UNIVERSITY OF LEEDS

This is a repository copy of *Modelling for Sustainable Cities: The Transport Sector.*.

White Rose Research Online URL for this paper:
http://eprints.whiterose.ac.uk/2090/

Monograph:
Kupiszewska, D. (1997) Modelling for Sustainable Cities: The Transport Sector. Working Paper. Institute of Transport Studies, University of Leeds , Leeds, UK.

Working Paper 521

Reuse
See Attached

Takedown
If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.

White Rose university consortium
Universities of Leeds, Sheffield & York

eprints@whiterose.ac.uk
https://eprints.whiterose.ac.uk/

White Rose Research Online
http://eprints.whiterose.ac.uk/

Institute of Transport Studies
University of Leeds

This is an ITS Working Paper produced and published by the University of Leeds. ITS Working Papers are intended to provide information and encourage discussion on a topic in advance of formal publication. They represent only the views of the authors, and do not necessarily reflect the views or approval of the sponsors.

White Rose Repository URL for this paper:
http://eprints.whiterose.ac.uk/2090/

Published paper
Dorota Kupiszewska (1997) *Modelling for Sustainable Cities: The Transport Sector.* Institute of Transport Studies, University of Leeds, Working Paper 521

White Rose Consortium ePrints Repository
eprints@whiterose.ac.uk

Working Paper 521

November 1997

MODELLING FOR SUSTAINABLE CITIES: THE TRANSPORTATION SECTOR

Dorota Kupiszewska

ITS Working Papers are intended to provide information and encourage discussion on a topic in advance of formal publication. They represent only the views of the authors, and do not necessarily reflect the views or approval of the sponsors.

UNIVERSITY OF LEEDS
Institute for Transport Studies

ITS Working Paper 521

November 1997

Modelling For Sustainable Cities: The Transportation Sector

Dorota Kupiszewska

This report is the third one in the series of four reports prepared by the author within the Sustainable/Quantifiable City project conducted in 1994-1996 at the Environment Centre. The author wishes to thank the grantholders: Prof. David Kay (Environment Centre), Prof. Tony May (Institute for Transport Studies) and Prof. Mike Pilling (School of Chemistry), as well as Dr Gordon Mitchell (co-researcher, Environment Centre) and Prof. Adrian McDonald (School of Geography) for their support.

Other reports in the series are:

Working Paper 519
"Computer implementation of the Quantifiable City Decision Support System (QCDSS)"
A colour version of this report is available on request from the publications secretary at the Institute for Transport Studies, Leeds University.

Working Paper 520
"Modelling for sustainable cities: Conceptual approach and an audit of existing sectoral models for transport, air pollution, land use, and population modelling" and

Working Paper 522
"MUPPETS: A computer tool for modelling and mapping emissions from urban tranport and stationary sources".
A colour version of this report is also available on request from the publications secretary at the Institute for Transport Studies, Leeds University.

Contents

A. Introduction

Since the publication of the Brundtland Report "Our Common Future" in 1987 and the 1992 Earth Summit in Rio, sustainable development has been widely accepted as an issue of strategic importance on global, national and local scales. The problems to be addressed under the sustainability heading are extremely diversified. On the one hand there are the developing countries of the South experiencing rapid population growth and environmental degradation. On the other hand there is the North with more stable population but very large consumption, putting higher pressure on the environment than the South. Also, the increase of consumption and wealth in the North does not necessarily parallel an improvement of the quality of life. Most severe and diversified problems are encountered in cities: from traffic congestion and air pollution to unemployment, disruption of social networks and crime.

This paper concerns urban sustainability issues related to transport, focusing on European cities. A conceptual model is described in which we have attempted to present impacts of transport on the human system and the environment, factors that determine the extent of that impact, and indicators that could be used as a measure of transport sustainability.

B. Development, transport and sustainability aims - defining the scope of the model

Hardly anybody would deny that the present transportation systems of most European cities are unsustainable. Congested centres, polluted air, busy streets representing insurmountable obstacles for elderly and children, are only some of the problems. Whom should we blame? Transport planners who have been trying for years to meet an increasing demand? To some extent - yes: "OECD cities acknowledge that they have made mistakes in managing the evolution of urban travel" [OECD 1996]. However, more fundamental reasons lie in the way in which the economies and societies have developed, and the way the cities have evolved. The intervening factors are numerous and even if one understands causes of the problems, optimal solutions are hard to identify. The difficulty lies among others in the multiplicity of goals and their often contradictory nature. For example, one of the basic incompatibilities, at least under current technological capabilities, is between people's tendency to travel faster, more comfortably, more frequently and over longer distances, and people's desire to maintain an attractive and healthy environment. More generally, there is a conflict between economic growth and environmental sustainability [Nijkamp and Priemus 1993].

A starting point for the development of a model of these complicated phenomena is to identify components of the system to be modelled, in particular to identify model inputs and outputs. In order to do this it is worthwhile to look back at definitions and principles of sustainability.

One of the most often cited definitions of sustainable development, given in the Brundtland Report, states that it is "development that meets the needs of present without compromising the ability of future generations to meet their own needs" [WCED 1987]. Another says that it is "development that improves the quality of human life while living within the carrying capacity of supporting ecosystems" [IUCN-UNEP-WWF 1991]. The most important sustainability objectives are:

- Preservation (or increase) of quality of life
- Social equity
- Preservation of resource stocks
- Preservation of environmental quality and climate
- Preservation of biodiversity.

The second of these objectives is the core of the intra-generational equity principle of sustainable development, while the remaining are important for the futurity, or inter-generational equity principle.

There are several other principles and concepts important for the issue of sustainable development, notably the concept of critical loads; the precautionary principle; and the concept of the internalisation of environmental costs . These have been defined as follows:

- "Critical load refers to an ecosystem's level of tolerance for a particular pollutant and also to an ecosystem's level of tolerance for the depletion of a particular natural resource, beyond which irreversible damage will likely occur" [OECD 1995b, p.18].
- The precautionary principle "recommends action in responding to potential environmental threats instead of waiting for absolute scientific proof" [OECD 1995b,

p.15]. "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (Principle 15 of the Rio Declaration).

- "Internalisation of environmental costs implies that market prices should reflect the environmental costs of the production and use of a product in terms of natural resource utilisation, pollution, waste generation, consumption, disposal and other factors" [OECD 1995b, p.13].

Given the above listed definitions and objectives it is clear that sustainability modelling must involve modelling processes from two sub-systems: the human sub-system, and the environmental sub-system, and especially interactions between them. Focusing again on transport, we come to a high level model presented in Figure 1. It points to the economic and socio-demographic components (sub-systems) as the main determinants of transport. Transport in turn has an impact on the environment, through resource use and pollutant emissions, and on the quality of life. Transport and land use policies, and economic and demographic development scenarios constitute the main inputs to the model, while the output is formed by the indicators of the quality of life and of the state of the environment.

Figure 1 does not show all the feedback loops, which will be presented later, but helps to understand why we need a new model. The reason is that existing urban modelling theories and operational land-use/transport models were developed before the priority of sustainability aims was generally accepted, and they have covered only a part of the issues that need to be considered when modelling transport sustainability. They have addressed transport demand (population, economic activities and land use boxes on Figure 1), and the effectiveness of transport policies in meeting this demand, but have often ignored the impact of transport on the environment. Also, the impact of transport on the quality of life has been treated in a very rudimentary way, by considering accessibility (in terms of time, money, or generalised cost) only.

While main principles and concepts of sustainable development are important for defining the scope of the model, the precautionary principle intervenes mainly during the interpretation phase of modelling. Here we can paraphrase it as follows: "If various models give different results, act if the one that predicts the worst consequences was correct".

C. Conceptual model of transport sustainability.

A comprehensive model of transport sustainability should reflect all the currently observed phenomena and provide indicators that would allow to evaluate the usefulness of various policies for achieving sustainability aims.

Figures 2-6, together with Table 1, provide a graphical representation of such a conceptual model. Figure 2 presents the components influencing transport, and summarises impacts of transport on the environment and on the human system, including basic feedbacks. Figure 3 and Figure 4 present a model of impacts of traffic and transport infrastructure on the environment. Figure 5 and Figure 6 represent respectively indirect (through environmental effects) and direct impacts of transport on the human sub-system.

Instead of a systematic description of all the diagrams and tables, we will discuss the most important issues and indicate the role played by various components in the model (issues/components represented as boxes in Figures 1-6 are denoted in the text by *Italic Arial* font). Some of the considered issues have been addressed in traditional transport models as well. Here, we will stress their importance for sustainability. Whenever possible we have tried to support the presentation of a problem with data for European cities, but it has proved a difficult task and we have often had to use national scale data instead. Most of the data come from the publications of (i) the European Conference of Ministers of Transport (ECMT, an inter-governmental organisation that comprises 31 European countries); (ii) the Organisation for the Economic Co-operation and Development (OECD - 27 countries, including twenty European countries); (iii) British Department of Environment; and (iv) Department of Transport.

C.1 Transport demand and traffic trends

A fundamental problem of contemporary transport is a steady increase of the number of cars and a rising share of travel by car in the passenger traffic. This increase is usually linked with phenomena taking place in various sectors represented in our conceptual model: *Economy, Demography, Land use, Transport supply* (see Figure 2). Probably the most important are economic reasons: growth of incomes and living standards [ECMT 1995, p. 33] [*Households budget* box in Figure 2] and the fact that "motoring costs have risen ... more slowly than incomes and considerably more slowly than bus, coach and rail fares" [Bendixson 1989, p.34] [*Mode performance characteristics*]. Table 2 shows the decline (in real terms) of car prices and running costs in Switzerland between 1960 and 1990.

The most important demographic phenomenon influencing car ownership is an increase of number of households due to the growing number of single-parents families and elderly people living alone [ECMT 1995, p.38]. Also, population ageing might prove to have a significant impact in future. It might seem that due to the lower mobility of elderly the overall car ownership should diminish, but it will probably grow because of the cohort effect according to which tomorrow's elderly will behave as when they younger rather than as today's elderly [Bonnafous 1993, Banister 1993].

An urban structure [*Land use* box], with out of town shopping centres and increasing number of jobs located in the suburbs, linked with poor public transport [*Transport supply* box] also favour travels by car [Deelstra 1993]. In addition, this decentralisation and dispersion of activities generates longer trips, both by car and public transport [*Impact from Transport demand box to Traffic patterns box*]. "In some cities there is a mismatch between residents and jobs: In Britain, for example, the inner areas house concentrations of the relatively unskilled, who must travel to the peripheral areas for the types of job they need, while more central jobs are occupied by white-collar suburban residents" [Webster et al 1985, p. 10].

Other factors affecting demand for transport, both private and public, are: increased female labour force participation rates (in the UK: from 12% in 1976 to 48 per cent in 1985 [Banister and Bayliss 1992, p.117]), and increased leisure time [Banister 1993, p.125-126] [*Lifestyles box*]. In Great Britain number of leisure journeys per person per week has grown from 3.8 in 1975-76 to 4.3 in 1985-86 [Banister 1993, p114]).

Economy and logistics play their role in goods transport [*Intensity and organisation of economic activities* box]. Growing demand for freight transport is linked with such phenomena as: (i) spatial division of the production and distribution of goods [Kaspar 1993, p.218]; (ii) "just-in-time" production and delivery systems and reduction in warehousing facilities [Klaassen 1991, ECMT 1995]; (iii) liberalisation of movement of goods within the EC [Kaspar 1993, p.210]; and (iv) specialisation and international division of labour, [Aurbach 1993, p.13]. Like passenger transport, freight is dominated by road transport, which accounted for 81 per cent of freight transport in 1990 in Britain [Brown 1992, p.210] (see also Table 3 for trends in modal split of freight transport in ECMT countries).

Between 1970 and 1992 car travel (car-kilometres) in OECD countries has been growing at an average rate of 3.3 per cent per annum, slightly slower than car ownership (3.5 per cent p.a.), but faster than gross domestic product (2.8 per cent p.a.) [ECMT 1995] (see also Figure 7). Road freight traffic has grown at 4.8 per cent p.a., even faster than car traffic. "According to OECD figures an economic growth of 1% causes an increase of 1.5% in the number of kilometres travelled and even 3% in goods transportation" [Deelstra 1993].

The proportion of cars and taxis in passenger transport (passenger-kms) in ECMT countries increased from 71 per cent in 1965 to 83 per cent in 1988 (Table 3). Proportion of bus transport declined from 16 to 10 per cent. In Great Britain, cars accounted for 62 per cent of passenger transport in 1965 and 85 per cent in 1990, while buses and coaches for 18 percent in 1965 and only 6 per cent in 1990 [Brown 1992, p.210].Car ownership in Britain increased from 42 per cent of households with car(s) in 1971 to 68 per cent in 1990 [DoT 1995].

Modal split of urban passenger transport depends to a large extent on city size (see Table 4 for data on selected German cities) and transport policies (e.g. priority for public transport in Zurich - see Table 4).

Table 6 and Figure 7 present selected transport-related data. They demonstrate the growth of traffic volumes, and car stocks and ownership in the UK, France, Poland and European OECD countries. The growth is particularly accelerated in Central European countries: In Poland road traffic volume increased 3.7 times between 1980 and 1993. In the same period car ownership increased 2.5 times. In Warsaw, car ownership increased from 46 per thousand population in 1970 to 157 per thousand in 1980, and to 322 in 1992 [Suchorzewski 1996, p.150], approaching the level of Western European countries. Following this, the share of public transport has been dropping (Table 5).

The overall effect of an increased traffic volume is that cities and roads have become congested. Transport management measures and building new roads [*Transport supply* and *Transport network* boxes] do not help much. New facilities generate more traffic, as the case of the London orbital has proved [Feedback from *Accessibility* to *Transport demand* box]. Congestion is worst in central and inner areas, which are affected for the most part of the day, but at peak hours suburban streets may also become congested.

