Environment: The third dimension of the land-use transport interaction.

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Abstract:

The role of road transport in our society is coming under increasing scrutiny as the issues of economics, the environment and social impacts become more prevalent. With traditional attitudes towards land-use and transport planning being challenged, there is a need to also address the environmental impacts of road traffic at all levels. Much debate has occurred over the interaction between land-use and transport for several decades. However, only more recently, has the role of the environment been recognised as an essential component of land use/transport planning

This paper outlines some of the interactions and relationships between traffic/transport systems, land-use and environmental amenity leading to a detailed discussion of a PC-based environmental impact assessment system. The system consists of a *traffic network model*, a *vehicle energy and emissions (noise and air) model*, a *pollutant dispersion model* and a *land-use impact model*. The *vehicle energy and emissions model* estimates the energy used; and the levels of noise and air pollution generated from traffic streams. These traffic streams are a function of traffic flow, travel conditions, vehicle type and fuel type.

The assessment system will allow the user to predict and assess the environmental impact of road traffic, transport infrastructure and travel demand management schemes. The system has the ability to detect relative differences in levels of pollution and energy use between alternative schemes, while the schemes are still in the planning stage. Considerable community benefits will result from the use of a method whereby route and facility location decisions can be made with full knowledge of the possible impacts.

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1. INTRODUCTION

Proposals for transport reform have considered a relationship between land use and transport for about three decades, however the environmental aspects have often been neglected or misunderstood. There is a need to assess the environmental impacts of road traffic within the context of social, economical and environmental considerations. Such considerations must incorporate an understanding of the way in which the environment interacts with transport and land use.

This need was recognised in 1963 with the release of Traffic in Towns (UK-MoT, 1963). This publication acknowledged that transport considerations were not just confined to producing roads that could handle travel demand and facilitate the individual's freedom to use a motor car. Elements such as land use, convenience, history and culture, architecture, variety of choice and environmental amenity all contributed to making towns *worth living in*.

An increasing awareness of the interaction between environmental, economical and social aspects has led transportation professionals to reconsider the trade-offs necessary for balanced transport reform. Table 1 summarises some of the issues which are the result of the failure of current transport policies to achieve the appropriate trade-offs.

Table 1 Problems to be addressed by transport reform

ENVIRONMENTAL	ECONOMICAL	SOCIAL
▫ Increased greenhouse gas emissions ▫ Traffic problems such as noise and severance ▫ Greater stormwater runoff ▫ Depletion of oil resources ▫ Photochemical smog	▫ Congestion costs ▫ High infrastructure costs ▫ Loss of productive rural land ▫ Loss of urban land to roadways	▫ Loss of street life ▫ Loss of community ▫ Loss of public safety ▫ Isolation for people without automobiles

Source: Newman (1993)

There is a need to assess the environmental impacts of road traffic within the context of social, economical and environmental considerations. These considerations must incorporate an understanding of the way in which the environment interacts with transport and land use. The importance of the environment in transport proposals is highlighted by a discussion of the adverse impacts of road traffic, followed by a detailed description of the relationships between transport, land use and the environment. The significance of environmental impacts of road traffic and the involvement of the environment in the land use-transport system emphasises the need for a procedure to predict and assess these impacts for transport proposals. Such a procedure provides the main focus of the latter half of this paper.

2. IMPORTANT ELEMENTS OF ENVIRONMENTAL IMPACTS

Road traffic in urban areas is responsible for a long list of environmental impacts. This list has increased as the general public and transportation professionals have become more aware of the magnitude and the extent of these impacts. Brown and Lam (1994) estimates that 25% of all Australian dwellings are likely to have their amenity reduced by road traffic. This section focuses mainly on the environmental impacts of road traffic due to noise and air pollution, with some mention made of other effects.

Noise and vibration

Road traffic is the major source of *noise* in the urban environment. In the London Noise Survey 60-70% of noise was attributable to road traffic (Hothersall and Salter, 1977). The effects of noise can be classified into the three broad categories of health effects, activity effects and annoyance.

Health effects include long term hearing loss and stress induced symptoms such as high blood pressure, increased heart beat and breathing rates. *Activity effects* involve disturbance of sleep and communication, and a lowering of concentration and efficiency levels. *Annoyance* is based on the individual's perception of the noise and may be influenced by factors such as the individual's surroundings or social background.

Vibration is directly attributable to the interaction of heavy vehicles with irregularities in the road surface. The effects of vibrations due to road traffic include human annoyance and damage to buildings.

Air quality

Air pollution from road traffic affects the environment in different ways at three distinct levels; locally, regionally and globally. The pollutants which affect the *local* environment include particulate matter, lead (Pb), carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and sulphur dioxide (SO_2). At the *regional* scale the main contributors to air pollution are hydrocarbons (HC), nitrogen oxides (NOx) and ozone (O_3). The pollutants which affect the *global* environment are greenhouse gases, mainly carbon dioxide (CO_2).

