Modelling the Land Use - Transport - Environment Interaction

Occasional Paper

This Paper briefly describes the LAND computer package and outlines studies to verify and apply it. The LAND computer package is an educational tool. It aims to replicate the land use/transport/environment interaction so as to allow the investigation of the long-term impacts of transport and land use policy on the environment. The model is based on a series of discrete steps.These steps relate to natural changes in population, migration of people within the city, movement of employment, creation of transport demand and assignment of this demand to the transport system. The environmental outputs are based on the traffic flows. Exogenous inputs into the model are the supply of urban infrastructure (housing and transport), increase in employment and in- or out-migration.

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Modelling the land use–transport–environment interaction

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FOREWORD

The LAND computer package is being developed by Associate Professor William Young and Mr Kevin Gu at Monash University to assist in the education of students and the community in the complexities of the land use–transport–environment system.

This paper represents the completion of a study, into the application of LAND, undertaken for the Bureau of Transport and Communications Economics (BTCE) between November 1992 and July 1993.

Dr Young's work at the BTCE builds on earlier research carried out for the Department of Arts, Sports, the Environment and Territories (DASET) and the Victorian Government Greenhouse Unit. The study was funded by the BTCE through a Research Fellowship to Dr Young. Mr Gu, a research student in the Department of Civil Engineering, Monash University funded by scholarships from the Australian Road Research Board and the Greenhouse Unit, worked in conjunction with Dr Young in improving and applying the LAND package. The BTCE also provided funds to Mr Gu to carry out a verification study of LAND for Adelaide.

Leo Dobes
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Canberra
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- The Department of Arts, Sports, the Environment and Territories (DASET) provided the initial funding for this project. Without this funding the project would not have been started. Geoff Anson, Strategic Transport Planning Department, VicRoads, provided the initial link with DASET, acted as the chief negotiator and provided useful input throughout the initial development of the program. Sophia Schyschow, The Greenhouse Unit, Victorian Department of Planning and Housing, assisted with the negotiations with DASET, and provided useful input throughout the development of the program. She also arranged for further funds to ensure the continuation of the development of LAND at Monash University.
- The Australian Bureau of Statistics (ABS) provided considerable assistance in collecting and providing the appropriate census data. Graeme Carter of the ABS provided considerable assistance in tracing and gathering the required data.

The authors would particularly like to thank Professor Michael Taylor, of the University of South Australia, for his assistance in programming and for access to the computing code of Monster Version 1.0. Monster formed the basis for development of the transport module in LAND and provided the data format for linking LAND with other models developed at Monash University.

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SUMMARY

Transport modellers have made considerable steps forward in the development of theory and the incorporation of this theory into computer models. Further, recent developments in computer software provide considerable potential for developing a user friendly, interactive, dynamic, easy to learn, and visually stimulating computer environment which will increase the community's acceptance of computer models. These developments need to be brought together. The report highlights attempts being made to make LAND, a transport–land use–environmental interaction model, as acceptable to the transport and general community as possible.

This report briefly describes the LAND computer package and outlines studies to verify and apply it.

The LAND computer package is an educational tool. It aims to replicate the land use–transport–environment interaction so as to allow the investigation of the long-term impacts of transport and land use policy on the environment. The model is based on a series of discrete steps. These steps relate to natural changes in population, migration of people within the city, movement of employment, creation of transport demand and assignment of this demand to the transport system. The environmental outputs are based on the traffic flows. Exogenous inputs into the model are the supply of urban infrastructure (housing and transport), increase in employment and in- or out-migration.

The model is built within the Microsoft Windows environment and is programmed using Visual Basic 2.0. Visual Basic provides easy access to flexible input procedures, the extended memory capabilities of recent PC's and multi-tasking facilities.

The study reported here involves the verification of the LAND model, using data describing Adelaide and Melbourne, over the period 1971 to 1991. The input data, the parameters of the LAND model and the simulation results, for Adelaide and Melbourne, are described. Comparisons have been made between the estimates from LAND and information derived from other sources. The comparison of the model, with data describing Adelaide and Melbourne, shows that the model is capable of replicating existing cities.

The study also investigated the use of the LAND package by students at the Australian Defence Force Academy (ADFA). The application of the package to a hypothetical city, similar in structure to Canberra, enabled the model's appropriateness for general use and sensitivity to network description to be ascertained. The application of the model to the hypothetical city showed that the package could be used by people other than the developers of the package.

Overall this study has shown that the LAND package can assist in investigating the interaction between land use, transport and the environment.

CHAPTER 1 INTRODUCTION

Transport, land use and the environment are interrelated. Changes in one will, in time, affect the other. The need to understand this relationship is increasing in importance as environmental problems increase and cities change. Further, the complexity of the interaction and the range of policy options that can be used to refine it require an understanding of the time scale and sensitivity of responses to policy changes. Understanding the interaction requires study and education. The project reported here aims to assist in the education process through the development of the land use, transport and environment interaction package: LAND.

The LAND package is an educational tool. It aims to assist students in gaining an understanding of the relationship between transport, land use and the environment. This report outlines the initial formulation, verification and application of the LAND land use–transport–environment interaction education tool. The study involved the application of the LAND package to Adelaide and Melbourne over the period 1971 to 1991, and the prediction of changes in a hypothetical city similar in size and layout to Canberra over the period 1981 to 2001.

The LAND package is in an early stage of development. In general, the development of a computer package consists of three distinct stages. These are:

- the determination of the main objectives of the package;
- the development of the package; and
- the testing of the package.

This report covers these aspects in seven chapters. The chapters are:

- Chapter 1 is the introduction.
- Chapter 2 presents the main objectives of the package. It provides a broad overview of the LAND package, its main philosophy and the programming environment selected for its development.

- Chapter 3 introduces the development of the land use–transport–environment simulation model in LAND. It does this by outlining the structure of the LAND model and its land use, transport and environment modules.
- Chapter 4 starts the discussion on the testing of the package. It presents the verification study carried out using data from Adelaide.
- Chapter 5 continues discussing the testing of the package by outlining the verification study carried out using data from Melbourne.
- Chapter 6 discusses the application of LAND to a hypothetical city similar in structure to Canberra.
- Chapter 7 concludes the report and comments on some directions for further research.

CHAPTER 2 THE LAND COMPUTER PACKAGE

Planning students' and the general community's understanding of the land use, transport and environment system is often guided by limited experience. The complexity of the system is, therefore, often not fully understood. The LAND computer package is being developed to assist in the education of students and the community in the complexities of the system.

The development of a high quality educational tool will allow access to transport models by more than just expert modellers. Politicians, managers, local pressure groups, university students, school children and many others will be able to investigate the impacts of transport strategies. To entice these people to use the models it is not only necessary to develop a high quality user interface, it is necessary to take a new view of models: the users view.

2.1 EDUCATIONAL TOOLS

Education tools like LAND aim to increase the level of understanding. Computer games are used by many people and could assist in providing users with an understanding of complex systems. For instance, children could build transport systems and assess how they perform. Concentration on public transport provision could be contrasted with the use of private transport networks. The games could assist the community to understand the different roles of these two transport modes.

Computer games have a number of requirements:

- a high standard of user interface;
- a challenge;
- an interactive environment;
- an acceptable level of user input; and
- entertainment.

As discussed above games must be attractive to the user. They require a minimum of input, a user friendly environment and a challenge. They can be educational or just plain fun. LAND is not a pure game, it is being developed to employ gaming concepts without loosing sight of its planning role and the flexibility to allow the user to develop a variety of planning scenarios. It is an educational tool.

2.2 THE LAND PROGRAM ENVIRONMENT

The LAND package is a computer game developed to educate students into the relationships present in the land use, transport and environmental interaction. It requires information on the private and public transport system, and the distribution of houses, jobs and households. This information is processed and predictions of the distribution of land use and travel are output. Overall measures of environmental outputs are provided.

LAND incorporates a dynamic simulation model that is updated each year. It consists of three components which are related in sequence. These components are land use, transport and environmental modules. Each of these modules will be described in chapter 3.

A major development in LAND is the user interface. Existing levels of expectation in the user environment require interactive editing, mouse facilities and pop up menus. The acceptance of the package therefore depends on creating such an environment. To facilitate these developments and to provide access to the full memory capabilities of the new PC's, the LAND educational tool was developed using Visual Basic 2.0 in the Microsoft Windows environment.

Visual Basic provides an opportunity to use the multi-tasking, mouse and other advantages of the Microsoft Windows environment. It builds on the developments in the Basic computer language while providing an opportunity to develop user-interfaces that are visually attractive and flexible.

The Microsoft Windows environment provides a number of advantages. It is window based and the user can call up a number of accessories to print files and present data. It automatically provides access to the full memory capabilities of the range of microcomputers (IBM-PC 386, IBM-PC 486 etc.) presently available. It is mouse driven and therefore does not require the user to be familiar with tedious operating system commands of MS DOS. Finally, Microsoft Windows allows multi-tasking and hence the opportunity to carry out a number of tasks at the same time. This is important since some applications of LAND may take a long time to run. The user can carry out other tasks while waiting for the model to finish.

The Microsoft Windows environment and Visual Basic provide a mechanism for taking a new look at transport model's user interface. The interface has lagged behind theoretical development in models. This lag is primarily due to the enormous effort that was needed to develop this interface and the professions demand for reality in the representation of the transport and land use systems. Visual Basic allows a high standard of user interface to be developed rapidly.

2.3 THE STRUCTURE OF LAND

The LAND package is entered through a Microsoft Windows icon. A mouse click on the icon will bring up the front form (figure 2.1). This form provides entry to the LAND main menu (figure 2.2).

The main menu shows the major components of LAND as:

- the system control options;
- data input;
- modelling;
- output presentations;
- view;
- setting of key variables; and
- help facilities.

These components provide the user with the facility of developing a land use pattern and transport network, running the model and viewing the output. This report is mainly interested in the LAND simulation model as distinct from the LAND user interface. The LAND user interface will not be described in this report. Those interested in a discussion of the interface are referred to Gu, Haines and Young (1992a, 1992b).

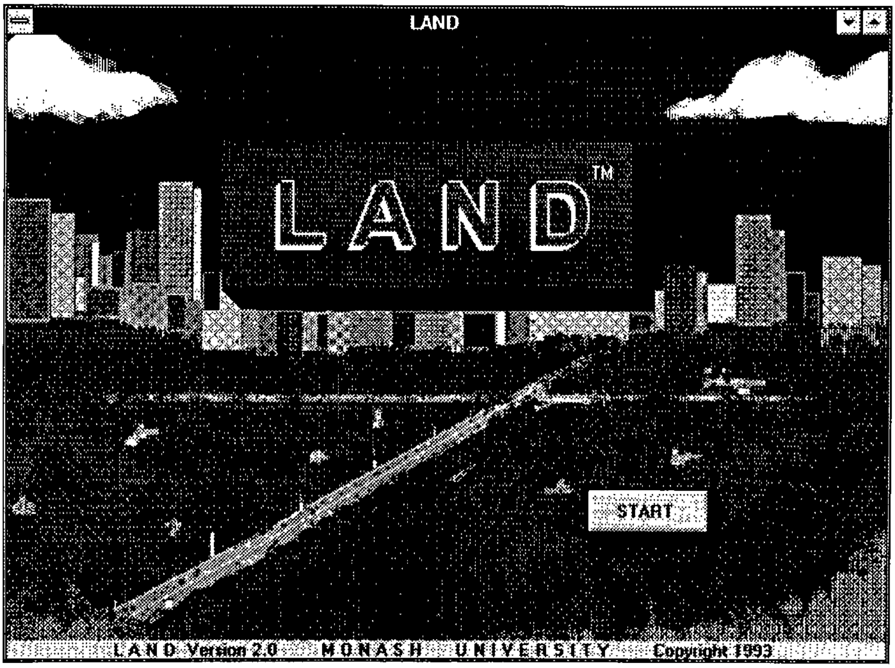

Figure 2.1 LAND entry form

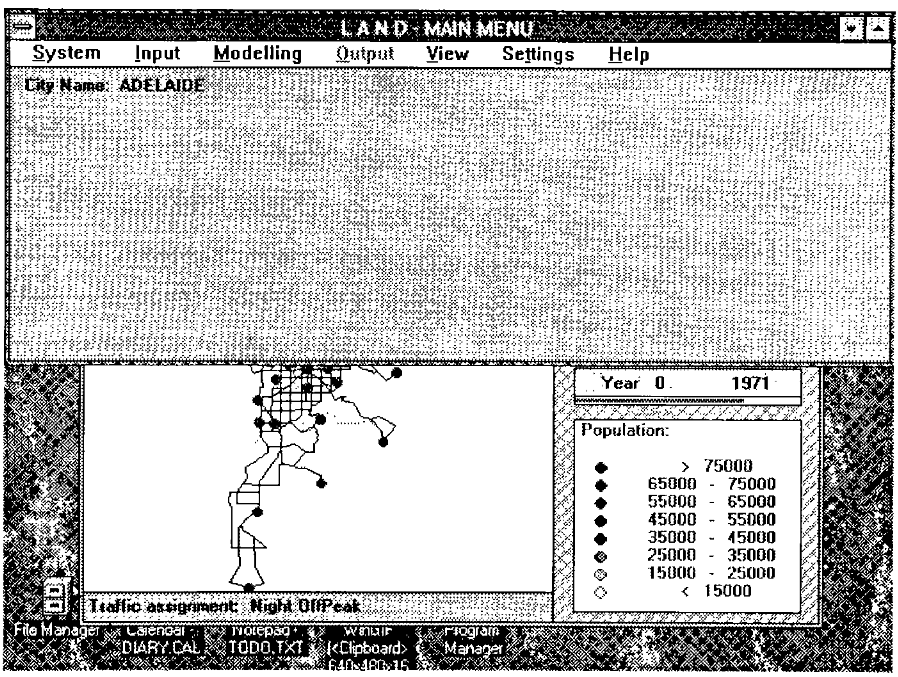

Figure 2.2 LAND main menu

CHAPTER 3 THE LAND MODEL

This chapter discusses the activities that occur behind the modelling form when the simulation model is running.

The modelling form (figure 3.1) is accessed by clicking the mouse on the modelling option on the main menu (figure 2.1).

3.1 THE LAND MODEL STRUCTURE

The structure of the LAND simulation model revolves around a dynamic updating of land use in a city using a one year cycle. The model requests that the base year and transport network for the study be set up. The city can start with no development or a city that is at a particular stage of development can be

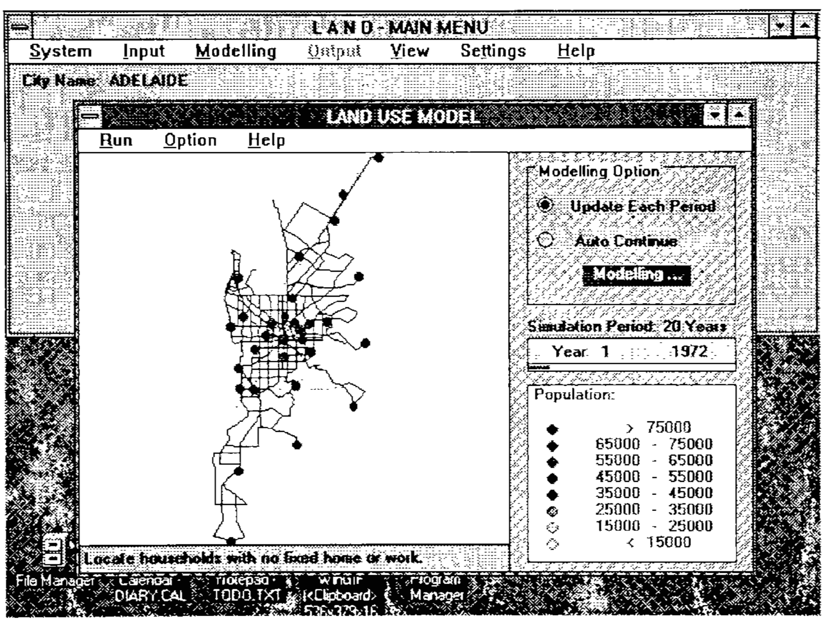

Figure 3.1 LAND model form

input. The input of this data is a relatively straight-forward task, provided the information is available (Gu, Young and Haines 1993). The networks used in setting up the model during the testing outlined in this report are a series of networks taken from road and public transport maps and a coarse representation of local government areas (LGA).

The overall model structure is outlined in figure 3.2. It follows a sequential path. The land use distribution for a particular year is determined. This distribution is used to determine the transport demands. The transport demands are then used to predict the environmental outputs. The land use, transport and environmental data is then used to determine the distribution of land use for the following year. This circular process continues until the model has reached the end of the study period.

More specifically, the model is based on the major decision making groups in urban areas. These are the household, businesses, developers, government bodies and governments. Not all bodies are considered in detail. The major detail relates to the household and businesses (employment). The developers are seen to cater for household needs, so measures of household demand indicates where developers will build. The developer activity is input exogenously in the form of new housing and employment facilities. The public bodies are considered in a similar fashion. Measures of deficiency can be provided and the user can update housing and job location exogenously. The role of the government is one of controlling land availability. The more complex interaction, the government of the day responding to the demands of the particular interest groups, is not modelled.

LAND starts from the land use module which estimates the location of activities in the different zones within the study area. The location activities consists of population, houses, households, employment, unemployment and jobs. These

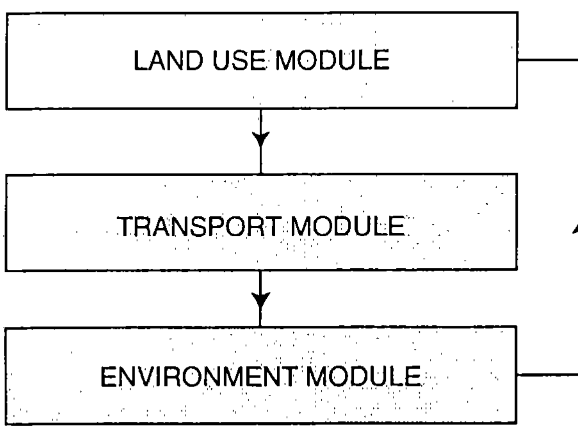

Figure 3.2 General structure of the LAND simulation model

in turn are inputs to the transport module in the form of trip matrices. The transport module determines the travel pattern, and the generalised travel costs which in turn impacts on further location decisions. After the travel pattern are estimated, the environmental impacts of the transport system are calculated. There are two linkages involved in the LAND model. The first is from location activities to the trip distribution and environmental impacts. Because of the characteristics of the transport system, it is assumed that this occurs instantaneously. The second feedback affects the location of activities, through changes in the generalised travel cost between zones and in the environment in the zone. This feedback is assumed to take place more slowly, because the activities will take some time to react to changes in accessibility and in the environment. The effects of changes in transport and the environment could take several periods to consolidate. LAND updates location activities, transport patterns and environmental impacts every year.

3.2 THE LAND USE MODULE

The LAND land use module is shown in figure 3.3. It takes as input in the base year information on the distribution of houses, jobs and households. It takes this information and develops home to work linkages. The general sequence of events is to age the population, determine the amount of unemployment and overcrowding, determine the movement of working households then determine the total population.

The age profile is updated simply by ageing the population and then considering the survival rate. Households are then varied depending on change in the age structure. The migration of households into or out of the city is considered when aging the population.

The total distribution of households is fed into procedures that determine the unemployment and proportion of overcrowding in the urban area. Unemployment results when the number of jobs are less than the number of workers. Overcrowding occurs when the number of houses are less than the number of households. Unemployment and overcrowding are distributed in proportion to population in each household type in the urban area. The proportion of overcrowding and employment is therefore assumed to be the same in each household group.

The module then considers the people moving within the urban area, considering in sequence, those with no fixed job and home, a fixed home, and a fixed job. The module considers the household structure. Households are divided into working households and retired households. Working households are further broken into three stages in 'life cycle' categories with household head of age 20–33, 34–47 and 48–60 years old. People age over 60 are considered as retired persons.