Increase in traffic has been followed by deterioration of urban air quality and increase in noise levels [*Pressure on the environment* and *State of the environment* boxes on Figure 2]. These and other consequences of transport growth will be considered in the next section.

C.2 Transport impacts

In our model, transport impacts have been classified into three groups:
(i) impact on the environment and the natural resources, represented in Figure 3 (impact of traffic) and Figure 4 (impact of the transport infrastructure, which includes road construction and car production);
(ii) indirect influence of transport on the human system, following environmental impacts (Figure 5);
(iii) direct impacts on the human system (Figure 6).
Table 7 lists main impacts related with pollution generated by transport.

C.2.1 Environmental impacts [Figure 3 and Figure 4]

"Motor vehicles are now generally recognised as responsible for more air pollution than any other single human activity" [Walsh 1989]. The increase of road traffic has caused a significant growth of emission levels (see Table 6), despite the reduction of emissions from individual vehicles [*Science and technology* box, Figure 3]. Main pollutants [*Emission of pollutants box,* Figure 3] include carbon monoxide, nitrogen oxides (NO and NO_2), volatile organic compounds (VOC), particulates (e.g. polycyclic aromatic hydrocarbons) and heavy metals. Some amounts of sulphur dioxide are also emitted. The approximate contributions of emissions from road transport in total emissions in the UK, France and Poland are shown in Table 8.

As shown in the table, the contribution of road transport to the overall emissions in the UK is increasing. Between 1980 and 1990, emissions of carbon monoxide from road transport increased by 46% and accounted in 1990 for 90 per cent of total CO emissions (almost 100 per cent in urban areas). Contribution of black smoke, coming mainly from diesel-fuelled vehicles (buses and heavy goods vehicles) more than doubled between 1980 and 1990. Emissions of NO_x from road transport increased by 72%, accounting for more than a half of total NO_x emissions in 1990. It is worth noting that at the same time (1980-1990) the share of emissions of nitrogen oxides from power stations dropped from 38% to 28% (Information in this paragraph is based on [DoE 1991]).

Lead emissions in the UK have decreased substantially since the introduction of unleaded petrol in 1986 [DoE 1991]. Between 1988 and 1990 total lead emissions dropped by around 30 per cent [Brown 1992, p.219]. In 1992 unleaded petrol constituted 46 per cent of petrol deliveries to petrol stations, compared with only 3 per cent in 1988.

Poland has reported reduction of emissions of NOx, VOC and particulates, and only 8 per cent increase of CO emissions [Table 6]. It would be interesting to investigate if this is a real effect (which would be very successful, given the 265% increase in passenger car traffic volumes and 65% increase in road freight traffic) or rather due to changes in the emission evaluation methodologies.

Amounts of emission per passenger-kilometre or per ton-kilometre differ between various transport modes [*Emissions/Noise characteristics by mode,* Figure 3] and are generally higher for road transport, especially for passenger cars, than for other modes (see Table 9 (passenger transport) and Table 10 (freight)). Emissions from road transport depend on fuel type, with diesels being responsible for the bulk of particulates but containing no lead, and petrol combustion being the main source of carbon monoxide.

Total emissions of pollutants depend mainly on the traffic volume for each mode, but are also influenced by the styles of drivers behaviour, in particular *speed*: Driving at 70 m.p.h. causes nine per cent more emissions of NO_x than driving at 50 m.p.h. [see data in CEST 1993, p.111]. Even more important are probably technical condition of a car and technological improvements [*Science and technology* box]. According to the Earth Resources Research the introduction of 3-way catalytic converters will allow for the reduction of CO emissions in the UK by 43%, VOC by 60% and NOx by 63% between 1993 and 2003 [CEST 1993, p.22]. The Central and Eastern European countries have still a long way to go: currently a large percentage of the rapidly growing car fleet constitute second hand, technically and ecologically outdated cars [Güller 1996, p.30].

Pollutants originating from road transport come mainly from vehicle exhaust, but some pollutants, such as "benzene, polynuclear aromatic hydrocarbons, lead, formaldehyde, toluene, ammonia, nitrous oxide, cyanide, hydrogen sulphide and dioxin .... are caused through the carburation of fuels, oil loss or wear of materials, such as brake linings, tyres and road surfaces" [Kürer 1993].

Some primary pollutants take part in chemical reactions leading to the production of secondary pollutants. In particular, NOx and VOC contribute to generation of ozone, a compound needed in the stratosphere, but harmful when present in a large amount in the troposphere. The equations describing chemical reactions are non-linear, so the contributions from various sources are not additive and an inventory of all contributing sources is required to calculate pollutant concentrations and to model population exposure [*Other sources of pollution* in Figure 3 and Figure 5]. Also, it is important to examine the pollutant concentrations both near the source and at greater distances, because they might respond differently to reduction of VOC and NOx emissions.

The actual concentrations of pollutants depend not only on volume of emissions, but also on the local topography (e.g. street canyon effect) and meteorological conditions, especially wind speed and direction, and amount of solar radiation [*Meteorology and topography* box on Figure 3]. The worst pollution occurs during stable atmospheric conditions which happen when there is no wind and temperature inversion prevents atmospheric mixing. Generation of secondary pollutants is enhanced during sunny, warm days [Brown 1992, p.13]. Table 11 shows concentrations of main pollutants measured in urban residential areas and city centres in Germany.

Emissions of pollutants by urban traffic lead not only to the deterioration of the air quality locally, but also have negative impacts on the environment on the regional, national and continental scales, through *Acid rain* and contribution to *Generation of ozone*. Ozone levels are generally higher in rural areas than in the cities.

Urban transport contributes to *soil contamination*, mainly through the *deposition of heavy metals* (Figure 3), and has an influence on water resources, both their quantity and quality, mainly through the modification of field drainage [*Change of water circulation* box on Figure 4] and the pollution of surface and groundwater by rainwater run-off [*Contamination of rainwater run-off* on Figure 3]. The latter effect includes pollution with lead, cadmium (from tyres), chemicals from oil spills, chloride substances used for de-icing, and toxic substances released after accidental spillage.

Urban vegetation has suffered a lot because of traffic. Many trees that used to grow along roads have died long ago because of pollution, and contamination of soil with salt in winter. Vegetation in distant locations is affected as well: forests because of acid rain [*Damage to forests* box, Figure 3], crops because of the tropospheric ozone [*Generation of secondary pollutants* and *Damage to plants* boxes].

Many researchers would argue that from the sustainability point of view the most important are the long-term global impacts of transport: consumption of energy resources and contribution to global warming through emissions of carbon dioxide. "It is primarily global warming which has led to the modern concern with sustainability, and is the focus for intergovernmental policy formulation" [Stokes and Dargay 1993].

In OECD, 32 per cent of the final *consumption of energy* was used in 1993 by the transportation sector [OECD 1995a, p.203]. In the UK, transport is the only major sector showing a growth of the energy consumption. "In 1991 it accounted for 31 per cent of total final consumption compared with 17 per cent in 1960" [Brown 1992, p.209]. Newman and Kenworthy [1989] have studied fuel consumption per capita for a global sample of 32 cities and have found that fuel consumption per capita drops exponentially with population density. This might support the idea of a compact city as an appropriate form of a sustainable city. In principle, public transport (buses and rail, with high loading) is more energy efficient than private cars. However, research by Banister have shown that between 1980 and 1990 in Britain the energy use per passeenger km by buses has increased by almost 100% and in 1990 it was only 36% smaller than that by private cars, when loadings are taken into account [Stokes and Dargay 1993, p.153].

Emissions of CO_2 from road transport have been steadily increasing. Road transport accounted for 19 per cent of CO_2 emissions in the UK in 1990 (see Table 8) and 17 per cent in Germany in 1988 [Kürer 1993, p.483]. These figures do not include emissions originating from the energy use for vehicle production and disposal.

Transport contributes also to another global threat: *the depletion of stratospheric ozone.* Chlorofluorocarbons (CFCs) and halons, ozone depleting species, are used during vehicle production and use stages [CEST 1993, p.47-48]. CFCs are mainly used during production of polyurethane foam used in steering wheel covers, dashboards, headrests and seat cushions. CFCs and halons are used in transportation refrigeration and air conditioning.

A number of transport-related environmental issues relate to *solid waste*. In France, scrapped vehicles generate each year 400 kt of waste, including 280 kt of old tyres, that cannot be further recycled [Dron et al 1995]. *Recycling* rates for various car components are as follows: 75 per cent of the mass of car bodies, 30 per cent of tyres, 66 per cent of oil and 80 per cent of batteries. The British dispose each year 25-30 millions tyres, 50 per cent of which are buried at landfill, illegally tipped or stockpiled [Friends of the Earth, cited after LEC 1996]. Large amount of ferrous metal is recovered from 2 million vehicles scrapped during a year [Brown 1992, p.162].

C.2.2 Influence of environmental impacts of traffic on the human sub-system [Figure 5]

Adverse health effects
Emissions from traffic "... cause or contribute to a wide range of adverse health effects including eye irritation, coughs and chest discomfort, headaches, heart disease, upper respiratory illness, increased asthma attacks and reduced pulmonary function. The most recent studies indicate that these emissions can cause cancer and exacerbate mortality and morbidity from respiratory disease [Walsh 1989] [*Pollution - Human health impact* in Figure 5]. Species potentially carcinogenic include: benzene, 1,3 butadiene and some particulates emitted by diesel engined vehicles.

There is a major concern about the relation between traffic and asthma. Although no causal link has been demonstrated, it is generally believed, and some research seems to confirm this, that the presence of pollutants in the urban atmosphere does increase the risk of asthma attacks in people already suffering from this disease.

Almost half of the urban population in the EU countries is adversely affected by road traffic noise, being exposed to either uncomfortable (55-65dB(A)) or unacceptable (exceeding 65dB(A)) levels (ECMT 1995, p.64). A survey carried out in 1986-1990 showed that road traffic was the most common source of noise in the UK. Road traffic was identified as a source of noise in 92 per cent of dwellings, and it was the main source of noise in 62 per cent of dwellings [DoE 1991].

Congested and polluted city centres are not attractive places to live any more, and people move to suburbs [ECMT 1995] [Feedback from *State of the environment* box to *Land use* on Figure 2, and influence of *Noise* and *Pollution* on *Residential, leisure and business location* in Figure 5]. This phenomenon is greatly facilitated by high car ownership and affects mainly the more affluent part of the society, which has led to changes in the social composition of the city centre population [Klaassen 1991, p.15]. Table 12 demonstrates population changes in nine West-European agglomerations.

Other impacts:
Use of space: the transport infrastructure uses a large fraction of the urban area (in London: 21 per cent), which reduces the amount of space available for other activities. 1.5 per cent of the total area of Britain is covered by roads [LEC 1996].
"Lower crop yields due to ozone pollution are estimated at 3-5 per cent in the Netherlands" [Kürer 1993]

C.2.3 Direct impacts of transport on the human sub-system [Figure 6]

Transport availability influences land use/locational decisions of firms and individuals. The high motorisation level allows firms to locate their activities on cheap land in the periphery of a city, or even outside agglomerations [Klaassen 1991, p.15]. Table 13 demonstrates changes in job opportunities in ten West-European agglomerations. Urban areas spread out (which, combined with the poor public transport, further increases dependence on a car), while city centres either decline, as is the case in many American cities, or at least lose their residents and some jobs (in Europe, many city centres keep vitality thanks to their historical and cultural attractions) [ECMT 1995]. With the dispersion of activities, "those without access to a car are becoming increasingly isolated from jobs and services" [ECMT 1995].

The primary goal for the development of a transportation system has been to improve the quality of life by improving the accessibility to jobs, services and leisure. But this stick has two ends. On the negative impacts end there are not only pollution problems mentioned above, but also more direct impacts [Figure 6: boxes linking *Transportation system* to *Quality of life, Health* and *Sociology*], the most important of which are probably accidents and severance.

From the statistics for the ECMT countries [ECMT 1993a] one may calculate that the number killed in road *accidents* has diminished by 17 per cent between 1975 and 1991, despite the 78 per cent increase of vehicle numbers (data refer to totals for 19 ECMT countries, that belong to EC or EFTA). However, the number of injured has been stable (it has diminished by less than 3%). The situation is much worse in Central-European countries. In Poland, the number of killed increased by 63% between 1988 and 1991.

In 1991 in 19 ECMT countries there were more than 1.9 million casualties (killed and injured) caused by road accidents. 66 thousand people have died following accidents, on average between 100 and 200 deaths per million population. (United Kingdom: 4520 killed, i.e. 81 per million; Poland: 7901 killed, 207 per million).

Severance, or the traffic barrier effect, is defined as "... the separation of residents from facilities and services they use within their community, from friends and relations, and, perhaps, form place of work as a result of changes in road patterns and traffic levels" [Manual of Environmental Appraisal, DoT; cited after Davis 1992]. Davis lists the following severance-related phenomena [Davis 1992]:

- Reduction of the degree of social interactions;

- Breakdown of social support networks (and resulting increased mortality)
- Restrictions on independent mobility, affecting children and elderly;
- Empty and disused streets.

Heavy traffic along main roads in residential areas is a reason for an increasing number of children taken to school by parents. According to a study by Hillman and Adams [1992], the fraction of seven and eight years old children accompanied to school has risen from 20 per cent in 1970 to 91 per cent in 1990. According to another study done in Great Britain the percentage of junior school children escorted to school increased from 14 per cent in 1971 to 64 per cent in 1990 [Davis 1992].

Up to now we have considered negative impacts only. But there are a great deal of advantages [e.g. Figure 6, *Satisfaction of the need for ...;* Impact from *Accessibility* box through *Residential, leisure and business location* to *Quality of life*]. We can travel faster and further. It has become possible to live in a nice, out of town surrounding, and at the same time profit from facilities provided by a city. For some people advantages seem to outweigh the drawbacks: "current transport and communication systems are generating new forms of urbanisation that are highly efficient, yet spread over thousands of square miles. I suggest that this calls for celebration, not commiseration. It promises unprecedentedly amiable living and working ... in pleasant surroundings and increasingly intimate contact with friends and associates, many of whom might be located miles away". [Webber 1985].