Of these eight air pollutants the major transport-related pollutants are carbon monoxide, hydrocarbons, nitrogen oxides, ozone, lead and carbon dioxide. A brief description of each one is given below, with some of their effects on the environment and personal health.

1. *Carbon monoxide* is a colourless, odourless gas. It is the result of the incomplete combustion of organic fuels such as petrol and diesel. CO affects human health by reducing the ability of blood to carry oxygen, and it can aggravate cardiovascular diseases and may impair psychomotor functions. At high concentrations, CO can be fatal to mammals.

2. *Hydrocarbons* are compounds of carbon and hydrogen. HCs are involved in chemical reactions in the atmosphere that produce nitrogen dioxide and ozone and therefore are often referred to as 'reactive hydrocarbons'. Methane which is one the most common HCs does not participate in these chemical reactions and hence air quality studies often refer to 'nonmethane hydrocarbons'. HCs are not directly harmful to human health at the concentrations usually found in urban air.

3. *Nitrogen oxides* is a general term given to gas consisting mainly of nitric oxide (NO) and nitrogen dioxide (NO_2) with some NO_3, N_2O_3 and N_2O_4. NO_2 is a brownish gas with a pungent odour and is responsible for the brownish colour of the sky in smoggy areas. NO_2 is mainly a secondary pollutant caused by oxidation of nitric oxide (NO), which is a product of the combustion of fossil-fuels. NO_2 is a pulmonary irritant which increases susceptibility to acute respiratory diseases. NOx reacts chemically in the atmosphere to form nitrous and nitric acid, nitrate salts and organic compounds of nitrogen, thus contributing to acid rain.

4. *Ozone* is a colourless gas with a pungent odour. It is a secondary pollutant formed by photochemical reactions involving HC and NOx. O_3 is one of the constituents of photochemical *smog* (along with NO, NO_2 and other organic and inorganic compounds). O_3 and NOx are the principal and best-understood smog constituents. O_3 is a pulmonary irritant which causes discomfort, clinical symptoms of respiratory illness and reduced pulmonary function in sensitive individuals.

5. *Lead* is a heavy metal that is poisonous to humans. The main source of atmospheric lead is the combustion of fuels containing lead antiknock compounds. The introduction of unleaded petrol and the reduction of the lead content in leaded petrol has helped to reduce the problems caused by this pollutant. Pb causes damage to the nervous system and kidneys and it has been shown to reduce IQ levels in children by as much as 15 points.

6. *Carbon dioxide* is a natural gas, exhaled by mammals and absorbed by plant life. Recently, however it has been classed as a pollutant due to its involvement in the so-called greenhouse effect. CO_2 has been given the status of the major greenhouse gas and hence is principally responsible for global warming. CO_2 is an unavoidable product of the combustion of fossil fuels and is directly proportional to (non-renewable) energy use.

Transportation is largely responsible for much of the CO, HC, NOx and Pb emissions in most developed countries. Targeting the transport sector is a pragmatic means of reducing the concentrations of these air pollutants in our environment, and hence reducing their adverse effects on health. Table 2 shows the estimated proportion of emissions due to motor vehicles in some of Australia's capital cities in 1985 (Source: Australian Environment Council, 1988).

The proportion of lead emissions from motor vehicles is expected to have decreased substantially since this emission inventory was developed, due to the introduction of unleaded petrol in 1986. As well as the introduction of unleaded petrol, the lead content in leaded (super grade) petrol has also been reduced significantly.

Table 2 **CO, HC, NOx and Pb emissions from motor vehicles**

Emission	Proportion of Emissions Due to Motor Vehicles (1985)			
Type	Adelaide	Melbourne	Sydney	Perth
CO	82%	86%	87%	86%
HC	41%	41%	45%	48%
NOx	58%	76%	80%	67%
Pb*	89%	87%	87%	93%

*Proportion of Pb emissions from on-road petrol engines

Visual intrusion and severance

Traffic and roads may be *visually intrusive* in many ways. Parked cars, moving traffic, street furniture and road structures are all disliked to varying degrees by people. Due to the highly subjective nature of visual intrusion, measurement techniques have been difficult to develop. Methods which have found use include the Bowers formula (OECD, 1975) and the Hopkinson method (Hothersall and Salter, 1977). Roads may also cause *severance* by physically limiting the access that individuals and communities have to desired activities in other locations.

3. CAUSE ⇨ EFFECT RELATIONSHIPS BETWEEN TRANSPORT, LAND USE AND THE ENVIRONMENT

In order to achieve, or move in the direction of, sustainable urban transportation it is essential that the interactions and relationships between transport, land use and the environment are clearly understood. An understanding of the forces influencing this system is a prerequisite of the ability to model these interactions and relationships and/or to predict the effect on the system due to a change in one or more of its components.