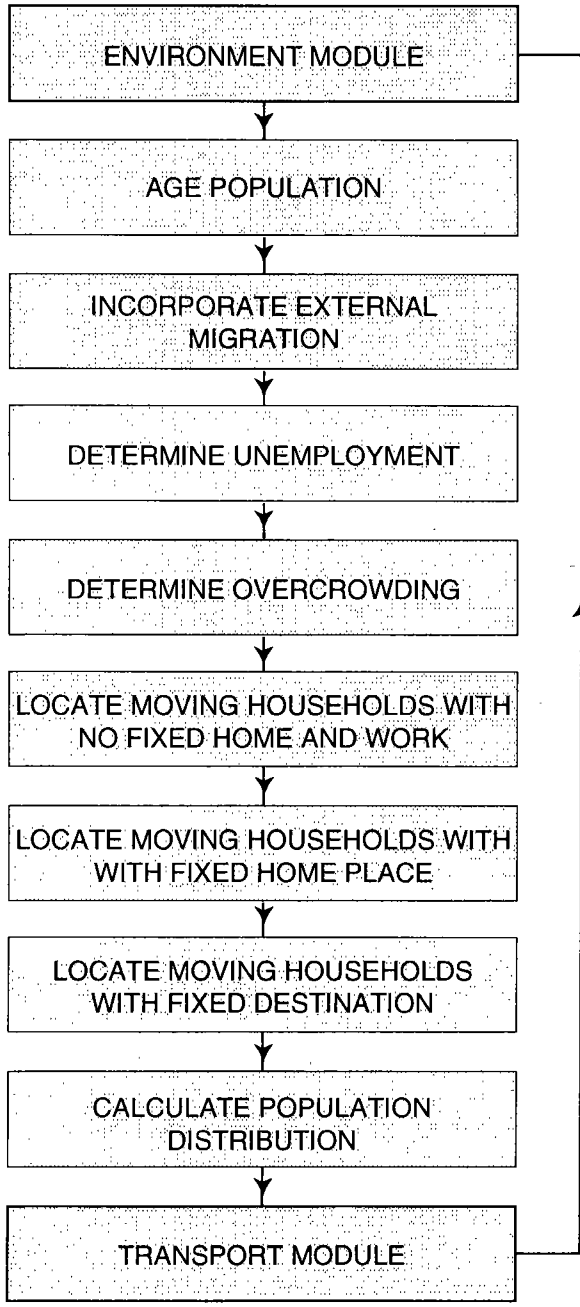

Figure 3.3 General structure of the LAND land use module

The number of movers and the household vacancies in the urban area are determined by LAND. Households are allocated to the vacancies in relation to the most favourable house and location combination. The most favourable location for employment based households is determined using accessibility to employment A^e_j:

$$A_j^e = \sum_{all\ i} E_i e^{-\beta c_{ij}}$$

where A^e_j is the accessibility to employment at zone j;
E_i is the employment in zone i;
C_{ij} is the average generalised travel cost for all modes from zone i to zone j (see Subsection 3.3.5); and
β is the travel impedance function coefficient.

The generalised cost functions are related to the general traffic flow, travel time and travel cost throughout the urban area.

The quality of house/location combinations is a linear combination of the house quality, the distance to the households work place and the accessibility to employment. The most favourable house/location combination is that with the highest value.

Business is considered in a similar fashion to households. Businesses do not move, fail or move. New businesses consider the options available. The best location is a function of accessibility to population (i.e. markets and work force):

$$A_j^p = \sum_{all\ i} P_i e^{-\beta c_{ij}}$$

where A^p_j is the accessibility to population, and
P_i is the population in zone i.

The quality of a job is a linear combination of the distance from the workers home and the best job location. The highest value of this combination is the most favoured job location.

Retired people are distributed in proportion to population in each household type in the urban area.

The zonal population distribution is a function of the resultant household pattern. It is the sum of number of people working, unemployed, young and retired.

3.3 THE TRANSPORT MODULE

The resultant land use pattern (households and employment) is used as a basis for determining travel patterns. LAND does not take into account other attracters like shops and recreational facilities in its present version.

The LAND transport module is a four step process which predicts the trips generated, the distribution of trips, the choice of mode and assigns the trips to a private and public transport network (figure 3.4). The transport module uses as input the distribution of population and households determined in the land use module. It outputs information of the distribution of trips to the environmental module.

Transport networks are represented using a node-link system. An intersection in the road system is represented by a node, and each one way road section is represented by a link.

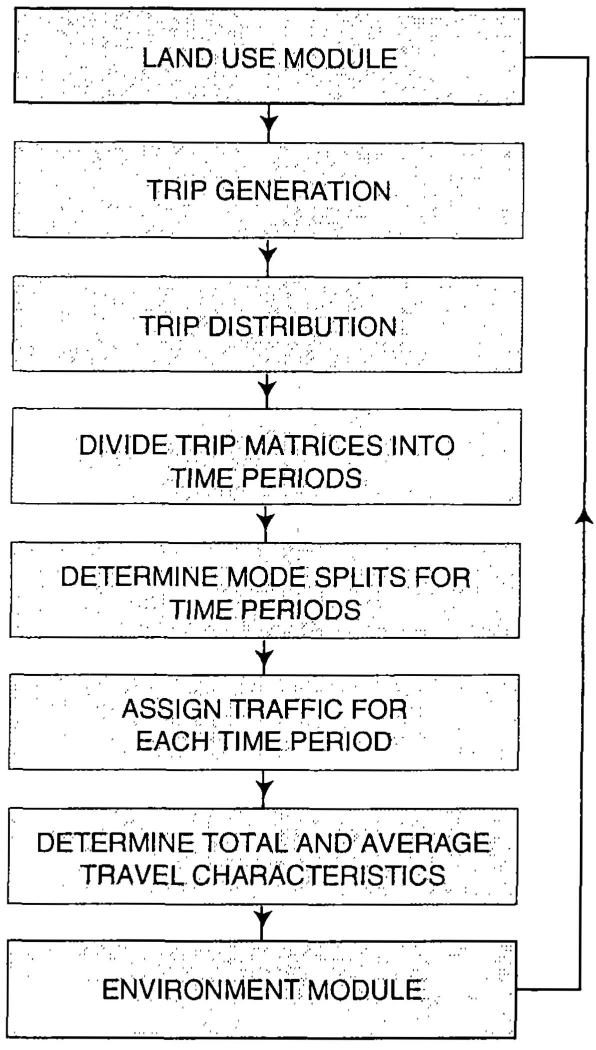

Figure 3.4 General structure of LAND transport module

3.3.1 Trip generation

The trip generation process transforms the zonal activities modelled by the land use module, into trip productions and attractions, that is, the number of trips produced from an origin and the number of trips attracted by a destination. Trip productions and attractions are a function of population and employment at the origin and the destination.

3.3.2 Trip distribution

Trip distribution is modelled by the double-constrained gravity model which adopts the travel impedance function of:

$$f(i,j) = e^{-\beta c_{ij}}$$

where β is the travel impedance coefficient, and
c_{ij} is the average generalised travel cost for all modes from zone i to zone j (see subsection 3.3.5).

Daily trips are divided into five periods of the day: morning off peak, morning peak, day time, afternoon peak, and afternoon off peak. The default percentage of trips generated in each period of the day is shown in table 3.1.

3.3.3 Modal split

The origin-destination trip matrices for each period are required for modal split and trip assignment. The modal split process is based on the utility function of:

$$P_{ij}^{r} = \frac{e^{-\beta c_{ij}^{r}}}{e^{-\beta c_{ij}^{r}} + e^{-\beta c_{ij}^{p}}}, \qquad P_{ij}^{p} = 1 - P_{ij}^{r}$$

where P^r_{ij} is the probability of a trip from i to j uses the road network r,
P^p_{ij} is the probability of a trip from i to j uses the public transport network p;
C^r_{ij} is the travel cost from i to j using road network (see subsection 3.3.5); and
C^p_{ij} is the travel cost from i to j using public transport (see subsection 3.3.5).

TABLE 3.1 PERCENTAGE OF TRIPS GENERATED IN EACH PERIOD OF THE DAY

Period	*Hours*	*Number of hours*	*Per cent of trips generated*
Morning off peak	00:00–06:00	6	5
Morning peak	06:00–09:00	3	25
Day time	09:00–16:00	7	29
Afternoon peak	16:00–19:00	3	25
Afternoon off peak	19:00–24:00	5	16

The origin destination trip matrices are split into road and public transport trip matrices for each period of the day.

3.3.4 Trip assignment

Trip assignment for each mode is modelled using the equilibrium traffic assignment method to assign the trips to the different routes available on the networks for each period. Dijsktra's algorithm is used to calculate the minimum travel cost between zones. The travel cost within a zone is taken as half the cost to the nearest zone's centroid. For private transport, it is assumed that vehicle trips are equal to person trips divided by vehicle occupancy. For public transport assignment, LAND considers passenger trips.

Daily travel patterns and travel summaries are determined by combining these five periods into figures for a 24 hour period.

3.3.5 Generalised travel cost and congestion relationship

The above accessibility functions, travel impedance function and model split utility function all involve a variable travel cost (C_{ij}). This has been defined as travel time between zone i to zone j by many existing land use and transport models. However, the travel cost has also been defined as the separation between two places (Hansen, 1959). With the rapid development of urban land use and transportation, and the appearance of the toll bridges, toll freeways or highways, and other methods of road pricing, the travel pattern has changed. Further, the increase in fuel costs and concern about the cost of providing public transport have influenced the choice of home and job location. The separation between one place and another is a function of distance, travel time, vehicle comfort, operating costs and travel cost. To combine these into one measure a common unit is required. An appropriate unit is the monetary travel cost. This is used in LAND.

The generalised travel cost consists of three elements. The cost associated with travel time, the cost associated with distance travelled and the cost associated with waiting. It takes the form:

$$C_{ij}^{k} = a_1^k t_{ij}^k + \left(a_2^k + a_3^k\right) d_{ij}^k + a_4^k w_{ij}^k$$

where C^k_{ij} is the generalised link cost of travel from zone i to zone j by mode k (cents),

d_{ij} is the link distance in kilometres from i to j,

t^k_{ij} is the link travel time in minutes from i to j by mode k which is calculated from the Davidson's congestion function introduced below,

w^k_{ij} is the walking, waiting and other access times in minutes associated with the journey i to j for mode k,

a^k_1 is the average value of time in monetary units (cents/min) in mode k,
a^k_2 is the average running cost of travelling unit distance (cents/km) in mode k
a^k_3 is the travel fare per unit distance (cents/km) for mode k, and
a^k_4 is the value of time (cents/min) for walking and waiting associated with the journey for mode k.

The LAND model incorporates generalised travel cost into the land use and transport modules. This is particularly useful in the travel demand module since it allows the investigation of transport policies involving financial charges (Ruhi and Dobson, 1976) and in assessing the impact of travel cost or road pricing on transport system and land use development.

The link travel time in LAND is determined using the Davidson's congestion function:

$$t_{ij}^{k} = t_{ijo}^{k}\left\{1 - J\left(\frac{u}{1-u}\right)\right\} \qquad u < p$$
$$= t_{ijo}^{k}\left\{1 - J\left(\frac{p}{1-p}\right) + \frac{J}{(1-p)^2}(u-p)\right\} \qquad u \geq p$$

where t^k_{ij} is the link travel time (min),
t^k_{ijo} is the free-flow link travel time (min),
J is Davidson's function factor, which reflects the road type and abutting land development,
u is the volume capacity ratio, defined as the ratio of link traffic volume q to capacity S, and
p is a predetermined constant, usually in the range of 0.85–0.95 to allow for over-saturation on the link (Taylor, 1992).

3.4 THE ENVIRONMENT MODULE

Recent transport research has focussed on solutions to urban congestion, energy conservation and environment problems (TRB, 1991). In terms of the energy and environmental impacts of road traffic systems, three aspects of concern to planners and the community are:

- fuel consumption;
- air pollution; and
- traffic noise.

If the community is to embrace the concept of sustainable development, there is an increasing need to assess the energy consumption and environmental impacts of changes to land use and transport systems. A number of computer models have been developed for the estimation of vehicle fuel consumption (Evans and Herman 1976, Biggs and Akcelik, 1986, Biggs 1987), for prediction of air pollution (Taylor 1982, Faiz and Gautam 1992) and for simulation of traffic noise (UKDoT, 1988, Matzoros and Van Vliet 1992a, 1992b). The environment assessment module in LAND builds upon these studies, in an attempt to integrate energy and environmental assessments into the land use–transport interaction. It generates data on air pollutants, fuel consumption and traffic noise based on network link traffic conditions. The use of a network representation of the urban road system, rather than area or zonal traffic measures, allows the effects of road type and configuration to be included.

The LAND environmental module takes as input information on the distribution and speed of travel output from the transport module. It transforms this information into measures of emissions, fuel consumption and noise (figure 3.5).

3.4.1 Air pollution and fuel consumption

Within an urban area, transport pollutant emission rates and energy consumption depend on the varying levels of congestion. The higher the levels of congestion (and thus the lower the travel speed), the higher are the levels of energy use and pollutant emissions (Sharpe, 1979). Therefore the traffic condition and location of the individual links in a network, and the interaction between links strongly influence transport energy consumption and pollution levels within a city. Other factors such as the type of vehicles travelling on a network and the fuel they use also need to be considered.

Road vehicles in LAND are divided into two major categories:

- cars and equivalents; and
- heavy vehicles.

Cars and equivalents are further broken up into four classes according to the fuel type they use:

- leaded petrol;
- diesel;
- unleaded petrol; and
- liquid petroleum gas (LPG).

Heavy vehicles are broken into petrol-engine and diesel-engine vehicles.

Link traffic flow can be expressed as:

$$Q = \sum_{m} p_m q_m$$

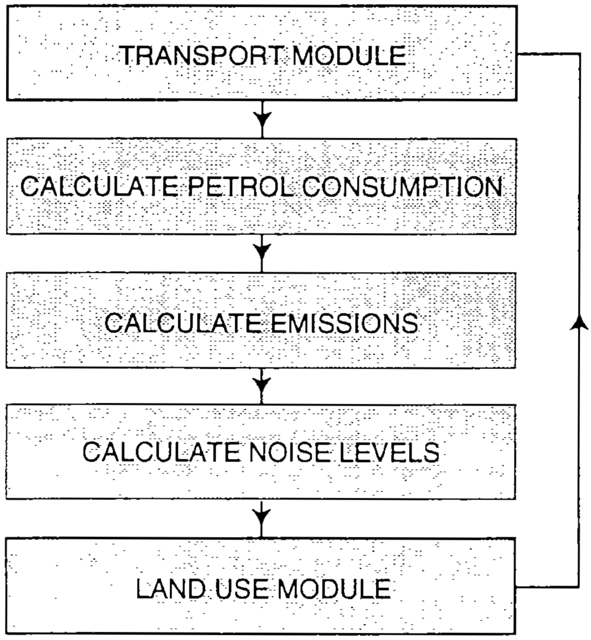

Figure 3.5 General structure of the LAND environment module

where Q is the total link traffic flow,
p_m is the proportion of type m vehicles, and
q_m is the link traffic flow of vehicle type m.

The total rate of emission or fuel consumption $E(x)$ can be defined as:

$$E(x) = \sum_m E_m(x) p_m q_m$$

where $E_m(x)$ is the mean rate of pollutant emission or fuel consumption (Taylor, 1992).

This link based model was established by Taylor and Anderson (1982) and Taylor (1992). As long as we can predict $E_m(x)$ for a range of traffic condition, the total pollution levels and fuel consumption can be estimated.

Since LAND presently concentrates on the urban level, the pollutant emission and fuel consumption are estimated using simple relationships based on vehicle type and travel conditions on network links. The generation rates $E_m(x)$ of pollutant emission or fuel consumption are assumed to be directly related to mean travel time per unit distance on a link, link flow and road type. Simple linear relationships between $E_m(x)$ and unit distance travel time have been shown to be appropriate in estimating pollution generation and fuel consumption for urban transport planning models (Evans and Herman 1976; Taylor and Anderson 1982; Taylor and Gipps 1982).

The linear function suggested by Evans and Herman (1976) takes the form:

$$E_m(X) = k_1 + k_2\omega$$

where $E_m(x)$ is the generation rate (g/km) of pollutant x or fuel consumption rate (litres/100 km) by a type m vehicle,

k_1, k_2 are coefficients, and

ω is the mean travel time per unit distance on a link (min/km).

The relationships have been used in the URPOL model (Taylor, 1982) and have been calibrated using the data collected by Kent (1980). These data cover the range 0.8–5.0 min/km for unit distance travel times (mean travel speeds 12–75 km/h) and thus adequately represent traffic conditions in most Australian urban areas. For more detailed estimation, other micro-scale level models are required. For example, a recent air pollution computer model has been developed based on the characteristics of interrupted flow and junction control (Matzoros van Vliet 1992a, 1992b). The model considers the four vehicle operating modes: cruising, deceleration, queuing and acceleration. The LAND environment module simplified these complexities to provide a reasonable estimate of pollution levels using a minimum data input.

The air pollutants considered in LAND include carbon monoxide, nitrous oxides, hydrocarbons and lead. Four types of fuel consumption for motor vehicles are considered: leaded petrol, diesel, unleaded-petrol and LPG.

For petrol-powered cars and equivalents, the coefficients of k_1 and k_2 used in the studies outlined in this report are shown in Appendix I. The emissions and fuel consumption for other types of vehicles were assumed to relate to those for petrol-powered vehicles (Taylor, 1982). The estimated rates of pollutants for other type of vehicles relative to petrol-vehicles are shown in table 3.2.

For diesel-powered cars and equivalents, the fuel consumption model was derived by a comparative study of fuel consumption on petrol and diesel vehicles (Weeks, 1981). It takes the form:

$$E_c(fd) = 4.15 + 1.54\omega$$

For commercial vehicles and heavy vehicles, Glazebrook's (1980) fuel consumption relation was adopted. It takes the form:

$$E_h(fuel) = 10\omega^2 + 12.6 + \frac{7.2}{\omega^2}$$

The ratios of fuel consumption for unleaded-engine and LPG-engine vehicles to fuel consumption of petrol engine cars and equivalents are 0.9 and 1.25 respectively.

TABLE 3.2 EMISSION RATE BY VEHICLE TYPE
(g/km)

	Cars and equivalents				*Heavy vehicles*	
Pollutants	*Leaded petrol*	*Diesel*	*Unleaded petrol*	*LPG*	*Petrol*	*Diesel*
Carbon monoxide (CO)	1.0	0.2	0.42	0.35	$1.0\gamma_p$	$0.2\gamma_d$
Hydrocarbons (HC)	1.0	1.6	0.47	0.61	$1.0\gamma_p$	$1.6\gamma_d$
Nitrous oxides (NOx)	1.0	1.0	0.80	0.90	$1.0\gamma_p$	$1.0\gamma_d$

Note γ_p is the ratio of petrol consumption of heavy vehicles to petrol consumption of cars and equivalents. γ_d is the ratio of diesel consumption of heavy vehicles to diesel consumption of cars and equivalents.

Source Taylor 1992.

3.4.2 Traffic noise

Traffic noise levels are also generated in the LAND model. These are based on link traffic conditions. The link-based traffic data output from the transport model are used as input to generate the noise emissions for each link using United Kingdom's Department of Transport's (UK DoT 1988) method.

The L_{10} (18 hours, 06:00–24:00) noise level in dBA (the noise level exceeded for 10% of the time period 06:00–24:00) is used as an index of noise pollution. The L_{10} noise levels are calculated for reception points 20 metres to the side and 3 metres above the road centreline of each link. This represents the average distance from dwelling facades from a roadway centreline (Brown and Patterson, 1990).

The L_{10} (18-hour) noise levels are then estimated using the equation:

$$L_{10} = 29.1 + 10\,log\,Q \qquad dBA$$

where Q is the 18-hour (06:00–24:00) link traffic flow.

Q can be derived from the proportion of the daily traffic flow which is simulated by the transport assignment model. Table 3.1, indicates that the 18-hour (06:00–24:00) link traffic flow accounts for 95% of total link vehicle flow.

The correction for traffic speed V and percentage of heavy vehicles p is:

$$C = 33\,log\left(V + 40 + \frac{500}{V}\right) + 10\,log\left(1 + \frac{5p}{V}\right) - 68.8 \qquad dBA$$

where V is mean travel speed (km/h), and
p is proportion of heavy vehicle in the traffic flow.

The correction for distance is:

$$C = -10\,log\left(\frac{d'}{13.5}\right) \quad dBA$$

where d' is shortest slant distance between the reception point and the source line.

