Space, time, economics and asphalt

An investigation of induced traffic growth caused by urban motorway expansion and the implications it has for the sustainability of cities

Doctor of Philosophy in
Sustainable Futures

By Michelle E Zeibots
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Statement of original authorship

I certify that the work in this thesis has not previously been submitted for a degree, nor has it been submitted as part of the requirements for a degree, except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of candidate:

Michelle Elaine Zeibots

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1964 – 2007

who loved cities, the people who live in them and fought hard to

improve the transport systems that support them

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Abbreviations and units

AADT	Annual Average Daily Traffic
AAPG	American Association of Petroleum Geologists
ABS	Australian Bureau of Statistics
ADT	Average Daily Traffic
AGO	Australian Greenhouse Office
AP	Accounting Period
ASPO	Association for the Study of Peak Oil
ARIMA	Auto-Regressive Integrated Moving Average
ARR	Amsterdam Ring Road
BRL	Bankstown Rail Line
BRF	British Roads Federation
CART	Citizens Against Route Twenty
CBA	Cost–Benefit Analysis
CBD	Central Business District
CO_2	Carbon Dioxide
DOTARS	Department of Transport and Regional Services
EPR	Energy Profit Ratio
EU	European Union
Gb	Giga barrels

GDP	Gross Domestic Product
GHE	Gore Hill Expressway
GLC	Greater London Council
GLDP	Greater London Development Plan
GRI	Global Reporting Initiative
GRP	Gross Regional Product
GST	General Systems Theory
GWH	Great Western Highway
HBR	Homes Before Roads
HMSO	Her Majesty's Stationery Office
IBRD	International Bank for Reconstruction and Development
ICLEI	International Council on Local Government Initiatives
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRL	Illawarra Rail Line
ISF	Institute for Sustainable Futures (University of Technology, Sydney)
ISTP	Institute for Sustainability and Technology Policy (Murdoch University)
LATA	London Amenity and Transport Association
LMAG	London Motorway Action Group
MIIM	Macquarie Infrastructure Investment Management

MP	Member of Parliament
NGO	Non-government Organisation
NRMA	National Roads and Motorists Association
NS	Natural Step
NPV	Net Present Value
OD	Origin and Destination
PTRC	Planning Transport, Research and Computation
RRL	Richmond Rail Line
RTA	Roads & Traffic Authority of New South Wales
RWRR	Rochester Way Relief Road
SACTRA	Standing Advisory Committee on Trunk Route Assessment
SARS	Severe Acute Respiratory Syndrome
SDP	State Domestic Product
SEAC	State of the Environment Advisory Council
SHLM	State Highway Lane Miles
SHB	Sydney Harbour Bridge
SHT	Sydney Harbour Tunnel
SMH	*Sydney Morning Herald*
SSD	Sydney Statistical Division
SSM	Soft Systems Methodology

STPP	Surface Transportation Policy Project
TBL	Triple Bottom Line
TDC	Transport Data Centre
TPDC	Transport and Population Data Centre
UITP	International Association (Union) of Public Transport Providers
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States (of America)
USGS	United States Geographical Survey
VKT	Vehicle Kilometres Travelled
WCED	World Commission on Environment and Development
WSRL	Western Sydney Rail Line

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Abstract

This thesis investigates the implications that urban motorway development has for the sustainability of cities. It does this by focusing on the sudden increase in road traffic that follows after the opening of additional motorway capacity, known as induced traffic growth, and asking whether induced traffic growth affects the ability of an urban system to sustain its essential economic functions. The investigation also addresses how urban systems impact on the biosphere.

Induced traffic growth, and the urban motorway development responsible for it, are often cited as a threat to sustainability because they are seen to increase fuel consumption and air pollution without necessarily improving accessibility within a city. Opponents to urban motorway construction claim that it merely represents a reshuffling of system elements, such that the spatial relationships between transport and land-use are changed, but the amount of time spent travelling, and the number of economic exchanges made by people, remain much the same. Motorway development advocates refute these claims, arguing that motorway construction reduces travel times, cuts emissions and fuel consumption and increases economic activity, thereby enhancing sustainability.

While it should be possible to resolve these issues through a program of empirical analysis, the phenomenon remains contested, raising questions about why and how its contested status affects transport decision-making and transport science. These questions are answered in this thesis by first investigating the social and political context in which debate over induced traffic growth has taken place. To do this, Soft Systems Methodology is used to investigate the way in which conflicts over urban motorway development have been resolved in London, Sydney and Zürich. The comparative analysis highlights differences between the rules of the political decision-making systems in each of the cities, and how these distribute power to different groups within society. While the history of conflicts is similar in each of the cities, more power is given to special interest groups from industry in London and Sydney. By contrast, the system in Zürich gives more power to resident populations through its system of

direct democracy. Consequently, urban motorway development, the induced traffic growth it gives rise to and the impacts they have on city operations are acted upon in Zürich to the extent that transport policy has focused more on the development of comprehensive public transport systems. This leads to the conclusion that the contested status of induced traffic growth is more a product of the socio-economic goals of particular interest groups within society than it is of shortcomings in the empirical record or essentially unresolved theoretical issues.

With the political context as background, the thesis then reviews the empirical analyses and theoretical explanations for the phenomenon. First, a review of past empirical analyses is undertaken to identify the grounds that have been cited to refute the induced traffic growth hypothesis. Two key areas are identified. The first involves difficulties with distinguishing the sources of induced traffic growth from traffic reassignment. The second concerns the absence of traffic data for routes that are potential alternatives to a new motorway from which traffic reassignment may have taken place. A case study of the M4 Motorway in Sydney is presented with data for all arterial through-routes that cross relevant screenlines, thereby overcoming several of the shortcomings identified in the review. This case study adds to the general literature of case studies that corroborate the induced traffic growth hypothesis, but provides the first substantial documented case for an Australian city.

A review of the theoretical explanations for the phenomenon finds that while both microeconomic evaluation and standard modelling procedures provide accounts for the phenomenon that meet institutional expectations of technical veracity, neither constitutes a substantial description of the causal mechanism for the phenomenon, leaving unanswered questions about some findings in the empirical record. This conclusion prompts the development of a systems-based explanation for induced traffic growth that defines it as a form of multiple system feedback processes controlled by a travel budget time constant. By accounting for the phenomenon and its effects in this way, an explanation is provided for changes to travel behaviour and patterns of land-use development that reveals how urban motorway development affects urban systems in an holistic way.

The final section of the thesis combines the insights gained by examination of the politics of the transport decision-making system with empirical analyses and theoretical explanations for induced traffic growth, to produce a general systems view of cities and their place within the earth's biosphere. This treatment considers the problems of oil depletion and global climate change, and the effects that urban motorway development has on the ability of urban systems to adapt to changes in the system environment brought about by these problems. The thesis concludes that urban motorway development and the processes that it triggers, which are embodied in the phenomenon of induced traffic growth, can undermine a city's comparative ability to sustain the accessibility needs of its residents.

It is ridiculous: we literally know more about the processes that go on inside the sun than we do about the processes that go on in our cities.

Jane Jacobs
The self-generating growth of cities
(1967)

1 Urban motorways and sustainability: introduction to the research problem

Transport is ubiquitous. There are few human activities that do not require movement or entail a transport component of some kind. Without the elaborate transport networks of today, the complex and intricate economies typical of modern life could not function. This logistical imperative can be most clearly seen in cities, where changes to a transport network can trigger rapid change in many other parts of the urban system.

The primary reason for building cities is economic (Jacobs as cited in Feeney 1997, p. 12). People build and live in cities in order to reduce the time it takes to travel across space to make economic exchanges. By living in close proximity, people are able to make large numbers of exchanges within relatively short time periods. This is essential to the creation of what economists call the *division of labour*, where individuals specialise in different tasks to increase their combined output (Samuelson et al. 1992, p. 704). Close proximity is essential to labour specialisation because other people must be present to do the tasks that an individual's own specialisation prohibits her or him from doing. As tasks become more particular, individuals become more dependent on one another and so need to make more exchanges within a short time period if they are to sustain their standard of living and society is to sustain its level of industrialisation. This is why spatial conditions within cities are of fundamental significance to industrial production (Prud'homme 1995, p. 730).

Obviously, not all urban activities have an immediate economic purpose or relate to labour productivity. Social networks, political movements, personal relationships, artistic and cultural traditions all contribute to the rich fabric of urban life. To define the building of cities as primarily for economic purposes might be seen to diminish the significance of these other activities. But human societies were accomplished in these activities long before they started building cities. Hunter-gatherer communities had sophisticated artistic and cultural traditions that pre-dated the rise of large fixed settlements around 10,000 years ago (Rudgley 2000, p. 68). However, these communities did not engage in manufacturing and infrastructure development on a scale commensurate with the large divisions of labour found only in cities. Even early cities reveal a calibre of activity that sets them apart from the lifestyle and economy of hunter-gatherers (Jacobs 1969, pp. 49–51; Nolan & Lenski 1995, p. 79). So, while social contact and culture are activities that take place in cities, and which add to their richness, they are not a distinguishing feature or dependent on the close proximity of large numbers of people that come with sedantism in the same way that complex economic activity is.

In the city, space, time and economics coalesce to form a unit of organisation critical to the human condition and aspirations for a high quality of economic life. But the city is also a unit that is indelibly reliant on the natural world, taking its cues from material conditions over which human ideals and ambition have no fundamental control. In this way the city system is a creation of both nature and artifice.

With the opportunities brought by close proximity, greater access to goods and services and potential reductions in travel times, come the drawbacks of urban congestion, access restrictions and potential increases in journey times. These apparently competing and contradictory forces create an essential tension within city systems that sits at the core of all their operations, forming the central dilemma of most urban transport problems.

The transport infrastructure that supports a city’s industries is not only fundamental to the city’s economic processes but is also critical to its spatial structure. The topology and logistical features of the various transport modes that constitute a city’s transport networks determine how much time it takes to travel to the various destinations in the city, as well as how many people can access those destinations and the consequent volume of economic exchanges possible (Marchetti 1994, p. 77). This topology distinguishes areas that are highly accessible from those that are less so. Patterns of land use development and building form are influenced by these accessibility differences. Where the transport system enables large numbers of people to access a relatively confined space, as is the case for districts served by a high-capacity mass transit system, building form clusters and concentrates at particular points. Where access is provided at low volumes, but over a wide area, as is the case with private motor vehicle transport, development is often diffuse (Thomson 1977, p. 94). This is how the morphology of the urban system is generated by the logistical properties of the transport network to create the shape and scale of market catchments (Cervero 2001, p. 1652; Smith 1776, pp. 15–17).

The resulting mix of transport service types, land uses and patterns of building form affects the amount of materials and energy needed to operate other infrastructures and industrial processes in the city. The flow of materials and energy has consequences for the economic performance of cities, their global competitiveness, environmental amenity and ability to accommodate social equity goals. A city's dependency on material inputs also has consequences for its resilience[1] to changes in the system environment from which inputs are drawn and outputs are traded or disposed of (Newman 1974, p. 261). In this way, transport networks form an essential lynchpin that draws together many other urban processes and functions. Transport policy provides a key lever through which adaptation to change can be facilitated.

From this perspective, two crucial questions arise about the form of urban transport that best serves urban communities. First, as human population numbers increase and the material throughputs required to run the world's transport systems balloon, are present forms of transport development sustainable given the finite nature of many material inputs on which modern cities and their urban transport networks are now dependent? And further, are the impacts of outputs from the transport sector, such as greenhouse gas emissions and other wastes, affecting the global ecological system in

1 In systems theory, resilience refers to the ability of a system to withstand changes or shocks exerted on its operations from external factors in the system environment.

such a way that sustaining human populations at present numbers (let alone greater numbers) is jeopardised?

The second crucial question is this: is our understanding of urban systems and their transport networks sufficient to guide development so that the longer term sustainability of the world's urban systems is assured and the human condition for which they are so critical is maintained and improved?

This thesis seeks to address these broad sustainability questions with a specific program of research that investigates the fundamental role that transport plays in city processes. The primary aim of this chapter is to define the parameters and terms of the research program and signal where original contributions to knowledge are made.

This chapter begins by exploring the issue of sustainability and how it can be applied to cities (Section 1.1). The critical issue of material and energy throughputs is raised, as is the interaction between cities engaged in international trade. A definition of what constitutes sustainable practice in the urban transport sector is provided, in addition to a general outline of the context from which the more specific research questions arise in the ensuing sections.

The second section provides a brief discussion of the role that different transport modes play in shaping the development of city systems (Section 1.2). It is shown that urban motorway development undermines the sustainability of cities more than other forms of transport development, because of the effects it has on their spatial structure and consequent level of resource use. This section introduces the particular problem of induced traffic growth that arises after the addition of urban motorway capacity.

The third section sets out the induced traffic growth hypothesis in some detail and describes its current status within transport studies (Section 1.3). A definition of induced traffic growth is provided in addition to a brief description of how it undermines the sustainability of cities and the economic activity that takes place within them. This section touches on the contested nature of the phenomenon, highlighting particular problems concerning our theoretical understanding of the cause and effects arising from it and the questions that this raises about whether or not we have the requisite understanding of urban transport and economic processes to make cities sustainable.

The fourth section outlines the value of adopting a systems approach for the thesis research program (Section 1.4). The final section (Section 1.5) provides an overview of the thesis structure and how it relates to the research questions raised about sustainability in Sections 1.1.2 to 1.1.4 and the questions about urban motorway development in Section 1.3.3.

The aim of this chapter is to present a broad overview of the research problem, progressively narrowing the research focus to specific research questions that address the effects of urban motorway development and the implications these have for the sustainability of cities.

1.1 Cities and sustainable development

The concept of sustainable development and the need for governments to actively pursue it as a policy goal, entered mainstream thinking after publication of *Our common future,* which summarised the findings of a four-year inquiry conducted by the World Commission on Environment and Development (WCED) at the request of the General Assembly of the United Nations. The WCED was asked broadly to propose long-term strategies for achieving sustainable development and advise how these might be translated into cooperative actions that would allow nations to pursue solutions to environmental problems at a global level. It also tried to define shared perceptions of environmental issues and how sustainable development strategies might incorporate the aspirational goals of the world community (WCED 1987a, p. ix).

The report does not outline specifically how these aims would be achieved in an operational sense. Instead, *Our common future* provides a set of guiding principles and reasons why sustainable development should be pursued, the most significant and often-cited being the general definition of sustainable development:

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED 1987a, p. 43).

As with all definitions, it is driven by key concepts, in this case the concept of human needs and the concept of limitations imposed on our ability to meet those needs:

> The concept of sustainable development does imply limits — not absolute limits but limitations imposed by the present level of technology and social organisation on environmental resources and by the ability of the biosphere to absorb the effects of human activities (WCED 1987a, p. 8).

The report goes to great lengths to stress the differences between developed and developing economies and hence the difference between basic needs and consumption over and above these basic needs:

> Sustainable development requires meeting the basic needs of all and extending to all the opportunity to satisfy their aspirations for a better life.
>
> Living standards that go beyond the basic minimum are sustainable only if consumption standards everywhere have regard for long-term sustainability. Yet many of us live beyond the world's ecological means, for instance in our patterns of energy use. Perceived needs are socially and culturally determined, and sustainable development requires the promotion of values that encourage consumption standards that are within the bounds of the ecologically possible and to which all can reasonably aspire (WCED 1987a, p. 44).

A far-reaching debate on sustainable development has ensued. Questions concerning what the limitations actually are, and how development might be managed within these restrictions, have occupied the global research community for many years and been the subject of wide public discussion. The same can be said for what constitutes basic needs. A basic need for a person living in a developed economy, or the North[2], might be the need to access job markets to earn an income. Driving a car might be perceived as the only practical way to do this because of the prevailing structure of the transport network in that person's city. By contrast, a basic need for a person living in a developing economy, or the South, might be the need to access clean drinking water and food. Satisfying these needs is more basic to survival than driving a car. The person from the North uses comparatively large volumes of scarce, non-renewable resources to

[2] In international development and trade literature, developed industrialised economies are often referred to as the *North*, given that most of these — the US, Europe and Canada — are located in the Northern Hemisphere. Poorer developing economies that are largely non-industrialised are referred to as the *South*, because most of these — Africa and South America — are located in the Southern Hemisphere (Bhaskar & Glyn 1995).

drive her/his car and satisfy what s/he considers a basic need, while the person living in the South uses far less.

To complicate the situation, high consumption of scarce and non-renewable resources by the North impacts on consumption in the South. First, by pushing up prices beyond the South's purchasing power, the ability of the South to consume is retarded (IBRD 1997, p. 21; Lean 1978, p. 172). Second, to maintain high consumption rates the North must access resources from the South in addition to its own domestic supplies because it cannot produce all it consumes itself (Bhaskar & Glyn 1995, p. 2). The US, for example, imports just over 60 per cent of its domestic oil consumption each year — most of which comes from Southern economies — and total consumption by OECD countries, or Northern economies, outstrips supply from Northern reserves by 56 per cent (BP 2004, pp. 6, 9 and 19). This can lead to political conflict. If consumption and living standards in Southern supply region economies increase, prices go up and global competition for scarce resources intensifies. This has negative implications for the North's ability to continue consumption at high levels, setting an imperative for Northern economies to maintain control over capital deployment and investment in Southern economies. This in turn restricts indigenous Southern access to capital. When access to capital and resources is restricted, developing economies are unable to invest and expand production in the same way that developed economies do, and so remain dependent and poor (DeSoto 2000, p. 5)

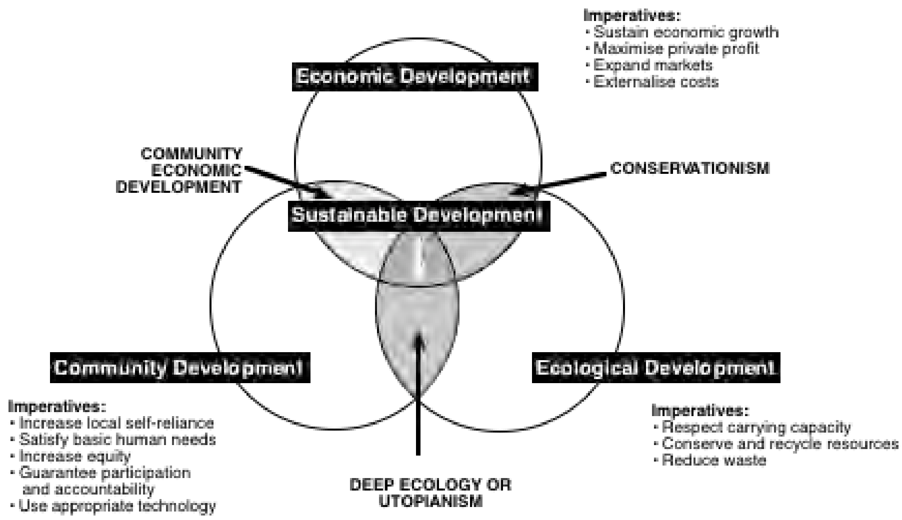
Our common future does not attempt to quantify limits or provide a universal definition of basic needs. Nor does it attempt to operationalise the concept of sustainable development. But despite this, or perhaps because of it, the concept of sustainable development and the impetus to pursue it has struck a resonant chord with many governments and communities throughout the world.