Table 3 below summarises the cause-effect relationships between transport, land use and the environment that are described in detail in the remainder of this section. The table should be read by considering a change in one of the components in the left column and the *effect* that it *causes* on one of the components in the top row.

The terms used in Table 3 need clarification. A distinction is made between traffic and the transport system. *Traffic* refers to road traffic activity which is described in terms of *volume* (flow), *speed* (instantaneous/average speeds for individual vehicles/traffic streams) and *composition* (proportion of each vehicle/fuel type). The term *traffic* also encompasses aspects of attraction and generation rates and travel behaviour (number of trips, trip length, mode choice etc.) The *transport system* represents the physical transport infrastructure (road network and public transport systems) and its operation.

Land use characteristics include land use *type* (residential, industrial etc.), land use *density* (residences per hectare or persons per hectare) and population *demographics* (age, income levels etc.).

Environmental amenity is the quality of the environment and is measured in terms of a number of factors including *noise* levels, concentrations of *air pollutants* and degree of *visual intrusion*.

Table 3 Summary of traffic/transport system-land use-environment relationships

EFFECT ⇨ **CAUSE ⇩**	**TRAFFIC/ TRANSPORT SYSTEM**	**LAND USE**	**ENVIRONMENTAL AMENITY**
TRAFFIC/ TRANSPORT SYSTEM		Existing traffic may influence characteristics of new developments Characteristics of transport system (physical or operational) may cause a change in land use type, density and/or population demographics	Increases in traffic *volume* will generally cause a decrease in environmental amenity (visual intrusion, safety, noise, air quality etc.) Decreases in *average* traffic *speed* generally give increased energy use and air pollution levels Traffic *composition* also affects energy use, air quality and noise levels
LAND USE	Changes in land use type, density and/or demographics affect traffic attraction and generation rates and travel behaviour		Regional land use distribution and density; and local land use mix and density influence travel characteristics and hence affect environmental amenity
ENVIRONMENTAL AMENITY	Extreme air pollution levels may affect driver behaviour (e.g. as a result of reduced visibility)	Decreased environmental amenity may cause a change in land use type, density and/or demographics	

It is worth emphasising here that the perceptions of a change in environmental amenity are often affected by the nature of the change, not only in terms of *magnitude* but also in terms of the *time* over which that change takes place. This is because people have the ability to adjust or adapt to changes more readily if the change is gradual. In fact a change in environmental amenity which is gradual may take place without those associated with the land use recognising the change. Brown and Law (1976) found that often people do not recognise that a pollution problem exists until someone from outside the area (e.g. a visitor) highlights the problem.

Traffic/transport system ⇨ land use

Although it is generally accepted that changes to a transport system can influence land use patterns, the nature of its influence is not well understood. Ker (1991, p35) commented that "we are very good at establishing the transport consequences of particular patterns of development .... We are not very good at translating transport characteristics into estimated impacts on land use...." In contrast, Brindle (1992, p117) points out that some authors believe "that transport influences not only the broad shape of urbanisation (urban form) but can also affect urban structure *at the detailed scale* in such characteristics as density, mix of uses and quality of the environment." Brindle himself draws the conclusion that "transport rarely, in itself, causes a predictable and significant change in urban development - certainly not to the extent that we could rely on it as a policy tool."

It is not a purpose of this paper to shed any new light on this subject. However, there is no doubt that land use affects travel behaviour, and there is some evidence that transport systems are at least partly responsible for land use patterns (Newman and Kenworthy, 1989). Hence, to achieve effective and sustainable transport systems and urban centres, land use development must occur in harmony with transport planning. Further research is required before policies and procedures are developed which will ensure such harmony.

Traffic activity or traffic conditions can *indirectly* influence *existing land use* characteristics as a result of the change in environmental amenity (usually a reduction) caused by road traffic. However new land use development adjacent to an *existing road corridor* (or road network) may well be *directly* influenced by the traffic activity or traffic conditions on that corridor or network. For example, consider a situation where land is made available for development along a high volume arterial road. If a residential area was developed it would (or at least should) exhibit certain characteristics which reflect attempts to ameliorate the adverse impacts associated with a road of this sort. Such characteristics may include a wide verge between the road and the adjacent property boundaries, provision of a service road for access and planting of foliage on the verge of the road (to lessen the impact of visual intrusion and noise).

Traffic/transport system ⇨ environmental amenity

A change in one or more of the descriptive traffic parameters will affect the level of environmental amenity in a local area. Traffic activity and traffic conditions directly affect the amount of energy used, the air pollutants emitted, the noise generated and the degree of visual intrusion resulting from the operation of a road transport system.