It is assumed that the source line is 0.5 metres above the link centre line. For a reception point at a horizontal distance d and height h, the slant distance d' is:

$$d' = \sqrt{(h-0.5)^2 + d^2}$$

The correction for low traffic flows (when d'<m and $1000 \leq Q < 4000$) is:

$$C = -16.6\left\{log\left(\frac{30}{d'}\right)\left(log\left(\frac{Q}{4000}\right)\right)^2\right\} \quad dBA$$

Calculations of noise level for traffic flow below 1000 veh/18-hour using the above approach are unreliable due to the background noise. The 1000 veh/18-hour noise level is applied in such circumstance.

Noise propagation is assumed to be over hard level ground, with no barriers between roadway and dwellings. Noise levels L_{10}(18-hour) are classified into five categories in LAND: >72, 72–68, 68–64, 64–59 and ≤59 dBA. Percentage of road length with noise levels in each category is calculated and presented in LAND's output.

3.5 RECURSIVE PROCESS

Once the land use pattern, transport demand and environmental output have been calculated the model provides the option of moving on to the next year (figure 3.2). The land use in the next year is allocated using the transport demands and travel costs from the previous year. The process of determining population location, travel demand and environmental impacts in LAND can continue for a designated period (eg. 10 years etc.). However, it can be interrupted and changes made to the system at the end of each year.

CHAPTER 4 VERIFICATION OF LAND: THE ADELAIDE STUDY

The preceding chapters have briefly described the LAND package and the land use–transport–environment model incorporated into the package. During the development of LAND it was applied to small hypothetical networks that bore no resemblance to any city. This enabled the general structure of the model to be developed and tested quickly.

There is a need to ensure that the model can replicate existing cities. The replication of real cities involved the determination of the values of the parameters used in the model and to comparison of the model output with data describing real cities. This process will be referred to as verification in this report. It needs to be distinguished from validation. Validation is where a model calibrated and verified on one city is applied to another city or the same city at another point in time. Validation is not carried out here. This must wait till the behaviour of the model is more clearly understood and the data are available.

The studies reported in this chapter and the next two chapters represent the first attempts to apply the model to existing cities. The verification of LAND consisted of three separate studies. These were:

- the application of the LAND model to Adelaide and the comparison of the model outputs with existing data;
- the application of the LAND model to Melbourne and the comparison of the model outputs with existing data; and
- the application of LAND by students from the Australian Defence Force Academy to a hypothetical city similar to Canberra.

This chapter looks at the Adelaide study. Chapters 5 and 6 will look at the Melbourne and hypothetical city studies respectively.

The Adelaide study involved the application of the LAND model to the city of Adelaide for the period 1971 to 1991. Comparisons between the model outputs and existing data were made. Parameters within the LAND model were adjusted to allow the model to replicate existing descriptions of Adelaide. This chapter is divided into three main parts:

- data requirements;
- simulation and output information; and
- verification of the model.

4.1 DATA REQUIREMENTS FOR THE ADELAIDE STUDY

One of the major tasks in this study was the collection of base and non-base year data for input into the model. There are five types of input data in LAND:

- set variables;
- link type variables;
- transport networks;
- zone boundaries; and
- land use data.

The set variables and link type data are initially set by the model. Users can change them if they wish. The transport network, zone boundaries and demographic data describe the city and are the minimum description required by LAND.

4.1.1 Set variables

The setting variables are the basic parameters used in the simulation model. These variables include:

Population distribution
Birth rate
Death rate
Employment utility parameters
Household structure
House quality
Location quality
Environment coefficients
Proportion of trips by time of day
Trip generation factors
Coefficient for travel impedance
Travel cost factors
Traffic composition
Vehicle occupancies.

Most of these data are available from the ABS, transport departments, or environment authorities. They can also be used to calibrate the model. The base year setting variables for Adelaide are shown in appendix I.

The setting variables can be changed each year. If a variable in a year is not available, the model takes the former year's value.

4.1.2 Link type variables

Link type data describe the traffic characteristics of the transport links. These include:

- Route type;
- Free travel speed;
- Davidson function parameter;
- Traffic saturation flow level; and
- Link charge or fares for private and public transport respectively.

The link type variables for Adelaide are shown in appendix II.

4.1.3 Transport networks

Two separated transport networks were coded for Adelaide City. They are the road network and the public transport network. They were coded using the Adelaide Urban Street Directory (UBD, 1987) for the road network and the Adelaide Public Transport Map (1975) for the public transport network.

The Adelaide road network coded into LAND (figure 4.1) consists of a total of 117 roads, 461 intersections and 1856 one way links. The links were classified using the link type option. The public transport network coded into LAND (figure 4.2) consists a total of 63 routes, 341 interchange stops and 852 one way links. The links were classified by bus route, tram route and railway line.

4.1.4 Zone boundaries

LAND allows any type of zonal boundaries to be specified. Local government area (LGA) boundaries were used in the Adelaide study since data describing the demographics in these areas could be obtained easily from the ABS. There were 32 LGA in Adelaide in 1971. Only 30 LGAs were considered in this study. Table 4.1 shows the LGAs included in the study.

Two LGAs were very small and were incorporated into other LGAs. These were Colonel Light Gardens and Unincorporated. Colonel Light Gardens was merged with Mitcham, and Unincorporated was excluded from the list of LGAs in 1986.

Figure 4.1 Adelaide road network

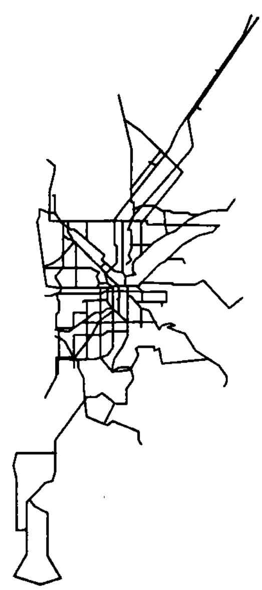

Figure 4.2 Adelaide public transport network

TABLE 4.1 ADELAIDE LOCAL GOVERNMENT AREAS

Local government area	*Area (km^2)*
Adelaide	16.972
Brighton	8.79
Burnside	29.11
Campbelltown	27.64
East Torrens	133.57
Elizabeth	21.57
Enfield	55.18
Gawler	11.22
Glenelg	5.03
Henley and Grange	7.19
Hindmarsh	5.51
Kensington and Norwood	3.94
Marion	56.21
Meadows (Happy Valley)	201.61
Mitcham	81.98
Munno Para	398.93
Noarlunga	180.94
Payneham	7.55
Port Adelaide	34.52
Prospect	9.00
St. Peters	4.03
Salisbury	184.34
Stirling	119.07
Tea Tree Gully	141.88
Thebarton	4.61
Unley	14.93
Walkerville	2.78
West Torrens	35.12
Willunga	193.48
Woodville	45.96

Adelaide LGA boundaries have been redefined from time to time. The 1971 and 1986 boundaries showed significant change. LAND is capable of adjusting to these changes by altering houses, households and the number of jobs in each zone. Figures 4.3 and 4.4 show the coded Adelaide LGA boundaries for 1971 and 1986 respectively.

4.1.5 Land use data

The demographic information was obtained from the ABS (available on microfiche) and South Australian Year Books (ABS, 1971–1993). The zonal information required by LAND is:

- houses in three house types;
- households in house types; and
- available jobs.

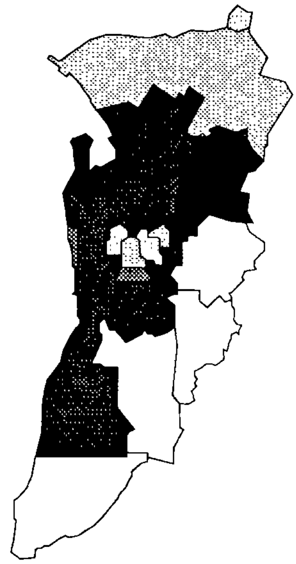

Figure 4.3 Adelaide 1971 LGA boundaries

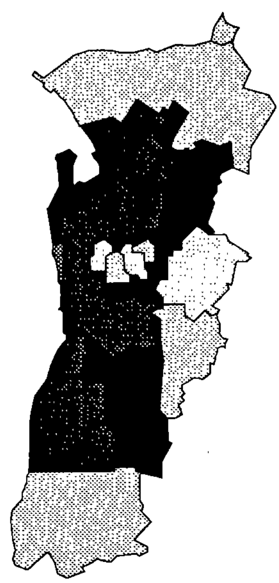

Figure 4.4 Adelaide 1986 LGA boundaries

TABLE 4.2 AGGREGATE ADELAIDE LAND USE INFORMATION FROM THE CENSUS, 1971–91

	1971	*1976*	*1981*	*1986*	*1991*[a]
Population	842 693	900 431	931 886	977 721	1 023 617
Houses	265 392	309 552	338 712	372 737	403 762
Occupied houses	252 103	290 162	320 165	349 048	365 875
Employment	345 595	394 225	393 159	414 838	464 916
Unemployment	6 565	14 653	35 627	43 706	48 875
Work force	352 160	408 878	428 786	485 544	513 791
Jobs available	352 646	402 301	406 881	434 686	474 405

a. 1991 data are estimated from the South Australian Year Book (1991) since the 1991 census data were not available at the time of this study.

In the Adelaide study, houses are grouped into three types according to quality:

- type 1: separated houses;
- type 2: semi-detached or attached houses, terrace houses, self contained units and flats; and
- type 3: non-self contained units, flats, improvised homes, caravans, non-private houses, and others.

As the base year (1971) job figures were not available, they were derived from 1981 data based on the assumption that job distribution was the same between these two years. The job data for 1981 and 1986 years were obtained from ABS.

Table 4.2 shows Adelaide land use information between 1971 to 1991. It can be seen that there has been an increased in population, housing, employment, unemployment and the available jobs between 1971 and 1991.

4.2 OUTPUTS FOR ADELAIDE

There are numerous input and output data files used in LAND. These are listed in Gu Young and Haines (1993). The major output data files are:

- Zonal land use information over the simulation period. The information includes population, houses, households, employment, unemployment, jobs available, accessibility to population and accessibility to employment.
- Zonal trip production and attraction information over the simulation period.
- Travel patterns for both private and public transport over the simulation period. This information includes generalised interzonal travel cost matrices, link traffic flow, link distances, link travel times and generalised costs.

- Daily travel summaries over the simulation period. These include vehicle kilometres travelled, vehicle hours travelled, total number of trips, average travel speed, average travel distance and average travel time.
- Daily environment information over the simulation period. These include air pollution emissions (Carbon monoxide, Hydrocarbons, Nitro oxides and lead) and fuel consumption (super, unleaded petrol, diesel and LPG).
- Traffic noise level and distribution over the arterial roads for the simulation period.

4.3 VERIFICATION OF LAND FOR ADELAIDE

The LAND model has been verified by applying the model to Adelaide. Then comparing the results with existing data. The parameters of the model were estimated during the verification. The modelled and existing data source were compared and a tolerance of 5 percent was used to indicate acceptable agreement. The verification was carried out on three levels:

- land use information;
- travel pattern; and
- environmental assessment.

4.3.1 Land use information

Table 4.3 to 4.6 present the comparison of land use information between census data and the LAND model estimates for Adelaide over the study period 1971–1991. LAND predicts land use in each zone. The following figures only show the total value for Adelaide.

At the time of this study the 1991 census data was not available. However, an estimate of the 1991 Adelaide population data was obtained from the South Australian Year Books (ABS, 1971–1993). The employment, houses, households, unemployment and work force data were estimated using the South Australian Year Books and by multiplying the South Australian figure by the ratio of Adelaide's and South Australia's population.

The census data in table 4.3, indicates that there was a 21 percent increase in population and a 53 percent increase in number of houses in Adelaide between 1971 and 1991. Comparison of the modelled and ABS data shown in table 4.3 indicates that there is reasonable agreement between the two. Since LAND inputs the total number of houses exogenously, the number of houses used in the LAND representation of Adelaide should always be matched the ABS information (see table 4.3).

TABLE 4.3 TOTAL POPULATION AND NUMBER OF HOUSES IN ADELAIDE, 1971–91

	Population			*Houses (total dwellings)*		
	Census	*LAND*	*Percentage error*	*Census*	*LAND*	*Percentage error*
1971	842 693	842 698	0.00	265 392	265 392	0
1972		859 530			274 224	
1973		878 608			283 056	
1974		892 052			291 888	
1975		904 806			300 720	
1976	900 431	915 724	1.70	309 552	309 552	0
1977		920 574			315 384	
1978		932 893			321 216	
1979		939 787			327 048	
1980		942 992			332 880	
1981	931 886	952 858	2.25	338 712	338 712	0
1982		964 604			345 517	
1983		986 938			352 322	
1984		995 327			359 127	
1985		1 000 313			365 932	
1986	977 721	1 001 876	2.48	372 737	372 737	0
1987		1 008 146			379 542	
1988		1 017 386			386 347	
1989		1 028 481			393 152	
1990		1 038 459			399 957	
1991	1 023 617	1 046 926	2.27	406 762	406 762	0

Note The Census estimates were derived from ABSSA (1971, 1976, 1981, 1986) and South Australian Year Book (ABS 1991).

Table 4.4 shows the total workforce and number of households in Adelaide obtained from the census and the model. It can be seen that the LAND model accurately predicted the work force and households over the study period. The work force is defined as number of people who are looking for jobs. The difference between the work force and employment is classified as unemployment. Table 4.5 presents the model predictions of total employment and unemployment in Adelaide. They agree with the census estimates. It shows that during the period 1976 to 1981, the employment figure remained the same, while the work force increased by 10%. As a result the unemployment rate increased from 3.6% to 8.3% (table 4.6).

Table 4.6 shows the model estimates of the total number of jobs available and the unemployment rate in Adelaide over the period 1971 to 1991. Since job data are an exogenous input in the LAND model, the census and model job figures should match. The unemployment rate was calculated as a ratio of unemployment to total work force. The census unemployment rates in table 4.6 were the South Australia figures obtained from the South Australian Year Books. It can be seen that the LAND model predicted the unemployment rate satisfactorily.

TABLE 4.4 TOTAL WORK FORCE AND NUMBER OF HOUSEHOLDS IN ADELAIDE, 1971–91

	Work force			*Households (occupied dwellings)*		
	Census	*LAND*	*Percentage error*	*Census*	*LAND*	*Percentage error*
1971	352 160	352 105	–0.02	252 103	252 022	–0.03
1972		363 069			264 783	
1973		374 769			268 970	
1974		386 523			274 093	
1975		397 577			280 597	
1976	408 878	408 228	–0.16	290 162	287 546	0.90
1977		413 675			292 561	
1978		420 364			298 082	
1979		426 592			298 977	
1980		430 071			306 963	
1981	428 786	434 293	1.28	320 165	312 776	–2.31
1982		440 708			318 878	
1983		448 744			331 258	
1984		455 506			339 613	
1985		461 249			347 339	
1986	458 544	467 592	1.97	349 048	353 791	1.36
1987		477 064			355 044	
1988		487 081			355 747	
1989		495 573			359 333	
1990		503 685			362 442	
1991	513 791	512 246	–0.30	365 875	364 603	–0.35

Note The Census estimates were derived from ABSSA (1971, 1976, 1981, 1986) and South Australian Year Book (ABS 1991).

TABLE 4.5 TOTAL NUMBERS EMPLOYED AND UNEMPLOYED IN ADELAIDE, 1971–91

	Employed			*Unemployed*		
	Census	*LAND*	*Percentage error*	*Census*	*LAND*	*Percentage error*
1971	345 595	345 576	0.00	6 565	6 529	0.55
1972		355 311			7 758	
1973		365 041			9 728	
1974		374 704			11 819	
1975		384 244			13 333	
1976	394 225	393 575	–0.16	14 653	14 316	–2.30
1977		394 206			19 469	
1978		394 745			25 620	
1979		395 457			31 135	
1980		396 169			33 902	
1981	393 159	396 917	0.96	35 627	37 376	4.91
1982		402 221			38 487	
1983		407 242			41 502	
1984		412 501			43 005	
1985		417 877			43 372	
1986	414 838	423 295	2.04	43 706	44 297	1.35
1987		431 019			46 045	
1988		438 704			48 377	
1989		446 373			49 200	
1990		453 977			49 708	
1991	464 916	461 330	–0.77	48 875	50 916	4.00

Note The Census estimates were derived from ABSSA (1971, 1976, 1981, 1986) and South Australian Year Book (ABS 1991).

TABLE 4.6 TOTAL NUMBER OF JOBS AVAILABLE AND UNEMPLOYMENT RATE IN ADELAIDE, 1971–91

	Jobs available			*Unemployment rate (per cent)*		
	Census	*LAND*	*Percentage error*	*Census*	*LAND*	*Percentage error*
1971	352 646	352 646	0	1.86	1.85	–0.54
1972		362 577			2.14	
1973		372 508			2.60	
1974		382 439			3.06	
1975		392 370			3.35	
1976	402 301	402 301	0	3.58	3. 51	–1.96
1977		403 217			4.71	
1978		404 133			6.09	
1979		405 049			7.30	
1980		405 965			7.88	
1981	406 881	406 881	0	8.31	8.61	3.61
1982		412 442			8.73	
1983		418 003			9.25	
1984		423 564			9.44	
1985		429 125			9.40	
1986	434 686	434 686	0	9.50	9.47	–0.32
1987		442 606			9.65	
1988		450 526			9.93	
1989		458 446			9.93	
1990		466 366			9.87	
1991	474 405	474 286	0	9.50	9.94	4.63

Note The Census estimates were derived from ABSSA (1971, 1976, 1981, 1986) and South Australian Year Book (ABS 1991).

4.3.2 Travel pattern

Transport information for the urban area of Adelaide is not generally available from the ABS. To enable to model estimates of travel behaviour to be compared with independent estimates, data was collected from a number of sources. The major sources were Newman and Kenworthy (1989), and the Australian Environmental Council (AEC 1976, 1985). Table 4.7 to 4.10 present the comparison of transport indicators between the model estimates and available sources. LAND predicts daily travel patterns for both private and public transport. Private transport indicators include total vehicle trips, vehicle kilometres travelled, average travel speed, average travel length and average

TABLE 4.7 TOTAL PRIVATE VEHICLE TRIPS AND KILOMETRES TRAVELLED IN ADELAIDE, 1971–91

	Total daily vehicle trips (10^6)			*Total daily vehicle kilometres (10^6)*		
	N.K./AEC	*LAND*	*Percentage error*	*N.K./AEC*	*LAND*	*Percentage error*
1970				12.472[b]		
1971		0.851			13.160	
1972		0.879			13.713	
1973		0.910			14.265	
1974		0.938			14.557	
1975		0.973			15.257	
1976		1.006		14.801[c]	15.806	6.79
1977		1.043			16.407	
1978		1.081			17.036	
1979		1.109			17.454	
1980	1.132[a]	1.159	–2.39	17.891[a]	18.318	2.39
1981		1.188			18.805	
1982		1.221			19.363	
1983		1.251			19.962	
1984		1.283			20.552	
1985		1.310		20.686[c]	21.084	1.92
1986		1.354			21.851	
1987		1.407			22.673	
1988		1.460			23.488	
1989		1.515			24.342	
1990		1.571			25.253	
1991		1.627			26.145	

N.K. Newman and Kenworthy (1989)

AEC Australian Environmental Council

a. Total vehicle trips (Newman & Kenworthy, 1989) for 1980 was estimated based on trip length 15.8 km from Table 4.6.

b. Newman and Kenworthy (1989)

c. AEC (1976, 1985)

travel time. Public transport indicators include total passenger trips, total passenger kilometres travelled, average travel speed, travel length and travel time. Detailed link traffic flow, travel time and generalised travel costs are also available in LAND output files.

Private Transport

Table 4.7 shows total daily vehicle trips and vehicle kilometres travelled. The total number of vehicle trips in 1980 was 1 132 000 while the number of vehicle kilometres increased from 12 472 000 in 1970 to 20 862 000 in 1985 (Newman & Kenworthy 1989; AEC 1976, 1986). Table 4.7 shows that there is reasonable agreement between the modelled and observed estimates. LAND predicted a 91% increase in total vehicle trips and a 99% increase in total vehicle kilometres travelled in Adelaide over the period 1971 to 1991.