1.1.1 Models and conceptions of sustainable development

Operationalising a concept like sustainable development is the essence of scientific and social research, engineering and public policy development. It can also become a stage for the theatre of diplomacy and realpolitik. Given the broad principles laid out in *Our* *common future*, at the outset most sustainable development programs set about defining what the concept means, given the particular context in which it is to be pursued (GRI 2002, p. 6).

One of the most common ways of conceptualising sustainable development is by separation of the global system into three domains of concern, or *three pillars of sustainability*: the economy, society and the environment. In the three-pillar model, sustainability is perceived as the position where these three areas intersect or find commonality. A diagram typically used to illustrate this is shown in Figure 1.1.

Figure 1.1 The three pillars of sustainability model



Source: ICLEI. 1996, *The local Agenda 21 planning guide: an introduction to sustainable development planning.* ICLEI, UNEP, Toronto.

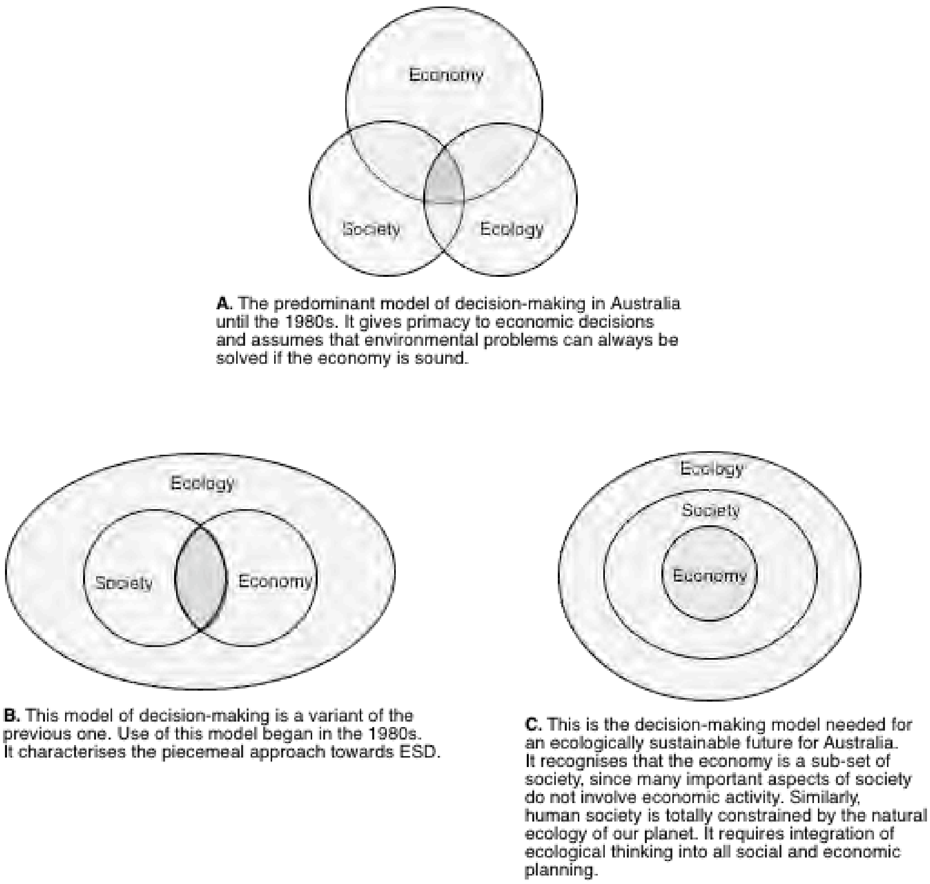
The intellectual segmentation of the natural world and human development into three categories follows the historical tradition of governments and industry that have worked on the basis of compartmentalised administration and specialised production units (SEAC 1996, pp. 10-13). The segmentation also corresponds to different academic and professional disciplines, their respective theories and analysis methods. This way of assessing sustainability problems is also referred to as the *triple bottom line*, or TBL approach to development, which has been widely used by the business community as a way of incorporating sustainability principles into its production processes (GRI 2002, pp. 7–8).

In practice the global system is contiguous. As noted in the WCED report:

> Ecology and economy are becoming ever more interwoven — locally, regionally, nationally, and globally — into a seamless net of causes and effects (WCED 1987b, p. 5).

While the WCED report stresses that sustaining activity in one area of concern should not be done at the expense of another (WCED 1987b, p. 4), the real outcome in many cases has been to draw a set of conclusions that sit within each of these intellectual partitions in a way that puts them at odds with each other (Diesendorf 1998, p. 8). The most common example is the conflict between the perceived economic imperative to maintain growth and the environmental imperative to respect and work within ecological limits. In relation to economic growth, some scholars and economic commentators argue that GDP must continue to grow, otherwise employment levels will decline as technological improvements generate greater efficiencies in the production process. Higher unemployment would then lead to a decline in aggregate demand and send the economy into a downward spiral (Windschuttle 1979, pp. 21–22). In many developed economies, GDP growth rates are maintained by increasing the rate of general consumption and the throughput of materials. Daly, among others, has argued that this consumption is above and beyond basic needs while at the same time placing significant pressures on the natural environment and resource base. These scholars argue that economic growth and development in these terms is not only a threat to environmental sustainability, but given that it is reliant on a steady increase in material throughputs from finite resource bases, it is ultimately a threat to economic sustainability as well (Daly 1996, pp. 27–30).

Figure 1.2 Changes to decision-making frameworks for ecological sustainability



Source: SEAC. 1996, *Australia state of the environment report 1996: an independent report presented to the Commonwealth Minister for the Environment*. CSIRO Publishing for the State of the Environment Advisory Council, Collingwood, ch. 10, p. 12.

In light of this conflict, many later models and definitions of sustainable development have sought to emphasise the dependency of human activity, including economic growth, on the earth's biosphere (Diesendorf 1998, p. 3). If particular conditions in the biosphere cannot be sustained, then, it is argued, neither can human economy and society (SEAC 1996, pp. 10–11). Rather than focus on the differences between economic, social and environmental development, later models have tried to emphasise areas of commonality by highlighting the dependent nature of the relationships between them, as shown in Figure 1.2.

A contributing factor to the conflict between economic and environmental concerns is the use of different theories to make sense of the subject matter that falls within each partition. Physical and biological science theories are used to understand and document the material processes and condition of natural ecosystems and human health, but economic theory is used to assess the status of economic conditions. The two conflict in several ways. First, there is no easy transition between the two on ontological[3] grounds. Or in other words, the way in which physical and biological science theories define the world and their subject matter is fundamentally different from the prescriptive values and priorities central to economic theory. Second, economic theory is essentially a-physical and poor at rendering spatial attributes in its subject matter (Prud'homme 1995, p. 731). By contrast, physical attributes are central to the concepts and explanations in physical science theories. When the two meet, it is as though two different languages are being spoken, and for which there is no direct translation for key concepts. Third, economic theory assesses system activity on the basis of pricing and money flows and the interaction of attributes assigned to money values. Physical science theories assess behaviour on the basis of material and energy flows. Fourth, notions of structure in economic theory are primarily about ownership relations rather than literal physical shapes and objects (Pemberton 1992, p. 19). Notions of structure in physical science theories embody a set of logistical conditions or physical properties. These issues concerning theory will be discussed in greater detail in Chapter Four as part of the literature review and again in Chapter Six when developing a systems theory of cities and induced traffic growth.

Administrative traditions and academic conventions aside, as Riedy points out, there is no theoretical justification for why sustainable development should function on the basis of the three areas of concern, or pillars of sustainability (Riedy 2005, p. 21). Markusen, among others, has criticised sustainability, classifying it as a fuzzy concept. She claims it lacks clarity and is difficult to operationalise because it can have two or more alternate meanings, so that different practitioners cannot apply it consistently or reliably. Markusen's primary complaint is levelled at its use in scholarly and scientific research in which the identification of generic operating principles is the goal. She claims that such an ill-defined concept makes this difficult and generally produces sloppy analysis (Markusen 2003, pp. 702–703).

3 Ontology is the study of the nature of objects or things. Ontology's primary concern is how the inherent nature of an object or thing affects what can be known about it (Flew 1984, pp., pp. 254–255). For example, material objects like rocks can be studied and understood in ways that things like social beliefs cannot.

In an attempt to overcome these shortcomings, a series of systems theories has been generated to define the nature of the global system and to identify where points of conflict or threats to sustainability might exist. The most well known of these systems theories is the Natural Step (NS) model, which was pioneered by a group of scientists under the leadership of Swedish cancer researcher and physician Karl-Heinrik Robert (Robert et al. 2002).

In the NS model, sustainability is conceptualised on the basis of the interaction of a system with its environment and the flow of materials and energy across system boundaries. This is seen as significant because it is at this point that different systems, with different goals or operating principles, and their environments can come into conflict. Conflict can come about in one of two ways. First, the system in question may take or receive material inputs from the system environment that cannot be sustained indefinitely because they cannot be replaced. Second, the system in question may produce outputs that change the system environment. If these changed conditions affect the functions of the system in question, then once again it may not be possible to sustain those functions. The NS model articulates these general system conditions by stating that:

> In the sustainable society, nature is not subject to systematically increasing …
> - Concentrations of substances extracted from the Earth's crust.
> - Concentrations of substances produced by society.
> - Degradation by physical means (Robert et al. 2002, pp. 198–199).

In these broad terms, sustainability rests on the degree to which the exchange of materials across the system boundary changes the internal functions of the system — in this case human systems or society — or those of the system environment — the biosphere and the Earth's crust. If changes through this exchange impede smooth interaction between the two, then either one or both will be compelled to undergo change that may dramatically transform general conditions. Sustainability relies on the degree to which systems can adapt to and absorb these changes and whether they have sufficient resilience to withstand any sudden disruptions when they occur (Kay et al. 1999, p. 723; Robert et al. 2002, p. 199).

Riedy points out that the NS model, and others like it, are subject to limitations. While these models provide a good framework for assessing physical system conditions, they have a tendency to treat people as *homogeneous* entities, denying their different values and by extension the complexity inherent within human society (Riedy 2005, p. 26). Confining investigation and explanation to physical system conditions undermines the potential to develop robust sustainability solutions, because it overlooks the practical problems of gaining social acceptance of change.

There is now an emerging field of what has been called *sustainability science* (Kasemir *et al.* 2003) Work in this field is highly dependent on systems thinking and in particular the use of *complex systems theory*. In these theories, the relationships between different elements and conditions within a system are articulated with a greater degree of sophistication than in the NS model. The treatment of social conditions is integrated with descriptions of physical conditions to produce a model of the system or sustainability problem in question. Riedy notes that this form of systems thinking is rare in practice (Riedy 2005, p. 23).

Throughout this thesis, a more sophisticated systems theory of cities and sustainable transport will be developed. However, for the purposes of introduction, it is enough to note the problems that have occurred with defining sustainability and the difficulties that arise when using simple models to describe them. While the soft systems theory of city planning and politics described in Chapter Two and the hard systems theory of city operations developed in Chapter Six are complex, the NS model principles provide a good starting point for the preliminary identification of problems.

In simple terms, there are problems concerned with key inputs to urban transport networks and the implications these have for the sustainability of cities, and there are problems that arise as a consequence of particular outputs and the impacts these have on the condition of the system environment or Earth's biosphere. Section 1.1.2 briefly examines petroleum energy inputs to urban transport networks while Section 1.1.3 examines outputs while focusing on greenhouse gas (GHG) emissions because of their implications for climate change. Problems also emerge when cities are engaged in trade with one another. While the urban transport sector requires a wide array of inputs to function, and produces a diverse set of outputs, a focus will be placed on the use of petroleum inputs and GHG outputs due to the high degree of attention these factors are now being given within transport circles, as well as their potential to effect dramatic change. Section 1.1.4 examines exchanges between cities. A working definition of sustainable urban transport will be outlined after discussion of these three problems.

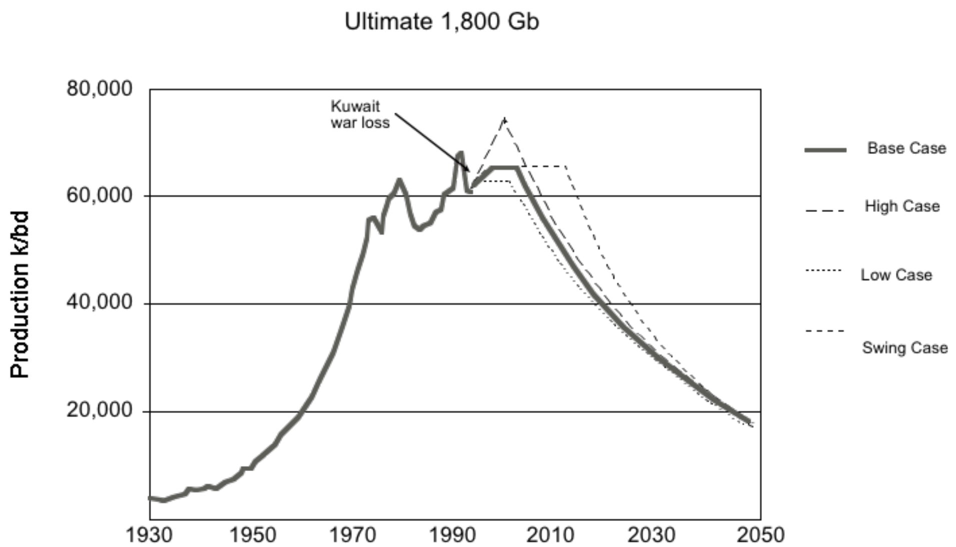
1.1.2 Urban inputs: oil dependency in cities

Oil is a finite resource. It is a unique source of energy because it is lightweight with a high energy yield and is cheap to acquire (Fleay 2003, pp. 2–3). It is the primary fuel that drives the urban transport networks of many cities throughout the world. A key problem currently confronting the sustainability of cities is the peaking of oil production and the impending prospect of oil depletion. These two material conditions have the potential to dramatically impact on accessibility within cities. This is because the structure of many modern cities has been built around road networks and is dependent on the availability of car use as the primary form of transport. Without ongoing access to low-cost oil, many of these networks will not be able to function and provide the level of accessibility that they currently do.

The prospect of a peak in oil production was first mooted by Hubbert in the 1950s and was based on the observation that once an oil well reached the mid-point in its production — half of total reserves — extraction slowed and became more costly. Hubbert reasoned that if this same pattern is applied to total global reserves, then just as extraction rates begin to slow for a single well, they should also slow and become more costly for global aggregate supplies (Hubbert 1956, p. 11). This points to a peak in production, whereby after that time it would not be possible to increase production rates unless ever-increasing investments were made in oil exploration, extraction, refining and distribution, resulting in significant increases in the marginal cost of oil production.

There have been numerous estimates by industry experts for when the peak in global production might occur. These have ranged from 2000 to 2030. Later estimates provided by government agencies (USGS 2000 as cited in IEA 2005, p. 29; Laherrere 2002, p. 1) are generally at variance with those from industry experts like Petroconsultants (Vidal 2005a, p. 16). The debate surrounding this issue will be examined in more detail in Chapter Seven.

Figure 1.3 Oil production scenarios

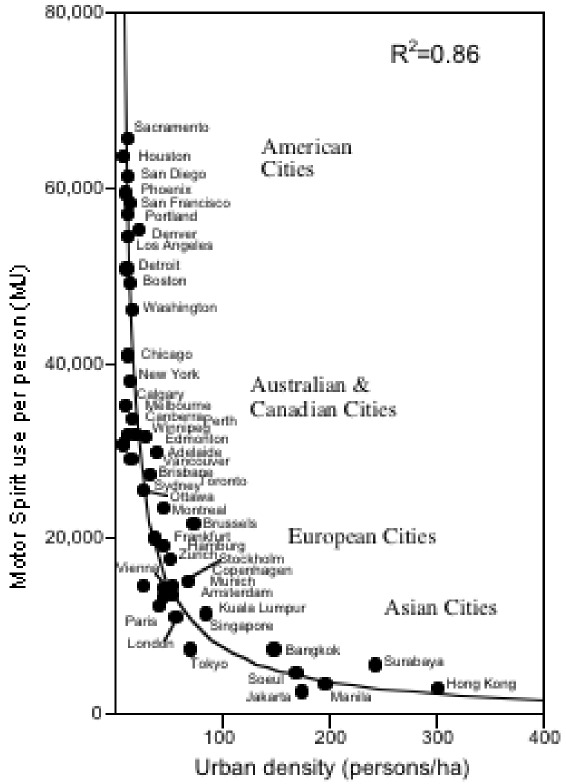


Source: Campbell, C. J. & Laherrere, J. H. 1995, *The world's oil supply 1930–2050*. Petroconsultants, Zurich. Figure 7-1.