"The transport industry accounts for about 4 per cent of GDP. Over 900000 workers are directly employed in transport, with a similar number in transport related industries" [Brown 1992, p.218].

C.3 Transport sustainability aims and indicators.

Table 1 lists the main transport sustainability aims and objectives, and corresponding indicators. They have been classified into four groups. The first two groups (Quality of life and Environment and resources) address directly main sustainability principles and impacts. The third group comprises operational indicators, i.e. "process indicators", that are needed to analyse the transportation system itself. They might be used as substitute measures, especially when an impact is directly proportional to a pressure (e.g. traffic volume or speed) and when an impact is difficult to quantify (e.g. severance). The fourth group concerns economic efficiency of policies. We have highlighted these indicators that are particularly important and that we recommend using when evaluating sustainability of strategies and policies. The remaining indicators should be used in detailed modelling of specific sustainability issues.

Certain indicators, although indispensable in the modelling process, should be used with caution when evaluating overall sustainability of a policy. For example, reduced costs of transport and increased percentage of car ownership indicate improvements of some aspects of the quality of life, but also lead to an increased traffic volume, and its environmental impacts. Larger speeds improve accessibility for road users but have negative consequences for residents through severance effects.

There are three types of indicators to be used in evaluating impacts of transport on the environment and indirect impacts on the human system (i) Pressure indicators, e.g. emissions volume, fuel consumption, traffic volume, modal split, speeds; (ii) State indicators, e.g. concentration of pollutants in the ambient air, noise levels; and (iii) Response indicators, e.g. percentage of cars with catalytic converters, percentage of cars with an access to electronic driver information systems , percentage of metal parts, tyres, oil, batteries recycled.

Emissions and air quality indicators

When talking about pollutants it is important to distinguish between emission volumes and actual concentrations in the air to which people are exposed, the latter being much more difficult to model. Values of emission volumes are usually based upon engineering estimates. Ambient levels refer usually to measured concentrations. Dispersion models aim to predict ambient concentrations basing on the data on emission rates and the knowledge about physical and chemical processes in the atmosphere. Emissions of air pollutants reported in national emission inventories are usually given in tons per year. For dispersion modelling purposes time dependent emission rates (e.g. kilograms per hour) are necessary. CO_2 emissions are also reported in terms of weight of emitted carbon (mtC). To transform into carbon dioxide weight units, emissions in carbon units (mtC) must be multiplied by 22/6.

There are two types of units used to express ambient concentrations of pollutants, which causes difficulties in comparing various data:

- Mass per unit volume, e.g. micrograms per cubic metre ($\mu g/m^3$) or milligrams per cubic metre (mg/m^3), giving the mass of pollutant in a unit volume of air;
- Volume per unit volume (known as volume mixing ratio), e.g. parts per billion (ppb) or parts per million (ppm), giving a ratio of the number of molecules of polluting species to the number of air molecules (also equal to the ratio of the volume of the polluting gas, if segregated pure, to the volume of the polluted air).

Because volume of a gas depends on atmospheric conditions (temperature and pressure), so do conversion factors allowing for transformation between the above sets of units. The appropriate formulas may be found in QUARG [1993, p.197]. Concentration of particulate pollutants can only be expressed as mass per unit volume.

Air pollutant concentrations are reported as averaged values, with averaging periods ranging from 15 minutes to one month.

Noise indicators

Noise level is measured in units denoted as dB(A), which is decibels weighted by the sensitivity of human ear to different sound frequencies [Brown 1992, p.168]. Decibels (dB) give intensity of the sound in a logarithmic scale, with 0 dB corresponding to the threshold of human hearing, 10 dB corresponding to the sound intensity 10^1 times larger, 20 dB to the intensity 10^2 times larger, etc., and around 120-140 dB being the loudest tolerable sound. For reporting purposes the following noise measures are used: L_{Aeq} - the average noise level; L_{A90} - the noise level exceeded 90 per cent of time (this is a measure of a background noise); and L_{A10} - the noise level exceeded 10 per cent of time (measure of noise from intermittent sounds). Noise from traffic is usually reported as $L_{A10,18h}$ - the average L_{A10} between 6 am and midnight on a normal working day.

Day time noise levels with L_{Aeq} exceeding 65dB(A) are unacceptable (noise black spots); 55-65dB(A) are undesirable (grey areas) [OECD 1986].

Sustainability indicators

Some authors insist on the development of sustainability indicators that would be different from traditional environmental indicators in that they would be expressed in relation to targets and standards. We do not agree with this approach because target and standards are not constant and it would be difficult to analyse trends in the values of indices based on such changing parameters. In some situations it might be appropriate to express sustainability indicators in relation to critical loads. However, given the current state of our knowledge, this approach does not seem realistic due to the very limited range of problems for which critical loads has been quantified. This applies for example to the known reserves of fossil fuels. "In recent years the volume of known reserves has grown dramatically meaning that we currently have more years supply of known reserves that we thought we had in 1970" (information from World Wide Fund for Nature, 1992; citation from [Stokes and Dargay 1993]).

Indicators referring to the direct impacts of transport on the human sub-system

Direct impacts of transport on the human system are measured using: (i) operational indicators referring to the transportation system, e.g. traffic volume (veh.-kms) and flow (veh./h), speeds; (ii) Quality of life indicators, e.g. accessibility to services, number of accidents. To address issues of intra-generational equity it is important to model the distribution of benefits and losses by social group, age, sex and/or geographical area.

The severance effect is difficult to quantify. A contingent valuation method has been used [Soguel]. It has been suggested that research to develop a severance index is required [Davis 1992]. Such an index might be derived assuming that the severance is proportional to the traffic density, and reduced by mitigation factors such as the presence of crossing facilities.

A potentially positive impact of transport on the quality of life is reflected through accessibility measures. An excellent review of various accessibility measures is given in [Jones 1981]. Accessibility has a double role of a sustainability indicator and a parameter of land-use/transport models. It is important to distinguish between "location accessibility", that is determined by travel costs, and "activity accessibility", that depends also on the intensity of a given activity in various locations. Travel costs used in accessibility evaluation are usually calculated as generalised travel costs, that are a combination of monetary costs and costs of time spend traveling. For travel by public transport, it would include in-vehicle time, walking time, waiting time, interchange time, fare charged, as well as penalty costs reflecting travel discomfort, safety, etc. [Ortuzar and Willumsen 1995]

External costs of transport
To evaluate the economic efficiency of alternative policies it is necessary to calculate external costs of transport, i.e. congestion, environmental and accidents costs. This is a difficult task and in most studies not all the elements are included. For example, costs of water and soil pollution, aesthetic impairment and traffic induced vibrations are usually neglected [Mauch et al. 1995].

When evaluating noise annoyance and air pollution one should take into account both damage costs and environmental protection costs. In the case of congestion costs there is a problem of differences in time valuation by different road users [Nijkamp and Premus 1993].

Possible approaches to the external cost calculation include for instance the damage-cost approach, avoidance cost approach, stated preference (contingence valuation) method, revealed preference (e.g. hedonic pricing used to analyse impacts on house prices), and travel cost method.

According to the estimates published in an OECD report [OECD 1989], average social costs of road transport are in the range 2.5 - 3.0 per cent of GDP. The more recently published values are even higher [ECMT 1995], with the following breakdown of external costs of road transport, in percentage of GDP: congestion - 2%, accidents - 1.5-2%, noise pollution - 0.3 %, local air pollution - 0.4%, non-local pollution 1-10%.

According to a report published in 1989 by the Confederation of British Industry, "...road and rail congestion is costing British business travellers and hauliers £15000 million a year" [Bendixson 1989, p. 34; taken from: Confederation of British Industry, The Capital at Risk, London, 1989].

D. Transport and integrated land-use transport policies for sustainable development

The conceptual model presented above should help to understand multiple factors influencing transport and their consequences for sustainability. Apart from the analysis of an existing situation it should facilitate the prediction of the impact of future policies and scenarios.

For many years the main goal of transport planning was to meet an increasing demand [Ferrary 1994]. Transport models have been designed to select such a policy that would lead to the lowest possible generalised travel cost (and so highest accessibility). With the commitment of countries to sustainable development and the recognition of problems described in previous sections it became clear that transport policies had to be modified and directed towards reduction of demand and traffic volume [ECMT 1995, Dittmar 1995]. Models have now a much more ambitious task to perform: one still wants to maximise accessibility (now it has to be assessed separately for different user groups in order to address the equity principle of sustainability), but there are a number of additional objectives, listed in Table 1. Finding a combination of policies that would best meet these objectives is far from trivial.

As described in previous sections, the transport provision has impacts on locational decisions and land use: a positive impact through an improved accessibility, and a negative impact through the environmental pollution. In turn, land use influences transport. This loop creates the need for an integrated approach to solving urban transport problems, in which land use and transport policies, and environmental problems are considered together. To facilitate the decision making process, integrated land-use/transport/environment models are needed.

Sustainable policy measures must address such factors as: mobility and transport needs, modal split, transport organisation, technical quality of vehicles and infrastructure [Kürer 1993]. Policy measures to be considered can be classified into:

- Education and information
- Fiscal and pricing measures
- Infrastructure provision
- Technological measures
- Management
- Land use planning
- Regulation by law, standards, targets

Table 14 gives examples of policy measures in each category, that can be considered in order to achieve sustainability goals.

In the past, infrastructure and management measures played a dominating role, but now more and more attention is given to land use planning and fiscal measures. Currently, the road users are not charged the high social costs of transport. It has been argued that market mechanisms internalising the external costs, and the polluter-pays principle should be introduced.

There are a number of difficulties in introducing fiscal and pricing measures, e.g.: possible loss of competitiveness; need of harmonisation between the countries (in the case of taxes); Market mechanism may lead to social polarisation; parking charges in city centres may push shoppers to go to out-of town shopping centres. Another aspect to take into account is that a policy might be theoretically sustainable, but will not be accepted by the society (e.g. road pricing). Education campaigns are important to change public attitudes.

When selecting an optimum set of policy measures one has to take into account the possibility of conflicts or synergy effects between various policies. Also, a policy might have a positive impact on one objective, but a negative on another. "For example, road schemes which increase vehicle speeds, save travel time, but might increase the number and severity of accidents and generate more traffic. On street parking controls might reduce congestion, but encourage through traffic" [ECMT 1995, p.80]. A combination of "push" policies (e.g. parking charges and road pricing) and "pull" measure (e.g. improved public transport, traffic calming) is needed to achieve the best effect. Techniques used in appraisal of various development schemes include cost-effectiveness analysis, cost-benefit analysis (similar to cost-effectiveness, but all benefits are expressed in monetary terms), and weighting and scoring methods.

Some authors have proposed to base transport sustainability modelling on the concept of environmental capacity [Stokes and Dargay 1993, Ferrary 1994]. Ferrary has suggested that environmental capacity might be taken into account in the assignment stage of traffic models, similarly to traffic capacity of links [Ferrary 1994, p. 181]. We do not think this approach would be appropriate, because it would not reflect the real situation, where people optimise their behaviour on the basis of generalised costs, not environmental impacts. On the other hand, the concept might be useful at the evaluation stage. In the methodology proposed by Stokes and Dargay the model would aim to calculate environmental loads for a given policy, which would then be compared with the environmental capacity [Stokes and Dargay 1993, p.155]. The difficulty lies in the current lack of a methodology to quantify environmental capacity. One possibility would be to express it as a composite indicator calculated using scoring and weighting methods, but it is not clear what is the relative importance of various contributing factors.

E. From a conceptual towards an operational model

Depending on the aims of a study, a sustainability model may include explicitly only some components of the comprehensive model, with remaining components treated as inputs. Current mathematical and computational techniques can deal with extremely complicated models and the main limiting factor is the understanding of the relative importance of various mechanisms, and the evaluation of parameters to support models. Therefore, simple models might be preferred to comprehensive ones, especially when new policies are going to be tested, when the public response is difficult to predict.

Figure 8 presents a sub-model of the comprehensive transport sustainability model, which can be used to develop operational models addressing particular problems. A common element of such models would often be a traditional four stage transport model [Ortuzar and Willumsen 1994]. The first three stages: generation, distribution and modal split form a demand model represented on Figure 8 and lead to the evaluation of the origin-destination matrices (i.e. matrices containing number of trips between zones, by mode, time of the day, etc.). In the next stage, trips are assigned to the road network. Traffic patterns are predicted and generalised costs of travel by various paths may be evaluated.

Traffic patterns determine environmental impacts and accidents. For CO_2 emissions and fuel consumption, total values for the whole modelled area should be calculated. For emissions of air pollutants, noise levels and traffic flows (a substitute measure of severance) the spatial distribution is needed to address the social equity principle of sustainability. Generalised costs and the information on the location of employment and basic services (shopping centres, hospitals, leisure centres etc.) are the basis for calculating accessibility to jobs and services. There is a feedback from environmental impacts and accessibility to the land use model, which reflects the impact of these factors on locational decisions.

In Section E.3 we describe two exemplar models comprising components of the model presented at Figure 8: (i) modelling influence of environmental impacts of transport on land-use, where socio-economic variables are exogenous, but the land use model plays an important role (ii) influence of transport policies on environmental impacts, where modelling begins with an assignment model with an O-D matrix as an input, and all demand modelling stages are exogenous. In the latter model emissions from traffic are combined with emissions from stationary sources, and an air quality sub-model is added in order to allow for a transition from pressure to state indicators.

E.1 Data requirements

Transport demand and supply modelling

The demand for the passenger transport is usually evaluated separately for the peak (am or pm) and off-peak hours. Variables used for calculating the number of trips originating in each zone are: population/household number, income, car availability, age, sex, education, employment status, profession, social group, stage in the life cycle, household structure. When calculating trip destinations, trips are split by purpose into the following groups: (i) home-based trips: work, education, services, leisure; (ii) non-home-based: business trips. Depending on trip purpose, important variables might be employment (split into sectors), shopping floorspace etc. Floorspace and/or sales and production figures are needed to model demand for goods transport.