Without any outside influence to ameliorate the impact, an increase in the *volume* or flow of road traffic will result in a corresponding decrease in environmental amenity for the adjacent land use. The air pollution rate of a single vehicle can be described in terms of the mass of pollutant emitted per distance travelled (g/km). Hence for a fixed length of road the air pollution generated by a traffic stream is directly proportional to the number of vehicles in the traffic stream (i.e. the volume of traffic). Similarly for energy use which is usually described in terms of the volume of fuel consumed per distance travelled (mL/km). The degree of visual intrusion is also directly affected by traffic volume. The noise generated by a traffic stream will increase with volume up to a threshold value. Traffic may produce levels of noise that are annoying to people at a certain volume but once this volume has been reached, further increases in volume are unlikely to have much impact on perceived loudness. Due to the logarithmic nature of noise, a doubling of noise level would require a tenfold increase in traffic volumes. This logarithmic relationship limits the amount to which amelioration measures can significantly reduce noise levels and highlights the importance of controlling noise at its source.

Energy use, air pollution and noise are all directly affected by traffic *speed*. Under steady speed conditions these three all increase with speed. However, although overall air pollution increases with speed some individual pollutants behave differently (e.g. NOx). Noise levels fluctuate due to the pass-by of individual vehicles. For interrupted flow, energy use and overall air pollution generally increase as average link (or trip) speed decreases. Some pollutants have an optimum speed range, either side of which the pollutant rate increases. There is evidence to suggest that noise from interrupted flow conditions, although not necessarily louder, is more annoying than for free flow conditions (Samuels, 1990). Vehicles in such conditions usually have lower speeds than free flowing traffic and the noise generated is intermittent due to the deceleration and acceleration of vehicles.

Traffic *composition* affects environmental amenity because different vehicle types have different characteristics in terms of the amount of noise they make, the energy they consume, the air pollution they generate and the degree of visual intrusion for which they are responsible. In general commercial vehicles (heavy vehicles) make more noise, consume more fuel, generate more air pollutants and are more visually intruding (because of their size) than passenger vehicles. Another characteristic of traffic composition is fuel type. Changes in composition in terms of fuel type will affect energy consumption and air pollution, as different fuels have different values of energy per volume and produce different proportions of pollutants in the combustion process.

Land use ⇨ traffic/transport system

The characteristics of land use can affect traffic activity and the transport system. Traffic activity is a function of trip generation and attraction rates, which are affected by land use density, type and population demographics. For example, a high density, inner-city residential area will *generate* more traffic in the morning peak and *attract* more traffic in the evening peak than a low density outer suburb of the same size. The main influence of land use type on traffic activity is the way in which trips are distributed over time. Population demographics (in terms of age, income level, car ownership etc.) determine the degree of mobility of residents. For example, mobility for young children is often restricted to that provided by their parents.

Land use characteristics can influence the demand for and the operation of transport systems. For example, public transport systems become more feasible as land use density increases. This in turn may cause a reduction in traffic activity on the road network brought about by a shift in mode choice, if the public transport system is made convenient and financially attractive.

Land use ⇨ environmental amenity

Land use characteristics, such as land use mix and density, influence travel behaviour (in terms of trip length, number of trips etc.) and hence environmental amenity. Each of these relationships have been described previously.

Environmental amenity ⇨ traffic/transport system

The environment can modify traffic activity by altering driver behaviour in a traffic stream. An example of this relationship is where extreme air pollution levels result in reduced visibility for road users. This air pollution may be on a regional scale such as photochemical smog or a localised incident such as a smoky vehicle which causes other vehicles to take evasive action to avoid the fumes.

Environmental amenity ⇨ land use

The type and density of *existing land use* is unlikely to be substantially affected by changes in environmental amenity, at least in the short term. However, if the magnitude of a change in environmental amenity is large and the period over which that change takes place is short, the land use type and/or density may be affected. For example, if a collector road with low traffic flow and sensitive adjacent land use was reconstructed as a major traffic corridor, the *increase in noise levels and air pollution* is quite likely to induce sensitive land uses to relocate, hence changing the characteristics of land use type. Such a scenario could also take place in the longer term as steady traffic growth leads to reduced environmental amenity.

Population demographics of land use are more likely to be influenced by changes in environmental amenity, and changes in demographics may take place in the short to medium term. A change in demographic characteristics may occur when a decrease in environmental amenity leads to the devaluation of residential properties. Residents with high income levels may sell their properties and move before property values fall to unacceptable levels. Having a high income level may also give them more freedom to move in order to improve their environment. Hence the demographic characteristics of the residential area will change in terms of average income level.