Figure 1.3 shows global production until 1994. This production profile was compiled by Campbell and Laherrere, using the industry database for global oil and gas reserves collated by Petroconsultants (Campbell & Laherre 1995). On the basis of this estimate, global oil production should have peaked in 2000 if there were no major disruptions to demand. After publishing the report, the economic recession in south-east Asia during 1997–98, the events of September 11 and the advent of SARS saw a downturn in global oil consumption. If these estimates are robust, then the peak of production should have been delayed by a few years. Recent price spikes in the global price of oil suggest that global oil production may be on the verge of peaking (AFR 2004; ODAC 2004; SMH 2005).

While access to viable reserves may be geologically possible for several decades into the future, eventually the problem of physical scarcity will affect supply too. These circumstances will have a substantial effect on the transport operations of cites, with the impacts felt most in those cities where transport systems are predominantly orientated around road and motorway networks and where car dependency is consequently high.

Figure 1.4 Fuel use for private cars vs urban density



Source: Kenworthy, J. R., Laube, F. B., Newman, P. W. G., Barter, P. A., Raab, T., Poboon, C. and Benedicto, G. 1999, *An international source book of automobile dependence in cities 1960–1990.* University Press of Colorado, Boulder.

Figure 1.4 shows levels of gasoline use per capita for 44 international cities. As can be seen, cities in the US use more gasoline per capita than other cities throughout the world. The logistical characteristics of road-and motorway-based transport systems give rise to a pattern of urban development that is dominated by single-use zones that are spatially diffuse (Laube 1997, pp. 21–22; Newman & Kenworthy 1996, p. 4). Urban density is a good numerical indicator of differences in urban morphology — the composite relationship between transport and land use patterns. Those cities with low per capita levels of gasoline use and high urban densities are dominated by transit and walking-based transport systems that give rise to a pattern of development characterised by mixed land-use zones and compact building form (Newman & Kenworthy 1996, pp. 2–3). More will be said about these relationships in Section 1.2

and later in Chapter Six. These cities are not as dependent on petroleum as cities in the US. While fuel is used in these cities for private motor vehicle transport, if access to fuel is cut, resident communities would still have access to many destinations within reasonable travel times using alternate mass transit, walking and cycling. This is not the case for many US cities. Accessibility, and sustaining the economic activity dependent on it, is potentially threatened if fuel availability drops below present levels or if demand rises substantially. In many US cities alternate mass transit systems are less available and walking and cycling less viable.

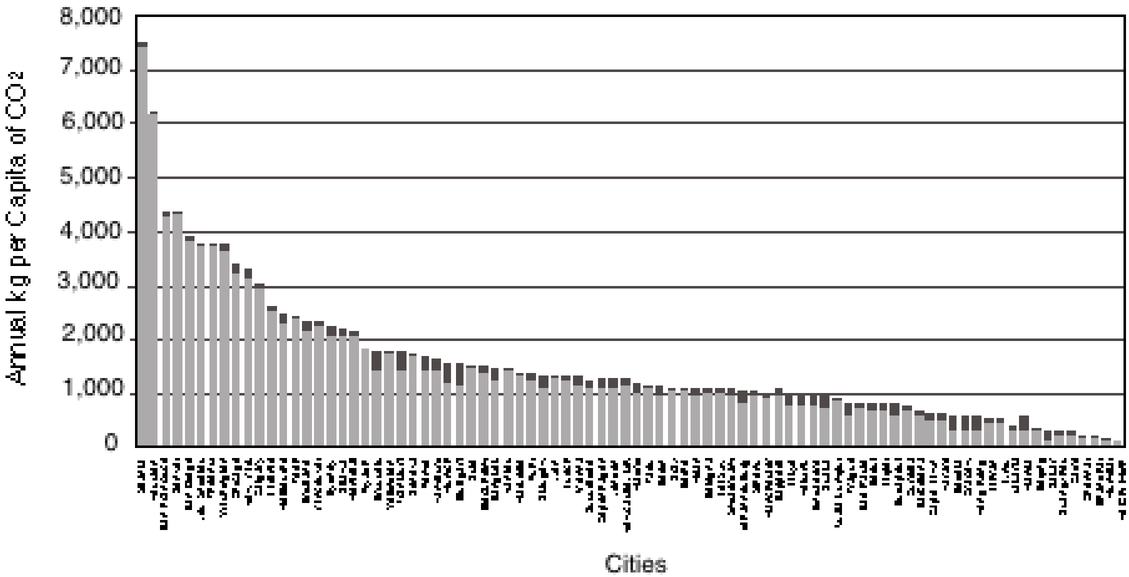
These structural conditions within cities raise questions about the ability to sustain transport functions and accessibility levels vital to core economic activity. While advances in car and alternate fuel technologies are often cited as substitutes, their economic viability is questionable, given the higher amounts of energy required to produce the fuels (Fleay 2003, pp. 4–5). These problems will be discussed in more detail in Chapter Seven.

1.1.3 Urban outputs: greenhouse gas emissions and global climate change

The sustainability of cities, and indeed the sustainability of all human systems, is dependent on the condition of the biosphere. Global climate change, brought about by increases in CO_2 and other greenhouse gases, poses a threat to the stability of the biosphere. It has the potential to affect agricultural production, the scale of arable lands, microclimates, the viability of water catchments and a suite of other ecosystem functions whose condition human economies are reliant on (IPCC 2001).While acknowledgement of global climate change as a serious problem is not universal, a majority of national governments from industrialised countries have accepted it and now support policies that attempt to shape development so that GHG emissions are minimised (Bodansky, Chou & Jorge-Tresolini 2004).

Transport is a significant source of the GHG emissions responsible for climate change. Transport emissions comprised 21 per cent of total global GHG emissions in 1998 and represented the fastest growing sector between 1990 and 1998. Emissions grew by 15 per cent during this period (OECD 2004, p. 169). Most of these emissions are produced by industrialised economies, and within this group, US cities emit much higher levels than other cities. Figure 1.5 shows per capita emissions of CO_2 from private and public transport sources. Emissions from US cities, where urban motorway development has been extensive, are far higher than in European cities where public transport systems are more comprehensive. US cities emit between three and seven times more CO_2 per capita than European cities and this is primarily due to the greater emphasis on road and motorway development within those urban systems (Kenworthy 2003, p. 18).

Figure 1.5 CO_2 emissions from urban passenger transport (private and public transport)



Source: Kenworthy, J. R. 2003, 'Transport energy use and greenhouse gasses in urban passenger transport systems: a study of 84 global cities' in *Network of Regional Governance for Sustainable Development: Second Meeting of the Academic Forum of Sustainable Development*, Perth, 17–19 September, p. 18.

In Australia, 14.4 per cent of net national emissions came from the transport sector in 2002. Of this, road transport contributed 88.2 per cent and passenger cars contributed 62.2 per cent. This represents increases of 27.3 per cent and 27.1 per cent for these sectors respectively from 1990 to 2002, making transport the fastest growing source of GHG emissions within the Australian economy (AGO 2004, p. 21).

The Kyoto Protocol, an agreement by industrialised countries to curb greenhouse gas emissions, came into force in 2005. While the Australian and US Governments have not ratified the Kyoto Protocol, these countries will be affected economically by its implementation in other industrialised countries throughout the world. A key component of the Kyoto Protocol is the introduction of emissions trading between countries and companies within them as long as those countries have ratified the Protocol. Those that emit above their quota have the option of buying the right to emit higher levels of GHG emissions by paying money to those with spare capacity because they emit below their quota (UNFCCC 2001). But countries that have not ratified and are high GHG emitters will also be potentially affected through the imposition of carbon taxes. This prospect has already been raised by Japan (Hopkins 2004). Because Japan has ratified the Kyoto Protocol, it must reduce its greenhouse gas emissions to 94 per cent of 1990 levels during the first commitment period between 2008 and 2012. By imposing a carbon tax on coal it buys from Australia, Japan hopes to shift power generation away from coal to cleaner fuels like natural gas. Japan may also impose a carbon tax on energy-intensive imports, such as steel and aluminium, from non-Kyoto countries in order to protect its local industries that operate under Kyoto restrictions.

The US and Australia are the world's highest per capita emitters of GHGs (Turton 2001) and both rely on exports to Kyoto signatory countries like Japan and the EU for a portion of their incomes. It is therefore possible that the Kyoto Protocol will give competitive advantages to those macroeconomic blocs and nations that produce less greenhouse gas emissions and so do not attract carbon taxes.

As with the use of non-renewable fuels, the volume of GHGs emitted from the urban transport sector is dependent on the structural conditions within cities. Those cities with a higher proportion of trips undertaken by private motor vehicles consume more fuel and produce more GHG emissions. However, unlike the sustainability issues associated with inputs to an urban transport system, all human populations are affected environmentally by outputs like GHG emissions, irrespective of what measures may have been introduced to curb emissions or who produces them, and the effects are not confined to the immediate surrounds of particular transport systems. Consequently threats to sustainability arising from the transport choices of decision-makers and communities within individual cities are not confined to the material boundaries of that city. For this reason, global responses like the Kyoto Protocol are being developed.

The Kyoto Protocol and its associated emissions-trading schemes raise questions about the economic proficiency of cities. Regardless of whether a particular industrialised country has ratified the Protocol or not, a global price will be placed on CO_2 emissions, meaning that cities with relatively low levels of greenhouse gas emissions have a competitive advantage over those cities with high emissions.

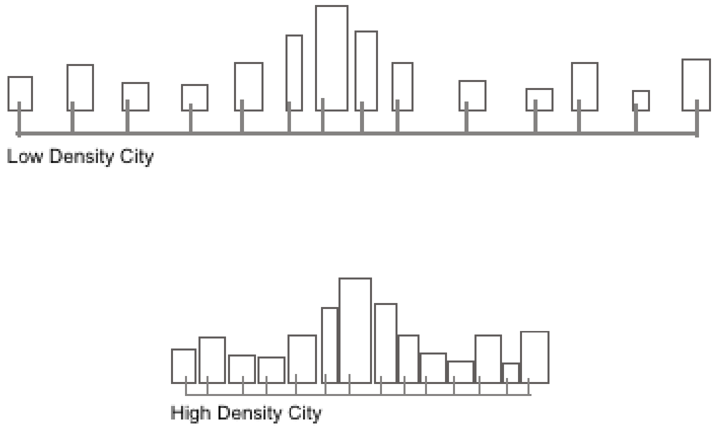
1.1.4 Urban exchange: trade between cities and economic sustainability

The sustainability of a city is not only dependent on its relationship with natural systems but also on its relationship with artificial systems, or other cities. As stated at the start of the introduction, cities are primarily built for economic purposes. The dynamics of inter-city trade affect the core economic functions of cities. Like the resource inputs and pollution outputs discussed in the previous two sections, urban exports and imports impact on the production processes that take place within an urban system and, through this, affect its ability to afford and sustain living standards for its inhabitants.

A critical factor in the trade performance of a city is the efficiency of its infrastructures. Just as the competitiveness of an individual firm is affected by the efficiency of its plant equipment, so too is the global competitiveness of a city's firms and industries affected by the efficiency of the infrastructures that support and link their production processes together.

If the various macroeconomies that make up the global economy are conceptualised as a network of cities and their hinterlands competing and trading with one another instead of nations competing and trading with nations (Jacobs 1984), then the suite of international cities shown in Figure 1.4 provides some potentially new insights on sustainable economic development and the role that transport infrastructures play in this equation. Clearly, Asian cities have lower rates of per capita fuel consumption than their US and Australian trading partners. As Figure 1.6 shows in a schematic way, this occurs because high-density cities have smaller distances between their operating units so that fuel use is less and non-motorised modes of transport like walking and cycling are more viable. This pattern no doubt extends to per capita transport costs generally because the spatial structure of the city also affects the provision and consumption of other factors that make up the transport system.

Figure 1.6 Comparative advantages for infrastructure costs in low-and high-density cities



Source: Zeibots, M. E. 2002, 'The macroeconomic structure of cities: indicators for sustainable urban infrastructure development' in *Regional cycles: regional economy towards sustainability.* ICLEI, Leipzig, p. 3.

The relative distances between operating units in a city not only affect transport, but other hard infrastructures as well. Water and sewerage, gas and electricity grids all have higher per capita provision and operating costs in low-density cities (Clarke 1997; Perkins 2003). More materials have to be used to bridge the gaps. The same occurs for soft infrastructures.[4] More schools, hospitals and emergency service units are needed to serve spatially diffuse urban populations (Capello & Camagni 2000). If data were available for combined consumption of other key infrastructures and plotted against urban density, a relationship similar to that found in Figure 1.4 would probably occur.

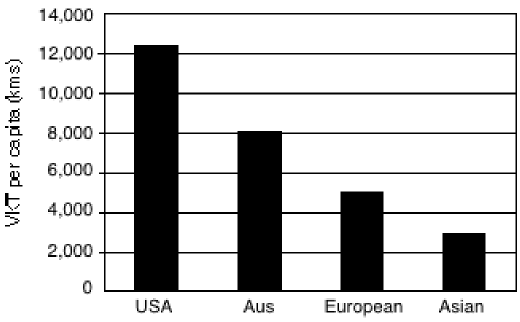
This raises several critical questions about the impact of transport infrastructure on economic activity generally. If per capita costs for all infrastructures are higher in low-density cities, then how does this affect economic performance at the macro level? Are the higher rates of resource use within the transport sector off-set by greater accessibility? Does this lead to higher rates of production? Or do higher levels of infrastructure consumption simply translate into higher inputs to production? Does this

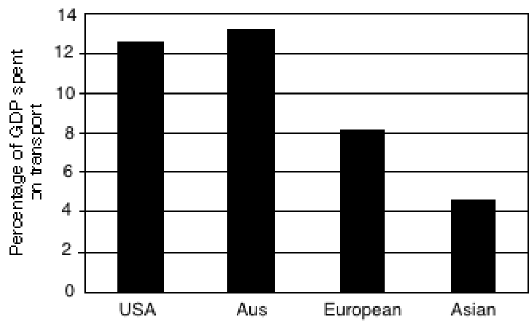
[4] Hard infrastructures refer to physical grids and networks like roads, public transport, water and sewerage systems and electricity and gas grids. Soft infrastructures refer to services like health care, education and civilian policing.

make the low-density urban systems typical of US and Australian networks less attractive as location points for export-producing industries?

Figure 1.7 provides some indication of what may be happening to production within cities across a range of transport system types. As can be seen, average values for Vehicle Kilometres Travelled (VKT) and the percentage of metropolitan GDP spent on transport for groups of industrialised cities show a similar trend. In step with per capita fuel consumption, per capita VKT in US cities is greater than for Australian, European and Asian cities respectively. A similar trend occurs for the percentage of production directed to transport. Where US cities direct on average 12 per cent of their metropolitan GDP towards transport, Asian cities direct around 4 per cent.

Figure 1.7 Average VKT and percentage of metropolitan GDP spent on transport (1995)





Average VKT per capita was calculated from a set of 32 international industrialised cities. The percentage of metropolitan GDP spent on transport was calculated from a set of 29 industrialised cities.

Source: Kenworthy, J. R., Laube, F. B., Newman, P. W. G., Barter, P. A., Raab, T., Poboon, C. and Benedicto, G. 1999, *An international source book of automobile dependence in cities 1960–1990.* University Press of Colorado, Boulder

From a systems perspective, a key point to identify is that transport infrastructures are an input to production. This is because they are fixtures and can only be consumed by the resident population and industries within the city in which they are located. They cannot be traded and so cannot become a potential export and used to earn the city an income.

The data in Figure 1.7 point to the possibility of an inverse relationship between a city’s infrastructure input sectors and industrial output sectors. When inputs are high, urban systems become less attractive as locations for many industrial production processes. Where infrastructure costs are high, labour costs need to be high so that individuals can afford to live in such settings. Under free trade conditions, such cities may not be as competitive as locations for export-producing industries. Where urban systems are more compact and resource use per capita for infrastructures remains comparatively low, a smaller percentage of net production appears to be directed to sustaining activity within infrastructure sectors. This would occur for two reasons, the first being that resource requirements are simply less. The second reason is that more industries are able to survive within these cities when exposed to competition from imported goods, as well as being more attractive to industries that may relocate to take advantage of the conditions.

If this is the case, then how might transport infrastructures affect the dynamics of inter-city trade and what are the implications for the sustainability of a city’s core economic functions when operating within the global market place? More will be said about these points in Chapter Seven. For now it is enough to acknowledge that the exchange of manufactured goods and services between cities within a competitive global market place extends the range of questions about the form of urban transport development most suited to sustaining city processes.

1.1.5 Principles for sustainable urban transport development

As outlined at the start of the introduction, a primary function of a city is to provide access that facilitates the exchanges necessary for complex industrial production and the division of labour. In principle, access should be maximised.

A sustainable urban transport system is one that enables accessibility to goods and services and other necessities to be maintained indefinitely. To do this, the transport system needs to take account of the resources available to carry out the transport task, the security of their supply and the ability to substitute inputs from other sources if necessary. These points were discussed in Section 1.1.2. Given that urban transport systems are sub-systems of cities and cities are sub-systems of the wider global ecological system, sustainability is also dependent on the integrity of the global system. Wastes from the transport sector should minimise impacts that cause instability or adverse change within the global ecological system in order to maintain its integrity. This point was touched upon in Section 1.1.3. The sustainability of the core economic functions of a city is affected by transport through its ability to provide access, but also by its ability to provide that access in a way that is competitive with other cities, as discussed in Section 1.1.4.

These principles of sustainable urban transport systems — maximisation of access opportunities coupled with the minimisation of material throughputs — will be elaborated upon and quantified in more detail in Chapter Seven. What is critical at this point is to grasp how different transport modes and their operating regimes produce different degrees of accessibility and require different amounts of resources to operate them.

1.2 Access and urban transport

Accessibility arises out of the synergy between the transport and land-use components of an urban system. Access, however, should not be confused with mobility. The ability to access facilities is not simply dependent on the speed of a transport mode, or the amount of movement a transport mode provides. Rather, accessibility is defined by the number and diversity of destinations that can be reached within a given time period, given the means and options available to individuals. As will be shown, some scholars have concluded that accessibility declines in cities where mobility is greatest (Cervero 1997; Ross 2000).