In strategic models, transport supply is often represented by the cost of travel (monetary cost and travel time) between each pair of zones. Additional data required to model mode choice might include variables characterising travel comfort, reliability, regularity and security. In tactical models detailed data on the road network are necessary.

Modelling environmental impacts

Environmental impacts depend to a large extent on traffic volumes, but there are numerous other inputs required. Some examples are given below:

Emission modelling: vehicle and fuel type, speed.

Modelling concentrations of air pollutants: emission inventory, meteorology, topography, chemical reactions, deposition mechanism.

Ozone modelling: time dependent emissions of NOx and VOC (hourly variations). A dynamic traffic model is needed if one would like to link traffic and air quality models.

Modelling traffic noise: traffic flow, average speed, street gradient, percentage of heavy traffic, topography.

E.2 Temporal and spatial dimensions of a transport sustainability model

The geographical extent of a model depends on the model purpose. For a policy development it would probably be the area administered by a local authority, with a coarse treatment of the surrounding area. In research applications (or in the case of a joint study conducted by a group of local authorities): all areas that generate a significant amount of traffic to or from a city should be included.

Most sustainability indicators (e.g. noise levels, accessibility, severance, carbon monoxide concentrations) would require a model of the averaged traffic pattern during the morning and afternoon peak, and during the off-peak hours. Some indicators (e.g. CO2 emissions, fuel consumption) would be based on the value of the total average daily traffic for the whole modelled area. An evaluation of ozone, NO_x and VOC levels would be done using a photochemical model, requiring hourly values of emissions.

Spatial units used in models vary depending on the model type. Transport demand and supply evaluation is based on the discrete modelling of space, with zones as the main spatial units. The size and number of zones must be a balance between the desire to have a detailed representation of trips and the requirements of the data collection stage: (i) zones should be large enough to give a statistically significant sample; (ii) the number of zones is limited by survey and modelling costs. The assignment stage of modelling requires in addition the detailed information on the individual links (road segments) of the road network

For modelling the combined impacts from transport and other sectors, e.g. industrial sources, and for providing an input to air quality models, values of emissions obtained for individual links should be recalculated into grid squares. The size of the grid depends on the lengths of the road links, and on the resolution requirements of the air pollution model.

Unlike transport models, air pollution models are based on equations where space is continuous. However, the resulting numerical models have obviously a discrete nature, and are usually based on a regular grid. Some most recent models use an irregular, adaptive mesh for an improved modelling of areas with high concentration gradients, but they still require grid-based emission data on input.

E.3 Implementation of exemplar models.

It would be difficult to develop from scratch a fully parametrised computer model of transport sustainability comprising all the elements discussed above. However, the implementation become feasible if one uses existing operational models as building blocks, concentrates on the development of missing components and links all the components into a comprehensive system. Below we present two examples which follow this direction.

The first sub-model concerns the land use → transport → environment → land use loop and is schematically presented in Figure 9. The model could be based on an existing strategic land use/transport model (e.g. START model [Bates et al 1991]) and a tactical transport model (e.g. SATURN). The main missing element is a model representing impacts of transport on land use. Research on relationships between accessibility, environment and location choice have been conducted in the Institute of Transport Studies of the University of Leeds [Bristow, May, Sheperds 1997; Wardman, Bristow, Hodgson 1997, Still 1997]. Transport related factors important for residential and bussiness location have been identified using stated preference surveys, which allowed to parametrise the integrated land use transport model (DELTA/START) newly developed for Edinburgh and Lothian region.

The second sub-model (Figure 27) concerns modelling of links between human activities, emissions from mobile and stationary sources, air quality, and impacts of air pollution on human health. It aims initially to model emissions from traffic, domestic emissions and emissions from industrial sources, and to provide a tool for testing an influence of transport policies on emission levels and their spatial distribution. At a later stage an air pollution model will be added, to model dispersion and chemical transformations of pollutants, and resulting pollutant concentrations. The latter component is indispensable to model concentrations of reactive and secondary pollutants, in particular ozone.

The core part of the second sub-model, called MUPPETS (**M**odelling and mapping **U**rban **P**ollutants **E**missions from **T**ransport and **S**tationary Sources), has been developed within the Quantifiable City project conducted in the Leeds Environment Centre [May et al 1995, Kupiszewska et al 1995] and is described in detail in [Kupiszewska 1996b]. MUPPETS is composed of two main sub-models: MUPPET and MESS (**M**odelling **E**missions from **S**tationary **S**ources), which address respectively emissions from mobile and stationary sources. Traffic flows needed to evaluate emissions from mobile sources are calculated for peak and inter-peak hours using the SATURN model, a combined simulation and assignment model that calculates traffic flows at equilibrium conditions [Van Vliet 1982]. The SATURN model has been developed at the Institute for Transport Studies of the University of Leeds and is commercially available from W.S. Atkins Consultants.

Calculation of emissions from stationary sources in MESS is based on the methodology described in [Ko 1995] and has three components: (i) emissions from industrial sources, based on employment figures for individual firms or industry sectors, and emission rates per employee by sector or Standard Industrial Classification; (ii) emissions from domestic sources, based on population data from Census (by enumeration district) and emission rates per capita, obtained from national emission inventories; and (iii) emission from biogenic sources (farming and natural sources), based on land use data and emission rates per hectare.

The model of emissions from mobile sources and the model of emissions from stationary sources are linked with GIS systems (MapInfo and ARC/INFO), which are used (i) for mapping purposes; (ii) for recalculation between link-based, grid-based and zone-based data formats; (iii) to overlay the traffic and environment data with the data from Census (or population model) in order to evaluate population exposure and social equity.

Several extensions of the core system are possible. In order to test the impact of land-use policies, the START model [Bates *et al* 1991] could be implemented, and the DELTA model [Simmonds 1997] could be used to model feedback from environment to land-use. Temporal variations of traffic might be evaluated using the DRACULA dynamic micro-simulation model [Liu 1995]. A promising candidate for the air dispersion model is the recently released ADMS-Urban model from Cambridge Environmental Research Consultants (CERC).

The sub-models presented in Figure 27 and Figure 28 exploit the START and SATURN models, but other combinations are possible, depending on the objectives of the modelling exercise and the availability of operational models to the user. For example, one might think of adopting one of the large scale urban models [see a review paper by Wegener, 1994] for sustainability modelling purposes. Two such models are available in the UK: MEPLAN [Echenique et al 1990] and LILT [Mackett 1983]. Good candidates for transport models that include a detailed representation of a transport network are TRIPS [MVA Systematica 1982] and EMME/2 [Babin et al 1982, INRO Consultants 1991].

Modelling links between air pollution and health is particularly difficult and we are not aware of any operational model that could be used here. Initial investigation might include overlay of air quality maps with a map of asthma cases (relevant data on admissions to hospitals by ward are available), however a possible correlation between high pollutant concentration levels and a number of asthma attacks would not necessarily imply any causal link between the two, due to the large number other intervening factors.

F. Conclusions

Current transport trends are unacceptable from the sustainability point of view. Changes of individual behaviour as well as actions from local and national governments are required. A transport sustainability model is needed to evaluate all social and environmental costs consequential to various policies and scenarios. Modelling transport sustainability requires an interdisciplinary effort, with inputs from many scientific areas including engineering, science and social sciences. Problems to be addressed range from local to global, and from short-term to long-term.

One of the difficulties is insufficient knowledge of people's behaviour. Much more effort is required to study individuals' and businesses' locational and transportation decisions. Moreover, there are processes and phenomena difficult to model quantitatively, e.g. a habitual and psychological dependence on car or severance effects. The conceptual model presented in this paper includes both measurable, as well as not easily quantifiable impacts. The final evaluation of a policy should combine an analysis of both.

A cost-effective method of developing an operational model of transport sustainability might be based on existing models. Transport models already in use in many local authorities might be linked with land use models to test integrated strategies. An environmental impact model might be constructed as an independent module that could interact with a number of transport models.

Acknowledgments

The work described in this paper has been carried out within the Quantifiable City project conducted at the Environment Centre of the University of Leeds and funded by the EPSRC Sustainable Cities program.

G. Bibliography

1. Aurbach (1993) Opening address, [in:] *Transport Growth in Question*, pp. 11-17, ECMT..
2. Banister, D. (1993) Demographic structures and social behaviour, [in:] *Transport Growth in Question*, pp. 109-150, ECMT.
3. Banister, D., Bayliss, D. (1992) Structural changes in population and impact on passenger transport. [in:] *ECMT Round Table 88*, ECMT, Paris.
4. Babin, A., Florian, M., James-Lefebre, L., Spress, H. (1982) EMME/2: interactive graphic method for road and transit planning. *Transportation Res. Record* 866, pp. 1-9.
5. Bates, J., Brewer, M., Hanson, P., McDonald, D., Simmonds, D. (1991) Building a strategic model for Edinburgh, PTRC 19th Summer Annual meeting, Proceedings of Seminar G.
6. Baumgartner, J.P. (1993) Impact of new technologies on efficiency and safety. [in:] *Transport Growth in Question*, pp. 449-474, ECMT.
7. Bendixson, T. (1989), *Transport in the nineties. The shaping of Europe*, The Royal Institution of Chartered Surveyors, London.
8. Bristow A.L., A.D. May, S.P. Shepherd (1997) Towards the sustainable city: the impact of land use -transport interactions. 25th PTRC Annual Meeting, Proceedings of Seminar C.
9. Bonnafous, A. (1993) Demographic structures and social behaviour. [in:] *Transport Growth in Question*, pp. 21-75, ECMT.
10. Brown, A. (Ed.) (1992) *The UK Environment*. HMSO, London.
11. CEST (1993) *The UK Environmental Foresight Project*. Volume 2: Road Transport and the Environment: The Future Agenda in the UK, HMSO, London.
12. Davis A. (1992) Livable streets through environmental capacity limits, Proceedings of Seminar B, PTRC Summer Annual Meeting, pp. 103-114.
13. Deelstra, T. (1993) Opportunities and limitations for sustainable traffic and transport in urban regions in Europe, Proc., 21st PTRC Summer Annual Meeting, Seminar A, pp. 1-12.
14. Dittmar, H. (1995) A broader context for transportation planning. Not just an end in itself. *Journal of the American Planning Association*, 61, pp. 7-13.
15. DoE (1991) *Digest of Environmental Protection and Water Statistics*, Department of Environment, HMSO, London.
16. DoT (1995), *Transport statistics for London*, p.27, HMSO
17. Dron, D., Cohen de Lara M. (1995) *Pour une politique soutenable de transport*, La documentation Francaise, Paris.
18. Echenique et al (1990) The MEPLAN models of Bilbao, Leeds and Dortmund, *Transport Reviews* 10, pp. 309-322.
19. ECMT (1990) *Statistical Trends in Transport 1965-1987*, ECMT, Paris.
20. ECMT (1993a) *Statistical Rapport on Road Accidents in 1991*, ECMT, Paris.

21.ECMT (1993b)*Transport Growth in Question*. 12th International Symposium on Theory and Practice in Transport Economics, ECMT, Paris.
22.ECMT (1995) *Urban travel and sustainable development*; ECMT, OECD; Paris.
23.Ferrary, C. (1994) A methodology for integrating environmental concerns into transport planning, Proc., 22nd PTRC Summer Annual Meeting, Seminar C, pp.169-185.
24.Güller, P (1996) Urban travel in East and West: key problems and a framework for action, [in:] *Sustainable Transport in Central and Eastern European Cities*, ECMT, OECD, Paris, pp. 21-50.
25.Hillman, M., Adams, J. (1992) Safer Driving - Safer for Whom. Conference on "Eurosafe: Safer Driving in Europe", The Association of London Borough Road Safety Officers. Cited after ECMT 1995.
26.INRO Consultants (1991) *EMME/2 User's Manual*, INRO Consultants, Montreal.
27.IUCN-UNEP-WWF. (1991) *Caring for the Earth*. Second report on World Conservation and Development. Earthscan, London.
28.Jones, S.R. (1981) Accessibility measures: a literature review, TRRL Report 967, DoE and DoT, Crowthorne.
29.Kaspar C. (1993) Economic trends and transport specialisation. [in:] *Transport Growth in Question*, pp. 205-229, ECMT.
30.Klaassen, L.H. (1991) Transport and spatial distribution of activities, [in:] *ECMT Round Table 85*, ECMT, Paris.
31.Kupiszewska, D., Mitchell, G., Kay, D. (1995) Integrated modelling for a sustainable city, *The Regional Review*, Yorkshire & Humberside Research Observatory, University of Leeds, 1995.
32.Kupiszewska, D. (1996a) *Computer implementation of the Quantifiable City Decision Support System (QCDSS)*. ITS Working Paper 519, Institute for Transport Studies, University of Leeds.
33.Kupiszewska, D. (1996b) *MUPPETS - a computer tool for modelling and mapping emissions from urban transport and stationary sources*. ITS Working Paper 522, Institute for Transport Studies, University of Leeds.
34.Kürer, R. (1993) Environmental, global and local effects. [in:] *Transport Growth in Question*, pp. 475-536, ECMT.
35.LEC (1996) Transport Fact File. *Environment City News*. The Newsletter of the Leeds Environment City Initiative, Issue No 12, Leeds.
36.Liu, R. (1994) (1994) *DRACULA microscopic traffic simulator*. Working Paper 431, Institute of Transport Studies, University of Leeds, U.K.
37.Mackett, R.L. (1983) *The Leeds integrated land-use transport model (LILT)*, TRRL Supplementary Report 805, Transport and Road Research Laboratory, Crowthorne, UK.
38.Mauch, S.P., Maibach, M., Walter, F., Neuenschwander, R., Suter, S. (1995) Transport policy and sustainability: from theory to an optimal policy mix, [in:] E. Reinhardt (ed.), *Social marketing of promising strategies in transport and urban energy management*, vdf Hochschulverlag AG an der ETH Zurich.
39.May, A.D., Mitchell, G., Kupiszewska, D.(1995) The Development of the Leeds Quantifiable City Model, [in:] Proceedings of the First International Workshop "*Environmental Impact Evaluation of Buildings and Cities for sustainability*", Florence, September 1995.
40.Monheim, R. (1996) parking management and pedestranisation as strategies for successful city centres. [in:] *Sustainable Transport in Central and Eastern European Cities*, ECMT, OECD, Paris, pp. 53-143.