Other important transport indicators are average trip length, travel speed and travel time. Table 4.8 shows the average private transport trip length and travel speed in Adelaide. Observed average trip length was not available, and only

TABLE 4.8 AVERAGE PRIVATE TRANSPORT TRIP LENGTH AND TRAVEL SPEED IN ADELAIDE, 1971–91

	Average trip length (km)			*Average travel speed (km/h)*		
	N.K.	*LAND*	*Percentage error*	*N.K.*	*LAND*	*Percentage error*
1971		15.5			47.0	
1972		15.6			46.7	
1973		15.7			46.5	
1974		15.6			46.0	
1975		15.7			45.7	
1976		15.7			45.1	
1977		15.7			44.3	
1978		15.8			43.5	
1979		15.7			42.7	
1980		15.8			41.7	
1981		15.8		42.8	41.0	–4.21
1982		15.9			40.4	
1983		16.0			40.0	
1984		16.0			39.5	
1985		16.1			38.8	
1986		16.1			38.1	
1987		16.1			37.4	
1988		16.1			36.5	
1989		16.1			35.6	
1990		16.1			35.6	
1991		16.1			34.5	

N.K. Newman and Kenworthy (1989)

one year's data (1980) is available for average travel speed. The average travel speed in 1981 was 42.8 km/h (Newman & Kenworthy 1989). Because of this lack of data, comparison of the LAND model and observed value only shows a rough indication of agreement.

Public Transport

Three transport modes were considered in public transport: trains, buses and trams. LAND predicts only total and/or average performance measures for all public transport modes. Table 4.9 presents the daily total public transport passenger trips and passenger kilometres travelled. It can be seen that the total number of public transport trips increased from 190 000 in 1970 to 212 000 in 1980 (Newman & Kenworthy 1989). This is appreciable less than the number of private transport trips. The number of vehicle kilometres travelled by public transport increased from 1 317 000 in 1970 to 1 671 000 in 1980 (Newman & Kenworthy 1989). Comparison of the LAND estimates and observed values

TABLE 4.9 PUBLIC TRANSPORT PASSENGER TRIPS AND KILOMETRES IN ADELAIDE, 1971–91

	Total daily passenger trips (10^6)			*Total daily passenger kilometres (10^6)*		
	N.K.	*LAND*	*Percentage error*	*N.K.*	*LAND*	*Percentage error*
1970	0.190			1.317		
1971		0.180			1.198	
1972		0.187			1.252	
1973		0.194			1.306	
1974		0.207			1.393	
1975		0.207			1.388	
1976		0.214			1.438	
1977		0.221			1.490	
1978		0.229			1.543	
1979		0.235			1.587	
1980	0.212	0.244	15.1	1.671	1.663	–0.48
1981		0.250			1.694	
1982		0.257			1.742	
1983		0.264			1.795	
1984		0.270			1.841	
1985		0.278			1.902	
1986		0.288			1.971	
1987		0.300			2.054	
1988		0.312			2.133	
1989		0.325			2.216	
1990		0.337			2.301	
1991		0.350			2.390	

N.K. Newman and Kenworthy (1989)

TABLE 4.10 PUBLIC TRANSPORT PASSENGER AVERAGE TRIP LENGTH AND SPEED IN ADELAIDE, 1971–91

	Average passenger trip length (km)			*Average passenger travel speed (km/h)*		
	N.K.	*LAND*	*Percentage error*	*N.K.*	*LAND*	*Percentage error*
1970	6.99			23.7		
1971		7.3			30.8	
1972		7.4			30.7	
1973		7.5			30.8	
1974		7.6			30.5	
1975		7.7			30.4	
1976		7.8			30.4	
1977		7.9			30.3	
1978		8.0			30.3	
1979		8.2			30.3	
1980	7.9	8.3	5.06	29.2	30.4	4.11
1981		8.4			30.2	
1982		8.5			30.1	
1983		8.6			30.1	
1984		8.7			30.0	
1985		8.8			29.9	
1986		8.8			29.9	
1987		8.8			29.9	
1988		8.9			29.8	
1989		8.9			29.8	
1990		8.9			29.8	
1991		9.0			29.8	

Note N.K. average trip lengths (for all public transport modes) were derived from Newman and Kenworthy (1989) by weighting the passenger trips in each mode to its trips length.

N.K. Newman and Kenworthy (1989).

showed reasonable agreement. Over the period 1971 to 1991, LAND estimated a 94% increase in total passenger trips and a 99% increase in total passenger kilometres travelled in Adelaide. This matches the growth in private travel.

Table 4.10 shows average passenger trip length and travel speed for public transport in Adelaide. The average trip length increased from 7.0 in 1970 to 7.9 in 1980 (Newman & Kenworthy 1989). The average speed rose from 23.7 km/h to 29.2 km/h over the same period (Newman & Kenworthy 1989). There is reasonable agreement between the modelled and observed values.

4.3.3 Environmental assessment

Information on transport environmental outputs in the urban area of Adelaide is not generally available from the ABS. However, two years air emission data were estimated by the AEC (1976, 1985). These data include air pollution emissions and fuel consumption. There is no existing data on noise levels in Adelaide. Since observed noise data are not available. Comparison could not be made between LAND estimates and observed data. LAND provides the only estimates of noise levels L10(18-hour) on arterial roads and their distribution.

Table 4.11 shows estimates of daily motor vehicle emissions in Adelaide. The AEC (1976, 1985) showed that during the period 1976 to 1985, carbon monoxide emissions rose from 590,800 kg/day to 616 500 kg/day, hydrocarbons fell from 87 400 kg/day to 75 900 kg/day, and nitrous oxides rose from 39 700 kg/day to 54 300 kg/day. It can be seen that there is reasonable agreement between the LAND and AEC (1976, 1985) estimates.

Emissions of lead from motor vehicles were estimated by LAND using the same method as the AEC (1985). This involves using estimated leaded-petrol usage and lead content level in leaded-petrol. It was assumed that 65% of the lead in petrol was emitted to the atmosphere. The lead content of unleaded petrol was assumed negligible. Table 4.12 shows the daily lead emission from motor vehicles in Adelaide.

TABLE 4.11 ADELAIDE DAILY EMISSIONS FROM MOTOR VEHICLES, 1971–91

10^3 kg/day

	Carbon monoxide			*Hydrocarbons*			*Nitro oxides*		
	AEC	*LAND*	*Per cent error*	*AEC*	*LAND*	*Per cent error*	*AEC*	*LAND*	*Per cent error*
1971		475.9			73.9			33.4	
1972		494.7			76.8			34.7	
1973		515.8			80.0			36.0	
1974		529.4			82.0			36.9	
1975		555.8			85.9			38.6	
1976	590.8	582.8	–1.35	87.4	84.0	–3.89	39.7	38.6	–2.77
1977		583.3			82.7			40.2	
1978		590.9			83.7			41.8	
1979		593.3			83.2			43.0	
1980		607.8			85.0			45.2	
1981		608.6			83.0			45.8	
1982		611.1			83.1			47.3	
1983		613.5			83.3			48.9	
1984		622.7			83.3			50.5	
1985	616.5	617.2	0.11	75.9	75.6	–0.40	54.3	53.1	–2.21
1986		636.5			77.7			54.8	
1987		641.3			79.0			56.4	
1988		648.6			80.3			57.8	
1989		652.4			81.5			59.4	
1990		655.1			82.6			61.1	
1991		658.4			83.8			62.7	

AEC Australian Environmental Council (1976, 1985)

TABLE 4.12 ADELAIDE DAILY LEAD EMISSIONS FROM PETROL-ENGINE VEHICLES, 1971–91

kgs/day

	Daily lead emissions (kg)				
	AEC	*LAND*	*Percentage error*	*Lead in leaded petrol (g/L)*	*Percentage of lead emitted to air*
1971		839		0.79	65
1972		871		0.79	65
1973		907		0.79	65
1974		930		0.79	65
1975		974		0.79	65
1976	1137	1033	–9.15	0.79	65
1977		1038		0.79	65
1978		1069		0.79	65
1979		1081		0.79	65
1980		1121		0.70	65
1981		1011		0.70	65
1982		1029		0.70	65
1983		1039		0.70	65
1984		1057		0.70	65
1985	989	984	–0.50	0.65	65
1986		1003		0.65	65
1987		984		0.65	65
1988		963		0.65	65
1989		938		0.65	65
1990		910		0.65	65
1991		877		0.65	65

AEC Australian Environmental Council (1976, 1985)

Table 4.13 shows the daily total fuel consumption of motor vehicles in Adelaide. LAND uses different methods from AEC (1976, 1985) to estimate fuel consumption. AEC (1976, 1981) estimates were based on total vehicle kilometres travelled and the rate of fuel consumption, while LAND estimates were based on link traffic flow and unit distance travel time on that link as described in Section 3.4. The AEC (1985) estimates that on average, 2 356 000 litres/day of petrol, 397 000 litres/day of diesel and 82 700 litres/day of liquid petroleum gas were consumed in Adelaide. It can be seen that the comparison of the LAND and AEC (1976, 1985) estimates is acceptable.

Noise levels on the road network are provided by LAND. There is, however, no readily available data to compare the model estimates with. The general trend in LAND's prediction will only be reviewed. Figure 4.5 shows the base year noise levels L10 (18-hour) on Adelaide arterial roads. Table 4.14 presents estimated noise level L10 (18-hour) on the Adelaide arterial roads from 1971 to 1991. It

TABLE 4.13 ADELAIDE DAILY FUEL USE FROM MOTOR VEHICLES , 1971–91

10^3 *litres/day*

	Petrol			*Diesel*			*LPG*		
	AEC	*LAND*	*Percent error*	*AEC*	*LAND*	*Percent error*	*AEC*	*LAND*	*Percent error*
1971		1633.8			352.3			53.6	
1972		1696.9			365.7			55.7	
1973		1766.8			380.5			58.0	
1974		1811.4			390.0			59.5	
1975		1896.8			407.9			62.2	
1976		2011.4			288.4			69.0	
1977		2020.9			332.5			70.3	
1978		2081.4			345.9			72.4	
1979		2105.4			353.6			73.1	
1980		2183.4			370.9			75.8	
1981		2222.5			335.4			76.9	
1982		2261.3			345.4			78.2	
1983		2284.1			355.8			78.9	
1984		2323.8			366.4			80.3	
1985	2365.0	2327.9	–1.57	397.0	378.0	–4.79	82.7	80.6	–2.54
1986		2762.9			389.7			83.7	
1987		2733.4			404.5			86.9	
1988		2699.5			419.7			90.4	
1989		2655.3			435.4			93.8	
1990		2604.9			452.0			97.4	
1991		2545.3			468.7			101.1	

Note Petrol estimates (LAND) after 1986 included both leaded and unleaded petrol.

AEC Australian Environmental Council (1976, 1985)

can be seen that the length of road with noise levels over 68 dBA (L10 (18-hour)) increased by 53% over the period 1971 to 1991.

4.4 REMARKS ON ADELAIDE STUDY

The study showed that the model could replicate data describing city growth over a 20 year period.

TABLE 4.14 LAND ESTIMATED NOISE LEVEL L10 (18-HOUR) DISTRIBUTION ON ADELAIDE ARTERIAL ROADS, 1971–91

(per cent road length)

	>72 dBA	*68–72 dBA*	*64–68 dBA*	*59–64 dBA*	*<=59 dBA*
1971	5.5	20.1	19.7	16.6	38.1
1972	5.6	20.3	20.0	16.3	37.8
1973	6.3	19.7	20.0	18.0	36.0
1974	7.0	20.1	20.6	15.4	36.9
1975	7.9	19.5	20.7	15.3	36.7
1976	8.5	19.6	20.1	15.0	36.9
1977	9.5	18.9	20.3	14.9	36.4
1978	9.9	18.7	22.0	14.3	35.1
1979	10.4	18.6	22.0	14.2	34.8
1980	11.4	18.2	22.4	13.4	34.6
1981	11.5	18.3	23.1	13.3	33.9
1982	12.6	17.8	23.3	12.7	33.6
1983	14.1	17.5	23.4	11.7	33.3
1984	14.1	18.3	24.5	13.0	30.1
1985	14.7	20.1	21.3	13.3	30.6
1986	16.1	19.3	21.3	14.0	29.3
1987	16.1	19.7	21.0	14.1	29.1
1988	16.8	19.6	21.2	13.9	28.6
1989	17.4	19.9	21.8	13.5	28.4
1990	18.1	19.9	22.6	11.9	27.5
1991	19.6	19.5	22.3	11.1	27.5

dBA Unit of sound pressure level.

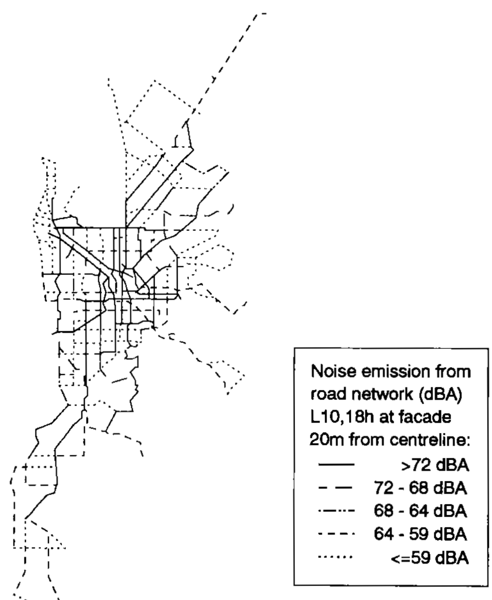

Figure 4.5 Estimated L10 (18-hour) noise levels on Adelaide arterial roads

CHAPTER 5 VERIFICATION OF LAND: THE MELBOURNE STUDY

Chapter 4 verified the LAND model using data from Adelaide. This chapter presents a similar study using data from Melbourne for the period 1971 to 1991. Melbourne is a different size to Adelaide and offers the opportunity to compare the models prediction for different sized cities.

5.1 DATA REQUIREMENTS FOR MELBOURNE

As stated in the Adelaide study, a major task in the developing a representation of a city is the data collection and input for the base year (for simulation) and some of other years (for verification). There are five types of input data in LAND:

- Set variables;
- Link type variables;
- Transport networks;
- LGA zone boundaries; and
- Demographic data.

Each of these will be discussed in the following subsections

5.1.1 Set variables

The setting variables are the basic parameters required by LAND to run the simulation. The variable included in the set variables option were outlined in subsection 4.1.1. The base year setting variables for Melbourne are shown in appendix I.

5.1.2 Link type variables

Link type data are the description of the characteristics of the transport links. The types of data required by this option were outlined in subsection 4.1.2. The link type variables for Melbourne are shown in appendix II.

5.1.3 Transport networks

Two separated transport networks were coded for Melbourne. They are the road network and the public transport network. They were coded from Melbourne Urban Street Directory (Melway, 1971) and a Melbourne Public Transport Map.

The Melbourne road network (figure 5.1) consists a total of 71 roads, 258 intersections and 762 one way links (classified according to road type). The public transport network (figure 5.2) consists a total of 41 routes, 214 interchange stops and 500 one way links (classified by bus route, tram route and railway line). Both these networks are less comprehensive than that specified for Adelaide.

5.1.4 LGA zone boundaries

There were 56 local government areas (LGAs) in Melbourne in 1971. This is considerable higher than present in Adelaide. All were considered in this study and are shown in table 5.1. Figure 5.3 shows the coded Melbourne LGA boundaries for this study.

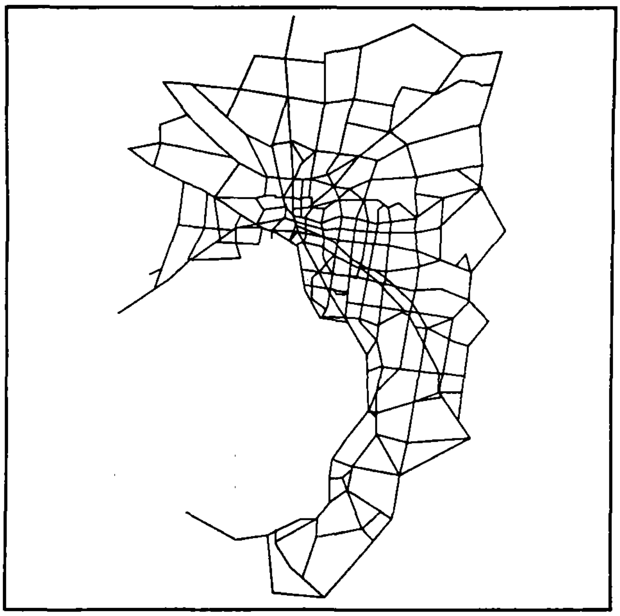

Figure 5.1 Melbourne road network

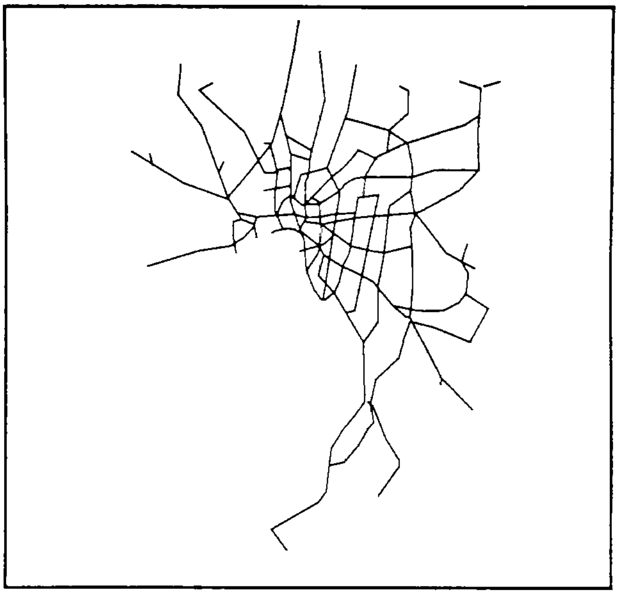

Figure 5.2 Melbourne public transport network

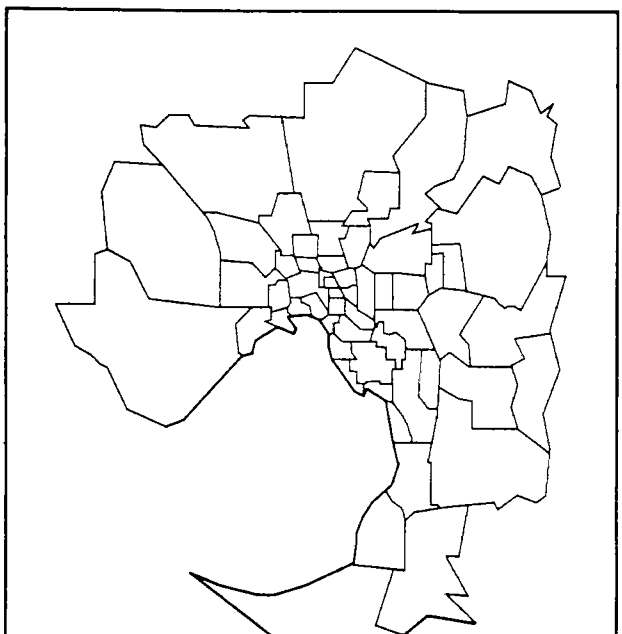

Figure 5.3 Melbourne LGA boundaries

TABLE 5.1 MELBOURNE LOCAL GOVERNMENT AREAS, 1971

Local government areas	*Areas (km^2)*
Altona	41.75
Berwick	130.19
Box Hill	22.11
Brighton	13.27
Broadmeadows	68.52
Brunswick	12.16
Bulla	403.18
Camberwell	34.14
Caulfield	20.34
Chelsea	22.93
Coburg	17,92
Collingwood	5.97
Cranbourne	344.22
Croydon	32.58
Dandenong	38.91
Diamond Valley	74.74
Doncaster and Templestowe	87.75
Eltham	259.62
Essendon	15.26
Fitzroy	3.42
Flinders	398.38
Footscray	17.84
Frankston	92.66
Hastings	256.77
Hawthorn	9.73
Healesville	283.19
Heidelberg	30.61
Keilor	99.44
Kew	14.33
Knox	108.72
Lilydale	373.05
Malvern	19.15
Melbourne	31.17
Melton	424.71
Moorabbin	50.85
Mordialloc	12.07
Mornington	117.84
Northcote	17.72
Nunawading	41.22
Oakleigh	31.58
Pakenham	133.6
Port Melbourne	9.74
Prahran	9.69
Preston	39.3
Richmond	5.93
Ringwood	22.45
St. Kilda	8.5
Sandringham	17.46
Sherbrooke	174.66
South Melbourne	12.47
Springvale	94.34
Sunshine	78.69
Waverley	62.1
Werribee	621.38
Whittlesea	538.64
Williamstown	14.45

TABLE 5.2 MELBOURNE LAND USE INFORMATION FROM THE CENSUS, 1971–91

	1971	*1976*	*1981*	*1986*	*1991*[a]
Population	2 503 450	2 604 035	2 722 817	2 832 893	3 150 000
Houses	773 854	860 639	947 424	1 034 209	
Occupied houses	734 862	813 402	897 407	957 225	
Employment	1 074 788	1 158 386	1 219 546	1 257 478	
Unemployment	17 267	42 622	69 852	88 398	
Work force	1 092 055	1 201 088	1 289 398	1 345 876	
Jobs available	1 074 788	1 158 386	1 219 546	1 257 478	

a. Estimated population since 1991 census was not available.