4. AN ENVIRONMENTAL IMPACT ASSESSMENT SYSTEM FOR TRANSPORT PLANNING

The community at large has realised that, not only does road traffic cause problems of congestion, safety and visual intrusion, it is also responsible for a high proportion of the environmental degradation in urban areas due to air pollution and noise.

What transportation professionals need are tools and procedures that will assist them to consider the social and environmental impacts of their transport systems, and to examine how they can best manage a transport system to ameliorate any adverse impacts in the early stages of planning. It has been demonstrated that the environmental impacts of a planned road network, due to air and noise pollution, can be explicitly included in travel demand modelling and network planning (Brown and Patterson, 1990). Such a capability would allow route and facility location decisions to be made with full knowledge of the environmental consequences.

The Transport Systems Centre at the University of South Australia, in collaboration with Griffith University, is developing a computer-based method for the formal assessment of the impact of road traffic systems. This method (Impact Model for the Prediction and Assessment of the Environmental Consequences of Traffic: IMPAECT) consists of a set of four PC-based computer models that are linked through a common data structure and make extensive use of interactive graphics displays. These models include a traffic network model, a vehicle energy and emissions (air and noise) model, a pollutant dispersion model and a land use impact model, as shown in Figure 1.

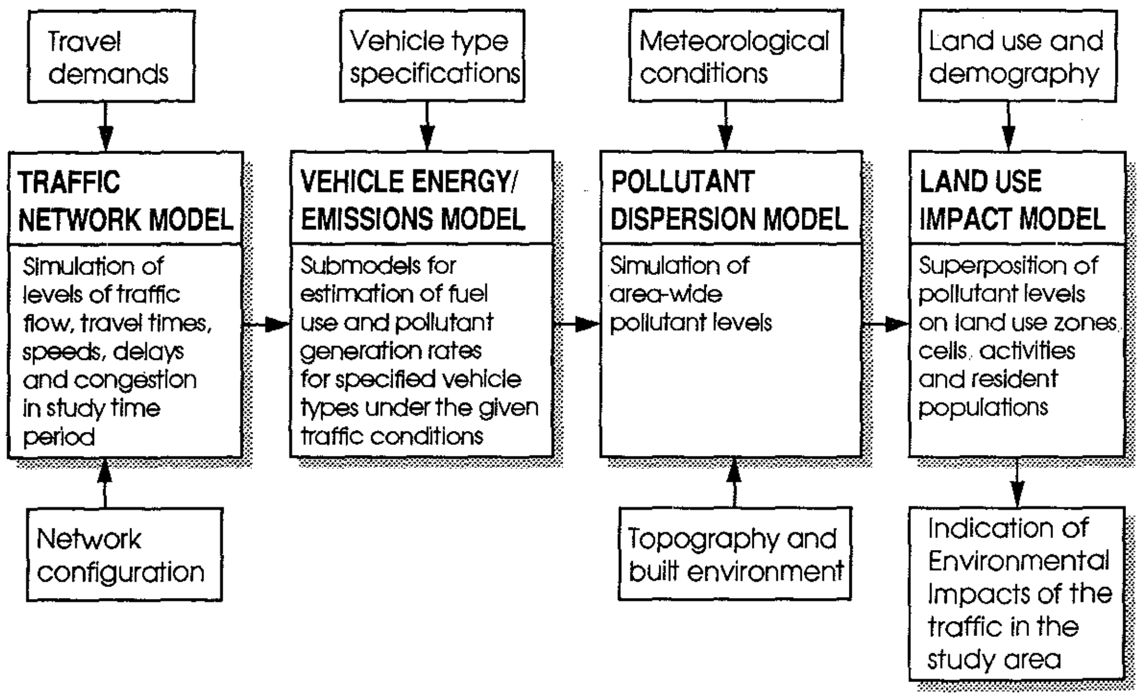

Figure 1 **Schematic of the impact model for the prediction and assessment of the environmental consequences of traffic (IMPAECT)**

The application of the modelling system to environmental impact assessment is based on the premise that although the absolute levels of pollution may be affected by many other factors besides those included in the component models, the system can reasonably detect relative differences in levels of pollution between alternative transport schemes.

Traffic Network Model

Once the details of the traffic management scheme have been entered, the Traffic Network Model is used to produce (by simulation and forecasting) the levels of traffic flow and travel conditions (in terms of travel time, delays, queuing and congestion) on a study area network under the given traffic management scheme. Such traffic network models usually incorporate a variation of the 4-step modelling procedure of trip generation, trip distribution, mode choice and trip assignment. An example of a traffic network model that can be used in this impact assessment procedure is TrafikPlan (formerly MULATM).