41.MVA Systematica (1982) *TRIPS highway assignment model*, MVA House, Woking, UK.
42.Newman P.W.G. and Kenworthy J.R. (1989) Gasoline consumption and cities. A comparison of U.S. cities with a global survey, *Journal of the American Planning Association,* Vol. 55, pp. 24-35.
43.Nijkamp, P. and Priemus, H. (1993) Infrastructure capacity and network access, [in:] *Transport Growth in Question*, pp. 327-371, ECMT, Paris.
44.OECD (1986) *Fighting noise*, Paris. Cited after [ECMT 1995].
45.OECD (1989) *The social costs of land transport,* Environment Directorate, Paris. Cited after [ECMT 1995].
46.OECD (1995a) *OECD Environmental Data Compendium 1995*, Paris.
47.OECD (1995b) *Environmental principles and concepts*. OECD Working Papers Vol. III, No 84, Paris.
48.OECD (1996) *Sustainable Transport in Central and Eastern European Cities*. ECMT, OECD, Paris.
49.Orski, C. K. (1987) Managing our way out of congestion. Paper given to a conference on Strategies to Allievate Traffic Congestion, US Institute of Transportation Engineers, Washington DC. Cited after [Bendixson 1989].
50.Ortuzar, Willumsen (1994) *Modelling transport*, Wiley&Sons.
51.QUARG (1993) *Urban Air Quality in the United Kingdom.* First Report of the Quality of Urban Air Review Group, Department of the Environment, London.
52.Simmonds D.C. (1997) The design of the DELTA land-use modelling package. David Simmonds Consultancy, Cambridge.
53.Still B. (1997) Transport impacts and land use: potential methods and their relevance to strategic planning. 25th PTRC Annual Meeting, Proceedings of Seminar C, pp.255-267.
54.Stokes, G., Dargay, J. (1993) What is a sustainable transport policy. Proc., PTRC Summer Annual Meeting, Seminar A, pp. 145-156.
55.Suchorzewskai (1996) Managing Traffic growth in Polish Cities, [in:] *Sustainable Transport in Central and Eastern European Cities*, ECMT, OECD, Paris, pp.145-177..
56.Umweltbundesamt (1991) *Verkehrsbedingte Luft- und Larmbelastungen - Emissionen, Immisionen, Wirkungen*, UBA-Texte 40/91, Berlin.
57.Van Vliet, D. (1982) SATURN - A modern assignment model. *Traffic Engineering and Control*, Vol. 23, pp. 578-581.
58.Walsh, M. (1989) *Vehicle Air Pollution.* ECMT Ad Hoc Group on Transport and the Environment, ECMT, Paris. Cited after [Bendixon 1989, p.41].
59.Wardman, M., A. Bristow, F. Hodgson (1997) Valuation of noise, air quality and accessibility. 25th PTRC Annual Meeting, Proceedings of Seminar D.
60.WCED (1987) *Our Common Future*, World Commission on Environment and Development, Oxford University Press, Oxford.
61.Webber, M (1985) The emerging metropolis: trends and trepidations. [in:] *Mobility for major metropolitan growth centers: A new challenge for public-private co-operation*, US Department of Transport, Washington DC. Cited after [Bendixson 1989].
62.Webster, F.V., Bly, P.H., Johnston, R.H., Paulley, N., Dasgupta, M. (1985) *Changing pattern of urban travel.* ECMT, Paris.
63.Wegener, M. (1994) Operational urban models. State of art. *Journal of the American Planning Association*, Vol. 60, No. 1, pp.17-29.

Table 1. Transport sustainability aims, objectives and indicators.

Aims and objectives	Indicators
<u>Environment and resources</u>	
Improvement of air quality	**Emissions** and/or concentrations of NO_x, VOC, SO_2, CO, PM10.
Reduction of noise pollution	**Noise** levels; % of population affected by high noise levels.
Reduction of resource use including	
• energy sources	**Fuel consumption**
• space	Use of space by transport infrastructure
• raw materials	Use of raw materials is evaluated indirectly by the number of cars and the length of roads. Further research required for more detailed modelling.
Reduction of environmental impact including	
• Contribution to global warming	**Per capita CO_2 emissions**
• Solid waste production	Number of scrapped cars per year Percentage of metal parts, tyres, oil, batteries recycled
• Influence on water system • Impact on animals and vegetation • Soil pollution	Impact on water system, fauna and flora is evaluated qualitatively. Modelling possible, but further research required.

Table 1 (cont). Transport sustainability aims, objectives and indicators.

Aims and objectives	Indicators
Quality of life	
Increasing accessibility and freedom of mode choice Depending on situation: • Decrease dependence on a car • Satisfy the need for car availability	**Accessibility** to jobs, shopping and leisure centres, by mode (expressed as time, cost and generalised cost) % of households with an access to a car (including neighbourhood street fleet/local rental schemes)
Safety improvement	**Accidents**/casualties/pedestrian fatalities
Increasing quality of public transport (density, frequency, speed, comfort, information)	Evaluated qualitatively, with some quantitative indicators (e.g. distance from public transport, frequency, speed)
Minimising severance and improving livability of residential streets	**Severance** is evaluated indirectly, by traffic flow (veh./h) and speed. Research to develop a severance index is needed. % of 10-11 years old children accompanied to school (indicates not only severance but also size of catchment areas, crime level, etc.)
Minimising aesthetic impairment and negative impact on built heritage	Aesthetic/built heritage impacts are evaluated qualitatively
Intra-generational equity (e.g. improving accessibility for those without a car)	**Distribution of benefits and negative impacts** by social group, age, sex and/or geographical area
Public participation in policy making	Public participation is evaluated qualitatively

Table 1 (cont.). Transport sustainability aims, objectives and indicators.

Aims and objectives	Indicators
<u>Intermediate objectives and operational/substitute indicators</u>	
Demand reduction/total traffic restraint	**Traffic volume** in veh.-kms (per capita?) Trip rates by purpose Car occupancy
• Shorter passenger trips	Average trip length by purpose Availability of local services (shopping, education, sport and leisure)
• Shorter freight trips	% of consumed goods produced locally
• Reduction of congestion	Ratio of peak hour and off-peak speeds
Control of motorisation level	Total number of cars Number of passenger cars per 1000 people
Reduction of traffic in sensitive areas (city centre, residential areas)	**Geographical distribution of traffic volume** (veh.-kms)
Shift to less environmentally-damaging modes	**Modal share** (for passenger transport) % of long distance goods transport by rail Length of traffic-free routes for cyclists and walkers
Traffic calming	**Speeds** (geographical distribution) % of roads length in residential areas with traffic calming
Increased use of technological improvements	Percentage of cars with catalytic converters Percentage of cars with an access to driver information systems
<u>Economic performance</u>	
Economic efficiency	**Net Present Value**
Internalisation of costs	Balance of all (internal and external, including environmental impacts) costs, and revenues. Difficult to do, further research highly recommended. Environmental taxes as % of fuel price
Providing money for sustainability-promoting actions	**Present Value of Finance**

Table 2 Comparison of car prices, costs, and charges for the user in Switzerland in 1960 and 1990 at 1990 prices (SF of 1990). Source: [Baumgartner 1993, p. 470].

Type of car: cylinder capacity	1000		2000	
Year	1960	1990	1960	1990
Purchase price in SF	25000	10000	32000	16000
Cost of petrol in SF/litre	1.6	0.96	1.6	0.96
Petrol consumption in litres/100km	9	6.5	10	7.5
Annual charges in SF excluding running costs per km (proportion of depreciation, interest, taxes and duties, insurance, garage, parking fees)	4500	3400	5750	5000
Running costs in SF per km (proportion of depreciation, fuel, oils, tyres, maintenance and repairs)	0.68	0.13	0.72	0.16
Total annual costs per kilometre travelled for 15000 km/year in SF per km	0.97	0.35	1.66	0.50

Table 3. Modal split (%) of passenger traffic (passenger-kms) and freight traffic (tonne-kms) in ECMT countries. Source: [Baumgartner 1993, p. 472].

Passenger traffic				Freight traffic			
Year	Rail	Road		Year	Rail	Road	Inland waterways
		Buses and coaches	Cars				
1965	13.1	15.8	71.1	1970	31.2	55.0	13.8
1970	10.1	13.0	76.9	1975	25.2	62.7	12.1
1980	8.3	11.9	79.8	1980	23.0	65.9	11.1
1988	7.0	10.0	83.0	1988	18.4	75.2	9.1

Table 4. Modal split (%) of passenger traffic in selected European cities (listed in a decreasing order of the city size) [Monheim 1996, pp. 68].

City	Year	All trips			Shopping trips		
		Walking and cycl.	Car	Public	Walking and cycl.	Car	Public
Hamburg	1991	8	30	62	5	25	70
Hannover	1990	19	33	48	13	25	61
Nurnberg	1989	25	35	40	21	25	54
Freiburg	1989	38	29	33	46	11	43
Zurich	1992	22	11	67	20	6	74

Table 5. Modal split for non-pedestrian journeys (%) in Warsaw. Source: [Suchorzewski 1996, p.151].

Year	Public transport	Car	Bike
1980	80.8	17.8	-
1987	79.1	20.9	-
1993	68.3	30.6	0.9

Table 6. Selected transport-related data for the UK, France, Poland and European OECD countries. Source: OECD 1995a, Suchorzewski 1996, ECMT 1990.

	UK			France			Poland			OECD-Europe		
	1980	1993	change	1980	1993	change	1980	1993	change	1980	1993	change
Road traffic volumes (billion veh.-kms)												
Passenger cars	197	334	70%	245	343	40%	20	73	265%	1322	2089	58%
Freight traffic	41	64	56%	49	94	92%	20	33	65%	244	386	58%
Road vehicle stocks (thousands)												
Passenger cars	14660	20344	39%	19130	24385	27%	2383	6771	184%	107339	159716	49%
Goods vehicles	2148	3220	50%	2516	4989	98%	618	1276	106%	11621	20919	80%
Road network length												
All roads (1000 kms)	339	365	8%	803	812	1%	299	368	23%	3199	3433	7%
Motorways (kms)	2585	3183	23%	5264	8100	54%	139	257	85%	31507	43734	39%
Energy consumption by road transport (million tons of oil equivalent)												
Petrol	20.49	25.43	24%	18.71	17.99	-4%	3.84	4.56	19%	112.3	137.8	23%
Gas oil or diesel	6.06	12.22	102%	9.42	20.96	123%	3.34	2.84	-15%	56.4	108.6	93%
Emissions from mobile sources (thousand tonnes)												
Carbon monoxide (CO)	3990	5163	29%	8100	6376	-21%	1457	1576	8%			
Nitrogen oxides (NOx)[1,2]	1022	1308	28%	860	1088	27%	463	420	-9%			
VOC	866	938	8%		1166		371	320	-14%			
Particulates[1]	124	232	87%	40	76	90%	24	22	-8%			
CO2 (million tonnes)	98.9	139	41%	94.9	133.2	40%	34	26	-24%			
Car ownership	1981	1992	change				1980	1992	change	1980	1987	change
Cars per 1000 population[3]	277	367	32%				67	169	152%	260	308	18%

[1] French data for 1992 instead 1993.

[2] French data refer to road transport.

[3] Data for OECD-Europe refer to the nineteen ECMT countries.

Table 7. Origin and impact of transport related air pollution and noise. Source: Kürer 1993, p. 506 (Original source: Umweltbundesamt 1991).

Pollutant	Source	Effects on: People	Vegetation and ecosystem	Climate	Materials and buildings
Hydrocarbons (HC)	Incomplete combustion, carburation	Direct, notably carcinogenic effects of individual components	Through build-up in soil, feed and food crops	High greenhouse potential (methane), ozone formation	
Nitrogen oxides (NO_x)	Oxidation of N_2 and N-compounds in fuel additives	Irritation, morphological changes in the respiratory system	Acidification of soil and water, over fertilising, increased risk of leaf and root damage	Very high greenhouse potential (NO_2), ozone formation	Weathering, corrosion
Ozone (O_3)	Photo-chemical oxidation with NO_x and HC	Irritation of mucus and respiratory system, premature aging of the lungs	Increased risk of leaf and root damage	Very high greenhouse potential	Decompositi on of polymers
Carbon monoxide (CO)	Incomplete combustion	Inadequate oxygen supply, in particular heart/circulation and central nervous system		Indirect through ozone formation	
Particulates	Incomplete combustion, source-specific emissions, dust thrown-up	Damage to respiratory system, toxic contents with broad range of effects	Reduced assimilation		Dirty buildings
Soot	Incomplete combustion	Carcinogenic			Dirty buildings
Carbon dioxide (CO_2)	Combustion			Quantitatively important greenhouse gas	
Noise	Engine, drive and rolling noise	Substantial nuisance, higher health risk			Reduced value

Table 8. Emissions from road transport as a percentage of total emissions of selected species.
Source: Own calculations based on DoE 1991 (Road transport) and OECD 1995a (All mobile sources)

	Road transport			All mobile sources					
	UK 1980	UK 1990	Urban areas	UK 1980	UK 1993	Poland 1980	Poland 1993	France 1980	France 1993
Carbon monoxide (CO)	82%	90%	100%	82%	92%	43%	75%	87%	65%
Nitrogen oxides (NO_x)	35%	51%	60%	43%	56%		38%	52%[5]	72%[4,5]
VOC[1]	38%	41%	50%	38%	40%	32%	41%		51%
Particulates[2]	21%	46%		22%	52%		1%	9%	33%[4]
Sulphur dioxide (SO_2)	1%	2%		2%	4%	2%	2%	4%	13%[4]
Carbon dioxide (CO_2)[3]	13%	19%		17%	25%	7%	7%	19%	36%

[1] Excluding methane.
[2] UK data refer to black smoke (suspended particulate of less than 15 μm diameter).
[3] Data on emissions from all mobile sources give the percentage of total emissions from energy use (CO2 emissions from energy use account for 99 per cent of total CO2 emissions in the UK and Poland, and for 88 per cent in France [OECD 1995]).
[4]. Data for 1992
[5]. Calculations of NO_x for France do not include mobile sources other than road transport.