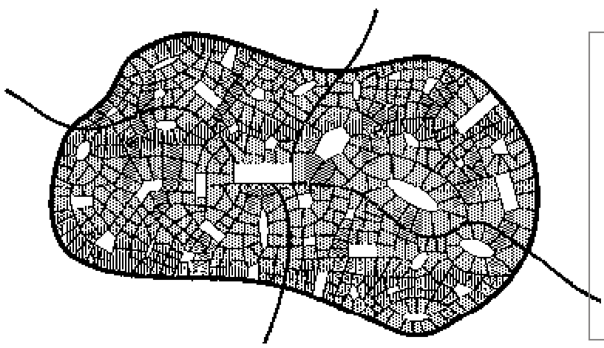
Historically, different city *typologies* have emerged upon the introduction of different transport technologies that in turn give rise to different accessibility profiles. This section provides a brief review of these features in order to demonstrate some basic features of accessibility and how they come about. This will then be used to assist in identifying and refining the thesis research questions in Section 1.3.

In an urban system, transport and patterns of land use and building form are related to one another by the need to move between them, linking their functions into the string of activities that become the day-to-day life of an urban community. The travel times and logistical properties of the transport system are of central importance to how this is done. There are five key logistical features of transport systems, which include the *speed* of the transport mode, the amount of space or *land take* required to operate the mode, the *degree of segregation* between transport carriageways and building spaces, the *capacity* of the transport mode and the *network geometry* of transport elements (Thomson 1977, pp. 93–96). Together, these five features work to organise building form in such a way that the activities they house can be amenably accessed within the time that individuals are able to assign to travel.

1.2.1 Three city typologies

The primary mode of transport that served early cities was walking. Most goods and services were accessed on foot. Where bulky goods needed to be transported, carts and animal-drawn vehicles were employed. As summarised in Figure 1.8, the logistical properties of walking are slow speeds, low land take, a high degree of integration between transport and land-use elements so that borders between areas for walking and other activity spaces are *fuzzy*, a high capacity, or throughput of people, and a dense network geometry that provides a high degree of permeability throughout the urbanised area.

Figure 1.8 Walking-city typology



Transport		Building form and land use patterns
Slow speed	→	Compact building form and mixed land uses to minimise access
Low land-take	→	Narrow streets enable close proximity of buildings
Movement integrated	→	Quick transition between transport and other land use areas
High capacity	→	Congestion minimised
Permeable street grid	→	high transport to building contact ratio maximising access

Adapted from: Newman, P. W. G. & Kenworthy, J. R. 1996, 'The land use – transport connection: an overview' in *Land Use Policy*. Vol. 13, No. 1, p. 2.

To maximise accessibility in light of these logistical properties, land uses need to be highly mixed. Residential, commercial and light industrial workshop uses can often be found in the same building in walking cities. Building form is compact and façades abut one another to maximise the number of different uses that can be accessed in the city within a given time period. Streets are narrow because the land take needed to accomodate walking is small. The degree of segregation between street traffic and other land uses to maintain safety is low and so the degree of integration between all urban activities is high. Narrow streets permeate the block structure at short intervals, enhancing access further by reducing travel times between different activities. Land uses are small in scale in these city typologies and the relative density is high. These features of walking-city building form can be seen in the aerial view of a mediaeval walking city shown in Figure 1.9.

The physical properties of this form of urban system are largely a product of the speed of walking and the scale of a human pedestrian. This changes dramatically when motorised vehicles are introduced to the transport system (Gehl 2001, p. 79).

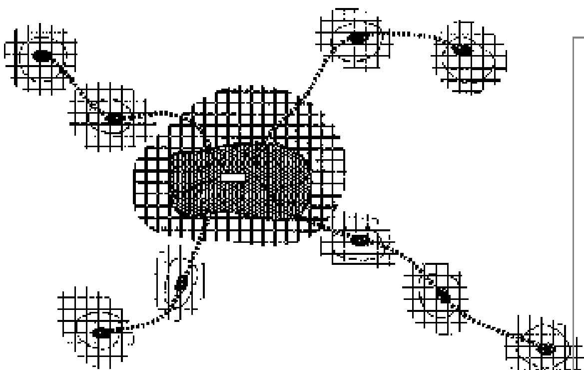
Figure 1.9 Walking-city building form

Aerial photogrpah of a mediaeval walking city showing compact building form and narrow streets that follow the natural contours of the site.

After the introduction of steam engines in the 19th century, the widescale use of trains, and later tramcar sets, transformed the structure of cities because of the dramatic increase in travel speeds. The distances that could be travelled within similar time periods by both people and bulky goods were greater and so the area over which a conurbation could be cohesively maintained was increased.

Figure 1.10 shows a schematic plan of a typical transit city. Many of the logistical features typical of walking cities are still present because walking remains an essential part of door-to-door access between origins and destinations. Buildings still house a mix of residential, commercial and light industrial workshop land uses. But where this pattern was contained within a single comprehensive mass, it becomes spread out along transit arms that extend from the central city area, forming nodal points of walking-city development within the walking catchment areas of rail stations. Where tramcar services are provided along on-street alignments, linear or *ribbon strip* sections of walking cities develop in accordance with the stretches of urban land within walking distance of tramcar services. The ability to travel longer distances more quickly means that some land uses can be separated, such as heavy industrial.

Figure 1.10 Transit-city typology



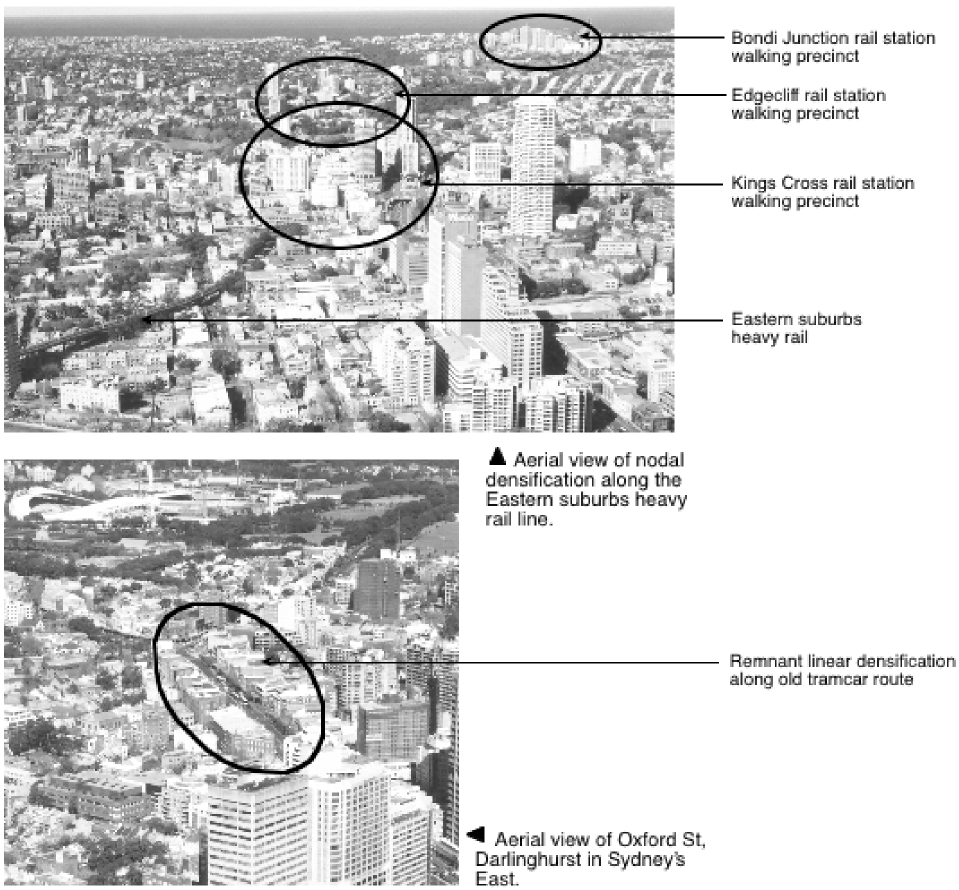
Transport		Building form and land use patterns
Slow / high speed mix	→	Compact building form and mixed land uses at nodal points to maximise access while extending city area
Low land-take	→	Narrow streets at nodes connected by wider trunk routes enable close proximity of most buildings
Movement segregated	→	Quick transition between transport and other land use areas
High capacity	→	Congestion minimised
Permeable street grid around nodes	→	High transport to building contact ratio maximising pedestrian access between transit zones

Adapted from: Newman, P. W. G. & Kenworthy, J. R. 1996, ‘The land use – transport connection: an overview’ in *Land Use Policy*. Vol. 13, No. 1, p. 2.

Unlike the walking city, transit cities generate discernable hierarchies in their building form and patterns of land-use development. This is because mass transit networks require segregation from other activities for reasons concerned with safety, while at the same time generating concentrations of pedestrians at designated stops along their route.

Similarly, tramcars require wider streets so that pedestrians and vehicles can move separately from one another. These features introduce a movement hierarchy into the city system that also influences land uses and building form. High volumes of pedestrians making their way to transit stops mean that some streets have higher volumes of pedestrian traffic. These zones potentially afford greater access because of their close proximity to the destinations accessible by the transit system. While land uses are still mixed, those located along transit routes tend to be higher in density to take advantage of the high volumes of pedestrian traffic and proximity to transit services. These features of transit-city building form can be seen in the aerial view of Eastern Sydney shown in Figure 1.11.

Figure 1.11 Transit-city building form

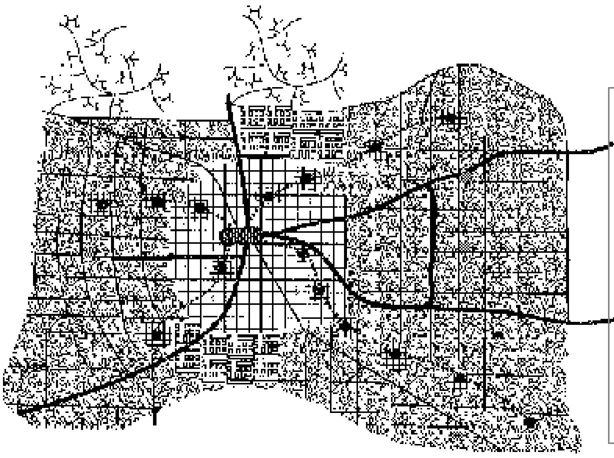


Source: Zeibots, M. E. 2003b 'How do cities work and why is transport so significant? Regional sustainability and the search for new evaluation tools' Conference proceedings in *Network for Regional Governance and Sustainable Development: Second Meeting of the Academic Forum for Sustainable Development*, Perth, pp. 16–17.

The next phase in the development of transport technology was the wide-scale introduction of the private motorcar in the early 20th century. Patterns of land-use development and building form changed dramatically once a high-speed form of mechanised transport was introduced, which, unlike mass transit, could provide door-to-door service and was not restricted to rail track alignments.

Figure 1.12 shows a schematic plan of an auto-based city and lists the logistical properties of private-car use and the effects these have on building form and land-use patterns. In addition to high speeds, space requirements are significantly greater, resulting in higher land take for transport. The degree of segregation is also greater. In addition to trunk routes, there is a need for footpaths on local and collector streets to separate pedestrians from cars. The emergence of wide-scale single-zone land-use development and large-scale buildings is a distinguishing feature of this typology.

Figure 1.12 Auto-city typology



Transport		Building form and land use patterns
High speed	→	Low density areas of single use development
High land-take	→	Wide streets and large car parking areas
Movement segregated	→	Quick transition in low density areas, slow transition in high density areas
Low capacity	→	High congestion levels during peak periods
Trub & local road hierarchy with restricted access	→	Low transport to building contact ratio

Adapted from: Newman, P. W. G. & Kenworthy, J. R. 1996, 'The land use – transport connection: an overview' in *Land Use Policy.* Vol. 13, No. 1, p. 3.

Land-use development supported by a predominantly road-and car-based transport system does not benefit from a high-density formation. This is because large spaces in relatively close proximity to destinations are required for car-parking. Ease of parking is needed to keep travel times short for trips by car. By contrast, a multiplicity of destinations needs to be close to service stops if accessed by mass transit so that they can be easily reached on foot. It is for this reason that land uses tend to be separated and the urban structure low in density. This outcome can be seen in the aerial view of Chicago shown in Figure 1.13 that illustrates the structure of auto-city building form.

While tramcars and trains have amenity impacts on the activity zones around them, these appear to be less than the noise, safety and pollution impacts of high volumes of private motor vehicles. In auto-based cities degraded amenity can affect the internal uses of buildings when occupants avoid using rooms and areas within buildings located close to busy roads (Appleyard, Gerson & Lintell 1981). This reinforces and compounds the isolation and diffusion of land-use activities within auto-based city systems (Gehl 2001, p. 73).

Figure 1.13 Auto-city building form

An aerial view of Chicago showing the high land take by road space and car-parking and the diffuse block structure of buildings.

Because private motor vehicle systems have relatively low capacities, high concentrations of people in cars quickly generate congestion, slowing network speeds and thereby reducing the number of destinations accessible within a given travel time. The same can happen when overcrowding occurs on mass-transit systems, although the problem is more controllable because public transport operates to a fixed schedule. Road congestion is more fluid and travel times potentially more variable, consequently road congestion is able to undermine accessibility more easily and by extension impact on the core economic functions of a city.

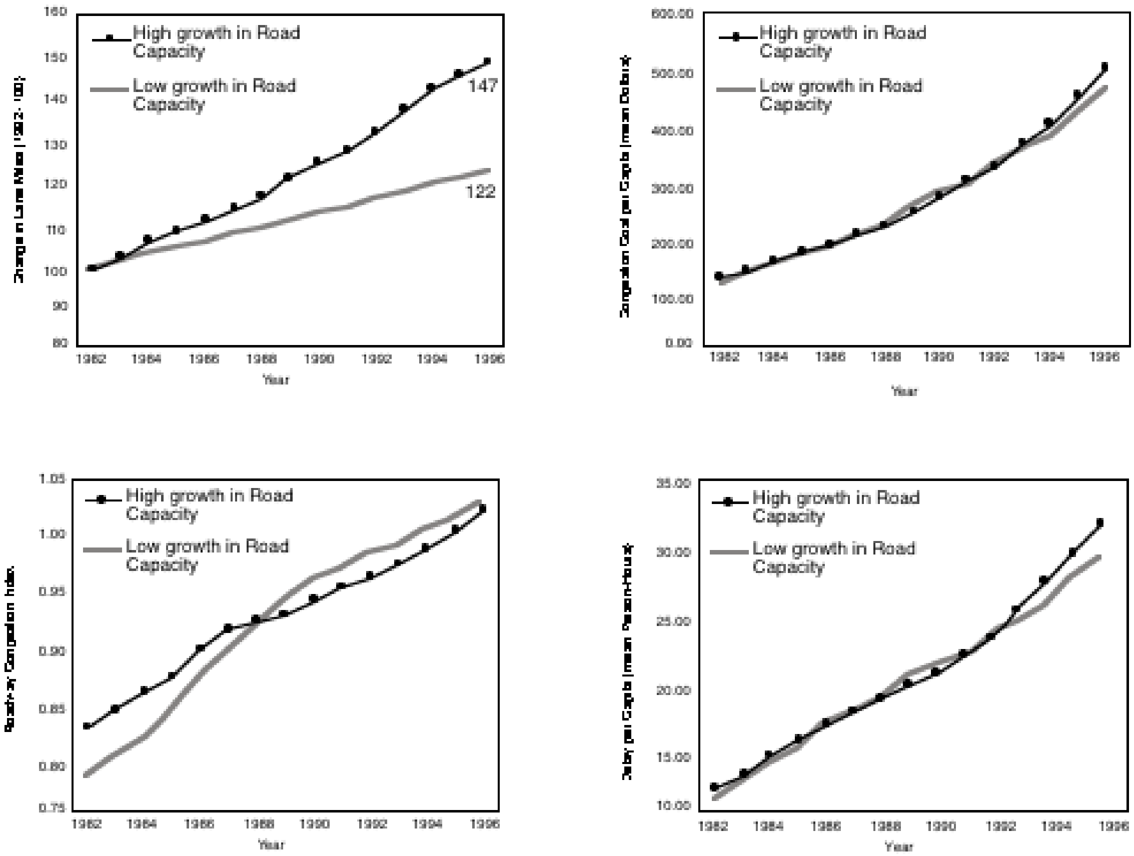
1.2.2 Accessibility and congestion in auto-based city systems

A common policy response to road traffic congestion has been the expansion of road capacity in the form of urban motorway development. In many cities extensive high-speed road and motorway networks have been built to bypass congested business districts, metropolitan centres and choke points in road networks in a bid to free up access.

Figure 1.14 shows the relationship between the growth in road space (both restricted and unrestricted access carriageways) and the cost of congestion for 70 metropolitan areas in the US. As can be seen, the metro areas with high growth rates in road capacity experience around the same levels of congestion as areas with comparatively low road capacity growth rates, suggesting that adding road space does not substantially reduce the amount of time people spend in transit or the costs attributed to congestion[5]. But if congestion and time spent travelling remain essentially the same regardless of additional road capacity, what happens to accessibility levels?

[5] Costing congestion is a contested area (for example, Mogridge 1997 and Prud'homme 1998), but even if the costing of congestion is misguided, analysis using this approach shows that travel times are not ultimately improved by adding road space and so support the contention that the practice gives rise to induced traffic growth.

Figure 1.14 Road space and congestion costs in US cities (1982–1996)



Source: STPP. 1998, *An analysis of the relationship between highway expansion and congestion in metropolitan areas: lessons from the 15-year Texas Transportation Institute Study.* Surface Transportation Policy Project, Washington, DC.

Accessibility is a difficult concept to measure. This is because accessibility is a condition that emerges from a variety of factors. The relative proximity of destinations and facilities, the time it takes to travel the necessary distances to reach them, the availability of different modes, the amenity and convenience of the trip, are all factors that contribute to how easily people can access a wide variety of activities.