Energy and Emissions Modelling in Traffic Streams (EEMITS)

The output from the Traffic Network Model is used as input for the EEMITS module (Energy and Emissions Modelling in Traffic Streams) along with vehicle parameters for a range of vehicle types. This module also requires information about the composition of the traffic on each link in the network, in terms of vehicle type and fuel type. The EEMITS module consists of two components: NetNoise and the vehicle energy use and air emissions model which are described in detail in the following two sections.

Noise emission generation and dispersion model (NetNoise)

NetNoise, which performs both noise emission generation and dispersion, is designed for operation at the network scale. Calculations are based on the United Kingdom Department of Transport's *Calculation of Road Traffic Noise* (UK-DoT, 1988). Although the model was developed using data collected throughout the United Kingdom, it has found widespread acceptance within Australia (Saunders et al., 1983).

NetNoise calculates noise emissions in dB(A) in terms of L_{eq}, L_{10} (18 hour) or L_{10} (1 hour) indices for each link in the network. Brown (1980) found that these indices correlated well with community annoyance. The spatial distribution of noise levels is determined across a network area at predefined receptor points.

The model has been implemented in the NetNoise program and utilises inputs and outputs in varying formats. Input can be in the form of TrafikPlan output data files, ASCII text files, MS ACCESS database format, and ARC/INFO and MapInfo geographic information systems. Output files can also be produced for the last four sources listed.

Data is organised into link-based groups in which both geometric and traffic attributes are stored. Basic traffic variables include volume, average speed and proportion of heavy vehicles. The proportion of heavy vehicles may be determined from commercial vehicle counts, AUSTROADS classification surveys (12 classes) or Australian Bureau of Statistics (ABS) data. In each case the classes that can be considered as consisting of heavy vehicles can be altered for calculations. The ABS data is not applied on a link by link basis but to the census collection areas for which the data was collected. Hence statewide statistics are applied over the entire road network whereas data covering a postcode area may be applied over part of the road network.

Other attributes that can be utilised include average positive link gradient; road surface type and texture depth; speed limits; and noise barrier details such as offset from link, side of link and height. NetNoise can apply either CoRTN or Samuels road surface corrections for road surfaces ranging from open graded asphaltic concrete to Portland Cement concrete pavements.

Traffic flow data can be accepted as 1 hour peak counts, 11 and 12 hour turning counts, 18 hour noise counts and 24 hour traffic counts. Conversions are made using typical relationships with annual average daily traffic (AADT) data and there is scope for the inclusion of user defined conversions and count data. Also taken into account is whether the majority of the network traffic conditions are congested, uncongested or rural.

The model accounts for the facade effect and positive road gradients and can apply user defined and Australian Road Research Board (ARRB) corrections (Saunders et al., 1983) to the final noise level if necessary.

Other additional capabilities of the model include a Radius of Influence: the range from which noise on surrounding links contributes to the noise level at a receptor point. The ability to alter the Radius of Influence and incorporate noise barriers allows the user to gain a concept of how the noise is influencing the environment within the network. A further limited capability is given in the form of average absorbent ground where the amount of absorbent ground between the roads and the impact areas for the network is estimated and accounted for in calculations.

Vehicle Energy Use and Air Emissions Model

The vehicle energy use and air emissions model estimates energy use and the air pollution generated by the traffic system under the modelled traffic conditions. The predicted energy use is given as an average fuel consumption rate in mL/km which can be converted to litres of fuel consumed for each link. The air pollution generated is specified as an average emission rate in g/km.

The fuel consumption and air emissions models incorporated in this system are based on the results of research carried out at ARRB (e.g. Bowyer et al., 1985). This work resulted in a family of four interrelated fuel consumption models. The four models cover four levels of detail and in increasing order of aggregation are:

(a) an energy-related instantaneous model;
(b) a four-mode elemental model;
(c) a running speed model;
(d) an average travel speed model.

These models are all of the *nondeterministic* or *lumped parameter* type of fuel consumption models. The detailed vehicle parameters such as engine performance characteristics, rolling resistance and aerodynamic drag are combined to obtain coefficients for relatively simple regression equations. Knowing these coefficients, predictions of fuel consumption and emissions can be made in terms of speed, acceleration and positive kinetic energy changes. This fact makes such models very useful to traffic engineers and transport planners, as the models can be readily incorporated in a range of traffic models that determine traffic volumes and speed profiles for a road network.

Each model can be used to predict the fuel consumption and air emissions of *individual* vehicles, given vehicle parameters, speed profile information and road geometry data. Given model parameters for a range of vehicle types and fuel types, and the composition of such vehicle types and fuel types for traffic on a road, allows the prediction of energy use and air emissions for a *traffic stream*.