Table 9. Transport related emissions (g/pkm) in Germany (1986) - passenger transport. Source: Kürer 1993, p.509 (Original source: Umweltbundesamt 1991).

	CO	CO_2	HC	NO_x	SO_2	Particulate/ Dust
Car: Gasoline[1]	14.40	180	2.50	2.40	0.03	0.01
Diesel	1.40	150	0.30	0.60	0.19	0.18
Bus: Local	0.60	65	0.50	0.90	0.09	0.20
Long-haul	0.05	20	0.05	0.40	0.03	0.02
Rail: Local	0.02	105	0.01	0.30	0.70	0.04
Long-haul	0.01	45	0.01	0.15	0.30	0.02
Air:	2.20	465	0.40	1.80	0.15	0.07

[1] Without catalyser.

Table 10. Transport related emissions (g/tkm) in Germany (1986) - freight transport. Source: Kürer 1993, p.509 (Original source: Umweltbundesamt 1991).

	CO	CO_2	HC	NO_x	SO_2	Particulate/ Dust
Road: Local	1.86	255	1.25	4.1	0.32	0.30
Long-haul	0.25	140	0.32	3.0	0.18	0.17
Rail:	0.15	48	0.07	0.4	0.18	0.07
Inland waterway:	0.18	40	0.08	0.5	0.05	0.03

Table 11. Air pollutant concentrations in urban residential areas and city centre streets in Germany ($\mu g/m^3$). Source: [Kürer 1993, p.512].

Pollutant	Residential areas		City centre streets	
	Annual average	98 percentile	Annual average	98 percentile
NO	40 to 60	200 to 300	80 to 200	350 to 800
NO_2	40 to 60	100 to 150	50 to 100	120 to 260
CO[1]	1 to 2	3 to 5	3 to 5	5 to 15
Soot	10 to 20	40 to 70	20 to 40	70 to 140
NMHC[2]	60 to 200	200 to 700	90 to 1200	400 to 3700
Lead	0.2 to 0.4		0.3 to 0.8	
Ozone	20 to 50	50 to 170	10 to 30	40 to 120

[1] mg/m^3
[2] Non-methane hydrocarbons

Table 12. Population changes in some West-European agglomerations (in annual percentages). Source: Klassen 1991, p.33.

	Town	Rest	Agglomeration	Period
Antwerp	-0.8	+1.2	0.0	1970-81
Birmingham	-0.8	-0.3	-0.5	1971-81
Copenhagen	-1.5	+1.0	-0.1	1970-85
Hamburg	-0.8	+1.9	+0.1	1970-81
Liverpool	-1.6	-0.4	-0.9	1971-80
Marseilles	-.01	+4.5	+0.5	1971-81
Milan	-.06	+1.3	+0.2	1971-82
Paris	-1.1	+1.0	+0.4	1968-82
Rotterdam	-1.6	+2.2	+0.2	1970-80

Table 13. Changes in the number of job opportunities in some West-European agglomerations (annual percentages). Source: Klassen 1991, p.34.

	Town	Rest	Agglomeration	Period
Antwerp	-0.7	+0.4	-0.5	1974-84
Bremen	-0.7	+0.5	_0.2	1961-83
Copenhagen	-0.3	+3.2	+1.3	1970-83
Hamburg	-0.8	+1.9	-0.3	1961-83
Hannover	-0.7	+1.1	-0.3	1961-83
Liverpool	-2.6	-3.1	-2.9	1974-84
Lower Ruhr	-0.8	-0.2	-0.6	1961-83
Milan	-0.9	+1.9	+0.7	1978-81
Rotterdam	-1.1	+1.5	+0.6	1975-84
Stuttgart	-0.5	+1.2	+0.6	1961-83

Table 14. Existing and potential policy measures:

Education and information
Campaigns in favour of public transport, cycling and walking
Public information systems on air pollution.
Improved public transport information.
Information for transit.
Encouraging consumption of locally produced goods and services.
Encouraging drivers to drive in a more fuel-efficient manner.
Car drivers training.
Traveller information systems.
Route guiding.

Fiscal and pricing measures
Public transport fares subsidy.
Improved public transport ticketing.
Toll charges/Road pricing.
Parking charges.
Fuel prices.
CO_2/Energy tax on fuel.
Vehicle purchase tax and road tax (subsidy of cleaner, consuming less fuel cars).
Road tax varied according to fuel consumption.
Tax on houses with two or more cars.
Transport levy on property developers and firms.
Increased penalties for speeding, and illegal parking.

Infrastructure provision
New roads/By-passes.
Roads improvements.
New rail/light rail lines.
Guided bus.
New stations, bus stops.
Parking supply.
Park and ride facilities.
Traffic-free routes for cyclists and walkers.
Pedestrian ways.
Safe parking for bicycles.
Noise screening.
Noise minimising road surfaces.
Use of recycled materials for road construction.
Safe road crossings.

Technology measures
Telematics.
Improved vehicle safety.
More efficient engines.
Alternative fuels.
Catalytic converters.
Asbestos-free brake system.

Management
Traffic calming.
Optimising traffic flow (green wave, application of telematics).
Increasing frequency of public transport.
Public transport lines to shopping centres .
Speed-up programme for public transport (bus lanes, priority at traffic lights).
High occupancy vehicle lanes.
Cycle lanes.
Access limitations.
Banning/restricting road freight traffic.
Management of freight traffic to decrease "empty trips".
Increase share of long distance freight transport by rail.
Limiting the through-traffic in the built area.
Public parking management / Parking time restrictions.
Private parking control.
Car sharing.
Emergency traffic restrictions when pollution is bad.

Land use planning and economy measures
Favorisation of "compact city".
Concentration of mixed activities in local centres.
Regeneration of city centres.
Designated growth areas and new towns.
Location of activities close to public transport.
Car-free zones.
Location of new transport infrastructure.
Teleworking, teleshopping
Varied working and opening hours.
Design of roads and buildings configuration in a way improving ventilation..
Increased share of locally produced goods in supermarkets and stores.

Regulation by law, standards, targets
Pedestrian priority.
Lower speed limits.
Targets for pollutant emissions, air quality, noise levels.
Targets for reduced fuel consumption and CO_2 emission levels.
Tightened and more frequent car tests.
Regulations regarding safety belts, children's seats, ABS, helmets.
Vehicle recycling standards and road material recycling standards.

Figure 1. Linkages between transport and other sectors and sub-systems.

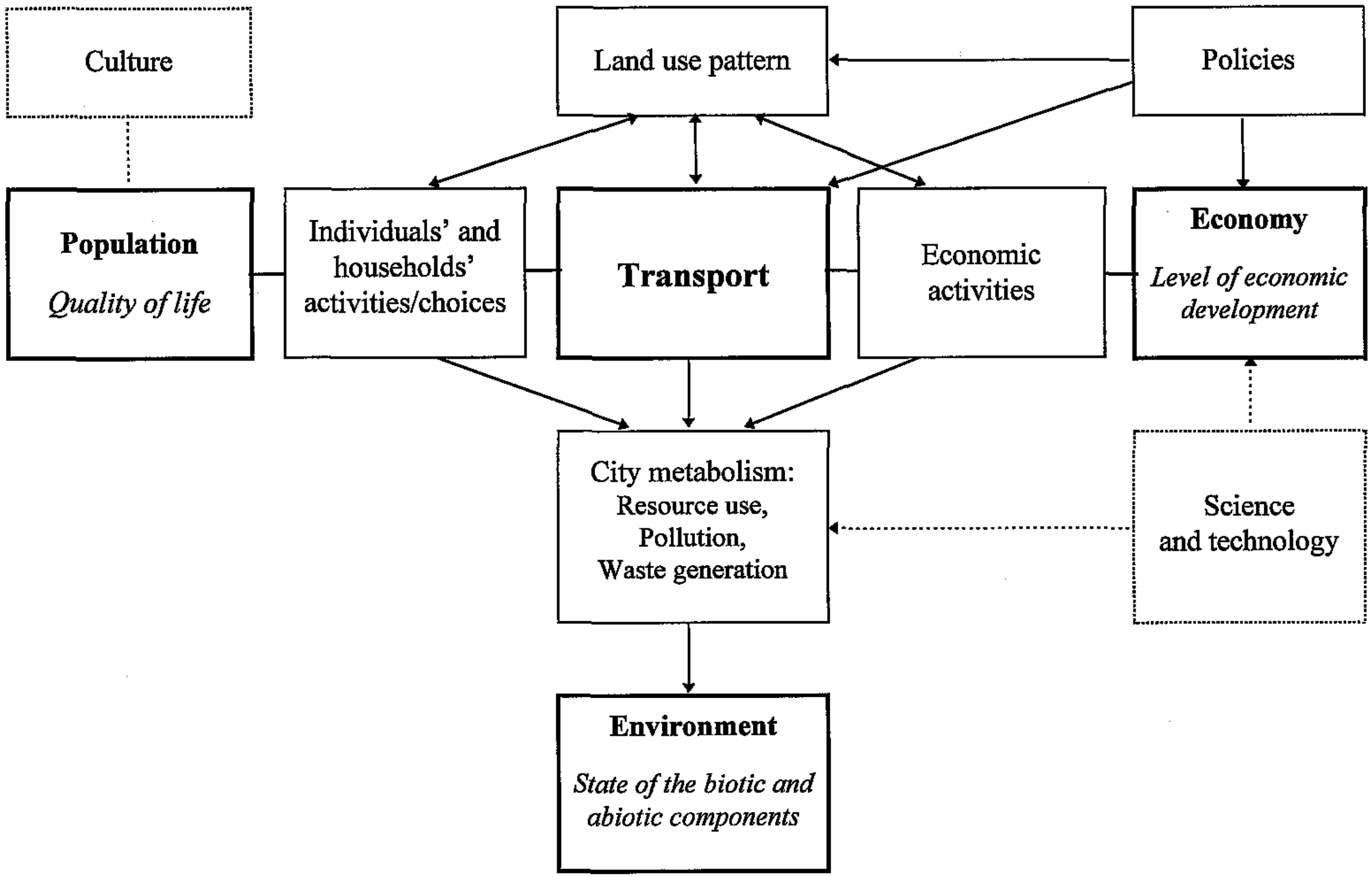


Figure 2. Transport demand, supply and impacts.

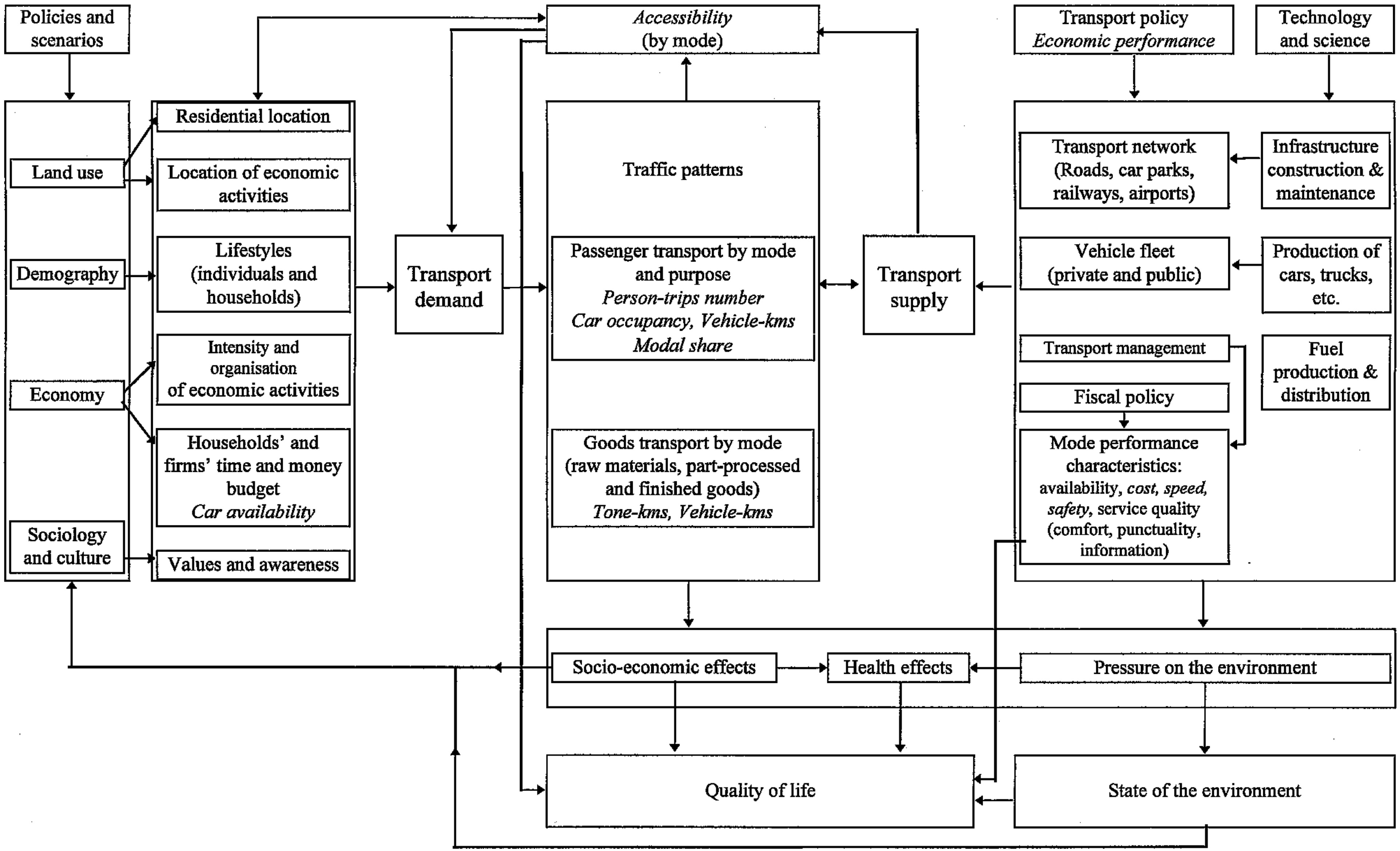


Figure 3. Main impacts of traffic on the environment.