Ross (2000) argues that accessibility declines as mobility increases. In cities where mobility is highest — measured in terms of VKT per capita — land uses are separated rather than mixed. Large suburban residential areas often site shopping, recreational and civic facilities in isolated groups rather than evenly mixed with residential land uses throughout the fabric of the city as is the case with transit-and walking-based system types (Ross 2000, p. 14).

The central question to emerge from this overview of city typologies is: what happens to an urban system as it makes the transition from a walking-and transit-based to an auto-based city form? What happens when road space is added to an urban system? What implications does this have for accessibility, and ultimately, what implications does this have for the sustainability of urban systems?

1.3 Urban motorway development and induced traffic growth

The transformation in urban structure and accessibility profiles that take place as a result of urban motorway development can be explained by what will be referred to here as the *induced traffic growth hypothesis*. Induced traffic growth refers to the increase in road traffic volumes that occurs after the opening of new roads and motorways.

This section introduces the topic of induced traffic growth as it is currently understood and studied within the traditional disciplinary boundaries of traffic engineering and transport economics. Later sections of this thesis (Chapters Six and Seven) will relate this relatively narrow understanding of induced traffic growth to the much wider problem of urban sustainability and the complex dynamics of urban systems.

To begin, a definition of induced traffic growth is useful. This will be followed by a brief discussion of some of the key arguments that have taken place around the phenomenon in public debate and professional circles.

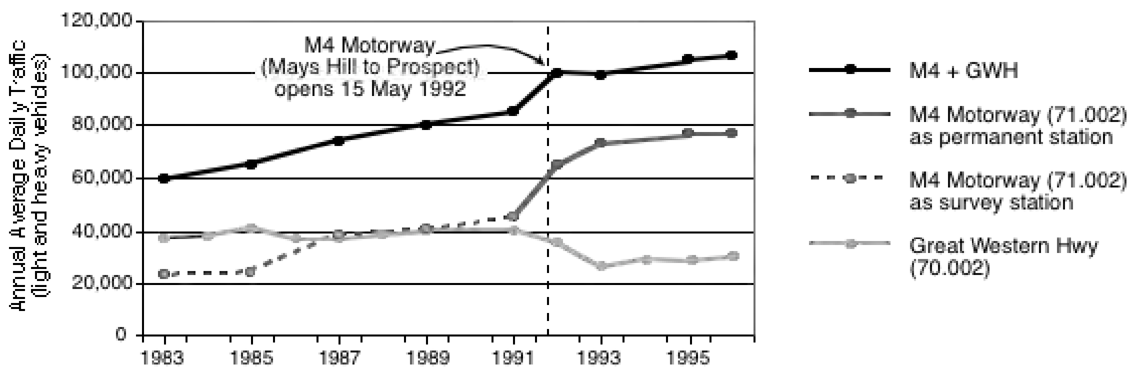
1.3.1 Definition of induced traffic growth: a contested phenomenon

Induced traffic growth is a contested phenomenon, although opposition to it has receded in the last ten years since publication of a UK Government-sponsored inquiry into whether or not it exists (SACTRA 1994). The disputes that surround it affect its definition so that a simple explanation without some background and qualification is difficult.

The definition of induced traffic growth varies between popular perceptions, scholarly argument and modelling practices. In popular discussions, induced traffic growth is generally understood to refer to the increase in traffic volumes that is experienced after increases in road capacity like the addition of a new urban motorway section. By increasing road capacity, congestion is eased and travel times for standard trips are reduced, making travel easier and more attractive. Consequently some motorists who choose to use the new road may also travel more than they had previously, causing traffic volumes to increase (CART 1989, pp. 10–11; Engwicht 1992, pp. 44–45; Jacobs 1964, p. 363).

In the case of urban motorways where demand is concentrated and higher levels of congestion act as a brake on further growth, traffic volumes can grow very quickly once capacity is increased and congestion reduced. Under these conditions congestion soon returns to levels on a par with those experienced before the capacity increase and net volumes become larger. In the popular literature, descriptions of the process that gives rise to induced traffic growth are often followed by the corollary 'Traffic grows to fill the available road space', which has served to give the phenomenon a status not unlike that of a law of physics (Hall 1980, p. 66).

Figure 1.15 AADT volumes for Sydney's M4 Motorway and Great Western Hwy



Source: RTA. 1995, *Traffic volume data for Sydney Region 1993*. Roads & Traffic Authority of New South Wales, Sydney. Armstrong, B. 2004, *Personal communication*. Roads & Traffic Authority of New South Wales, Sydney.

The time series data in Figure 1.15, based on research for this thesis, illustrate just such an increase. In the period immediately after the opening of a new section of the M4 Motorway in Sydney's western sector, a sharp increase in Annual Average Daily Traffic (AADT) volumes occurred on the motorway. The pattern that can be observed in this example is typical of what occurs in many such cases. The sharp increase is referred to as the *ramp-up period*. In practice this occurs quickly and its impact can be perceived by individuals using the network. When the increase is large in scale, the changes can become a cause for travel delays and queuing, public complaint and political unrest (see, for example, Hutchings 1992, p. 1).

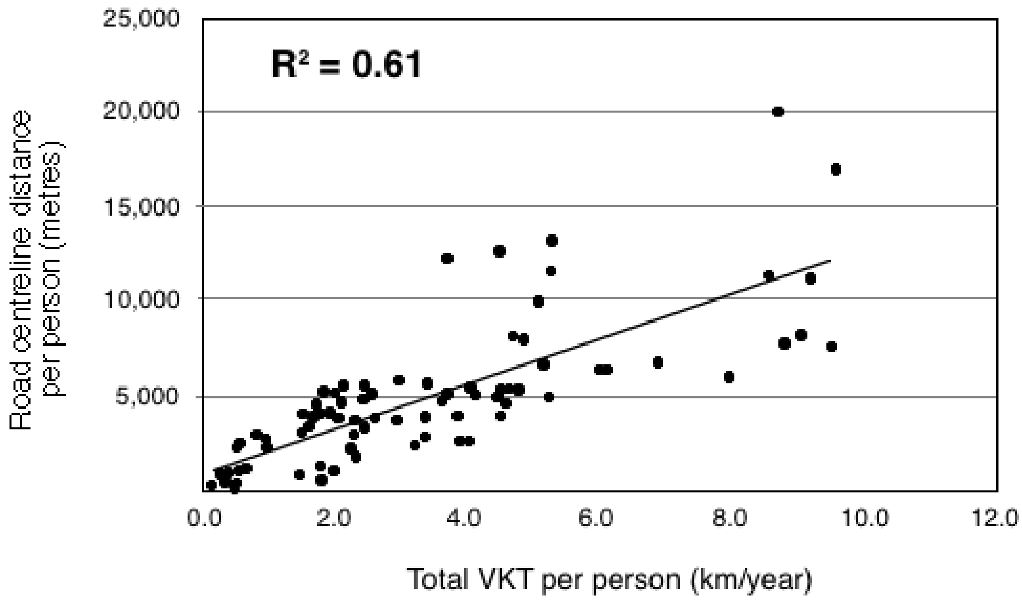
The scholarly definition of induced traffic growth is more complicated, however, and reliant on how the phenomenon can be measured and tested for, as well as how it might appear in traffic models. The time series data in Figure 1.15 show AADT volumes for two roads, however, and as can be seen, there was a decline in traffic volumes on an alternate route — the Great Western Highway — whose alignment runs parallel to the M4 Motorway. Clearly, motorists switching from this other arterial road generated some of the increase in motorway traffic. This being the case, it is not true to say that all of the traffic increase, or *ramp-up*, comprises an actual rise in traffic or trip numbers. Much of it can be explained as a redistribution of traffic.

It is for this reason that professional and scholarly definitions of induced traffic growth are more elaborate and highly qualified by comparison with those that form the basis of popular perceptions and which have gained currency in popular debates. Alternate explanations for traffic volume increases like redistribution are also the reason why the very existence of the phenomenon has been contested.

The example cited in Figure 1.15 will be examined in more detail in Chapter Three where it will be shown that, in addition to the Great Western Highway, traffic also shifted from several other roads that run parallel to the M4 Motorway. Interest groups and government transport agencies that support the construction of urban motorway development often cite this as a refutation of the induced traffic growth hypothesis, claiming that the observed increase in traffic volumes is not an increase at all but merely traffic shifting from multiple routes across the network (SACTRA 1994, p. 54). But as will be shown in later empirical analyses, the processes that a new motorway section trigger are not that simple.

The difficulty with the argument that ramp-up periods simply comprise traffic displaced from other routes, so that there is no increase in VKT, is that data that compare the relative amounts of per capita travel for whole cities show a systemic relationship between the amount of urban road space and the amount of travel undertaken in that city. In cities where road space is high, VKT per capita is high. Where per capita road space allocation is low, VKT is also low. This relationship is shown in Figure 1.16, suggesting that some general principle is at work.

Figure 1.16 VKT vs road length per capita for 78 international cities (1995)



Note: Road capacity is measured as centreline road distance and not centreline *lane* distance, due to data availability. The latter would be a more accurate measure of operating capacity.

Data source: UITP 1995, *Millennium Cities Database.* International Association of Public Transport Providers (UITP), Brussels.

The whole-system data shown in Figure 1.16 add weight to the induced traffic growth hypothesis. They also reveal the usefulness of examining whole urban systems in tandem with changes to particular parts of the system, even though the source of these increases cannot be identified precisely. For example, it is unknown whether these increases occur as a result of trip distribution, trip generation, network reassignment or mode-shifting (Noland & Cowart 2000, p. 5).

The more detailed example in Figure 1.15 serves to demonstrate some of the difficulties encountered when trying to define what is meant by induced traffic growth. This is because the increase in travel speed that occurs after an increase in road capacity triggers several different forms of travel behaviour change that take place simultaneously. For example, some commuters may find that the new or improved road is more attractive than an old route and so switch from one to the other as illustrated in the example above. This is called *traffic reassignment*. Alternately, some people may find that travel by car on a new or improved road is able to provide a faster trip than using parallel rail or public transport services, and they therefore change modes. This is called *mode-shifting*. An increase in road capacity may also reduce congestion during peak travel periods and so encourage some people who had scheduled their trips outside the peaks to change their departure time, thereby increasing peak period traffic volumes. This is called *trip rescheduling*. Some commuters who were travelling as a passenger in another's motor vehicle may choose to drive their own car. This source of increase in vehicle numbers comes about because of a decline in *vehicle occupancy rates*. Changes in prevailing travel speeds may also mean that preferred destinations that had previously taken too long a time to access fall within reasonable travel time budgets, inducing people to travel to more distant destinations for some of their standard trips. This is called *trip redistribution*. Faster network speeds may also result in people choosing to make more trips as part of their standard travel routine. These are classified as *induced trips* (SACTRA 1994, p. 51 and 53). Over long periods of time, patterns of land-use development may also change as access to new areas is made easier by the addition of new motorways. This is sometimes referred to as *development traffic* (Purnell, Beardwood & Elliott 199 p.31).

Some of these responses result in an increase in the absolute amount of car travel or VKT. But others can result in a decline, which occurs if traffic is reassigned from a circuitous to a shorter or more direct route. So while an increase in traffic may take place on some parts of the network after the expansion of motorway capacity, others may experience a decline. Alternately, an increase in motorway capacity may encourage drivers to use a longer route for some of their standard trips because the speeds are faster. This would result in an increase in VKT but trip rates would remain essentially the same, as would Origin and Destination (OD) combinations (SACTRA 1994, p. 20 and 22).

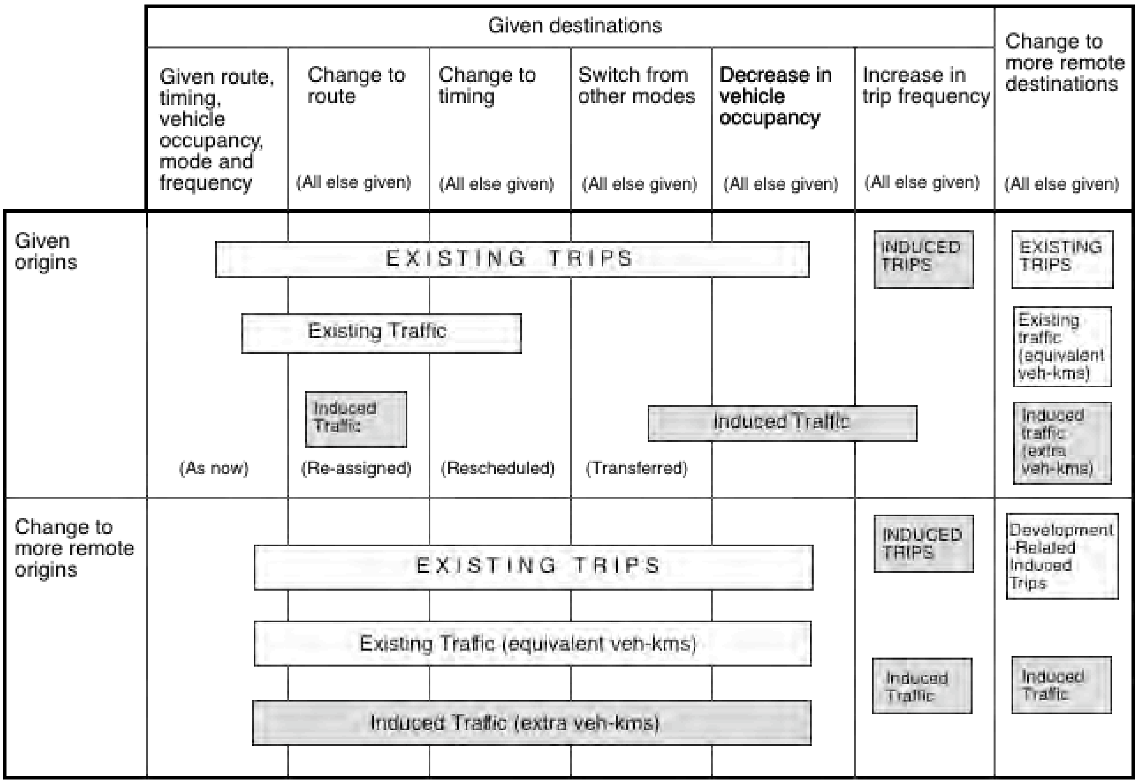
A meaningful definition of induced traffic growth is critically dependent on understanding what is happening to the urban transport network as a whole and not simply one section that has been intellectually isolated for the purposes of analysis or discussion.

Much of the professional and scholarly argument about the definition of induced traffic growth is revealed in disputes over the merits of fixed-trip vs. variable-trip matrixes[6] in traffic models (SACTRA 1994, pp. 22–25). The key question in these disputes is whether or not changes to the transport network induce changes in the OD pairs and the patterns of linked trips that comprise the travel behaviour of any given population. For example, if motorway capacity is added to the network and changes prevailing road speeds, some people may choose to switch from using public transport to driving their cars. In this instance there is no change to OD pairs, or induced trips, as set out in the fixed matrix model, but there is induced traffic growth as the road induced individuals to change modes, which resulted in an increase in motor vehicle movements. The same is true if people choose to drive their own vehicles rather than travel as a passenger while someone else drives. The OD pairs remain the same, but traffic volumes and VKT increases.

The end result is a composite of several different responses that include an increase in trip numbers, longer trips and mode-shifting from public transport. These responses occur when road travel speeds increase after an increase in motorway capacity and all are assumed to result in a net increase in Vehicle Kilometres Travelled (VKT) by road traffic.

[6] A fixed-matrix model works on the basis that OD combinations will stay the same after changes to the transport network. By contrast, the variable-trip matrix model works on the basis that OD combinations will change. Variable-trip matrix models consequently incorporate algorithms to account for changes in travel behaviour that fixed-matrix models do not.

Figure 1.17 Definitions of existing and induced traffic and trips



Source: SACTRA. 1994, *Trunk roads and the generation of traffic*. HMSO, London, p. 21.

Figure 1.17 charts these various changes to travel behaviour. The responses highlighted in grey correspond to those changes that generate an increase in either the number of trips or trip distances undertaken by car. Both generate an increase in VKT. The Standing Advisory Committee on Trunk Route Assessment (SACTRA), commissioned by the UK government to investigate the existence and implications of induced traffic growth, identified these definitions (SACTRA 1994, pp. 20–21). This thesis uses the SACTRA definitions in later empirical analyses and theory development, due to the general acceptance of the report’s findings.

It must be acknowledged that induced travel is not a phenomenon restricted to road networks. It is possible to induce more or longer trips as well as mode-shifting by reducing travel times on rail and public transport services. This raises the important issue of interaction between the rail and public transport network of a city and its hierarchy of roads.

The few empirical analyses of induced traffic growth on Australian road networks include road traffic generated as a result of mode-shifting from the rail to the road network as induced traffic growth (Mewton 1997, p. 31). In these cases it is not known whether mode-shifting has generated new trips or new economic exchanges that would correspond to a change in OD pairs and patterns as outlined by SACTRA (SACTRA 1994, p. 126), but it has most likely resulted in the transport of traffic in a less efficient manner and impacted on the revenue stream and financial viability of public transport services (Mewton 1997, pp. 40–42). Like the generation of new trips, this can be perceived as not in the public interest, but in order for such a judgment to be made it is also necessary to understand precisely what mode shifting does to the core functions of the urban system and this is different from the generation of new and longer trips.

1.3.2 The ‘counter-productive’ nature of urban motorway development

This section briefly outlines how induced traffic growth and the motorway development that gives rise to it can work against the core economic functions of a city system. As stated previously, people build and live in cities for reasons concerned with enhancing economic exchange and industrial production. Maximising the number of exchanges made within a given time period, or accessibility to production inputs, is essential to achieving this.