5.1.5 Demographical data

The demographic information was obtained from the ABS (1971, 1976, 1981, 1986). The zonal information required for input are:

- houses in three house types;
- households in house types; and
- available jobs.

Table 5.2 shows Melbourne land use information from 1971 to 1991. Like Adelaide there has been an increase in population, housing employment and unemployment during the period 1971 to 1986. Melbourne is approximately two and a half time the size of Adelaide.

5.2 VERIFICATION OF MELBOURNE RESULTS

The LAND model has been verified by applying the model to Melbourne. The parameters of the model are estimated during the verification. The verification consists of three aspects:

- land use information;
- travel pattern; and
- environmental assessment.

Each of these will be discussed in turn.

5.2.1 Land use information

The demographic information was obtained from the ABS. Information was required on the three major model inputs: available houses, available jobs and households. The available houses and jobs were input into the model and are used as constraints. The households were input and the setting variables used to determine the population and employment.

House information

Table 5.3 presents the number of dwellings in Melbourne for the study years. It does not include holiday houses, since these are usually second homes, and a proportion of the households where the residents were temporarily absent. It can be seen (table 5.3) that there was a 33 percent increase (260 255 dwellings) in the number of dwellings between 1971 and 1986. At the time of this study the 1991 census was not available. However since data was available for travel and environmental outputs in 1991 the model was run for a period 1971 to 1991. The change in housing between 1981 and 1986 was assumed to continue until 1991. The number of houses input into the model for the years 1971 to 1986 matches that of the census. Between 1986 and 1991 it was assumed there was a net increase of 86 735 dwellings in Melbourne.

Not all the houses in the urban area are occupied. Some may be in the process of being sold, may not be let or may be vacant for repairs. Table 5.4 presents the number of occupied dwellings for the study period. The vacancy rate shows that there has been a small but steady increase in the proportion unoccupied dwellings between 1971 and 1986.

TABLE 5.3 TOTAL NUMBER OF HOUSES IN MELBOURNE STUDY AREA, 1971–91

	Census estimates	*Model estimates*	*Percentage error*
1971	773 854	773 854	0
1972		791 211	
1973		808 568	
1974		825 925	
1975		843 282	
1976	860 639	860 639	0
1977		877 996	
1978		895 353	
1979		912 710	
1980		930 067	
1981	947 424	947 424	0
1982		964 781	
1983		982 138	
1984		999 495	
1985		1 016 852	
1986	1 034 209	1 034 209	0
1987		1 051 566	
1988		1 068 923	
1989		1 086 280	
1990		1 103 637	
1991		1 120 994	

Note Census estimates from ABSVIC (1971, 1976, 1981, 1986).

TABLE 5.4 CENSUS ESTIMATES OF MELBOURNE OCCUPIED DWELLINGS DURING STUDY PERIOD, 1971–86

	Occupied dwellings	*Proportion of unoccupied dwellings*
1971	734 862	0.95
1976	813 402	0.95
1981	892 407	0.94
1986	957 225	0.93

Note Census estimates from ABSVIC (1971, 1976, 1981, 1986).

Households

Table 5.5 show the census figures and the model estimates of the number of households. The number of households in Melbourne rose from 734 862 in 1971 to 957 225 in 1986. The number of households in the census match the number of occupied dwellings predicted by LAND. The level of error in the prediction varied between 0.6 and 1.5 percent.

The household information is transformed into population measures in the model. Table 5.6 presents the census and model population estimates. It can

TABLE 5.5 HOUSEHOLD ESTIMATES FOR MELBOURNE, 1971–91

	Census estimates	*Model estimates*	*Percentage error*
1971	734 862	745 791	1.5
1972		767 412	
1973		784 620	
1974		798 969	
1975		811 781	
1976	813 402	825 863	1.5
1977		838 648	
1978		857 454	
1979		872 255	
1980		889 002	
1981	897 407	905 100	0.9
1982		916 488	
1983		930 943	
1984		943 829	
1985		956 050	
1986	957 225	965 263	0.8
1987		983 177	
1988		1 001 169	
1989		1 013 940	
1990		1 025 936	
1991		1 037 520	

Note Census estimates from ABSVIC (1971, 1976, 1981, 1986).

TABLE 5.6 POPULATION ESTIMATES FOR MELBOURNE, 1971–91

	Census estimates	*Model estimates*	*Percentage error*
1971	2 503 450	2 452 646	–2.0
1972		2 534 563	
1973		2 567 533	
1974		2 601 197	
1975		2 617 380	
1976	2 604 035	2 634 153	1.1
1977		2 657 851	
1978		2 680 505	
1979		2 714 367	
1980		2 734 420	
1981	2 722 817	2 748 908	1.0
1982		2 776 730	
1983		2 797 180	
1984		2 811 503	
1985		2 822 683	
1986	2 832 893	2 849 274	0.6
1987		2 882 360	
1988		2 930 934	
1989		2 990 506	
1990		3 048 861	
1991	3 150 000	3 106 722	–1.4

Note Census estimates from ABSVIC (1971, 1976, 1981, 1986).

be seen that the population in Melbourne rose from 2 503 450 in 1971 to an estimated 3 150 000 in 1991. This represents a drop in persons per household from 3.4 in 1971 to 3.0 in 1986. Comparison of the census estimates and LAND estimates shows acceptable agreement between the two values.

Available jobs

The number of available jobs for the census years 1971 to 1991 are shown in table 5.7. They range from 1 074 788 in 1971 to 1 257 478 in 1986. The model estimates and census estimates show acceptable agreement.

There will be a turnover in jobs and some jobs will remain vacant. Since no information was available on the proportion of free positions the number of employed people was assumed to be equal to the number of available jobs. The employment in the study area is presented in table 5.2. Table 5.8 presents a comparison of the total workforce predicted by the model and the census estimates. The difference is within 5 per cent.

TABLE 5.7 TOTAL AVAILABLE JOBS IN MELBOURNE STUDY AREA, 1971–91

	Census estimates	Model estimates	Percentage error
1971	1 074 788	1 074 747	0.0
1972		1 091 188	
1973		1 107 629	
1974		1 124 070	
1975		1 132 356	
1976	1 158 386	1 148 797	–0.8
1977		1 160 993	
1978		1 173 189	
1979		1 185 385	
1980		1 197 581	
1981	1 219 546	1 209 777	–0.8
1982		1 218 063	
1983		1 226 349	
1984		1 234 635	
1985		1 242 921	
1986	1 257 478	1 251 207	-0.5
1987		1 263 403	
1988		1 275 599	
1989		1 287 795	
1990		1 299 991	
1991		1 312 187	

Note Census estimates from ABSVIC (1971, 1976, 1981, 1986).

TABLE 5.8 WORK FORCE ESTIMATES FOR MELBOURNE, 1971–91

	Model estimates of employment	Model estimates of unemployment	Model estimates of work force	Census estimates	Percentage error
1971	1 074,747	17 338	1 092 085	1 092 055	0.0
1972	1 091 184	32 991	1 124 175		
1973	1 107 622	35 305	1 142 927		
1974	1 124 011	37 329	1 161 340		
1975	1 131 961	36 928	1 168 889		
1976	1 147 686	32 093	1 179 779	1 201 008	–1.8
1977	1 158 884	36 067	1 194 951		
1978	1 169 680	38 440	1 208 120		
1979	1 180 866	42 599	1 223 465		
1980	1 192 190	42 425	1 234 615		
1981	1 203 601	41 010	1 244 611	1 289 298	–3.5
1882	1 210 717	44 006	1 254 723		
1983	1 218 093	44 112	1 262 205		
1984	1 225 658	42 130	1 267 788		
1985	1 233 029	39 161	1 272 190		
1986	1 240 471	40 636	1 281 107	1 345 876	–4.9
1987	1 251 899	42 448	1 294 347		
1988	1 262 647	55 075	1 317 722		
1989	1 273 726	66 084	1 339 810		
1990	1 284 977	76 820	1 361 797		
1991	1 295 988	87 525	1 383 513		

Note Census estimates provide by ABS.

TABLE 5.9 PRIVATE VEHICLE TRIPS PER DAY IN MELBOURNE, 1971–91

	External estimates ($x10^6$)	*Model estimates ($x10^6$)*	*Percentage error*
1970	2.35[a]		
1971		2.27	
1972		2.30	
1973		2.41	
1974		2.47	
1975		2.54	
1976		2.58	
1977		2.70	
1978		2.80	
1979		2.95	
1980	3.01[a]	3.02	–0.3
1981		2.98	
1982		3.43	
1983		3.78	
1984		4.07	
1985		4.32	
1986		4.88	
1987		5.12	
1988		5.57	
1989		5.90	
1990		6.49	
1991	6.35[b]	6.61	4.3

a. Newman and Kenworthy (1989).
b. VicRoads, information obtained from Strategic Planning section (pers. comm.).

5.2.2 Travel pattern

Information on travel in the urban area of Melbourne is not as generally available as the demographic and dwelling data provided in the census. To enable model estimates of travel behaviour to be compared with independent estimates, data was collected from a number of sources. These sources were Newman and Kenworthy (1989), the Public Transport Corporation and VicRoads. Table 5.9 to 5.14 present the estimates obtained from these sources. The following discussion on the travel patterns will be divided into private and public transport. The discussion will focus on private vehicle kilometres, public transport trip kilometres, average trip speed and average trip distance. These variables are independent and provide a good basis for comparison, while allowing other variables like trips, trip hours and average trip time to be calculated.

Private transport

Table 5.9 to 5.11 present the observed and model estimates of private transport usage in Melbourne. Comparison between the Melbourne and Adelaide data shows that:

- there is approximately three times the number of vehicles trips in Melbourne than in Adelaide;
- that the average Melbourne trip length is slightly lower then that in Adelaide; and
- that vehicle speeds in Adelaide are slightly lower than those in Melbourne.

Table 5.9 presents estimates of the number of vehicle trips made by private vehicles. The number of trips has increased from 2.35 x 10^6 trips in 1970 to 6.35 x 10^6 trips in 1991. This represents over a two fold increase. This is markedly higher than the rate of population growth in Melbourne and indicates that the trip generation rate has increased over the study period. The model estimates can be seen to agree with the estimates obtained from VicRoads and Newman and Kenworthy (1989).

The average speed of vehicles in Melbourne is shown in table 5.10. It can be seen that this has dropped from 48.2 km/hr in 1970 to 43.0 km/hr in 1991. The model estimates agree with this range for the period 1970 to 1980. The model predicts a travel speed 13.8 precent lower than the VicRoads estimate for 1991. This is primarily due to the use of a 1971 road and public transport network for

TABLE 5.10 PRIVATE VEHICLE AVERAGE TRIP SPEED IN MELBOURNE, 1971–91

	External estimates (km/h)	Model estimates (km/h)	Percentage error
1970	48.2[a]		
1971		48.0	
1972		46.3	
1973		47.7	
1974		46.8	
1975		47.0	
1976		47.1	
1977		46.6	
1978		46.1	
1979		46.5	
1980	47.5a	47.6	0.2
1981		46.1	
1982		43.0	
1983		42.9	
1984		40.6	
1985		40.3	
1986		39.4	
1987		38.5	
1988		37.8	
1989		37.3	
1990		35.6	
1991	43.0[b]	37.1	–13.8

a. Newman and Kenworthy (1989).

b. VicRoads, information obtained from Strategic Planning section (pers. comm.).

TABLE 5.11 PRIVATE VEHICLE AVERAGE TRIP LENGTH IN MELBOURNE, 1971–91

	External estimates (km)	*Model estimates (km)*	*Percentage error*
1970	12.3[a]		
1971		12.6	
1972		12.5	
1973		12.5	
1974		12.6	
1975		12.8	
1976		13.0	
1977		12.7	
1978		13.3	
1979		13.6	
1980	14.4[a]	14.1	–2.3
1981		13.6	
1982		13.4	
1983		13.1	
1984		13.0	
1985		12.9	
1986		13.0	
1987		12.6	
1988		12.7	
1989		12.4	
1990		12.1	
1991	11.2[b]	11.7	4.5

a. Newman and Kenworthy (1989).
b. VicRoads, information obtained from Strategic Planning section (pers. comm.).

the Melbourne study. A more recent network would have higher capacity and higher speeds. The specification of the network will be discussed further in the following sections.

Table 5.11 presents the average trip length for private vehicles in Melbourne. The estimates from Newman and Kenworthy (1989) increase from 12.3 km in 1970 to 14.4 in 1980. The VicRoads estimate in 1991 was 11.2, lower than both of the earlier estimates. The model estimates a steady increase in travel distance from 1971 to 1980. Between 1981 and 1991 the average travel distance fell. The 1980 model estimate is similar to that obtained from Newman and Kenworthy (1989) while the 1971 and 1991 models estimates would appear to be overestimates.

Public transport

Table 5.12 to 5.15 summarise the comparison of the model predictions with estimates from other sources for public transport. Comparison of the external estimates for Melbourne and Adelaide indicate:

TABLE 5.12 PUBLIC TRANSPORT PASSENGER TRIPS PER DAY IN MELBOURNE, 1971–91

	Estimates *(x10⁶)*	*Model estimates* *(x10⁶)*	*Percentage error*
1970	0.91[a]		
1971		0.87	
1972		0.90	
1973		0.76	
1974		0.76	
1975		0.63	
1976		0.66	
1977		0.56	
1978		0.59	
1979		0.53	
1980	0.63[a]	0.57	–9.6
1981		0.50	
1982		0.52	
1983		0.57	
1984		0.61	
1985		0.61	
1986		0.65	
1987		0.64	
1988		0.74	
1989		0.66	
1990		0.70	
1991	0.69[b]	0.65	–5.8

a. Newman and Kenworthy (1989).
b. VicRoads, information obtained from Strategic Planning section (pers. comm.).

- there are approximately three times as many public transport trips in Melbourne than Adelaide;
- public transport trips in Adelaide appear to be rising while those in Melbourne are decreasing;
- public transport trips in Melbourne are approximately fifty percent longer than those in Adelaide; and
- public transport speeds in the two cities are comparable.

Table 5.12 presents the total number of trip kilometres made by public transport passengers. It can be seen that it has declined from 0.91 x 10^6 trip kilometres 1971 to 0.69 x 10^6 trip kilometres in 1991. The model estimates are consistent with this trend.

Table 5.13 presents the trip speed for public transport for the period 1971 to 1991. It can be seen that the public transport trip speed in lower than that for private transport. It rises from 28.7 km/h in 1970 to 34.5 in 1991. The model replicates this trend between 1971 and 1980. The travel speed for 1991

TABLE 5.13 PUBLIC TRANSPORT PASSENGER TRIP SPEED IN MELBOURNE, 1971–91

	Estimates (km/h)	*Model estimates (km/h)*	*Percentage error*
1970	28.7[a]		
1971		30.3	
1972		29.9	
1973		29.1	
1974		28.4	
1975		27.7	
1976		27.3	
1977		26.3	
1978		26.4	
1979		26.0	
1980	27.8[a]	26.5	–4.7
1981		25.5	
1982		24.5	
1983		23.9	
1984		23.6	
1985		23.1	
1986		22.6	
1987		21.9	
1988		21.8	
1989		20.8	
1990		20.0	
1991	35.4[b]	19.7	–44.0

a. Newman and Kenworthy (1989).
b. VicRoads, information obtained from Strategic Planning section (pers. comm.).

predicted by the model is considerable lower than the Public Transport Corporation's estimations. This discrepancy is likely to be due to the use of the 1971 public transport network in 1991. The need to update the transport network over the period of the study is clearly illustrated by these results. The need for an accurate description of the network is discussed further in chapter 6.

Table 5.14 presents the trip length for public transport for Melbourne. It ranges from 11.2 km in 1970 to 13.4 km in 1991. LAND replicates this trend.

5.2.3 Environmental assessment

Like Adelaide, information on environmental outputs from the transport system in Melbourne are not readily available. Appropriate data were only available for 1991. These data were obtained from VicRoads and the Office of Environment. There is a likelihood that more data will become available in the future but it is unlikely that accurate data prior to 1991 will become available.

The environmental assessment will only consider total fuel consumption and emissions. It is not possible to look at other measures due to the lack of data. Table 5.15 and 5.16 present the results.

TABLE 5.14 PUBLIC TRANSPORT PASSENGER TRIP LENGTH IN MELBOURNE, 1971–91

	Estimates (km)	*Model estimates (km)*	*Percentage error*
1970	11.2[a]		
1971		11.7	
1972		11.6	
1973		11.1	
1974		11.0	
1975		10.5	
1976		11.0	
1977		10.9	
1978		11.6	
1979		12.0	
1980	13.0[a]	12.7	–2.4
1981		12.3	
1982		12.0	
1983		11.9	
1984		11.9	
1985		12.3	
1986		12.8	
1987		13.0	
1988		13.5	
1989		13.7	
1990		13.5	
1991	13.4[b]	13.4	0.0

a. Newman and Kenworthy (1989).
b. VicRoads, information obtained from Strategic Planning section (pers. comm.).

TABLE 5.15 PETROL CONSUMPTION IN MELBOURNE, 1991

Measure	*Modelled*	*Observed*	*Percentage error*
Total fuel consumed (litres per day 10^6)	6.04	6.14 [a]	–1.6

a. The observed measures of fuel consumption were obtained from VicRoads (pers. comm.)

TABLE 5.16 EMISSIONS IN MELBOURNE, 1991

Measure (10^3 kg/day)	Modelled	Observed	Percentage error
Total emissions of carbon monoxide	296.1	300.0 [a]	–1.3
Total emissions of oxides of nitrogen	76.1	77.80 [a]	–3.2
Total emissions of hydrocarbons	14.9	14.63 [a]	–1.8

a. The observed measures of emissions in this table were obtained from VicRoads (pers. comm.)

Fuel consumption

Table 5.15 presents the total fuel consumption for Melbourne for 1991. VicRoads estimated that the total fuel consumed in Melbourne was 6.14 x 10^6 litres per day. This is approximately three times as great as that used in Adelaide. LAND predicted that 5.97 x 10^6 litres per day would be used. This is within acceptable limits of accuracy.

Emissions

The carbon monoxide, nitrogen oxides and hydrocarbon emissions for Melbourne are shown in table 5.16.

Comparison of the Adelaide and Melbourne data shows that:

- the carbon monoxide estimated provided for Melbourne by the Office of Environment are approximately half those provided for Adelaide;
- the nitrogen oxide estimates for Melbourne are approximately 20 percent higher than those for Adelaide; and
- the hydrocarbon estimates for Melbourne are approximately 20 percent of those obtained for Adelaide.

These differences cast some doubt on the observed estimates. The LAND model was able to replicate the Melbourne estimates. However, it is suggested that further research into the accuracy of the two sources be carried out before the parameter values to be used in LAND are finalised.

5.3 REMARKS ON MELBOURNE STUDY

This chapter has briefly described the verification of the LAND model using data from Melbourne. The study showed that the model could replicate data describing the cities growth over a 20 year period.

CHAPTER 6 APPLICATION OF LAND TO A HYPOTHETICAL CITY: THE CANBERRA STUDY

Chapters 4 and 5 compared the LAND model predictions with data describing land use, transport and environment patterns in Adelaide and Melbourne. It indicated that the model could be calibrated to predict land use, transport and environment changes in urban areas. The third part of this study was to apply the model to a hypothetical city and to compare the estimates of land use, transport and environmental activity for a number of growth scenarios. This could not be carried out using the calibrated Adelaide and Melbourne models since these were not complete when the application started. Further, it was considered that the application of LAND to a city of a different size to Adelaide and Melbourne could provide further insight into its robustness.