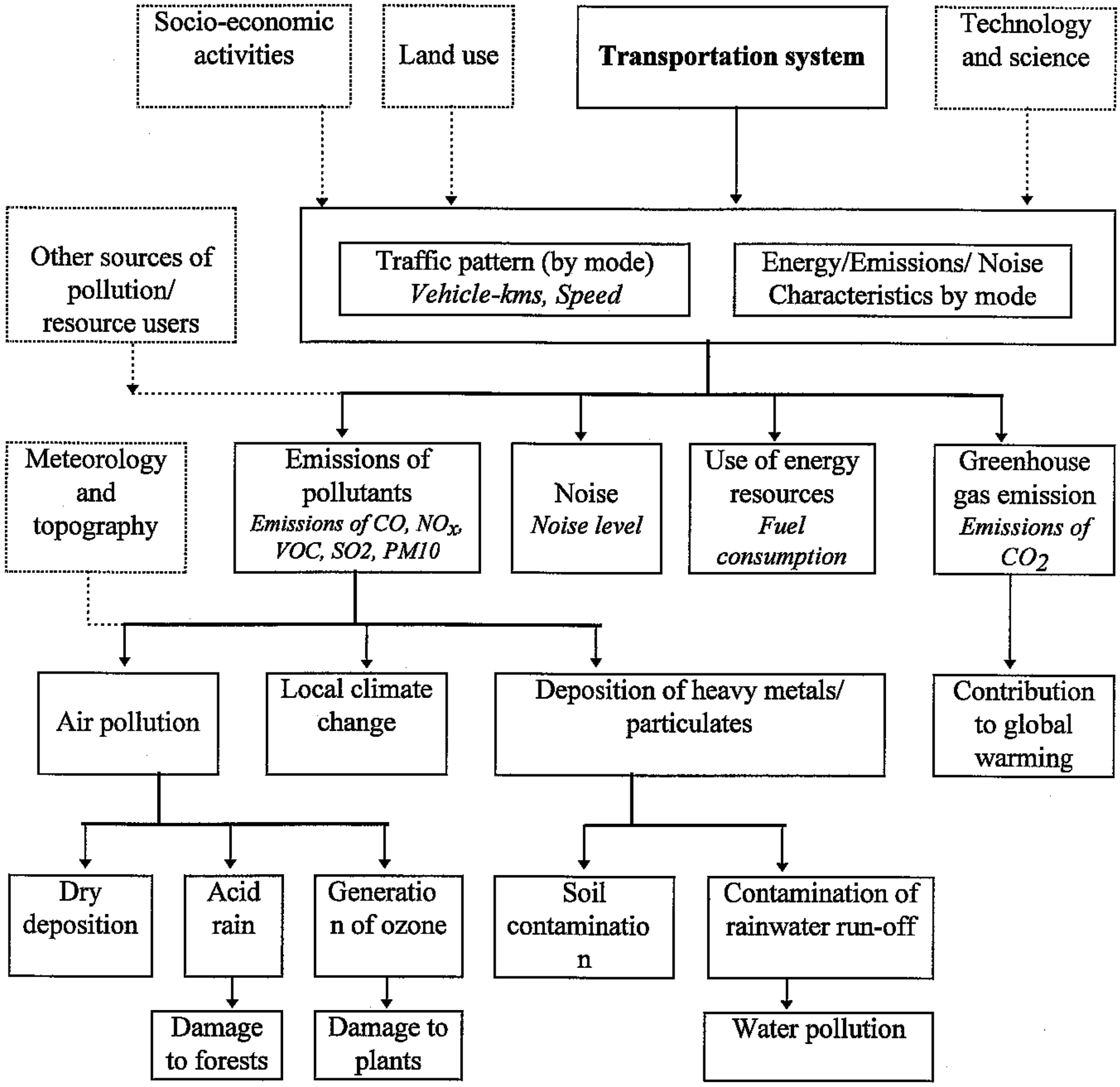


Figure 4. Impacts of transport infrastructure on the environment.

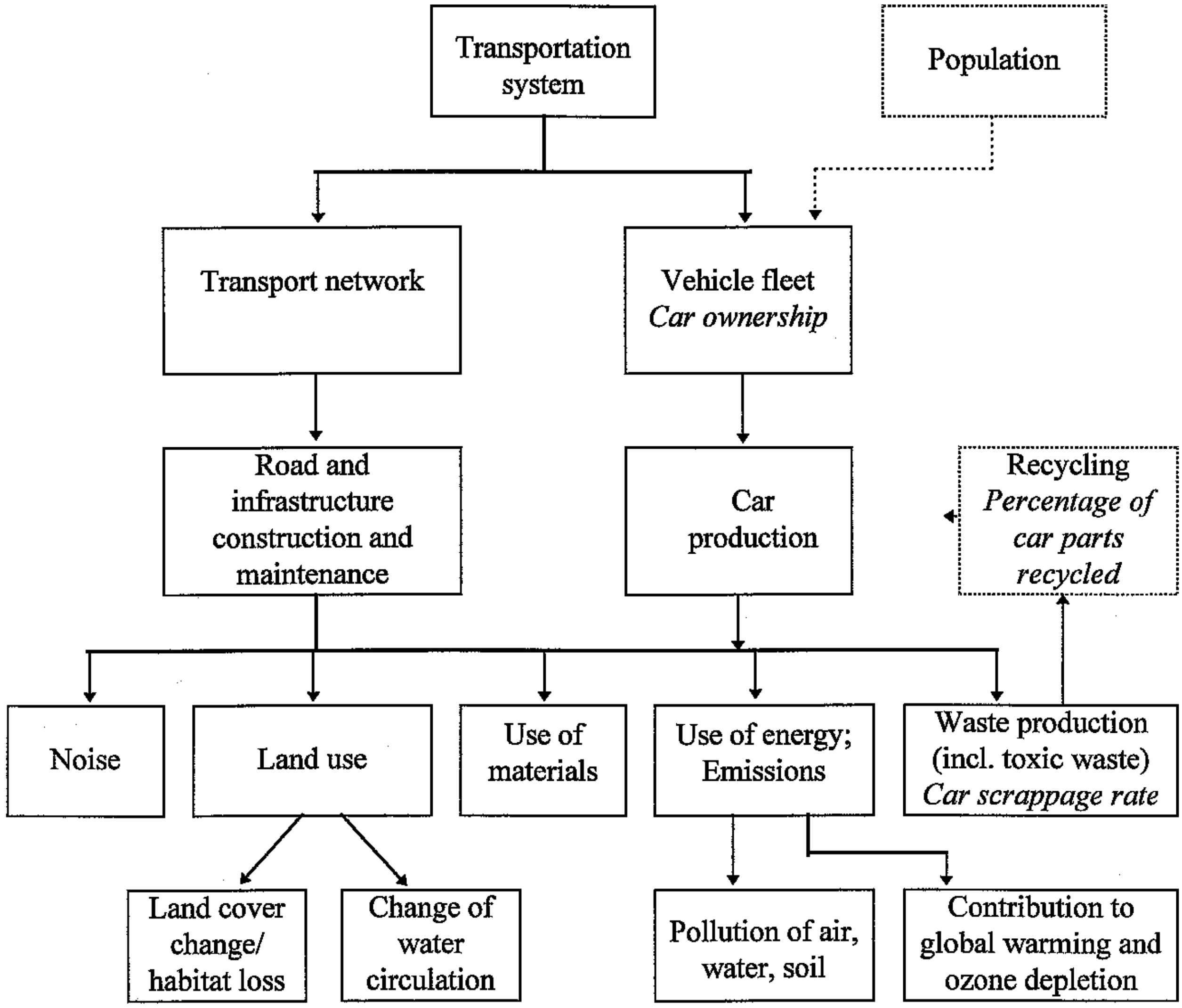


Figure 5. Indirect impacts of the transportation system on the human system (through environmental impacts).

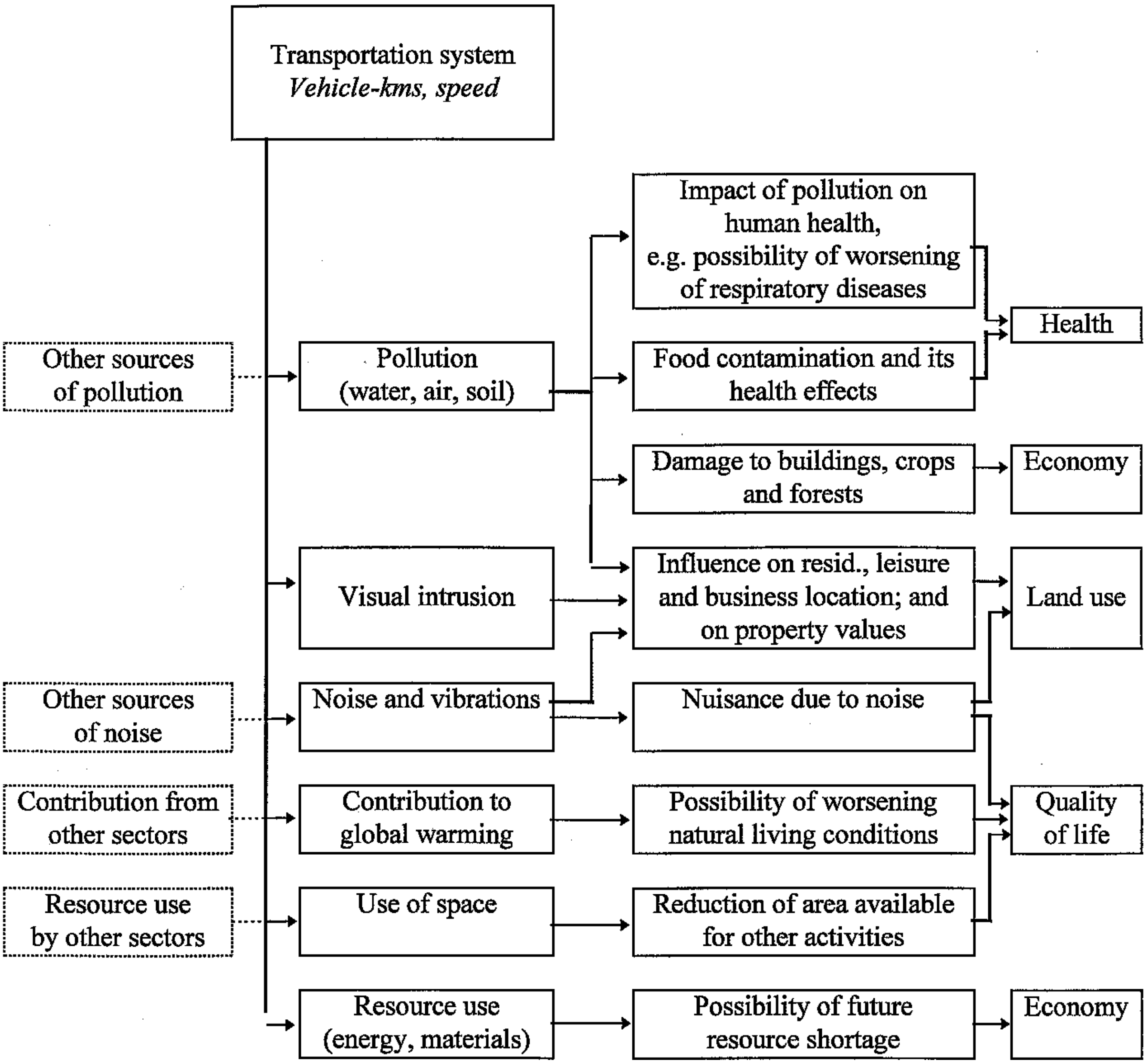


Figure 6. Direct impacts of the transportation system on the human system.