Most governments justify the construction of urban motorways on the basis that they will relieve traffic congestion, improve access and generate economic gains for the community (for example, RTA 2003a, p. 2). Examination of the conditions before and after the opening of new urban motorway sections has prompted many scholars to conclude that what really happens is quite different. Instead of reducing traffic congestion and delays, the consequences of induced traffic growth mean that congestion soon returns, patronage on alternate public transport declines (Mogridge 1997, p. 5) and the previous relationships between transport and land-use sectors are altered in such a way that accessibility is reduced rather than enhanced (Cervero 1997, p. 10).

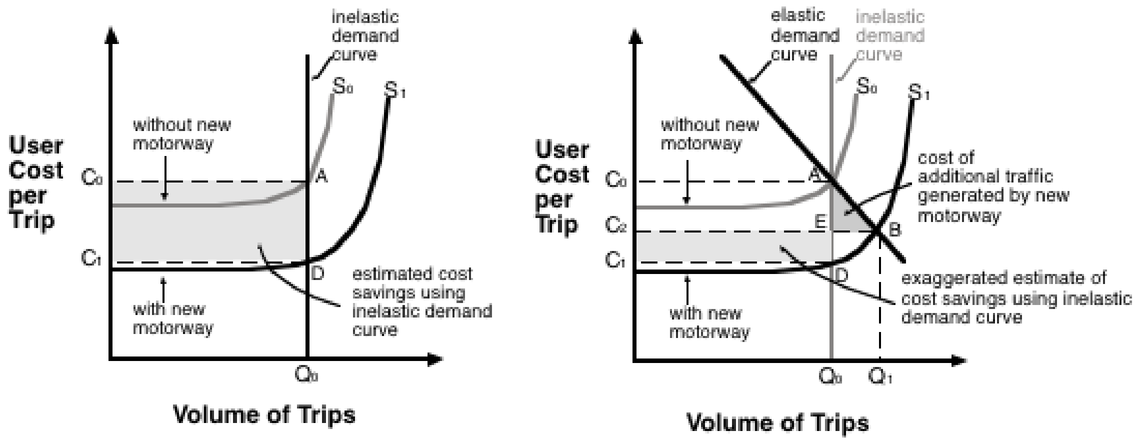
But which set of claims is correct and why? To answer this question it is necessary to understand the logic on which such claims are based.

Accessibility changes are currently evaluated on the basis of marginal cost savings to the *generalised cost*[7] of transport. In the case of urban motorway projects, reductions in travel time form the bulk of benefits listed in the Cost–Benefit Analysis (CBA) for projects. In the past these have been as much as 75 per cent of the total benefits (Goodwin 1981, p. 99). More recent analyses put these as high as 80 and 90 per cent (Rayner 2003, p. 1; Welch & Williams 1997, p. 231). For many urban motorway projects, on a person-by-person basis the travel-time savings are of only a few minutes' duration. But because urban motorway traffic volumes are large, when added together and multiplied by an hourly rate based on an average wage, a large monetary value results (Zeibots 2003, p. 23).

Figure 1.18 shows two examples of how microeconomic theory is used to represent user benefits. The first example uses an inelastic demand curve, the second an elastic one. Use of an inelastic demand curve assumes that trip OD combinations before a proposed motorway is opened will remain the same, as will trip volumes. As stated in Section 1.3.1 — which defined the various travel behaviour responses that make up induced traffic growth — trip redistribution and induced trips mean that new and different OD combinations occur in response to the changed conditions. Other sources like mode-shifting and decline in vehicle occupancy result in an increase in the volume of trips. So the first example does not recognise induced traffic growth, and estimates much larger reductions to the marginal cost of trips for a proposal than is achieved in practice when induced traffic growth occurs.

[7]The generalised cost of transport includes all components directly associated with undertaking travel. These include infrastructure and maintenance costs, vehicle and running costs, fuel and travel time.

Figure 1.18 Estimation of marginal cost savings arising from a proposed urban motorway



Adapted from: SACTRA. 1994, *Trunk roads and the generation of traffic.* HMSO, London, pp. 115–119.

In the second example, where an elastic demand curve is used, induced traffic growth is recognised. Reductions in individual travel-time savings are not as large because the additional traffic creates congestion. Consequently, reductions to the marginal cost of trips are smaller. Clearly, economic evaluation for an urban motorway within a framework such as that shown in the second example produces lower values for the benefits of a project and so, within the terms of CBA, might return a no-build result in some cases.

A significant point raised by urban motorway advocates is that benefits arise from having a larger number of trips in the system, as this is indicative of a greater number of economic exchanges, which generate economic growth and are good for the economy generally (Foster 1995, p. 27).

The validity of this argument depends on what form of induced traffic growth is at play. If redistributed and induced trips are taking place then this may mean that more or preferred exchanges are being made. But if the source is mode-shifting or a decline in vehicle occupancy then a less efficient[8] outcome has been achieved. If a loss of patronage on parallel public transport services generates a reduction in farebox revenue, this could lead to a decision to reduce service levels. Passengers who did not shift modes

[8] Less efficient in this case refers to efficiency in a social resource sense, it may not be the case in a traditional microeconomics sense of individual utility maximisation. This point will be discussed in more detail in Chapter Four.

would then be subjected to a service with slower travel times, so that accessibility for them would be reduced. Similarly, the commercial viability of businesses and services orientated around rail stations or public transport nodes may decline if significant levels of mode-shifting take place. Individuals who accessed those local services on foot may then be compelled to use others at more distant locations, so that in the final equation, the population affected by a motorway development will include individuals who can no longer access their destinations of choice. At present these potentially counter-productive outcomes are not incorporated into economic evaluations for motorways.

But there are other problems with the way that space, time and economic relationships are treated within the terms of this framework. These problems are concerned with the way the method defines the concept of utility[9] and how it is presumed to be transferred within an economic system.

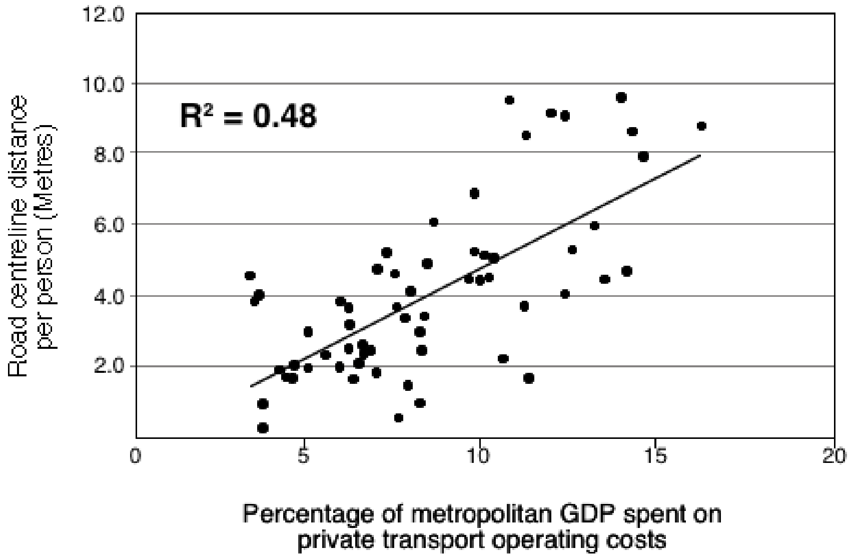
The accepted view is that the value of time saved is a proxy for the utility of time spent on something else and this includes additional travel to other destinations because greater utility is derived from the new destinations that are now more accessible (Goodwin 1981, pp. 99–100).

At a cursory glance this seems reasonable enough, but problems emerge on closer consideration of the impacts arising from induced traffic growth caused by mode-shifting where OD pairs remain the same. The argument relies on the implicit assumption that all utility transferred through travel-time savings is positive or beneficial. But because some of these processes generate disutilities, confidence in the assertion is misplaced (Zeibots 2003, p. 24).

The credibility of standard practice is dependent on what happens at the whole system level. The implicit assumptions about utility transfers in microeconomic analysis can be tested by assessing whole-system or macroeconomic data.

[9] Utility refers to the amount of *satisfaction* derived from consumption of a given good or service (Samuelson et al. 1992, pp., p. 714).

Figure 1.19 Metropolitan GDP spent on operating private transport vs road space (1995)



Note: Road capacity is measured as centreline road distance and not centreline *lane* distance, due to data availability. The latter would be a more accurate measure of operating capacity.

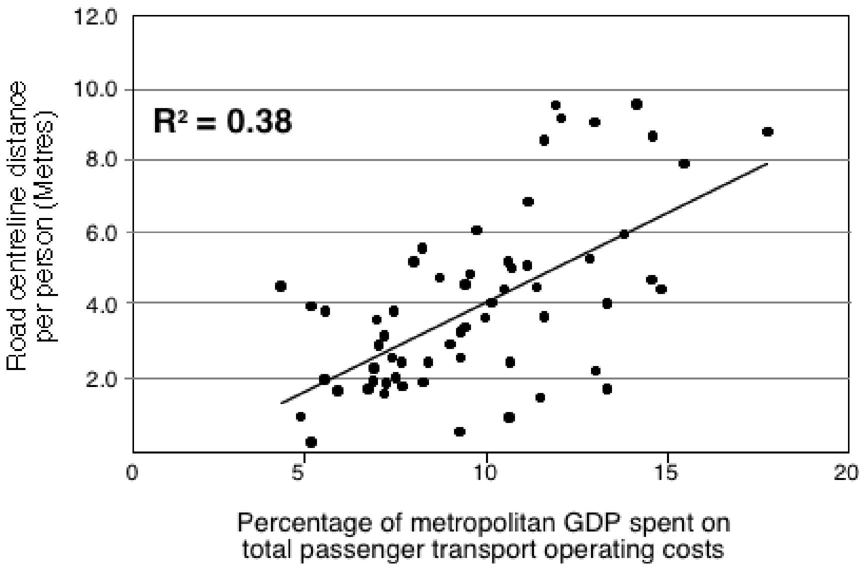
Source: UITP. 2000, *Millennium cities database.* UITP, Brussels.

In Figure 1.19 the percentage of total metropolitan GDP spent on private transport operating costs is shown to have a positive linear relationship with the centreline distance of metropolitan roads per capita for a sample of 55 international cities with developed economies. In the cities where more roads and urban motorways have been built, a greater proportion of the city's total productive output is spent on transport operating costs. The logic central to microeconomic evaluation methods, as shown in Figure 1.18, dictates that by reducing the marginal cost of trips a utility gain occurs which is transferred to other sectors of the economy. Transport then poses a lower opportunity cost to other sectors of the economy, enabling the resources saved to be reinvested and so enhance economic production. Or at least that is what is supposed to happen. But on examination of the macro, or whole-system data, the percentage of metropolitan GDP spent on operating private transport is generally greater, not less, for those cities with more roads.

These empirical results generally contradict the assumptions implicit in the microeconomic evaluation shown in Figure 1.18. In this way, the results of evaluation by assessment of change at the margins do not correspond well with those from evaluation of change to the system as a whole.

It could be argued that two different things are being compared — that not all transport costs are being included in Figure 1.19, so the efficiencies gained using the form of evaluation shown in Figure 1.18 are being misrepresented, because those cities with greater mode splits to public transport and therefore higher public transport costs have not been included.

Figure 1.20 Metropolitan GDP spent on total passenger transport vs road space (1995)



Note: Road capacity is measured as centreline road distance and not centreline *lane* distance, due to data availability. The latter would be a more accurate measure of operating capacity.

Source: UITP. 2000, *Millennium cities database.* UITP, Brussels.

If the same relationship between road centreline distance is compared with total passenger transport costs as a percentage of metropolitan GDP, as shown in Figure 1.20, a similar, albeit slightly weaker, correlation results. So the objections appear to hold up — the claim that urban motorway development is counter-productive may have some merit. Whether it does or not rests on identifying more clearly what actually happens when the space-time attributes of urban markets change in response to changes to the transport system.

Resolving this problem hinges on how the representation of utility transfers from transport improvements to the economy is handled by the intellectual framework of the evaluation method. Or, in other words, the space, time and economic relationships within an urban system are in need of greater definition.

1.3.3 Research questions about induced traffic growth and the implications it has for the sustainability of cities

There are two reasons why urban motorway development and the induced traffic growth it causes have been used as a starting position from which to investigate the broader questions about the sustainability of cities. The first is that from a research perspective the induced traffic growth hypothesis functions as a useful heuristic for generating a theory about the fundamental role of transport and how it affects the wider operations of urban systems. This is because the essential nature of the effect can only be understood when observed as part of the whole urban system. In Chapters Two and Four it will be shown that analyses that attempt to isolate the phenomenon by divorcing it from other urban processes actually cloud understanding.

The second reason is that because the existence and implications of the phenomenon strike at such a fundamental aspect of a city's economic functions, there are many competing interests at stake. Some interest groups derive benefit from the occurrence of induced traffic growth, while for others it constitutes a significant cost or externality. If true, the economic integrity of the urban system as a whole is potentially undermined by induced traffic growth so that the macroeconomic implications are negative. Because of this, the phenomenon is often contested. Competing interests have complicated the social and political context in which transport science has been developed. As a consequence, the descriptive veracity of what in many cases passes for transport science can and has been challenged and so the impacts of urban motorway policy constitute a problem worthy of more detailed investigation.

The general aim of this thesis is pursued in four ways:

1. Review of previous empirical analyses of changes to travel behaviour as a result of urban motorway development, as well as theoretical explanations for why it

occurs and debates about the existence of induced traffic growth and its policy implications.

2. Empirical analysis of induced traffic growth under Australian conditions with an eye to investigating particular facets of the phenomenon that have not previously been documented in the international literature.

3. Refinement of the theoretical explanation for what causes the phenomenon, using General Systems Theory (GST).

4. Examination of the sustainability implications that induced traffic growth and urban motorway expansion have for the sustainability of city systems.

Before outlining how these four research aims have been drawn together into a comprehensive program of research, it is important to outline what type of intellectual framework has been used to make sense of the various ideas and concepts discussed so far.

1.4 Positioning the research problem and contribution using General Systems Theory as an intellectual framework

This section addresses the issue of how and where the knowledge contribution made in this thesis is situated within the array of engineering, planning, economics, urban geography and urban design disciplines concerned with transport and urban systems. This section also outlines how what could be viewed as a disparate array of ideas has been organised into a coherent intellectual framework using General Systems Theory (GST).

1.4.1 Positioning the research within conventional disciplinary boundaries

At a cursory glance, it seems reasonable to assume that the research contribution made by this thesis should fit neatly and easily within the discipline of traffic engineering. But this is not the case. For when the practical question of sustainability is introduced as a research problem, the range of factors that need to be considered in the analysis increases greatly, as does the number of disciplines that would usually play host to the study of these factors.

From a sustainability perspective, the significance of induced traffic growth can only be realised when examined as part of the whole system, of which both the motorway and the traffic it carries are merely parts. In this way, the nature of the problem as it occurs in practice, rather than academic convention, dictates the boundaries of the analysis. This of course raises the dual questions of what a whole system is, or what functional unit of organisation might be used to examine pertinent problems, as well as how the analysis of such a unit might be approached.

As stated in previous sections, the unit of organisation best suited for this purpose is the city system. Transport is fundamental to the many economic processes to which a city plays host and the complex sets of relationships that characterise its operations. A broad array of concepts from different disciplines have been used to generate a single picture of the complex life of an urban system and the subsequent effects that a motorway can have on travel behaviour and the many key relationships crucial to the operations of that system. This has not only made answering questions concerned with the impact of urban motorway development on the sustainability of cities more cogent. It has generated novel responses to some outstanding questions surrounding the phenomenon of induced traffic growth as it currently stands within the narrow disciplinary boundaries of traffic engineering.

The difficulty with this approach, however, is that the research output does not sit easily within any one discipline. In addition to traffic engineering, this thesis draws on ideas from town planning, urban design, urban geography, economics, political science and public policy. Systems concepts developed in the biological and social sciences have also been used to fuse these ideas together. In this way traditional disciplinary boundaries have not merely been crossed, but a new way of describing cities and their transport networks has been developed that occupies a position currently outside these existing boundaries. This puts much of the knowledge contribution made by this thesis in the category of *transdisciplinary research* (Carew 2004, p. 60).

While there are aspects of the research output that are recognisable within the terms of the source disciplines, assessment becomes difficult when foundation concepts are unfamiliar. Increasingly, academic institutions are becoming aware of the need to support and recognise transdisciplinary research (Carew 2004, p. 48), however, given that it is still in its infancy, it is important to signal this key difference at the outset, stressing the efforts that will be made in subsequent chapters to explain this aspect of the thesis findings.

Most researchers attempting to understand and solve sustainability problems argue that a transdisciplinary approach to analysis is required (Carew 2004, pp. 36–38; Crawford 2004, pp. 19–20; Fane 2005, pp. 20–21; Kay et al. 1999, p. 722; Meadows 2001; Riedy 2005, p. 26). Indeed, the PhD in Sustainable Futures, for which this thesis has been submitted, is explicitly viewed as a transdisciplinary degree (ISF 2001). This arises primarily out of the recognition that in the real world everything is in some way connected to everything else, and in order to understand these complex connections knowledge from a variety of different disciplines must be consulted. And further, because the concept of sustainability only makes sense as an applied form of knowledge, a way has to be found to accommodate this complexity and the real impacts that relationships across disciplines exert (Meadows 2001).

Traditionally, scientific analysis has worked on the basis of specialisation, whereby parts of reality are intellectually isolated from their wider context and then examined as discrete subject areas or disciplines (Laszlo 1972, pp. 3–4). While reductionism has contributed to many important discoveries — and indeed some parts of the empirical analysis presented in this thesis fit this cast — historically many solutions conceived solely within a single scientific discipline, or purely reductionist framework, fail in application. This is because their wider effects and systemic relationships with other factors that fall outside specific disciplinary partitions were not considered and incorporated into the research program (Checkland 1976, p. 27).

