction models. The potential range of issues to be addressed is much larger than the issues incorporated into past applications of state-of-the-practice land-use/transport models. Here, we identify four challenges.

The first challenge is related to estimating land-use, transport and accessibility indicators in a theoretically sound and consistent manner. This requires land-use and transport models estimates to be based, in general, on a behavioural representation of all the different processes and actors involved. None of the operational land-use/transport interaction models today is ideal in this sense; however, the models included in this review seem sufficiently advanced to model the major behavioural responses triggered by land-use and transport policies. Especially PROPOLIS, LOIS-LASER and DELTA/START are advanced land-use/transport models, and focus explicitly on all land-use and transport subsystems. However, given the complexity of issues, it important that the models' shortcomings are recognised and described in practical applications.

The second challenge relates to the economic impacts of land-use and transport developments, and related policies. To date, land-use/transport interaction models are able to address a large range of potential economic impacts. Some models offer state-of-the-art economic evaluation modules, which can be used to compare alternative land-use and transport policies or scenarios using cost-benefit analysis techniques. These include impacts on transport costs and external costs for items such as noise, air pollution and accidents. The current generation of land-use/transport interaction models do not fully capture the wider macro-economic effects. The models do include distributional effects but are not able to model productivity gains and economic growth. However, the state-of-the art related to appraisal methods in this area is not yet well developed and results are still often subject to heavy debate. Furthermore, current economic appraisal methods do not include option and existence values. This is not surprising, considering that theoretical and empirical knowledge on the relevance of these impacts is lacking.

The third challenge is to generate more knowledge to understand ecological and social impacts, and to develop related indicators and methodologies to calculate them. The most important shortcomings are:

- The number of social impacts that are quantitatively or qualitatively analysed with land-use/transport interaction models is fairly limited. Present efforts focus on estimating location-based accessibility measures, traffic safety, noise and air pollution. Other relevant social impacts such as health impacts, community cohesion, psychosocial impacts, and visual quality of the built and natural environment are not addressed. This is primarily due to the current lack of knowledge and availability of methods, tools and techniques to measure the impacts of transport system changes, and the high spatial resolution needed for computations. There is certainly a need for more research to include these impacts in sustainability impact assessments.
- Equity and social justice impacts, often considered the most important category of social impacts, receive relatively little explicit attention. An in-depth analysis would require a disaggregate level of population modelling (split up according to socio-economic groups) at a relatively high spatial resolution, which, at present, is beyond the state-of-the-practice of most land-use/transport interaction models. Although recent model developments taken from the PROPOLIS study facilitate a far more comprehensive analysis than is common practice today, there is still a need to conduct theoretical and practical studies on equity and justice impacts.
- Environmental impact analysis seems to focus on emission rather than immision modelling. However, an analysis of ecosystem and human health impacts requires land-

use and travel behaviour modelling at a relatively high spatial resolution, and the use of environmental submodels for air quality, traffic noise, land take and ecosystems. Of the models included in this paper, only PROPOLIS and the Environment Explorer are able to address this wide range of environmental impacts due to their relatively high spatial resolution.

The final challenge is related to the presentation and integration of results. Integration refers to the concept of sustainability, a concept not only relating to the economic, ecological and social impacts themselves, but to the 'right' balance between them. What the right balance is, will be a subjective, politically defined choice. But once choices are made, models can be used to integrate economic, economic and social impacts. And models can also be developed for a systematic comparison of scenarios, for example, by presenting the *differences* between scenarios with respect to indicators. For this presentation, one might also consider creating a better link with CBA and MCA. A CBA might be preferable if most of the effects are related to indicators that can be relatively easily translated into monetary terms. But if major changes occur with respect to indicators that are more difficult to attach a price tag to, such as nature or landscape effects, MCA might be the preferable evaluation method.

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