The application of LAND was, therefore, carried out by obtaining data, from ABS and the Australian Capital Territory Planning Authorities, for Canberra and its predicted growth over the period 1981 to 2001. A further dimension to this exercise was introduced since the study was not carried out by the developers of LAND, but was undertaken by a number of students from the Australian Defence Force Academy (ADFA). This provided an indication of the reaction of novice users to the software. The study reported in this chapter was carried out by three student groups. The groups were:

- Major Michael Healy, Captain Dechlan Ellis and Anton Kandiah (group 1);
- Anthony Farrel, Stephen Fester, George Yacoub and Graham Tippets (group 2); and
- Lieutenant Commander John Jacobi, Captain Kerry Marshall and Captain Ian Stoppard (group 3).

The reporting of the results consists of taking one of the studies (group 1) and reporting it in sections 6.1 to 6.3 in some detail. These are compared with the results obtained from the other two groups in section 6.4.

6.1 BASE VARIABLE SETTINGS FOR CANBERRA STUDY

LAND provides the opportunity to vary the base parameters describing the urban area being studied. The process of calibration and verification carried out in chapters 4 and 5 indicate how this can be carried out. The student study of Canberra was simplified to avoid undue workload being placed on the students. The major simplification was to provide the students with a set of base variable values (appendix I) and link descriptions (appendix II). Students could change these if they wished but it was suggested that they hold them constant. Some student groups carried out a number of sensitivity tests using these variables.

6.2 DEVELOPMENT OF CANBERRA NETWORK AND STRATEGIES

The data, obtained from ABS provided information on 82 suburbs. This data was provided to the students. However, running the model at this level of detail would have increased the workload on the students to an inappropriate level and defeated the general educational philosophy built into LAND. Future applications of LAND at this finer detail may, however, be a useful exercise.

Group 1 aggregated the data on the 82 suburbs into 10 zones (see figure 6.1). Ten zones provided an appropriate level of detail for the student application of

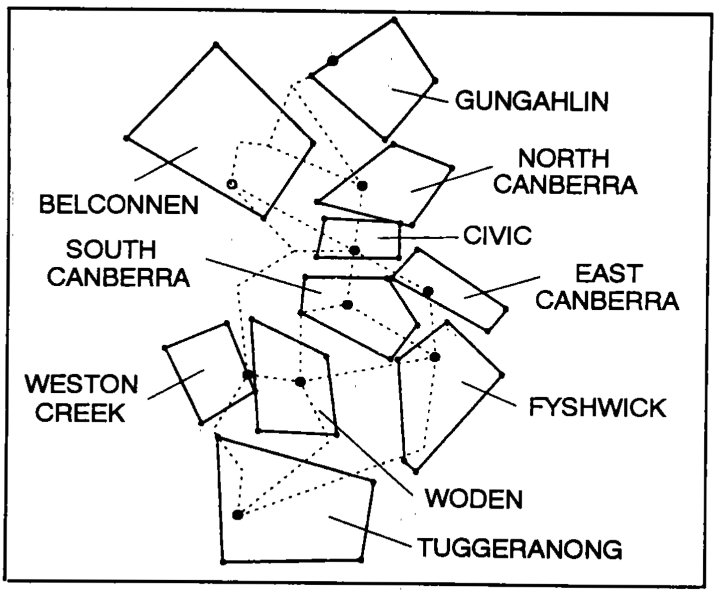

Figure 6.1 Canberra zonal pattern used by student group 1

TABLE 6.1 BASIC ZONAL INFORMATION FOR CANBERRA USED BY GROUP 1

Zone	*Area (km^2)*	*Population 1981*	*Jobs available 1981*
Belconnen	48.45	80 127	14 448
North Canberra	16.73	34 128	4 719
Civic	9.24	9 283	22 4547
South Canberra	18.66	25 968	18 230
Woden	21.13	39 471	12 936
Fyshwick	25.80	832	8 713
Tuggeranong	47.01	29 100	1 454
East Canberra	10.75	5 096	9 713
Weston Creek	16.34	29 112	2 541
Gungahlin	21.23	291	798
Total	235 34	253 408	96 099

Source ABSACT (1981).

TABLE 6.2 NETWORK DESCRIPTION FOR CANBERRA USED BY GROUP 1

Road	
Zone centroids	10
Centroid connectors	1
Nodes	20
Roads	18
Links	27
Public transport	
Zone centroids	10
Centroid connectors	0
Nodes	14
Roads	14
Links	14

LAND. The basic zone information is presented in table 6.1. Although the zones were not equal in size they were encompassed by natural boundaries. Importantly, the study did not take into account the population of Queanbeyan and its effect on the Canberra employment market and therefore could not be considered an accurate study of Canberra.

The road network (figure 6.2 and table 6.2) was represented by a total of 20 nodes, 18 roads and 27 links. The capacity of each road is modelled as the road capacities in 1993. No attempt was made to improve the road network throughout the modelling period. The public transport network (figure 6.3 and table 6.2) was represented by 14 nodes, 14 roads and 14 links. Both networks are relatively simplistic.

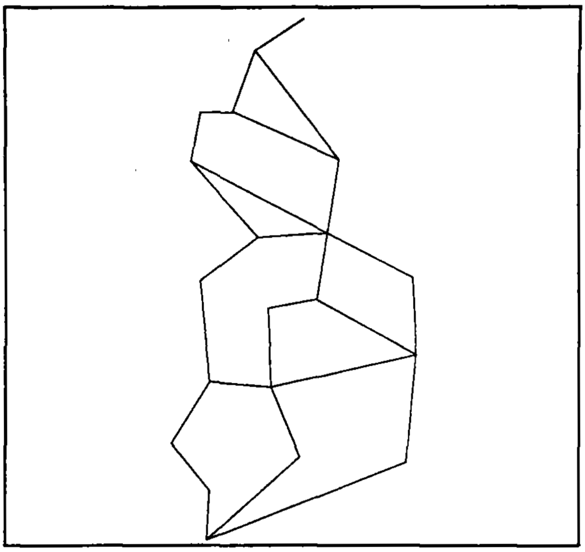

Figure 6.2 Canberra road network used by group 1

Overlaid on the zone and transport network is demand information. The land use information for the year 1981 is presented in table 6.3. The housing ranged from a low of 79 in Gungahlin to a high of 22 437 in Belconnen. The distribution of households was similar to that of houses. There was a high of 24 171 households in Belconnen and a low of 87 households in Gungahlin. Jobs were located primarily in Civic (22 547) with a few jobs in Gungahlin (798).

Changes in the land use pattern, due to house building, job increases and household migration, were assumed to take place after the 1981, base year. The changes used in the study are presented in table 6.4. The housing, jobs and in-migration were assumed to grow slowly between 1982 and 1984 and stabilise at over 3 000 houses, 4 000 jobs and 1 000 migrating households per year between 1984 and 2001.

To investigate the predictions made by LAND several strategies were chosen. The strategies chosen by student group 1 were:

Do-nothing strategy

The do-nothing option involved the running of the model for 20 years without inputting any growth in housing or jobs, and without any migration into or out of

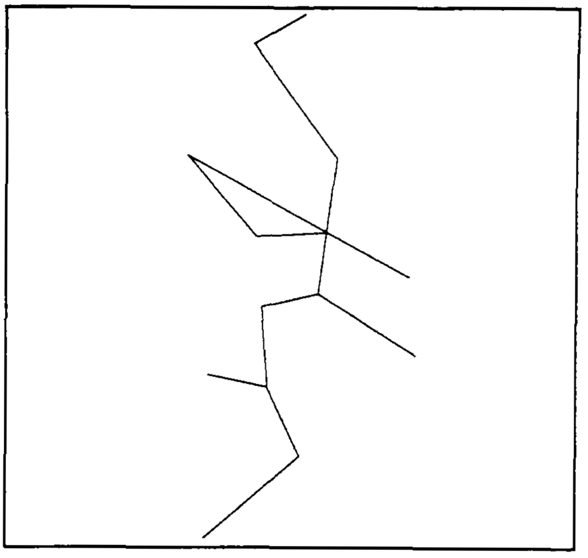

Figure 6.3 Canberra public transport network used by group 1

TABLE 6.3 BASE YEAR LAND USE INFORMATION FOR CANBERRA, 1981

Zone name	*Housing*	*Work force*	*Households*
Belconnen	22 437	14 918	24 171
North Canberra	9 817	4 919	10 295
Civic	2 742	22 601	2 800
South Canberra	7 342	18 382	7 833
Woden	11 007	13 167	11 907
Fyshwick	265	8 717	251
Tuggeranong	8 126	1 625	8 778
East Canberra	1 482	9 742	1 537
Weston Creek	8 152	2 712	8 782
Gungahlin	79	798	87
Total	71 449	97 581	76 441

Source ABSACT (1981).

TABLE 6.4 GROWTH IN CANBERRA LAND USE FOR PERIOD 1981 TO 2001

	Housing	*Jobs*	*Households*
1981	0	0	0
1982	550	600	155
1983	550	600	155
1984	2 310	4 600	1 200
1985	3 070	4 600	1 450
1986	3 070	4 600	1 450
1987	3 070	4 600	1 300
1988	3 070	4 600	1 300
1989	3 070	4 600	1 250
1990	3 310	4 300	1 250
1991	3 310	4 300	1 140
1992	3 310	4 300	1 140
1993	3 310	4 300	1 140
1994	3 310	4 300	1 140
1995	3 310	4 300	1 140
1996	3 310	4 300	1 140
1997	3 310	4 300	1 140
1998	3 310	4 300	1 140
1999	3 310	4 300	1 140
2000	3 310	4 300	1 140
2001	3 310	4 300	1 140

Canberra. The option provided a base for the comparison of the other strategies.

Centralise option

In the centralised option, all growth in housing and jobs was put in one zone, namely Civic, for each of the 20 non-base years. No limit was set on the number of houses that could be located in this zone. Although this is unrealistic it served to demonstrate the transport and environmental trends that would be present under this type of strategy.

Decentralised strategy

In the decentralised strategy, all growth in housing and jobs was divided between three outer zones, namely Belconnen, Gungahlin, and Tuggeranong. It was assumed that the percentage of total growth in housing and jobs is spread over each of these zones. The growth was varied over time in five year increments over the 20 year period. The distribution used is shown in table 6.5.

This strategy is more realistic than the centralised option although it is still an extreme. It serves to illustrate the opposite extreme to the centralised option.

TABLE 6.5 GROWTH SPLITS IN CANBERRA FOR THE DECENTRALISED OPTION BY GROUP 1

(Percentage of total growth)

	1982–86	*1987–91*	*1992–96*	*1997–2001*
Belconnen	30	30	20	20
Gungahlin	0	0	40	60
Tuggeranong	70	70	40	20
Total	100	100	100	100

TABLE 6.6 GROWTH SPLIT IN CANBERRA CHOSEN BY GROUP 1 FOR DEVELOPMENT STRATEGY

Zone	*Growth (Percentage of total growth)*
Civic	30
Belconnen	20
Woden	20
North Canberra	10
South Canberra	10
South Canberra	10
Total	100

Development option

Each group was allowed to develop a proposed strategy for Canberra and compare this to the other three strategies. Group 1 chose the growth splits shown in table 6.6.

Group 1 chose this strategy since it aimed to:

- encourage strong growth in housing and jobs in the Civic zone;
- recognise that there will be continued growth in the regional centres in Belconnen and Woden;
- actively limit growth in Tuggeranong and Gungahlin to stop urban sprawl; and
- encourage moderate growth in the inner zones adjacent to Civic (i.e. north, south and east Canberra).

6.3 COMPARISON OF CANBERRA STRATEGIES

The comparison of the strategies by group 1 was carried out by investigating the land use, transport and environmental dimensions separately. The finding of group 1 are presented in the following subsections.

6.3.1 Land use comparisons.

LAND produces six outputs that can broadly be described as land use information. These outputs are the distribution of population, households, houses, jobs available, employment and unemployment. Only population and employment will be discussed in detail.

Population distribution

Canberra in 1981 had a population of approximately 250 000 people spread over an area of 235 km^2. The average density was therefore slightly more than 100 persons/km^2. Vast areas were unoccupied and therefore the average density tended to be misleading, but even so the maximum density of a zone was 1 868 persons/km^2. The results of modelling change over the period 1981 to 2001 for each strategy is shown in table 6.7.

The do-nothing option had little effect on population densities. The population grew slowly and the density grew proportionally in all zones, increasing by approximately 25 percent. It is notable that Gungahlin did not attract any increase in development with the population density remaining at about 10 percent of other dormitory areas such as Belconnen and Tuggeranong.

The centralised option increased the population in Civic from 9 200 in 1981 to over 225 000 in 2001. Although the 1981 density is low the 2001 density is unrealistically high. The model showed that as the Civic area grew the surrounding areas slowly declines.

The decentralised option resulted in strong growth in Belconnen and Tuggeranong. Belconnen increased from 80 000 to 132 000 and Tuggeranong from 29 000 to 106 000 over the 20 year period. The density of the two zones increased proportionally, and was approaching 2 000 persons/km^2 in Belconnen in 2001. Given that the overall zone density is similar to that of Central Melbourne it is unlikely that Belconnen would have the vast open spaces which it had in 1981. The impact on Civic and the surrounding north, south and east Canberra areas was minimal. The population of these areas fluctuated by up to 25 percent with an initial reduction in population but then returned to close to the 1981 figure after 20 years.

The development option resulted in a significant growth in Civic. The population increased from 9 200 to 68 800 with a commensurate increase in density from

TABLE 6.7 POPULATION CHARACTERISTICS IN CANBERRA IN 2001 FOR GROUP 1 FOR EACH STRATEGY

	Do-Nothing	*Centralised*	*Decentralised*	*Development*
Belconnen	98 080	73 092	132 226	108 940
North Canberra	40 765	26 750	31 725	50 053
Civic	13 021	225 350	9 311	68 800
South Canberra	33 990	19 361	24 040	42 332
Woden	53 257	29 986	38 011	74 339
Fyshwick	1 178	657	866	812
Tuggeranong	40 537	9 512	106 680	20 503
East Canberra	7 091	4 215	5 105	24 993
Weston Creek	40 148	26 665	27 632	24 687
Gungahlin	457	181	40 172	246
Total	328 524	415 769	415 768	415 765

1 005 to 7 445 persons/km^2. Unlike the centralised option the zones surrounding Civic also increased their population slightly, except for east Canberra. East Canberra's population increased by a factor of four to bring its density to a level similar to that of the other zones. The strategy also allowed the Belconnen area to increase its population slightly. Tuggeranong decreased progressively from 29 000 to 20 503.

Employment distribution

Canberra, in 1981, had 96 000 jobs available and this increased to 160 000 by 2001 in all but the do-nothing case. The four development strategies considered allocated these jobs to workers in different proportions (table 6.8).

The number of jobs allocated in the do-nothing case remained static throughout the study period. In 1981, 1 400 people were unemployed. With natural growth in population this increased to 16 300 by 2001.

The centralised option located new jobs in Civic, increasing the jobs available from 22 500 to 103 000 progressively over the 20 year period. The effect of this was to increase the density of jobs in Civic by more than ten times.

The decentralised option concentrated on the Belconnen, Tuggeranong and Mitchell/Gungahlin zones. Initially this had little effect on the traditional employment zones of Civic and east Canberra, but in the last quarter of the modelling period people were drawn from their jobs in these areas to take up jobs closer to where they live. As there was an oversupply of jobs from 1987, the jobs left vacant were those in the inner area. The model therefore clearly showed that people prefer to live and work in the same location.

TABLE 6.8 EMPLOYMENT CHARACTERISTICS IN CANBERRA IN 2001 FOR GROUP 1 FOR EACH STRATEGY

	Do-Nothing	*Centralised*	*Decentralised*	*Development*
Belconnen	14 448	14 448	34 268	28 175
North Canberra	4 719	4 006	4 719	11 775
Civic	22 547	102 947	16 626	43 070
South Canberra	18 230	13 443	18 230	24 245
Woden	12 936	12 936	12 936	26 779
Fyshwick	8 713	6 425	6 425	5 942
Tuggeranong	1 454	305	40 534	1 341
East Canberra	9 713	3 086	7 162	16 384
Weston Creek	2 541	2 541	2 541	2 345
Gungahlin	664	181	16 396	57
Total	95 965	160 318	159 837	160 113

The development option doubled the number of jobs in Civic, east Canberra, Belconnen and Woden. The jobs in the dormitory areas were all taken up.

6.3.2 Transport comparison

This section compares the three strategies with the do-nothing strategy based on transport implication. The daily travel characteristics, at the end of the 20 year period, for each strategy are shown in table 6.9. There was a linear change between 1981 and 2001.

Road network comparisons

As expected the centralised option has the lowest number of vehicles kilometres travelled, with a reduction of around 20 per cent from the do-nothing option. The real benefit of the centralised option in reducing total vehicle kilometres would be greater than this figure, as it includes growth, whereas the do-nothing option did not. This also applies to all further comparisons. The decentralised option almost doubles the total vehicles kilometres travelled compared to the do-nothing option. The development option reduced the total vehicle kilometres travelled by approximately 5 per cent. The centralised option located all growth in housing and jobs into Civic, which is already a large source of jobs. Hence fewer and fewer people had to drive outside the zone to get to work. The decentralised strategy located all housing and jobs on the fringe, but there was already many people living closer to Civic, hence more and more people had to drive outside the zone to get to work. The development solution was somewhere in between the centralised and decentralised options, and reduced the total number of vehicle kilometres travelled compared with the decentralised case. This trend is also reflected in the figures for total number of trips, mean trip distance and mean trip time, for the same reasons.

TABLE 6.9 DAILY TRAVEL CHARACTERISTICS IN CANBERRA FOR THE YEAR 2001 FOR GROUP 1

Transport statistics	*Do-nothing*	*Centralised*	*Decentralised*	*Development*
Road network				
Vehicle kilometres	6 429 757	5 234 035	12 528 969	7 976 338
Vehicle hours	103 817	87 049	249 923	143 467
Trips	594 452	566 184	826 386	762 778
Mean travel speed (km/h)	61.9	60.1	50.1	55.6
Mean trip distance (km)	10.8	9.2	15.2	10.5
Mean trip time (minutes)	10.5	9.2	18.1	11.3
Public transport network				
Trip kilometres	883 757	1 006 143	938 216	944 483
Trip hours	15 448	18 281	16 264	16 887
Trips	115 310	156 574	97 144	129 00
Mean travel speed (km/h)	57.2	55.0	57.7	55.9
Mean trip distance (km)	7.7	6.4	9.7	7.3
Mean trip time (minutes)	8.0	7.0	20.0	7.9
Trip Flow				
Links with highest flow (Vehicles)	Belconnen Way and Commonwealth Avenue (46 513–61 910 veh/day)	Belconnen Way and Commonwealth Avenue (43 898–73 570 veh/day)	Gundaroo Drive and Tuggeranong Parkway (67 426–78 717 veh/day)	Belconnen Way and Commonwealth Avenue (49 037–65 944 veh/day)
Links with highest flow (Public transport)	Belconnen Way (21 353–21 533 trips/day)	Belconnen Way (29 924–32 019 trips/day)	Belconnen Way (15 387–20 897 trips/day)	Belconnen Way (24 060–28 723 trips/day)

The mean trip speed shows a different trend. The decentralised option had the lowest mean speed, followed by the development option, the centralised option, and as expected the do-nothing option had the highest speed. It would intuitively be expected that the centralised option would have the lowest speed, as all growth was in the built up area. Similarly it would be expected that the centralised option would have the highest speed, as the network links were 80 km/h and, in some parts 100 km/h dual carriageways for most part. However, it could be that the increased traffic caused by the decentralised option is causing increased congestion and thus decreasing mean speeds.

Public transport comparison

Comparing to the do-nothing option, the centralised strategy increased the total trip kilometres of travel on public transport by approximately 14 per cent, the decentralised strategy by 6 per cent and the development strategy by 7 per cent. The reason for these increases are different in each case. The centralised strategy also increased the total trip hours of travel and the total number of trips, but decreased the mean trip distance and time. This indicates the more people were using public transport, due to the centralised growth they had shorter trips on average. This trend is probably a function of the fact that the Civic zone is the best served by public transport as it is the central node of the five major routes. The decentralised strategy on the other hand decreased the total number of trips, and increased the total trip hours, mean trip hours and average travel time. This indicates that fewer people were using public transport and due to the decentralised growth they had longer trips on average. The development solution showed the same trend as the centralised option, but not as drastically, due to the distribution of growth selected.