1.4.2 General Systems Theory (GST): an alternative to reductionism

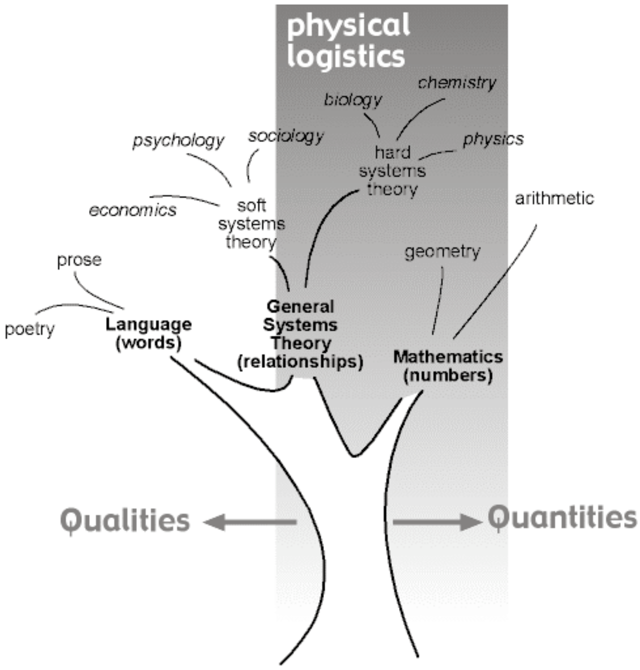
But if a program of research is to move beyond traditional disciplinary boundaries and synthesise knowledge from these into a cohesive format, a way needs to be found to relate and order these ideas.

General Systems Theory (GST), or *systems thinking* as it is sometimes called, has been used to do this. To introduce how GST has been used in this thesis it is first necessary to outline what GST is and how it has been used in some of the disciplines mentioned so far.

GST is a form of intellectual conceptualisation that sits between language — which is a predominantly qualitative way of thinking about the world — and mathematics — which is quantitative. Figure 1.21 illustrates this point and attempts to show how this spectrum relates to the content type of a variety of conventional disciplines.

GST is concerned with the way different objects are strategically related to each other to form an organised group or system (Bertalanffy 1956, p. 44). The concepts used to describe organisation that form the basis of GST can be discerned in a wide variety of natural and artificial, social and physical systems. In this way GST acts as a general intellectual tool, like mathematics, that can be used to organise and analyse subject matter (Bunge 1977, pp. 34–35) but is not a discipline in its own right (Checkland 1999, p. 99).

Figure 1.21 Disciplines supported by General Systems Theory



Source: Zeibots, M. E. 2004, 'Rethinking transport evaluation methods: do we have the best tools to help us make cities more sustainable?' in *Network of Regional Governance for Sustainable Development: Third Meeting of the Academic Forum of Sustainable Development*, Cardiff, March 22–25, p. 3.

As indicated in Figure 1.21, there are two main branches of GST commonly referred to as hard and soft systems theory. Hard systems comprise relationships between physical objects, or concrete problems, where the object and focus of study does not involve conscious thought (Zeibots 2004, p. 4). The behaviour of these systems is in principle less random and more predictable because outcomes are dependent on material properties that are relatively fixed and easy to identify and defined as determinate (Holwell 1997, p. 126). Physical sciences like physics, chemistry and biology are typical hard systems theories. Many engineering disciplines apply this knowledge and then design systems to perform in a particular way, given the known operating features established in physics and chemistry.

By contrast, soft systems comprise sets of relationships between people who, unlike material objects, are able to think and have self-conscious goals that they may wish to change. This means the system has a teleological controller, whereby a conscious goal of the system works to define the systems structure and operating characteristics to suit that goal (Checkland 1999, p. 75). The ideas and goals, opinions, beliefs and emotions that contribute to the relationships that are the study focus of soft systems vary widely and so are difficult to predict, unlike the workings of hard systems (Zeibots 2004, p. 4). In and of themselves, soft systems do not have fixed physical attributes — hence the term *soft*. Political science, sociology and economics all play host to soft systems theories.

Checkland provides another way of making the distinction between hard and soft systems, cautioning that this distinction is more subtle and difficult to grasp than the differences cited previously. He argues that soft systems are an ongoing process of inquiry and learning undertaken in a systemic fashion (Checkland 1999, pp. A10–A11). In this way generic conditions are laid open to the possibility of change, whereby the conventions for behaviour and relationships between the players in a system can become fundamentally different. This should not be confused with cases in which relationships remain essentially the same but a single factor rises to predominance sending others into recession, for this does not qualify as essential change to the organising principles of a system but merely changes to the ratio of inputs. Understanding the workings of soft systems has required a new language and set of terms to track changes to systemic relationships, many of which are alien to practitioners familiar with those used to solve problems involving hard systems (Checkland 1999, pp. A16–A31).

GST is well positioned to provide a language and framework for the study of cities. Of key significance to the formation of all systems, whether they are soft or hard, are the organisational properties of *hierarchy*, *emergence, communication* and *control* (Checkland 1999, p. 75). These concepts provide a language that enables representation of the logistical properties of transport systems in ways that mere quantification and arithmetic relationships are not able to do this. These concepts will be discussed in greater detail in Chapter Six.

1.4.3 What type of system is a city and what role do transport networks play?

But what kind of system is a city? Are its components relatively fixed and its behaviour predictable, thereby revealing a generic set of operations common to all cities, as is the case with the hard systems studied by physicists, chemists and biologists? Or are cities soft systems, dominated by the opinions and ideals of the people who live in them — constantly changing — so that behaviour is random and defies predictability? Further to this, are urban systems soft in the sense that they embody an on-going process of inquiry and learning so that from time to time the ground rules that describe a city's operations and essential components change to something that is almost unrecognisable?

The answer is: a bit of both. Cities are composite systems, incorporating both hard and soft sub-systems. As will be shown in Chapter Six, travel behaviour and the operations of urban transport systems fall into the category of hard systems. Material space–time conditions place constraints on people's options so that aggregate behaviour forms distinct and consistent patterns. However, conscious decisions have to be made about the form of transport systems provided. The residents of cities determine this through their planning and systems of government and so have the ability to change the way they build in response to lessons and failures from the past. At times they can disagree and fight with one another over how a city should be built, so that policy shifts. At other times individuals cooperate and agree with one another, creating and building complex structures or engaging in elaborate processes that dramatically alter a transport system and the life of a city forever. From this perspective, cities evoke many of the subtle qualities that Checkland uses to define soft systems.

In this way city systems straddle both nature and artifice. On the one hand cities are governed by unconscious or inevitable response, as is the case with any natural ecological or hard system. On the other, they provide a theatre for the wilful pursuit of goals and ideologies, which is in the realm of soft systems.

It is important to acknowledge both of these distinct system types and how they interact with one another, otherwise it is difficult to make sense of induced traffic growth as a phenomenon. Sifting and separating normative functions from positive behaviour enables the clear identification of what causes the phenomenon to occur and why.

1.5 The thesis structure: review, observation, theory and application

In keeping with the general aims of this thesis, the research results are presented in six chapters that can be conceptually summarised as review, observation, theory and application.

1.5.1 Review: the strange life and controversial times of an urban system feedback process

The second, third and fourth chapters comprise the literature review for this thesis. They examine past empirical analyses of induced traffic growth from the international and Australian literature (Chapter Three) as well as theoretical explanations for why and how the phenomenon occurs (Chapter Four). Review of these aspects of the phenomenon has been set within the social and political context in which debate over induced traffic growth has taken place (Chapter Two).

Chapter Two explains the workings of a soft-systems model that has been generated to identify the social and political context in which debate occurs over induced traffic growth and the urban motorway development that often gives rise to it. The model articulates the relationships between the various stakeholders, interest groups, government authorities and technical experts that contribute to the decision-making process that determines whether or not an urban motorway or some other form of transport development should be built. This soft-systems model makes explicit the bargaining power of different interest groups, and the influence they can exert under different situations, as well as the aims and interests that motivate these different groups. The model exposes how this bargaining power and the interests that motivate it can in some cases distort transport policy away from conclusions based on the rules of evidence — such as those achieved through Commissions of Inquiry and Royal Commissions (for example, Kirby 1981a). It has also been used to identify where and on what grounds policy is able to drift away from analyses guided by the accepted norms of empirical science in preference to positions that draw heavily on ideology for their justification.

The empirical and theoretical literature has been reviewed within this framework for two reasons. First, because the phenomenon of induced traffic growth is contested, it is important to understand who is contesting it, why and on what grounds. What is striking about the literature on induced traffic growth is that the vast majority of academic studies confirm the induced traffic growth hypothesis and yet many, if not most, government transport agencies have denied its existence. It is crucial to understand why this has happened if attempting a critical appraisal of the literature. Science necessitates that a concerted effort be made to distinguish description from ideological prescription, otherwise the research output is poor because the reasons for accepting or rejecting arguments were not based on an understanding of generic operating principles that apply to the subject matter in question (Wynn & Wiggins 1997, p. 144). Where an application is involved, generating creative solutions and viable alternatives becomes problematic if founding ideas have arisen from some misconception or dogma.

The second reason for reviewing the literature in this fashion is that by making explicit the role that planning authorities play in determining transport decisions, it becomes possible to articulate more precisely that travel behaviour is not just the product of individuals or market forces. It is clearly also a product of the policy position deliberately pursued by government agencies responsible for providing transport services and infrastructures. For example, where public transport services are not provided, there is no option for people to use public transport. If car use is high in these cities, it is not because people prefer or 'love their cars', but rather because government agencies made the planning decision to build roads and motorways so that road network speeds are faster than those for mass transit. Identifying and analysing the forces within society that are responsible for lobbying and influencing governments to pursue such a policy position is important when trying to explain dynamic system feedback effects and mode splits.

There have been several substantial reviews of the literature on induced traffic growth, but none explicitly address the political and social context when commenting on the findings. In this way the literature review for this thesis provides an original contribution to the ongoing appraisal of induced traffic growth analyses.

The review of empirical analyses is used to inform the Sydney case studies presented in the following chapter as well as to highlight gaps in the literature that are addressed by them.

1.5.2 Observation: before and after Sydney's M4 Motorway

The fifth chapter of this thesis presents the results of a *before and after* study of a motorway development that took place in Sydney in the early 1990s — the M4 Motorway from Mays Hill to Prospect. The results from this analysis support the induced traffic growth hypothesis.

In the last ten years the international body of empirical analyses of induced traffic growth has increased considerably. Most of these have focused on motorway developments in the industrialised economies of cities in the European Union, United Kingdom and the United States of America. However, despite international interest, there have been few analyses of urban motorways in Australia, and most government transport authorities do not incorporate the phenomenon and its effects into project evaluations, although there have been some recent exceptions.

Besides the case study in this thesis, there are only two other Australian studies that attempt to compare road and mass transit network conditions before and after the opening of new urban motorways (Luk & Chung 1997; Mewton 1997). While the organising principles that underpin urban travel behaviour are generic to all urban systems, the implications of a problem always seem more real when demonstrated in your own city or country. This generates more discussion and awareness of the problem within domestic transport planning circles. Increasing the number and breadth of induced traffic growth studies for Australian cities is an important objective and contribution of this thesis.

While increasing the number of Australian case studies has implications for domestic knowledge, there are more general research aims served by the particular case study. The unique geometry and topology of the Sydney transport network means that it is easier to isolate some of the different responses that constitute induced traffic growth. The structure of Sydney is dominated by a series of radial road and rail trunk routes that give rise to distinct corridors so that movement is relatively confined and robust screenlines[10] can be drawn across urban sectors. This has made possible the differentiation of area-wide traffic redistribution from other sources of increased traffic volume.

The quality of the Sydney data has also made it possible to gain a greater insight into the nature and timing of the ramp-up period. The ramp-up period is significant because during this time the urban system undergoes a quick succession of changes. Many of the alternate explanations for traffic increases that involve changes in population, economic activity and patterns of land-use development cannot feasibly take place within this short time-span. Observing what takes place during this period not only enriches our descriptive understanding of the phenomenon but also enables rejection of several counter-arguments against the induced traffic growth hypothesis. This constitutes an original contribution to the international literature of empirical analyses of induced traffic growth.

The material presented in this chapter provides a working illustration of the various forms of system feedback, or changes to urban travel behaviour, that will be explained in the following chapter.

1.5.3 Theory: a systems theory of cities and travel

The sixth chapter of this thesis presents a systems theory of cities using General Systems Theory. The primary aim of this chapter is to provide an articulation of the mechanism responsible for causing the various forms of changes to travel behaviour that are classified as induced traffic growth. By using GST, a more literal way of representing the cause for changes to travel behaviour is achieved than when using

[10] A *screenline*, or traffic cordon, is a conceptual line drawn across a section of the urban system that attempts to capture all traffic movements between the same broad set of origins and destinations. Where several different routes could be taken for the same trip, a screenline draws a boundary across all of these, thereby accounting for all the traffic moving in and out of the areas on either side.

microeconomic theory and changes to the generalised cost of transport. Significantly, this theory represents time as spatial data, or travel time contours, rather than as an a-spatial monetised value. This enables specific identification of those areas within the urban system where accessibility is enhanced by a transport development. It also identifies those areas that may experience a decline. The reason for this break with current convention is the need to clarify the issues concerned with positive and negative utility transfers, as outlined in Section 1.3.2. Because this theory is also able to explain changes to patterns of land-use development and building form arising from transport developments, a more complete picture of the impacts of transport on the system as a whole is provided.

It is argued that this theoretical framework provides explanatory insights of how changes to the transport network, such as the addition of urban motorway capacity, affect accessibility and economic activity within a city system. The theory is a substantial progression from earlier theoretical development work undertaken on urban systems theory within the Cities Research Program at Murdoch University's Institute for Sustainability and Technology Policy (ISTP) (Laube, Kenworthy & Zeibots 1998). This is an original contribution to the theoretical knowledge of city structure and the dynamic processes that characterise the relationship between transport and land-use sectors.

1.5.4 Application: combining observation and theory to address emerging sustainability problems

The seventh and final chapter of this thesis applies the GST of cities developed in Chapter Six to the problems of oil depletion, global climate change and trade between cities. It examines the implications that expanding urban motorway capacity and induced traffic growth have for the ability of an urban system to adapt to pressures exerted on the urban system through interactions with the system environment.

A substantial literature exists on the impending impacts of oil depletion on the operations of urban systems. Much has also been written on global climate change and the role that urban transport plays in contributing to greenhouse gas emissions.

Research on the comparative advantages to macroeconomic performance bestowed on cities through their transport networks is scant, however, and constitutes a significant gap in the knowledge base of transport economics (SACTRA 1997, p. 32). This is another area of research where this thesis makes an original contribution, by articulating some of the ways in which the spatial structure of cities — instigated by the form of transport system that supports their operations — affects their macroeconomic performance. In addition, the final chapter examines the impacts of oil depletion and global climate change on the competitiveness of cities when engaged in international trade with one another, so that these three forms of system interaction are investigated in tandem with one another.

The thesis concludes that many of the effects of induced traffic growth, brought about by increases to urban motorway capacity, are in most cases detrimental to the economic purpose of cities and ultimately their long-term sustainability.

This introduction has outlined in broad terms the scope of the research problem and the specific research questions used to focus the examination. The next three chapters set out the background for this research, providing a starting-point from which current knowledge is used to build a basis for new research presented in the subsequent chapters.

All great science, indeed all fruitful thinking, must occur in a social and intellectual context — and contexts are just as likely to promote insight as constrain thought.

Stephen Jay Gould
The upwardly mobile fossils
(1998)

2 The controversial life and times of an urban system feedback process: politics and induced traffic growth studies

The next three chapters review the literature on induced traffic growth. They examine the array of past empirical analyses of the phenomenon as well as theoretical accounts of why it takes place. In this review, these two strands of science — observation and theory — are examined within the context of four decades of public debate over the existence of induced traffic growth and its implications for transport policy. This chapter (Chapter Two) examines the social and political context. The next chapter (Chapter Three) reviews past empirical analyses of induced traffic growth and Chapter Four reviews theoretical explanations for why it occurs.

Any literature review of induced traffic growth cannot help but reveal the deep divisions that have occurred within the academic and technical community over the subject. These divisions are a reflection of the various positions occupied by interest groups within the wider community, in Australia and internationally. In both communities, positions vary from acceptance of the phenomenon to opposition and rejection, with various qualified positions between the two ends of this spectrum.

The dynamic of the division — or who is winning the debate and with what qualifications — has changed over time within academic and industry literature. It has also changed within the general community. In each case the dynamic appears to rely on the degree of pressure brought to bear on governments and agencies ultimately responsible for constructing the roads that cause induced traffic growth. From time to time specific road proposals and roads programs generate a high level of public opposition to their construction and the additional traffic they are likely to generate. At other times, industry and commercial business interests exert inexorable pressure for the construction of roads, citing additional road traffic as a benefit. Taken as a whole, the ebb and flow of these broader pressures generated by interest groups create a social and political context that has affected the science that explains changes to travel behaviour like induced traffic growth. With this in mind, a well-considered review of the literature cannot be confined to the views and ideas expressed in formal academic journals and publications, but must also encompass the findings of government reports and inquiries, and by extension, an appreciation of the political context responsible for the initiation of such inquiries. This realisation — that the science is related to a wider social context that provides both opportunities for and constraints on the development of ideas and acceptance of findings — has been used to guide the assessment of the material presented in this literature review.

This chapter examines the social and political context in which discussion on induced traffic growth is embedded. As road-building is usually undertaken by the state, government administrations have played a key role in the development of transport science. As will be shown, government sponsorship has cultivated and legitimised what might be called *mainstream transport knowledge* and forced other views into *fringe positions*, within the academic community. To understand why, this chapter examines the politics and debate that has taken place over the issue of induced traffic growth and the effect this has had on elected governments. It also poses the question of how a sound descriptive understanding of a material phenomenon can be distinguished from a politically or ideologically motivated account.

The most significant document in the literature on induced traffic growth is the report *Trunk roads and the generation of traffic* (SACTRA 1994, p. 30). The *SACTRA Report*, as it is often called, summarises the findings of a two-year UK Government commissioned investigation into whether or not induced traffic growth is a real phenomenon and what response would be appropriate in relation to assessment methods. More detailed analysis of the SACTRA Report is provided in Sections 2.2.1 and 3.2. However, it is worth noting some key points at the start of this chapter.