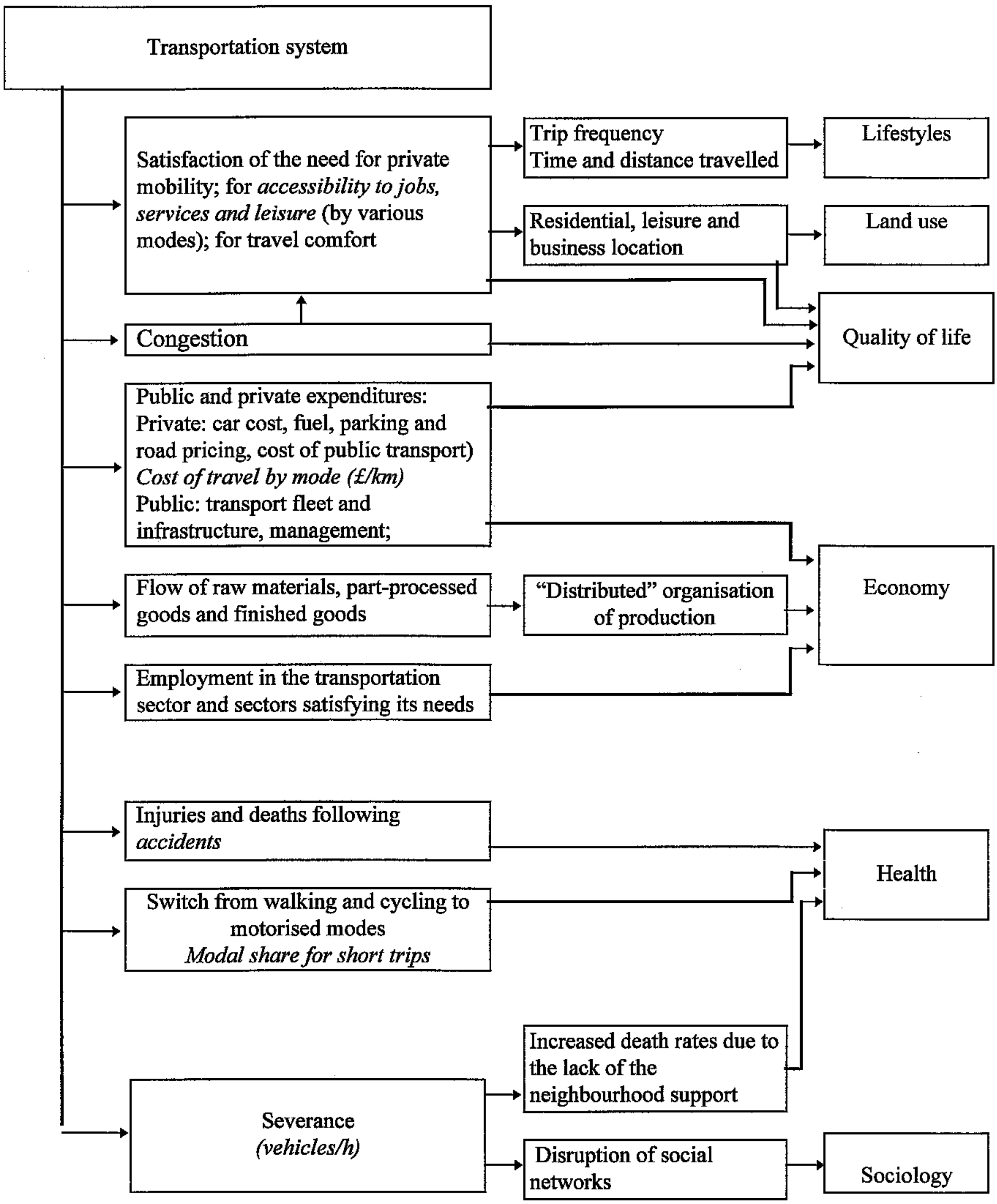
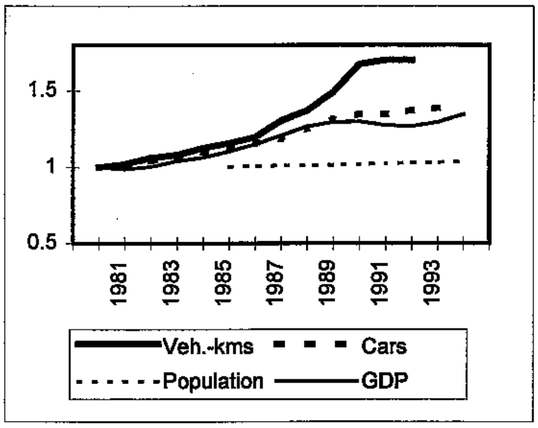
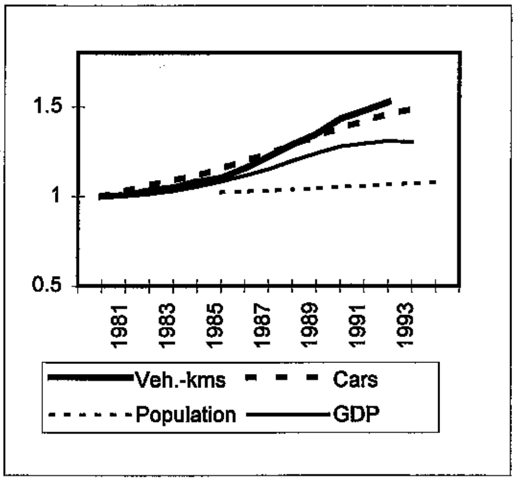


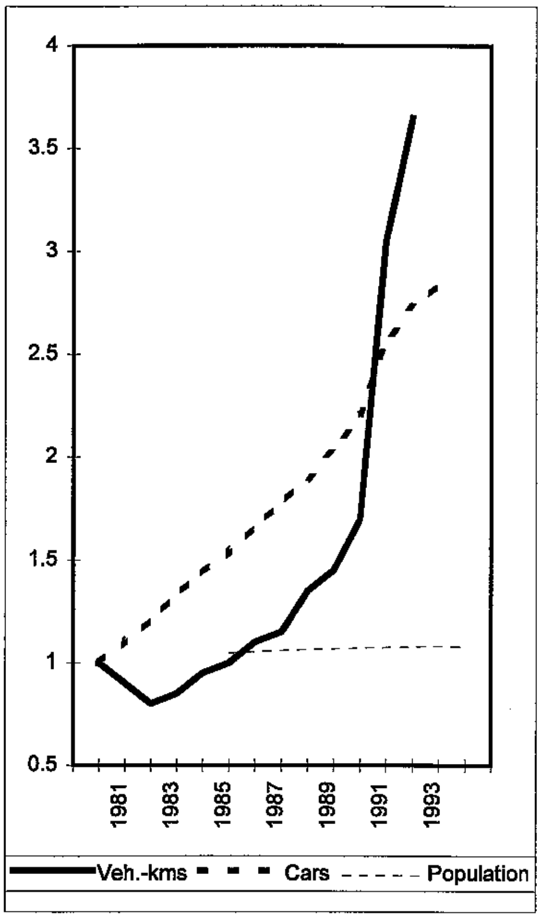
Figure 7. Population, GDP, car stock and traffic volume trends in the UK, Poland and European OECD countries (1980 = 1). Source: data form [OECD 1995a].



UK



OECD-Europe



Poland

Figure 8. Simplified structure of a transport sustainability model.

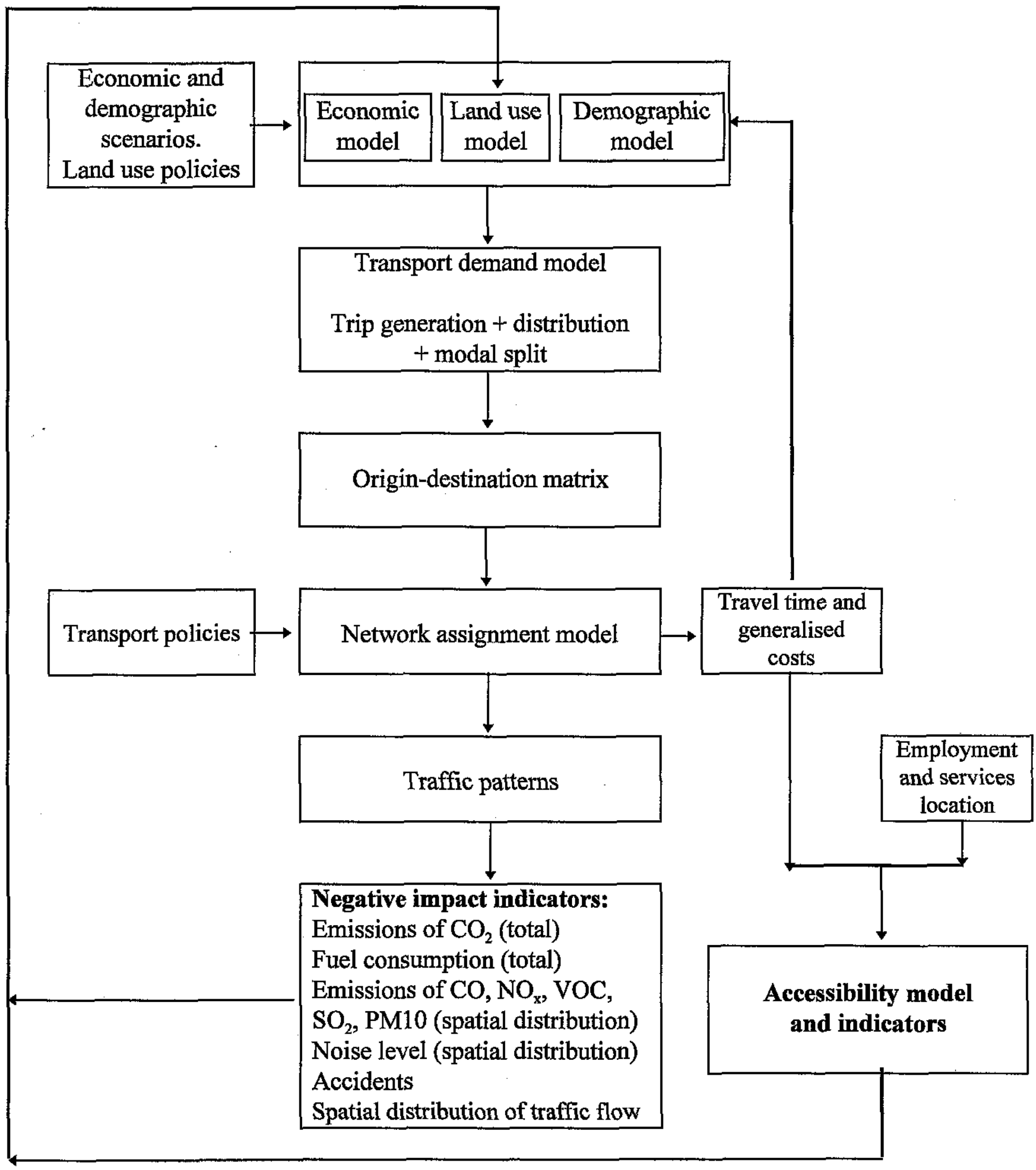


Figure 9. Modelling land use - transport - environment interactions.

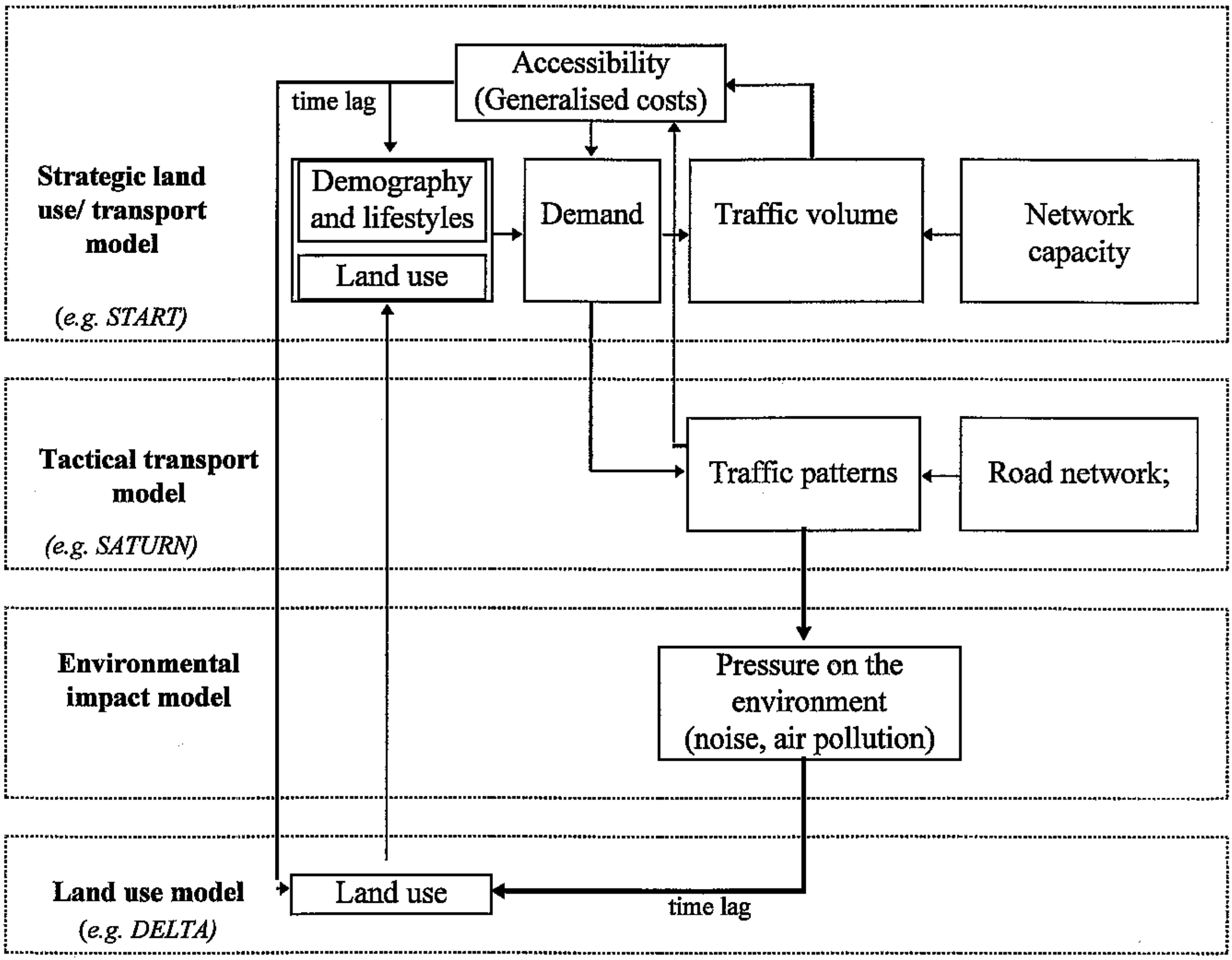


Figure 10. Modelling traffic and stationary sources -air quality - population exposure to pollutants.