Peak trip flow comparison

Table 6.9. includes a summary of the links with the highest flow of vehicles and public transport users for each option. This is intended to illustrate the choke points caused by each option, and their relative seriousness. For the do-nothing, centralised and development strategies, the links with the highest vehicle flows were Belconnen Way and Commonwealth Avenue, with similar peak flow values. This demonstrates the importance of these routes in connecting the Belconnen and Woden/Tuggeranong regional centres with Civic. For the decentralised option, the peak flows were on Gundaroo Drive and the Tuggeranong Parkway. Gundaroo Drive is the only route into Gungahlin, and the Tuggeranong Parkway is the most direct route from Belconnen to Tuggeranong, so the trend in these figures is as expected. The link with the highest flow for public transport in all strategies was Belconnen Way.

6.3.3 Environmental impact comparison.

LAND provides information about fuel-consumption, air pollution and traffic noise. Group 1 discussed each of these. Their discussion is presented below.

Fuel consumption comparison

Fuel consumption figures are summarised in table 6.10.

As expected, the centralised strategy had the lowest fuel consumption, with a reduction of approximately 18–19 per cent in the total fuel consumed compared to the do-nothing strategy. This is because the centralised option encouraged an increase in housing density and jobs in the Civic zone, which decreased the number of people having to travel long distances to work. However, in the decentralised option people had to travel long distances to their job locations, which increased fuel consumption by approximately 96–98 per cent compared to the do-nothing strategy. The development option showed an increase in fuel consumption of approximately 24 per cent compared to the do-nothing strategy, which is a significant improvement on the decentralised option.

TABLE 6.10 FUEL CONSUMPTION COMPARISONS IN CANBERRA FOR 2001 FOR GROUP 1

(kilolitres per year)

Fuel type	*Do-Nothing*	*Central*	*Decentralised*	*Development*
Petrol	122 000	99 000	240 000	151 828
Unleaded petrol	16 800	13 700	33 200	20 998
Diesel	62 500	50 700	122 000	77 320
Liquid petroleum gas	9 350	7 600	18 400	11 643

Air pollution comparison

Air pollution figures for the year 2001 are summarised in table 6.11.

There is a strong correlation between fuel consumption and air pollution for all strategies. The percentage changes in air pollution are very similar to those for fuel consumption for all three strategies when compared to the do-nothing option.

Traffic noise comparisons

Traffic noise figures in 2001 are summarised in table 6.12.

The traffic noise diagram for the central strategy shows reduction in traffic noise in the outer suburbs, particularly Tuggeranong, Gungahlin, part of Western Creek, Belconnen, north Canberra and Fyshwick. The centralised strategy also caused traffic noise increases in the Civic zone. For the decentralised strategy, the traffic noise diagram shows an increase in traffic noise to a maximum of 72 dBA on most of the links except Canberra Avenue, Hindmarsh Drive and Ginninderra Drive. For the development strategy, noise levels are higher in the growth areas specified. When comparing the development strategy with the centralised option, noise levels in the Civic and the surrounding areas are more or less the same (except Adelaide Avenue and Parkes Way between City and east Canberra).

TABLE 6.11 EMISSIONS COMPARISONS FOR CANBERRA FOR 2001 FOR GROUP 1

(tonnes per year)

Air pollution	*Do-Nothing*	*Central*	*Decentralised*	*Development*
Carbon monoxide	12 000	9 908	24 619	15 307
Hydrocarbons	2 800	2 319	5 632	3.556
Nitrogen oxide	5 450	4 400	10 519	6.711
Lead	47	39	94	59

TABLE 6.12 NOISE LEVELS IN CANBERRA FOR 2001 FOR GROUP 1

Noise level	*Do-Nothing*	*Central*	*Decentralised*	*Development*
>72 dBA	Northbourne Avenue, Commonwealth Avenue, Belconnen Way, Adelaide Avenue, Hindmarsh Drive, Monaro Highway (between Fyshwick and east Canberra), Tuggeranong Parkway (between Western Creek and City)	Belconnen Way, Commonwealth Avenue, Northbourne Avenue, Tuggeranong Parkway, Adelaide Avenue, Hindmarsh Drive, Monaro Highway (between Fyshwick and east Canberra)	All roads except Canberra Avenue, Hindmarsh Drive and Ginninderra Drive.	Belconnen Way, Northbourne Avenue, Tuggeranong Parkway, Hindmarsh Drive, Parkes Way (between City and east Canberra), Adelaide Avenue, Yamba Drive
68–72 dBA	Canberra Avenue, William Slim Drive, Erindale Drive, Yamba Drive, Drakesford Drive, Monaro Highway (between Tuggeranong and Fyshwick)	Parkes Way (Between City and east Canberra), Canberra Avenue (Between south Canberra and Fyshwick)	Canberra Avenue, Hindmarsh Drive, Ginninderra Drive	Canberra Avenue, Parkes Way
64–68 dBA		Erindale Drive, Hindmarsh Drive, Ginninderra Drive		Erindale Drive, Ginninderra Drive, Yamba Drive, William Slim Drive
<64 dBA	Ginninderra Drive, Barton Highway	Drakesford Drive		Drakesford Drive, Monaro Highway (between Tuggeranong and Fyshwick), Barton Highway, Ginninderra Drive

dBA Unit of sound pressure level.

6.4 COMPARISON OF STUDENT PROJECTS ON CANBERRA

The previous three subsection briefly described the study carried out by group 1. A useful extension of this study is to compare the results of a number of groups to obtain an indication of the sensitivity of the model to the differing assumptions made. In particular, does the number of zones and the network developed influence the model output?

6.4.1 Network description

Table 6.13 presents a comparison of the networks developed by groups 1 to 3. It can be seen that group 1 divided Canberra up into 10 zones while the other two groups used 12. Group 3 chose a similar road network to group 1 but a slightly simpler public transport network. The most complex road and public transport networks was developed by group 2. It contained almost twice the number of roads and links as the other two network.

6.4.2 Model predictions

Comparison of the outputs of the models for the do-nothing option are shown in table 6.14. This was the only option studied by each group which had the same distribution of land use and any difference could be attributed to differences in the networks chosen. It can be seen that the land use predictions for the three models are relatively stable. The transport, fuel consumption and air pollution predictions for groups 1 and 2 were also relatively similar although group 1 did predict higher public transport use. Group 3, however, predicted considerably more travel on public transport and less travel on the road system than the other two groups. This resulted in lower fuel consumption and air pollution estimates. The mode usage obtained by group 1, given car occupancies level used in the model of 1.25, was of the order to 25 per cent compared with 12 per cent for group 2. This variation was primarily due to the different specification of the transport networks and indicates that care must be taken in developing an appropriate level of detail in the network description.

TABLE 6.13 NETWORK DESCRIPTION FOR CANBERRA FOR THREE GROUPS

Network information	*Group 1*	*Group 2*	*Group 3*
Road			
Zone centroids	10	12	12
Centroid connectors	0	0	0
Nodes	20	50	28
Road names	18	36	27
Links	27	71	54
Public transport			
Zone centroids	10	12	10
Centroid connectors	0	0	0
Nodes	14	28	10
Road names	14	14	12
Links	14	36	12

TABLE 6.14 DAILY TRAVEL CHARACTERISTICS IN CANBERRA FOR DO-NOTHING OPTION FOR THE YEAR 2001 FOR THREE GROUPS

	Group 1	*Group 2*	*Group 3*
Land use			
Population	328 524	329 468	334 348
Households	95 073	95 543	96 023
Houses	71 449	72 438	73 43
Available jobs	96 099	96 103	96 290
Employment	95 965	95 845	95 723
Unemployment	16 353	16 932	17 684
Road Network			
Vehicle kilometres	6 429 757	6 266 269	4 842 140
Vehicle hours	103 817	114 003	76 528
Trips	594 452	583 912	472 280
Mean travel speed (km/h)	61.9	55.0	63.3
Mean trip distance (km)	10.8	10.7	10.3
Mean trip time (minutes)	10.5	11.7	9.7
Public transport			
Trip kilometres	883 757	609 424	1 576 939
Trip hours	15 448	10 493	27 462
Trips	115 310	85 164	193 420
Mean travel speed (km/h)	57.2	58.1	57.4
Mean trip distance (km)	7.7	7.2	8.2
Mean trip time (minutes)	8.0	7.4	8.5
Fuel Consumption			
Petrol (kl/yr)	122 000	123 000	90 708
Unleaded petrol (kl/yr)	16 800	17 032	12 562
Diesel (kl/yr)	62 500	62 962	46 793
LPG (kl/yr)	9 350	9 458	6 978
Air Pollution			
Carbon monoxide (tons/yr)	12 000	12 477	8 935
Hydrocarbons (tons/yr)	2 800	2 886	2 121
Nitrogen oxides (tons/yr)	5 450	5 436	4 089
Lead (tons/yr)	47	48	35

kl/yr kilolitres per year
km kilometres
km/h kilometres per hour
tons/yr tons per year

6.4.3 Comparison of strategies

Another comparison that can be carried out relates to the outputs of the four strategies. These strategies were not specified in exactly the same manner by each groups but were similar in general trend. Table 6.15 presents the results. A ranking was given to each strategy depending on the level of pollution, vehicle travel and fuel consumption. The best ranking (1) was given to the strategy with the lowest vehicle travel, pollution and fuel consumption. Higher rankings were given as the vehicle travel, pollution and fuel consumption increased. It can be

TABLE 6.15 DAILY TRAVEL CHARACTERISTICS IN CANBERRA FOR THE YEAR 2001 FOR THREE GROUPS

	Group 1	*Group 2*	*Group 3*
Do-nothing strategy			
Road vehicle (kms)	6 429 757	6 266 269	4 842 140
Public transport trip (kms)	883 757	609 424	1 576 939
Petrol consumption (kl/yr)	122 000	123 000	90 708
Carbon monoxide (tons/yr)	12 000	12 477	8 935
Ranking	2	2	1
Centralised strategy			
Road vehicle (kms)	5 234 035	5 613 730	5 196 826
Public transport trip (kms)	1 006 143	683 047	1 577 210
Petrol consumption (kl/yr)	99 000	111 000	98 627
Carbon monoxide (tons/yr)	9 908	11 823	9 937
Ranking	1	1	2
Decentralised strategy			
Road vehicle (kms)	12 528 969	11 502 485	8 290 806
Public transport trip (kms)	938 216	601 740	2 238 526
Petrol consumption (kl/yr)	240 000	233 000	157 000
Carbon monoxide (tons/yr)	24 619	25 980	15 759
Ranking	4	3	4
Development strategy			
Road vehicle (kms)	7 976 338	12 865 036	5 498 325
Public transport trip (kms)	944 483	555 057	1 800 897
Petrol consumption (kl/yr)	151 828	252 000	103 000
Carbon monoxide (tons/yr)	15 307	26 730	10 155
Ranking	3	4	3

kl/yr	kilolitres per year
kms	kilometres
tons/yr	tons per year

seen tha the do-nothing and centralised options tended to get the best ranking, whilst the decentralise and development strategies received the poorest ranking. However, the rankings provided by each group were not consistent. This could be due to differences in their specification of each strategy, but is also the result of the differing choice of public and private transport network.

6.5 REMARKS ON CANBERRA STUDY

This chapter has briefly described the application of the LAND model to a city similar in structure to Canberra. The studies reported were carried out by students of the Australian Defence Force Academy. They showed that students could use the model and obtain results which indicated the direction of change in the key variables land use, transport and the environment. Comparison of the students studies showed that the model was sensitive to the specification of the network and an appropriate level of detail should be provided.

CHAPTER 7 CONCLUDING REMARKS

This study has outlined the LAND model and its application 'to Adelaide, Melbourne and a city similar in character to Canberra. The comparison of the model with Adelaide and Melbourne showed that the model was capable of replicating existing cities. LAND can reasonably predict the population movements, travel pattern and environmental impacts of a Metropolitan city over a study period.

The application of LAND, by Australian Defence Force Academy students, to the city of similar character to Canberra showed that the model could be applied to investigate different growth strategies and their impacts.

The application of LAND to a number of cities has shown that the package can be used to investigate the interaction between land use, transport and the environment. LAND can also be used as a planning tool to assist engineers and planners to develop a variety of planning scenarios.

LAND is an educational tool aimed at improving the understanding of the interaction between land use, transport and the environment. It contains a dynamic simulation model designed to replicate the interaction. There is considerable potential for further development. Further research efforts should be devoted to:

- investigate the level of detail required in the transport network description for consistent model predictions;
- develop the interaction between private transport and public transport;
- investigate variations in parameter estimates for different cities (eg. Adelaide and Melbourne) to determine stability of parameters;
- validate LAND through the application of the model calibrated and verified for one city to another (eg. apply calibrated and verified Adelaide model to Melbourne);
- improve and broaden the gaming concept and user interface; and
- introduce a pollution dispersion module and providing a feed back between pollution levels and land use.

There is no doubt that the priorities placed on these options will depend on the users and the availability of research funds. Any suggestions as to the appropriate direction to take would be welcome.

APPENDIX I BASE YEAR SET VARIABLES

TABLE I.1 BASE YEAR SET VARIABLES FOR ADELAIDE

Proportions of total population in each age group from 0 to 101 years old

0.01741	0.01741	0.01758	0.01710	0.01691	0.01763	0.01788	0.01882	0.01914	0.01937
0.02013	0.01976	0.01982	0.01952	0.01956	0.01886	0.01893	0.01886	0.01903	0.01820
0.01740	0.01695	0.01638	0.01656	0.01814	0.01344	0.01344	0.01344	0.01344	0.01344
0.01159	0.01159	0.01159	0.01159	0.01159	0.01163	0.01163	0.01163	0.01163	0.01163
0.01263	0.01263	0.01263	0.01263	0.01263	0.01302	0.01302	0.01302	0.01302	0.01302
0.01093	0.01093	0.01093	0.01093	0.01093	0.00997	0.01000	0.01000	0.01000	0.01000
0.00799	0.00799	0.00799	0.00799	0.00799	0.00612	0.00612	0.00612	0.00612	0.00612
0.00188	0.00188	0.00188	0.00188	0.00188	0.00188	0.00188	0.00188	0.00188	0.00188
0.00180	0.00180	0.00180	0.00180	0.00180	0.00180	0.00180	0.00180	0.00180	0.00180
0.00180	0.00180	0.00180	0.00180	0.00180	0.00180	0.00180	0.00180	0.00180	0.00180
0.00180									

Birth rate in each age group from 1 to 101 years old

0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.02120	0.02120	0.02120	0.02120	0.02120	0.08315
0.08315	0.08315	0.08315	0.08315	0.06980	0.06980	0.06980	0.06980	0.06980	0.03505
0.03505	0.03505	0.03505	0.03505	0.01665	0.01665	0.01665	0.01665	0.01665	0.00475
0.00475	0.00475	0.00475	0.00475	0.00030	0.00030	0.00030	0.00030	0.00030	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000									

Death rate in each age group from 0 to 101 years old

0.01792 (infants mortality)

0.00077	0.00077	0.00077	0.00077	0.00034	0.00034	0.00034	0.00034	0.00034	0.00024
0.00024	0.00024	0.00024	0.00024	0.00119	0.00119	0.00119	0.00119	0.00119	0.00115
0.00115	0.00115	0.00115	0.00115	0.00085	0.00085	0.00085	0.00085	0.00085	0.00129
0.00129	0.00129	0.00129	0.00129	0.00165	0.00165	0.00165	0.00165	0.00165	0.00233
0.00233	0.00233	0.00233	0.00233	0.00385	0.00385	0.00385	0.00385	0.00385	0.00656
0.00656	0.00656	0.00656	0.00656	0.00808	0.00808	0.00808	0.00808	0.00808	0.01702
0.01702	0.01702	0.01702	0.01702	0.02913	0.02913	0.02913	0.02913	0.02913	0.04751
0.04751	0.04751	0.04751	0.04751	0.06938	0.06938	0.06938	0.06938	0.06938	0.11191
0.11191	0.11191	0.11191	0.11191	0.20817	0.20817	0.20817	0.20817	0.20817	0.20817
0.20817	0.20817	0.20817	0.20817	0.20817	0.20817	0.20817	0.20817	0.20817	1.00000
1.00000									

TABLE I.1 BASE YEAR SET VARIABLES FOR ADELAIDE (CONT.)

Employment utility parameters			
Access to employment			1
Distance from work to home place			1
Household structure			
Family size (adults) with head age 20–33			1.336
Family size (adults) with head age 34–46			1.336
Family size (adults) with head age 47–60			1.336
Retired family size with head age >60			1.336
Average number of families per household			1.529
Average number of jobs per family			1.135
Maximum houses that can be full			0.950
Maximum jobs that can be full			0.980
Household quality for each household type and maximum household quality			
House type 1			10
House type 2			6
House type 3			2
Maximum quality value			10
Location utility parameters			
House type			1.0
Access to jobs			1.0
Distance to work			1.0
Environment coefficients		*Constant k_1*	*Parameter value k_2*
Carbon monoxide		2.69	28.20
Hydrocarbons		1.88	1.88
Nitrous oxides		2.00	0.00
Fuel consumption		7.76	4.10
Lead content in petrol		0.79	
Proportion of lead in petrol emitted to air			0.65
Trip generation factors			
Trip generation for population			2.501
Trip generation for employment			0.788
Trip attraction for employment			2.607
Average local trip distance			2.500
Average interchange distance for cars			0.000
Average interchange distance for public transport			0.600
Proportion of trips of the day			
Morning off peak	(00:00–06:00)		0.05
Morning peak	(06:00–09:00)		0.25
Daytime off peak	(09:00–16:00)		0.29
Afternoon peak	(16:00–19:00)		0.25
Afternoon off peak	(19:00–24:00)		0.16
Model constants			
Travel impedance coefficient			0.1653
Travel cost factors			
Average value of time in a vehicle (cents/min)			10
Average unit distance travel cost (cents/km)			15
Average value of time for walking and waiting for a trip			20
Average walking and waiting time for private transport			1.5
Average walking and waiting time for private transport			10

TABLE I.1 BASE YEAR SET VARIABLES FOR ADELAIDE (CONT.)

Traffic composition	
Cars and equivalents with petrol-engine	0.85
Cars and equivalents with diesel-engine	0.20
Cars and equivalents with unleaded-petrol engine	0.00
Cars and equivalents with LPG-engine	0.30
Heavy vehicles with petrol-engine	0.25
Heavy vehicles with diesel-engine	0.75
Vehicle occupancy	
Cars and equivalents	1.90
Heavy vehicles	1.05

TABLE I.2 BASE YEAR SET VARIABLES FOR MELBOURNE

Proportions of total population in each age group from 0 to 101 years old									
0.01900	0.01900	0.01900	0.01900	0.01900	0.01900	0.01900	0.01900	0.01900	0.01900
0.01800	0.01800	0.01800	0.01800	0.01800	0.01700	0.01700	0.01700	0.01700	0.01700
0.01800	0.01800	0.01800	0.01800	0.01800	0.01500	0.01500	0.01500	0.01500	0.01500
0.01400	0.01400	0.01400	0.01400	0.01400	0.01300	0.01300	0.01300	0.01300	0.01300
0.01200	0.01200	0.01200	0.01200	0.01200	0.01200	0.01200	0.01200	0.01200	0.01200
0.01100	0.01100	0.01100	0.01100	0.01100	0.00900	0.00900	0.00900	0.00900	0.00900
0.00700	0.00700	0.00700	0.00700	0.00600	0.00600	0.00600	0.00600	0.00600	0.00600
0.00300	0.00300	0.00300	0.00300	0.00300	0.00200	0.00200	0.00200	0.00200	0.00200
0.00200	0.00200	0.00200	0.00200	0.00200	0.00100	0.00100	0.00100	0.00100	0.00100
0.00100	0.00100	0.00100	0.00100	0.00100	0.00100	0.00100	0.00100	0.00100	0.00100
0.00000									
Birth rate in each age group from 1 to 101 years old									
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.02195	0.02195	0.02195	0.02195	0.02195	0.02195	0.08785
0.08785	0.08785	0.08785	0.08785	0.10220	0.10220	0.10220	0.10220	0.10220	0.05155
0.05155	0.05155	0.05155	0.05155	0.02395	0.02395	0.02395	0.02395	0.02395	0.00615
0.00615	0.00615	0.00615	0.00615	0.00040	0.00040	0.00040	0.00040	0.00040	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000									
Death rate in each age group from 0 to 101 years old									
0.01465 (infants mortality)									
0.00070	0.00070	0.00070	0.00070	0.00040	0.00040	0.00040	0.00040	0.00040	0.00025
0.00025	0.00025	0.00025	0.00025	0.00100	0.00100	0.00100	0.00100	0.00100	0.00125
0.00125	0.00125	0.00125	0.00125	0.00090	0.00090	0.00090	0.00090	0.00090	0.00115
0.00115	0.00115	0.00115	0.00115	0.00160	0.00160	0.00160	0.00160	0.00160	0.00265
0.00265	0.00265	0.00265	0.00265	0.00505	0.00505	0.00505	0.00505	0.00505	0.00765
0.00765	0.00765	0.00765	0.00765	0.01195	0.01195	0.01195	0.01195	0.01195	0.01965
0.01965	0.01965	0.01965	0.01965	0.03235	0.03235	0.03235	0.03235	0.03235	0.05010
0.05010	0.05010	0.05010	0.05010	0.08365	0.08365	0.08365	0.08365	0.08365	0.12675
0.12675	0.12675	0.12675	0.12675	0.22465	0.22465	0.22465	0.22465	0.22465	0.22465
0.22465	0.22465	0.22465	0.22465	0.22465	0.22465	0.22465	0.22465	0.22465	1.00000
1.00000									

TABLE I.2 BASE YEAR SET VARIABLES FOR MELBOURNE (CONT.)