The model parameters for a vehicle are determined by detailed analysis of a large set of speed profile and fuel consumption/emissions data. The speed profile and fuel consumption data can be collected on a chassis dynamometer or by on-road experiments. For the speed profile and exhaust emissions data a chassis dynamometer is usually necessary. In this research the focus has been on on-road data collection with an *instrumented vehicle*. The first vehicle was a 1991 Toyota Camry sedan with a 2.0L, 4-cylinder, fuel-injected engine and a 4-speed automatic transmission. The vehicle was purchased by the University and installed with the Fuel Consumption and Travel Time Data Acquisition System (FCTTDAS) developed by ARRB. This system measures speed, distance and fuel consumption on a time basis (e.g. every second) and the data is logged by software that runs on a portable computer. The Camry was used to collect data for over 1200 km of urban driving and 300 km of controlled-test driving, before being traded in on a 1993 Ford Falcon wagon. This vehicle has a 4.0L, 6-cylinder, fuel-injected engine with a 4-speed automatic transmission and has also been fitted with the FCTTDAS.

Fuel consumption model parameters have been developed for the Camry and data is being collected and analysed to obtain parameters for the Falcon. Emissions data for the Camry was collected on a chassis dynamometer at the Vehicle Testing Station of the Environment Protection Authority, Victoria. Parameters have also been obtained for a number of other vehicles from testing carried out by other researchers.

The instrumented vehicles have not only provided fuel consumption data but have also given a large set of extremely useful speed profile data, travel time data, data for average link speeds and percent stopped time data.

Fuel consumption and air emissions models for traffic streams require information about the composition of vehicles in terms of vehicle type and fuel type. Where the composition of the traffic is not known, assumptions must be made about the proportion of each vehicle type/fuel type. Data from the Australian Motor Vehicle Census and the Survey of Motor Vehicle Use, conducted every three years by the ABS, has been used to draw conclusions about the *characteristics* and *dynamics* of the Australian/South Australian vehicle fleet.

Pollutant Dispersion Model

The third stage of the IMPAECT system is the Pollutant Dispersion Model, POLDIF. This model uses information from the EEMITS module coupled with data on meteorological conditions, topography and the built environment. Gaussian dispersion is used to estimate the spread of the air pollution over the study area. NetNoise uses the CoRTN procedure which *generates and disperses* noise from the road network. The spatial distribution is represented by pollution levels given for a set of grid points over the study area. Pollution from each link in the network is accumulated to give the pollutant load on the study area.

Land Use Impact Model

The final component of the four stage environmental impact assessment package is the Land Use Impact Model which superimposes the calculated pollution levels on land use zones, activities and resident populations in the study area. This model is being developed by Lex Brown and his team at Griffith University.

The model will provide a database of *acceptable limits* of noise pollution and each of the air pollutants. These limits will be based on the land use characteristics which include type of land use (residential, commercial, industrial and recreational); density of land use (e.g. residences per hectare); setback of buildings from carriageway and location of sensitive land uses (e.g. schools, hospitals, retirement villages).

The four-stage IMPAECT system can be applied within the framework of the procedure portrayed in Figure 2. This figure represents a 'technical procedure' to be used as a decision support tool within a community decision making process. This 'procedure' provides for fine-tuning of a traffic management scheme so that environmental impact objectives may be met in terms of specified criteria.

These criteria consist of noise and air pollution *limits* that are compared with the pollution *levels* predicted by the emissions model. A Geographical Information System (GIS) will be used for this comparison process. A GIS has the ability to display all kinds of spatial data and the problem of pollution impacts on land use has a clearly spatial context. A GIS can also superimpose a number of layers that show different information. Each layer contains its own unique set of point, line and area objects with appropriate attributes associated with them.

For the environmental impacts modelling system the data necessary to assess the impacts of the pollution on the land use would be associated with objects in three main layer types as shown below.

1. *a traffic network layer* with road link and node objects;
2. *a land use layer* with areas of land use type;
3. *pollution level layers* with the pollution levels calculated at grid points as discussed previously. There would be at least 5 layers; one for each air pollutant (CO, CO_2, HC, NO_x) and one for noise levels. From the pollution levels at the grid points, the

GIS could be used to provide visual information regarding the spatial distribution of the pollutants through the use of contours and coloured bands. This allows a rapid assessment to be made of the areas of land use with the highest pollution levels. Population attributes associated with the land use layer will allow the GIS to be used to provide data on the numbers of people adversely affected by the noise or air pollution.

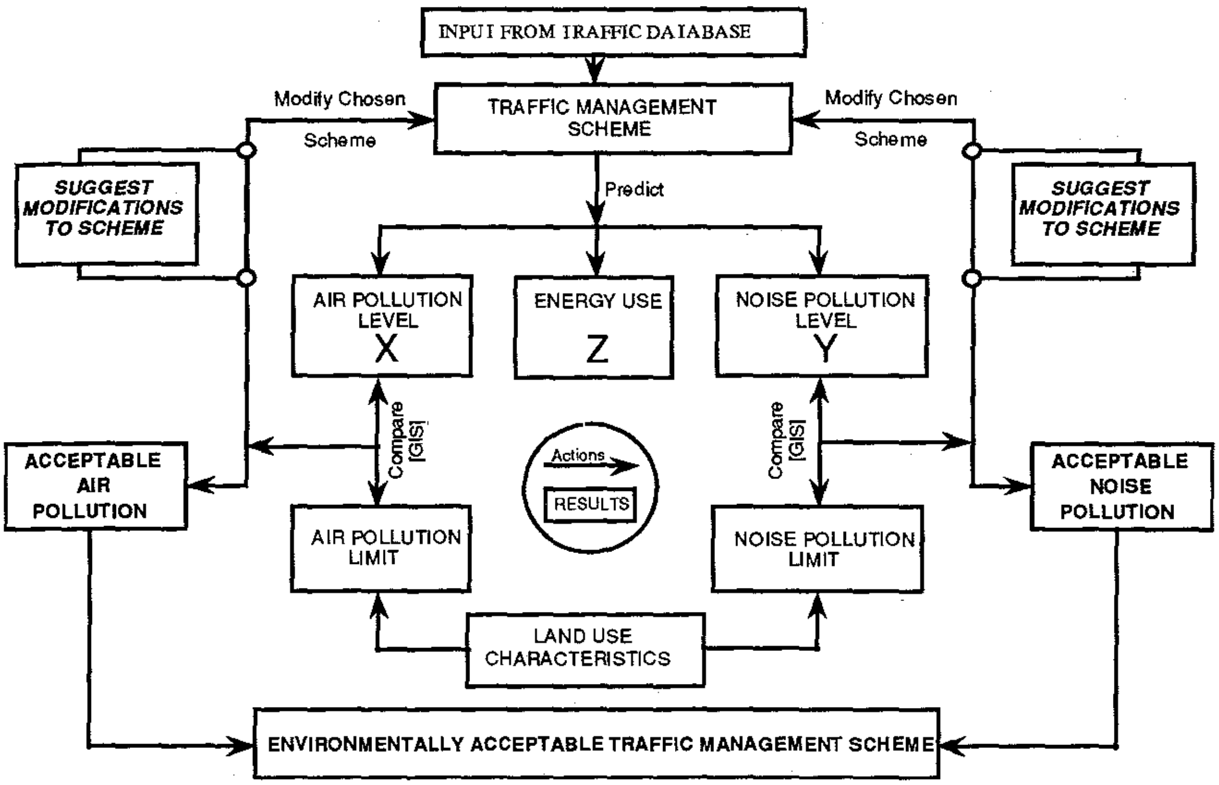

Figure 2 Schematic of environmental impact prediction and assessment procedure

Once the comparison of the pollution levels with the pollution limits is complete, a conclusion can be made regarding whether the criteria for air and noise pollution are met. If not, it will be necessary for the transport planner or traffic engineer to modify the scheme in such a way as to reduce the air and/or noise pollution to acceptable levels. This may involve reducing vehicle speeds and/or volumes etc., or applying some mitigation measures such as noise barriers.

Provision for feedback

It is of limited use for the system to simply reveal that a proposed traffic management scheme does not satisfy the environmental criteria. To *aid* the decision making process, the user would like to know:

- whether the adverse impacts are due to noise pollution, air pollution, energy use or any combination of these;
- what areas are adversely affected;
- the size and characteristics of the population adversely affected within those areas;
- the magnitude of the impact for each area that is adversely affected (e.g. how many dB(A) the noise level is over the limit);
- whether there are any obvious reasons why certain areas fail the environmental criteria, and if so, what they are (e.g. high speeds, volumes or commercial vehicle content, high-density or sensitive land uses, inadequate setback of buildings etc...).

Such advice could be provided within the framework of an Expert System. It should be made clear however, that advice from such a system should only be used to *aid* the decision making process; it should not be used as the sole basis of the decisions themselves. If a traffic management scheme was 'blindly' modified, this may well result in simply transferring the problem elsewhere in the road network. A decision support tool such as IMPAECT can help guard against problem migration of this sort

5. CONCLUSION

The importance of the environment in land use and transport planning processes has been investigated by this paper. The goal of sustainable urban transportation necessitates an understanding of the relationships between land use, transport and the environment. There is a deficiency in the ability of existing transport planning models to describe both the effect of traffic/transport systems on the environment and the consequent impact of reduced environmental amenity on land use.

The IMPAECT procedure outlined in this paper has the ability to predict and assess the environmental impacts of road traffic, thus enabling the potential environmental problems of a proposed transport system to be foreseen in the planning stages of a project. This avoids the need for costly remedial treatment and aids the quest for environmental amenity and sustainability.

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