Employment utility parameters		
Access to employment		1
Distance from work to home place		1
Household structure		
Family size (adults) with head age 20–33		1.285
Family size (adults) with head age 34–46		1.285
Family size (adults) with head age 47–60		1.285
Retired family size with head age >60		1.285
Average number of families per household		1.578
Average number of jobs per family		1.123
Maximum houses that can be full		0.9349
Maximum jobs that can be full		1.0
Household quality for each household type and maximum household quality		
House type 1		10
House type 2		6
House type 3		2
Maximum quality value		10
Location utility parameters		
House type		1.0
Access to jobs		1.0
Distance to work		1.0
Environment coefficients	*Constant k_1*	*Parameter value k_2*
Carbon monoxide	0.32	3.4
Hydrocarbons	0.57	0.57
Nitrous oxides	2.39	0.00
Fuel consumption	6.64	3.59
Lead content in petrol	0.60	
Proportion of lead in petrol emitted to air		0.65
Trip generation factors		
Trip generation for population		1.62
Trip generation for employment		0.61
Trip attraction for employment		2.12
Average local trip distance		1.50
Average interchange distance for cars		0.00
Average interchange distance for public transport		4.8
Proportion of trips of the day		
Morning off peak (00:00–06:00)		0.05
Morning peak (06:00–09:00)		0.25
Daytime off peak (09:00–16:00)		0.29
Afternoon peaK (16:00–19:00)		0.25
Afternoon off peak (19:00–24:00)		0.16
Model constants		
Travel impedance coefficient		0.4553
Travel cost factors		
Average value of time in a vehicle (cents/min)		10
Average unit distance travel cost (cents/km)		15
Average value of time for walking and waiting for a trip		20
Average walking and waiting time for private transport		2.0
Average walking and waiting time for private transport		10

TABLE I.2 BASE YEAR SET VARIABLES FOR MELBOURNE (CONT.)

Traffic composition	
Cars and equivalents with petrol-engine	0.65
Cars and equivalents with diesel-engine	0.10
Cars and equivalents with unleaded-petrol engine	0.10
Cars and equivalents with LPG-engine	0.05
Heavy vehicles with petrol-engine	0.05
Heavy vehicles with diesel-engine	0.05
Vehicle occupancy	
Cars and equivalents	1.25
Heavy vehicles	1.05

TABLE I.3 BASE YEAR SET VARIABLES FOR CANBERRA

Proportions of total population in each age group from 0 to 101 years old

0.01900	0.01900	0.01900	0.01900	0.01900	0.01900	0.01900	0.01900	0.01900	0.01900
0.01800	0.01800	0.01800	0.01800	0.01800	0.01700	0.01700	0.01700	0.01700	0.01700
0.01800	0.01800	0.01800	0.01800	0.01800	0.01500	0.01500	0.01500	0.01500	0.01500
0.01400	0.01400	0.01400	0.01400	0.01400	0.01300	0.01300	0.01300	0.01300	0.01300
0.01200	0.01200	0.01200	0.01200	0.01200	0.01200	0.01200	0.01200	0.01200	0.01200
0.01100	0.01100	0.01100	0.01100	0.01100	0.00900	0.00900	0.00900	0.00900	0.00900
0.00700	0.00700	0.00700	0.00700	0.00600	0.00600	0.00600	0.00600	0.00600	0.00600
0.00300	0.00300	0.00300	0.00300	0.00300	0.00200	0.00200	0.00200	0.00200	0.00200
0.00200	0.00200	0.00200	0.00200	0.00200	0.00100	0.00100	0.00100	0.00100	0.00100
0.00100	0.00100	0.00100	0.00100	0.00100	0.00100	0.00100	0.00100	0.00100	0.00100
0.00000									

Birth rate in each age group from 1 to 101 years old

0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.02195	0.02195	0.02195	0.02195	0.02195	0.02195	0.08785
0.08785	0.08785	0.08785	0.08785	0.10220	0.10220	0.10220	0.10220	0.10220	0.05155
0.05155	0.05155	0.05155	0.05155	0.02395	0.02395	0.02395	0.02395	0.02395	0.00615
0.00615	0.00615	0.00615	0.00615	0.00040	0.00040	0.00040	0.00040	0.00040	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
0.00000									

Death rate in each age group from 0 to 101 years old

0.01465 (infants mortality)

0.00070	0.00070	0.00070	0.00070	0.00040	0.00040	0.00040	0.00040	0.00040	0.00025
0.00025	0.00025	0.00025	0.00025	0.00100	0.00100	0.00100	0.00100	0.00100	0.00125
0.00125	0.00125	0.00125	0.00125	0.00090	0.00090	0.00090	0.00090	0.00090	0.00115
0.00115	0.00115	0.00115	0.00115	0.00160	0.00160	0.00160	0.00160	0.00160	0.00265
0.00265	0.00265	0.00265	0.00265	0.00505	0.00505	0.00505	0.00505	0.00505	0.00765
0.00765	0.00765	0.00765	0.00765	0.01195	0.01195	0.01195	0.01195	0.01195	0.01965
0.01965	0.01965	0.01965	0.01965	0.03235	0.03235	0.03235	0.03235	0.03235	0.05010
0.05010	0.05010	0.05010	0.05010	0.08365	0.08365	0.08365	0.08365	0.08365	0.12675
0.12675	0.12675	0.12675	0.12675	0.22465	0.22465	0.22465	0.22465	0.22465	0.22465
0.22465	0.22465	0.22465	0.22465	0.22465	0.22465	0.22465	0.22465	0.22465	1.00000
1.00000									

TABLE I.3 BASE YEAR SET VARIABLES FOR CANBERRA (CONT.)

Employment utility parameters			
Access to employment			1
Distance from work to home place			1
Household structure			
Family size (adults) with head age 20–33			1.34
Family size (adults) with head age 34–46			1.34
Family size (adults) with head age 47–60			1.34
Retired family size with head age >60			1.34
Average number of families per household			1.57
Average number of jobs per family			1.123
Maximum houses that can be full			1.0
Maximum jobs that can be full			1.0
Household quality for each household type and maximum household quality			
House type 1			10
House type 2			6
House type 3			2
Maximum quality value			10
Location utility parameters			
House type			1.0
Access to jobs			1.0
Distance to work			1.0
Environment coefficients		*Constant k_1*	*Parameter value k_2*
Carbon monoxide		0.81	8.5
Hydrocarbons		0.57	0.57
Nitrous oxides		2.39	0.00
Fuel consumption		6.64	3.59
Lead content in petrol			0.60
Proportion of lead in petrol emitted to air			0.65
Trip generation factors			
Trip generation for population			3.41
Trip generation for employment			1.28
Trip attraction for employment			4.49
Average local trip distance			1.500
Average interchange distance for cars			0.000
Average interchange distance for public transport			2.5
Proportion of trips of the day			
Morning off peak	(00:00–06:00)		0.05
Morning peak	(06:00–09:00)		0.25
Daytime off peak	(09:00–16:00)		0.29
Afternoon peak	(16:00–19:00)		0.25
Afternoon off peak	(19:00–24:00)		0.16
Model constants			
Travel impedance coefficient			0.1653
Travel cost factors			
Average value of time in a vehicle (cents/min)			10
Average unit distance travel cost (cents/km)			15
Average value of time for walking and waiting for a trip			20
Average walking and waiting time for private transport			2.0
Average walking and waiting time for private transport			25

TABLE I.3 BASE YEAR SET VARIABLES FOR CANBERRA (CONT.)

Traffic composition	
Cars and equivalents with petrol-engine	0.65
Cars and equivalents with diesel-engine	0.10
Cars and equivalents with unleaded-petrol engine	0.10
Cars and equivalents with LPG-engine	0.05
Heavy vehicles with petrol-engine	0.05
Heavy vehicles with diesel-engine	0.05
Vehicle occupancy	
Cars and equivalents	1.25
Heavy vehicles	1.05

APPENDIX II LINK TYPE DATA

TABLE II.1 ROAD LINK TYPE DATA FOR ADELAIDE

Road link type	V_0 (km/h)	J	S (veh/h)	C (cents/km)
Centroid connector	15.0	0.000	1 800	0
2 lane 2 way road	50.0	0.475	1 334	0
Undivided/2 lane	52.2	0.475	2 668	0
Undivided/3 lane	66.6	0.468	4 975	0
Undivided/4 lane	70.0	0.486	6 764	0
Divided/2 lane	56.6	0.374	3 214	0
Divided/3 lane	72.3	0.415	5 583	0
Divided/4 lane	76.0	0.419	7 644	0
Freeway/2 lane	85.7	0.138	5 510	0
Freeway/3 lane	85.7	0.138	7 510	0
Freeway/4 lane	85.7	0.138	9 310	0

Note V_0 is the free-flow travel time, J is the Davidson's function factor, S is the link capacity and C is the link charge fare.

TABLE II.2 PUBLIC TRANSPORT LINK TYPE DATA FOR ADELAIDE

Link type	V_0 (km/h)	J	S (trip/h)	C (cents/km)
Connector	15.0	0.000	5 500	12
Bus route	55.0	0.496	5 500	12
Railway line	65.0	0.238	25 000	10
Tram route	50.0	0.486	5 500	12

Note V_0 is the free-flow travel time, J is the Davidson's function factor, S is the link capacity and C is the link charge fare.

TABLE II.3 ROAD LINK TYPE DATA FOR MELBOURNE

Road link type	V_0 *(km/h)*	*J*	*S* *(veh/h)*	*C* *(cents/km)*
Centroid connector	30.0	0.000	3 960	0
2 lane 2 way road	69.0	0.435	2 938	0
Undivided/2 lane	67.2	0.435	5 336	0
Undivided/3 lane	81.6	0.438	10 950	0
Undivided/4 lane	85.0	0.446	14 890	0
Divided/2 lane	71.6	0.344	7 070	0
Divided/3 lane	87.3	0.375	12 279	0
Divided/4 lane	91.0	0.379	16 816	0
Freeway/2 lane	100.7	0.128	12 122	0
Freeway/3 lane	100.7	0.128	16 522	0
Freeway/4 lane	100.7	0.128	20 482	0

Note V_0 is the free-flow travel time, J is the Davidson's function factor, S is the link capacity and C is the link charge fare.

TABLE II.4 PUBLIC TRANSPORT LINK TYPE DATA FOR MELBOURNE

Link type	V_0 *(km/h)*	*J*	*S* *(trip/h)*	*C* *(cents/km)*
Connector	5.0	0.000	3 600	15
Bus route	48.0	0.315	14 000	12
Railway line	60.0	0.230	15 000	15
Tram route	40.0	0.415	17 000	12

Note V_0 is the free-flow travel time, J is the Davidson's function factor, S is the link capacity and C is the link charge fare.

TABLE II.5 ROAD LINK TYPE DATA FOR CANBERRA

Road link type	V_0 (km/h)	J	S (veh/h)	C (cents/km)
Centroid connector	15.0	0.000	1 800	0
2 lane 2 way road	50.0	0.475	1 334	0
Undivided/2 lane	52.2	0.475	2 668	0
Undivided/3 lane	66.6	0.468	4 975	0
Undivided/4 lane	70.0	0.486	6 764	0
Divided/2 lane	56.6	0.374	3 214	0
Divided/3 lane	72.3	0.415	5 583	0
Divided/4 lane	76.0	0.419	7 644	0
Freeway/2 lane	85.7	0.138	5 510	0
Freeway/3 lane	85.7	0.138	7 510	0
Freeway/4 lane	85.7	0.138	9 310	0

Note V_0 is the free-flow travel time, J is the Davidson's function factor, S is the link capacity and C is the link charge fare.

TABLE II.6 PUBLIC TRANSPORT LINK TYPE DATA FOR CANBERRA

Link type	V_0 (km/h)	J	S (trip/h)	C (cents/km)
Connector	15.0	0.000	1 800	15
Bus route	60.0	0.315	7 000	13
Railway line	70.0	0.230	15 000	14
Tram route	50.0	0.415	8 500	13

Note V_0 is the free-flow travel time, J is the Davidson's function factor, S is the link capacity and C is the link charge fare.

APPENDIX III BASE YEAR LAND USE INPUT FILES

TABLE III.1 BASE YEAR LAND USE INPUT FILE FOR ADELAIDE

	Houses					
Zone	*Type 1*	*Type 2*	*Type 3*	*Total*	*Households*	*Jobs available*
1	1 428	2 990	682	5 100	4 442	83 468
2	5 748	1 687	95	7 530	7 115	3 961
3	10 584	3 060	198	13 842	13 073	10 225
4	9 572	1 370	51	10 993	10 674	5 852
5	1 151	48	16	1 215	1 094	3 436
6	4 714	3 848	21	8 583	8 385	11 256
7	15 454	6 306	167	21 927	21 397	26 224
8	1 585	264	42	1 891	1 796	3 284
9	2 891	3 585	247	6 723	6 136	3 261
10	3 605	1 794	171	5 570	5 181	1 948
11	2 491	808	87	3 386	3 223	9 081
12	2 052	1 885	245	4 182	3 878	7 730
13	16 167	4 162	86	20 415	19 815	16 359
14	1 614	40	52	1 706	1 566	2 556
15	16 350	2 231	174	18 755	17 975	16 447
16	3 416	1 676	28	5 120	4 895	3 240
17	8 299	523	54	8 876	7 922	11 416
18	4 416	1 471	132	6 019	5 715	4 034
19	9 612	2 471	297	12 380	11 800	14 754
20	6 222	1 205	145	7 572	7 212	4 405
21	2 330	1 088	162	3 580	3 359	3 610
22	12 838	1 826	55	14 719	14 219	18 406
23	2 762	125	35	2 922	2 578	1 739
24	10 116	121	35	10 272	9 813	10 059
25	2 591	1 075	132	3 798	3 636	8 835
26	9 909	4 322	374	14 605	13 809	11 908
27	1 901	612	44	2 557	2 431	2 231
28	12 708	3 974	145	16 827	16 174	21 031
29	1 541	95	18	1 654	836	1 584
30	18 000	4 407	266	22 673	21 888	30 306
Total	202 067	59 069	4 256	265 392	252 037	352 646

TABLE III.2 BASE YEAR LAND USE INPUT FILE FOR MELBOURNE

	Houses					
Zone	*Type 1*	*Type 2*	*Type 3*	*Total*	*Households*	*Jobs available*
1	7 070	760	124	7 954	7 670	8 670
2	5 346	632	67	6 045	5 828	6 600
3	13 963	2 111	230	16 304	15 461	16 192
4	9 936	3 533	269	13 738	13 247	7 178
5	23 164	1 392	255	24 811	23 924	22 213
6	10 261	5 948	543	16 752	16 144	26 127
7	1 870	98	30	1 998	1 926	5 050
8	26 691	5 985	514	33 190	32 004	15 280
9	16 668	13 875	746	31 289	30 171	15 857
10	6 399	1 938	138	8 475	8 170	2 766
11	16 569	2 613	405	19 587	18 886	19 674
12	2 453	3 864	259	6 576	6 340	23 970
13	3 440	176	54	3 670	3 537	2 133
14	7 530	549	82	8 161	7 868	8 002
15	9 173	2 187	201	11 561	11 143	18 317
16	9 235	298	69	9 602	9 258	4 502
17	17 126	488	107	17 721	17 085	8 586
18	6 488	512	90	7 090	6 835	3 089
19	12 745	5 851	633	19 229	18 539	12 796
20	2 046	5 455	651	8 152	7 859	17 233
21	5 674	681	111	6 466	6 233	3 838
22	14 302	3 310	601	18 213	17 559	37 404
23	15 620	1 693	227	17 540	16 911	11 648
24	2 461	162	58	2 681	2 582	4 062
25	5 911	8 751	787	15 449	14 895	15 636
26	1 438	131	58	1 627	1 567	1 320
27	15 153	3 709	262	19 124	18 439	16 671
28	13 697	824	160	14 681	14 155	11 792
29	7 016	2 802	286	10 104	9 742	8 690
30	14 854	916	154	15 924	15 352	9 910
31	9 975	528	197	10 700	10 318	7 194
32	10 709	7 051	606	18 366	17 707	15 151
33	4 991	17 856	2 440	25 287	24 381	263 387
34	1 637	30	15	1 682	1 619	612
35	28 498	3 730	235	32 463	31 303	45 341
36	6 936	2 981	175	10 092	9 729	7 501
37	3 383	1 282	66	4 731	4 560	4 354
38	13 268	6 158	332	19 758	19 050	19 082
39	23 287	2 139	185	25 611	24 695	17 884
40	13 930	2 005	234	16 169	15 589	38 312
41	0	0	0	0	0	0
42	1 344	2 040	113	3 497	3 369	29 085
43	6 405	16 592	1 521	24 518	23 640	24 046
44	21 241	3 789	308	25 338	24 430	32 041
45	4 358	5 099	436	9 893	9 537	27 346
46	9 303	681	94	10 078	9 717	8 884
47	4 196	21 055	2 329	27 580	26 593	15 237
48	9 393	2 205	164	11 762	11 340	7 436
49	6 219	446	151	6 816	6 570	3 265

TABLE III.2 BASE YEAR LAND USE INPUT FILE FOR MELBOURNE (Cont.)

Zone	Houses				Households	Jobs available
	Type 1	Type 2	Type 3	Total		
50	2 846	5 982	814	9 642	9 296	48 663
51	14 061	2 040	206	16 307	15 722	13 777
52	17 275	2 540	358	20 173	19 450	29 597
53	25 112	920	94	26 126	25 192	21 884
54	5 470	372	117	5 959	5 743	7 910
55	7 797	353	82	8 232	7 936	7 200
56	7 139	2 007	214	9 360	9 022	14 352
Total	563 072	191125	19 657	773 854	745 838	1 074 747

TABLE III.3 BASE YEAR LAND USE INPUT FILE FOR CANBERRA

Zone	Houses				Households	Jobs available
	Type 1	Type 2	Type 3	Total		
1	19 825	2 597	15	22 437	19 825	14 448
2	7 820	1 939	58	9 817	8 444	4 719
3	1 174	1 554	14	2 742	2 297	22 547
4	5 735	1 557	50	7 342	6 425	18 230
5	8 502	2 496	9	11 007	9 766	12 936
6	169	91	5	265	206	8 713
7	7 896	223	7	8 126	7 200	1 454
8	1 120	359	3	1 482	1 261	9 713
9	7 343	770	39	8 152	7 203	2 541
10	77	2	0	79	72	798
Total	59 661	11 588	200	71 449	62 699	96 099

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ABS	Australian Bureau of Statistics
AEC	Australian Environmental Council
ITE	Institute of Transportation Engineers
ARRB	Australian Road Research Board
REAAA	Road Engineering Association of Asia and Australasia
SAE	Society of Automotive Engineers
ATRF	Australasian Transport Research Forum
TRB	Transportation Research Board
UKDoT	United Kingdom Department of Transport

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