While the report is not exceptional in a technical sense — there is nothing new or revelatory in its findings — the great significance of the SACTRA Report lies in the fact that it was produced by a government committee, sanctioned by an administration that had previously dismissed the problem. Up until its publication, most governments throughout the world did not acknowledge that the addition of road space under congested conditions leads to an increase in road traffic volumes. Publication of the SACTRA Report broke that intellectual logjam, starting a series of reviews of evaluation conventions, as well as spawning a new generation of empirical research, not just in the UK, but also in many other countries throughout the world.

The status of the SACTRA Report exemplifies the degree to which governments and state-based transport authorities control what is accepted as transport science or knowledge. As noted in the SACTRA Report, there had been a 'long tradition based on informal argument' that road capacity affected traffic levels (SACTRA 1994, p. 31). Many prominent individuals within the transport research community had observed and documented the phenomenon or provided explanations for why it occurs (for example, Bressey & Lutyens 1937, p. 25; Downs 1962; Mogridge et al. 1987; Plowden 1972, pp. 14–16; Thomson 1977, pp. 81–83). But despite these efforts, before release of the SACTRA Report, their observations and theoretical explanations were not accepted or incorporated into modelling and evaluation procedures for urban motorway projects. Instead, induced traffic growth was expressly denied by some government agencies (SACTRA 1994, p. 55) or else, while acknowledged, dismissed as being of little consequence (Ministry of Transport 1963, p. iii; O'Flaherty 1967, pp. 124–125; SACTRA 1994, p. 29; Wohl & Martin 1967, pp. 204–205).

These circumstances illustrate how knowledge acquired using the accepted norms of empirical science and the logical extension of existing theory can be sidelined by wider political objectives. As will be shown in Section 2.1.2, the SACTRA Report was released after the last section of London's M25 orbital motorway was opened. The motorway section opening generated chronic traffic congestion and emergence of the now infamous super-jams that periodically saw commuters stuck in traffic for several hours at a time (Elliot 2006, pers. comm.). Within the ensuing climate of public outcry and political crisis, government acceptance of SACTRA's findings was inevitable (Goodwin 2004, pers. comm.).

Seen in this context, the SACTRA Report shows that what is deemed materially true or false about induced traffic growth is dependent on the degree to which the interests of various groups within society are affected by the outcome and the degree of power they are able to muster over government when trying to have their problems addressed. This raises critical questions about the criteria used to determine what is accepted and what is rejected as transport knowledge or legitimate transport science within government agencies responsible for the provision of urban transport policy.

This chapter has three general aims. The first is to make explicit the dynamics of the political and social context in which transport research takes place, with a specific focus on how this affects the investigation and treatment of induced traffic growth. The second is to gauge how and when the accepted norms of empirical science are able to take precedence over political or ideological interests. The third is to arrive at some conclusions about how to measure the merits of the contribution to knowledge made by this thesis and other research works in which the induced traffic growth hypothesis is confirmed, and similarly, how to measure the worth of counter-claims that draw opposing conclusions, given the role that politics plays.

These issues have been resolved through development of a soft-system model of the transport decision-making process. Section 2.1 outlines how soft-system models work while developing a model of the generic actors involved in the decision-making process for urban motorways. Section 2.2 uses the model to analyse the structure of conflicts over motorway development by applying it to cases in London, Sydney and Zürich. The comparison serves to highlight the way in which different political decision-making systems can affect transport science. The final section (Section 2.3), draws conclusions about the conflict and debate that has taken place over induced traffic growth and its status as a phenomenon within the terms of philosophical materialism.

2.1 A soft systems model of the motorway decision-making system

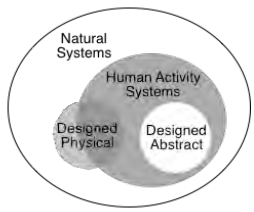
As discussed in Section 1.4.3, city systems comprise a complex mix of natural and artificial processes. The natural processes, or hard system functions, that make up an urban transport network encompass the interaction between commuters and other users, and the logistical properties of the material transport system — such as its capacity, speed and operating characteristics. While these systems have been purposefully *designed* by people, once they are in operation the travel behaviour that takes place on them can be viewed as *natural*, because just like other ecological systems that involve the interaction between living plant and animal populations and their material environment, aggregate travel behaviour is not directed by a single conscious goal[11] (Laszlo 1972, p. 23). The distinct patterns indicative of urban travel behaviour are a collective phenomenon — the result of a multiplicity of individual decisions bounded by the same confluence of material factors, where in none of the individual decisions intended the resulting collective outcome as a conscious goal (for example Stokes 1994, p. 26). More will be said about these patterns of behaviour and hard system aspects of urban transport networks in later sections.

By contrast, the artificial processes, or soft system functions relating to urban transport, refer to those aspects of urban systems that are *purposeful*, such as the relationships that give voice to the prescriptive values used to decide what transport services and infrastructures should be provided and why (Holwell 1997, pp. 126–127).

This section investigates the *artificial*, the political, the purely human-made or soft system relationships that contribute to the process of accepting or rejecting urban motorway proposals. A critical factor in this process is the veracity of the transport

[11] System types have been classified in several different ways. Sandquist (1985), for example, classifies systems according to structural features — *deterministic*, *stochastic*, *feedback* and *controllable* (Sandquist 1985, pp. 33–36). Checkland (1972, 1999) defines four basic system typologies according to ontological characteristics — *natural*, *human activity*, *designed physical and designed abstract systems*. All are a subset of natural systems, however, designed physical systems are not entirely a subset or invention of human activity as shown in the accompanying diagram. This is because their operations are also bound by the conventions of the physical world. Classification on the basis of ontology enables consistency on the basis of epistemology and analysis methods as well, avoiding confusion (Skyttner 2001, p. 171).

Basic classes of system



Adapted from: Checkland, P. B., 1972, 'A systems map of the universe', in J. Beishon & G. Peters (eds), *Systems behaviour*, Harper & Row Publishers, London, p. 53.

science used to inform decisions. This section makes explicit the dynamics of the political context, or soft system structure, in which the empirical basis of transport science is generated and its theoretical frameworks articulated.

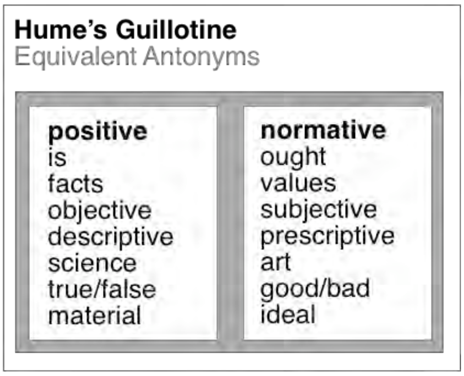
2.1.1 The *science* of soft and hard system distinction

Traditionally, science draws a distinction between hard and soft systems by use of the terms *positive* and *normative* (Flew 1984, p. 251 and 283). The distinction extends to both subject matter and methodology. It is significant because positive systems usually form the basis of physical sciences like physics, chemistry and biology, while normative systems are usually the focus of humanities subjects like politics and cultural studies, as well as the arts (Checkland & Scholes 1990, pp. 2–3).

Critically, as Hume has pointed out, positive, or descriptive facts cannot be logically deduced from normative, or prescriptive values, and vice versa (Hume 1748, pp. 71–76). Each represent fundamentally different logical categories and logical deductions can only be made from subject matters that are similar. So, for example, an evaluative statement like *cars are good and public transport is bad* cannot be deduced from a description of the material operating characteristics of each mode. Only other evaluative arguments can be used to persuade others of the prescriptive veracity of such a statement. Similarly, a statement like *cars are a low-capacity transport mode while mass transit is a high-capacity mode*, cannot be deduced or verified from a set of values. An appeal to empirical evidence is required to vouch for the statement's reliability.

This logical problem is known as *Hume's Guillotine,* or *Hume's Fork* (Flew 1984, p. 156). A transgression of Hume's Guillotine — using value statements to create or justify descriptive facts and vice versa — has the potential to create confusion and ultimately exposes a theory to failure (Blaug 1992, p. 112).

Figure 2.1 Hume's Guillotine



Source: Blaug, M. 1992, *The methodology of economics or how economists explain*, 2nd edition. Cambridge University Press, Cambridge, p. 113.

Figure 2.1 lists a set of equivalent antonyms used to describe the differences between these logical categories. A systems theorist would add the terms *hard system* to the list of positive elements and *soft system* to the list of normative. Critically, *non-teleological* would also be added to the list of positive elements and *teleological*, or *purposeful*, added to the normative list. This is because the functions of a hard system are not controlled or directed by a conscious decision or goal. This is one of the reasons why they can only be described. By contrast, soft systems are driven by human values and so are inherently prescriptive.

Complex systems like cities comprise sets of hard and soft systems that co-exist as subsystems. They are able to do this without transgressing Hume's Guillotine because of structural relationships known as *nesting.* In a nested system, each subsystem retains its internal integrity as a discrete hard or soft system, but when sited in an active relationship with other objects or systems, the properties of subsystems *emerge* as part of a different type of system (Laszlo 1972, pp. 108–109). This concept is used by biologists to account for the emergence of living organisms, which have purposeful capabilities that ultimately emerge as part of the soft systems defined here, from the hard systems that make up non-living matter (Taylor & Jefferson 1995, p. 1).

This section will develop a soft system model of the social process used to decide whether or not to build an urban motorway. Soft Systems Methodology (SSM) will be used to develop this model. Checkland pioneered the development of SSM to address cases where human error was responsible for the failure of a hard system (Checkland & Scholes 1990, p. A35 and xiii). A good example of an SSM application would be the development of a set of operating procedures for a complex rail network. There might be adequate capacity and safety features in the rail hardware, but if social relations between the various specialists operating and managing the system are poor or inappropriate, the system may not perform well in practice. These social relations involve normative elements like personal differences and power structures. In this example, the various hard systems of the network are nested within the soft systems responsible for organising how the hard systems are operated.

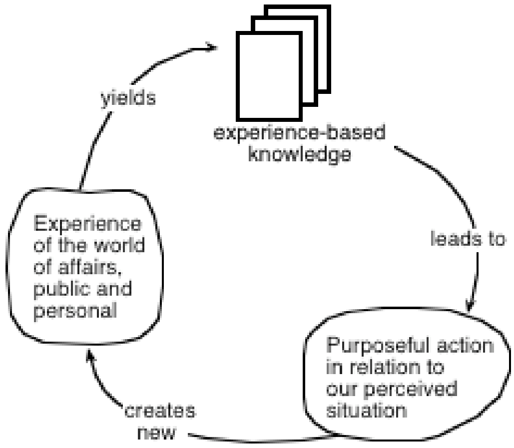
There are two kinds of soft system models that can be derived using SSM. The first is called a *primary task system* that maps an organised, purposeful system with boundaries that coincide with those of a real-world organisation. An example of a primary task system would be a model of the decision-making structures used to organise a government transport department. The second kind of soft system model is called an *issue-based relevant system,* in which the purposeful activity in question does not neatly correspond to the boundaries of a real-world organisation and can involve a multitude of different people and institutions that contribute to the final outcome (Checkland & Scholes 1990, pp. 31–32). An example of an issue-based relevant system would be a model of the decision-making process used to accept or reject an urban motorway proposal. The boundaries of such a system potentially cross numerous organisational boundaries within a society and would possibly follow a different course each time such a decision is made. Experience from previous decisions may affect ensuing decisions in such a way that structural changes to the system occur over time. Understanding this type of system is referred to as a *wicked problem,* owing to the controversy that can surround the specification of the problem, debate over its method of resolution and difficulty in testing the outcome (Crawford 2004, p. 8; Rittel & Webber 1973, p. 160).

Despite the apparent randomness of wicked problems, they can be shown to have a discernible structure. SSM is one way of identifying such structures. Checkland makes the point that all human activity systems are inherently prescriptive and based on particular interpretations of the world involving bias and prejudice. SSM enables individuals to make these explicit so that they can decide whether or not the biases and prejudices operating in their particular system suit their organisation's goals (Checkland 2001, p. 69). In these applications — the reform of management structures and procedures — SSM is used as a guide to changing particular activities where the *burden of proof*, associated with descriptive analysis, does not apply because the veracity of the model is determined by agreement between those involved in the process of review.

SSM is used in this thesis partly to maintain methodological consistency with the empirical analysis and theoretical work presented in later sections, but also because systems thinking is a more familiar intellectual framework for transport researchers and professionals who do not usually undertake political analyses. Social and political scientists would typically use methods like *discourse analysis* or *phenomenography* for the analysis of the social and political context surrounding urban motorway approval processes (Crotty 1998, pp. 78–86 and 143–144). Within the context of this thesis, such methods would be jarring. Although the use of SSM as a tool for social and political description is unconventional, its use in this way provides new insights and is compatible with the broader systems framework that will be used in Chapter Five.

The methods of empirical science used to investigate hard systems are based on particular beliefs about the nature of the material world. These will be discussed at some length in Section 2.2.1. SSM is founded on the belief that soft systems are *experience-based* systems. Checkland and Scholes (1990) argue that knowledge gained through experience follows a cycle like that illustrated in Figure 2.2.

Figure 2.2 The experience–action cycle



Source: Checkland, P. B, and Scholes, J. 1990, *Soft systems methodology in action*. John Wiley & Sons, Chichester, p. 3.

SSM leans heavily on this concept of the experience–action cycle to develop models of social processes. While there is a set of generic system elements used as a starting point for the development of any soft system model, these can change as the model is run through experience cycles in order to develop and explore the structure of the system responsible for the social process in question.

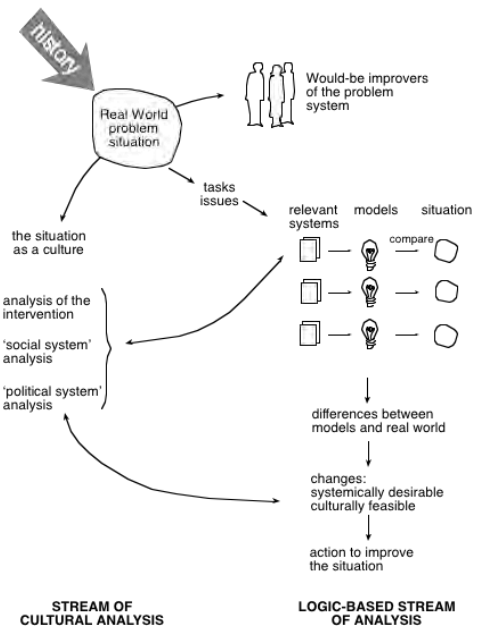
The next section explains the various stages and cycles in the development of a soft system model, as well as the nomenclature of SSM, while using the decision-making process for whether or not to build an urban motorway as an illustration.

2.1.2 Development of a soft system model of the decision-making process to approve or reject an urban motorway proposal

There are two forms of analysis required to produce a soft system model. The first is referred to as the *Logic-based stream of analysis* and the second is called the *Stream of cultural analysis.* The Logic-based stream of analysis deals with mechanical aspects of the model such as identification of system elements and relationships between them. The Stream of cultural analysis addresses thematic issues such as how power structures are manifest in the system relationships (Checkland & Scholes 1990, pp. 31–51).

Figure 2.3 shows how these two streams of analysis interact. Once a real-world problem and its attendant history have been identified, the tasks and issues from which the problem emerges are depicted as a model using the Logic-based stream of analysis. Central to the Logic-based stream of analysis is identification of a *root definition*, which is a statement that encapsulates the purpose of the system. How well the model represents problem situations of the kind described by the root definition is then tested by running it through experience cycles like that described in Figure 2.2. During these runs, issues concerned with the social dynamic between different groups and individuals can be explored, as can power relations and how power might be wielded in the particular problem situation under investigation. These issues comprise the Stream of cultural analysis and, in most applications of SSM, lead to a discussion of what can be feasibly changed to improve system outcomes. In this application, the aim is to merely describe what takes place around motorway approval processes because of the impact this has on transport science and the acceptance or rejection of induced traffic growth. The purpose is not to prescribe what should take place. It is for this reason that some parts of the cultural analysis, as shown in Figure 2.3, will not be undertaken. These include how the act of analysis itself might affect the system and what actions need to be taken to improve it.

Figure 2.3 The process of Soft Systems Methodology



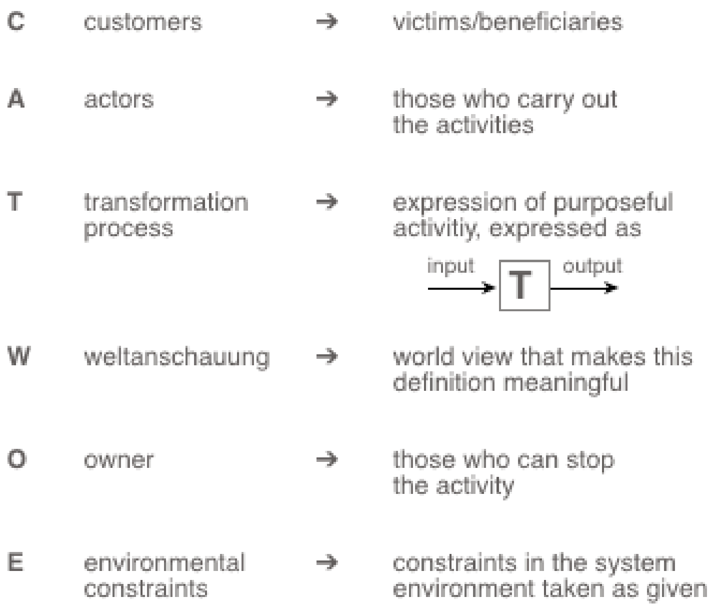
Source: Checkland, P. B, and Scholes, J. 1990, *Soft systems methodology in action.* John Wiley & Sons, Chichester, p. 29.

The core purpose of any soft system model is to map and explore a purposeful activity, which Checkland calls a *transformation process* (Checkland 2001, p. 74). A transformation process involves changing an input via some social process to produce an output. An example of an input is a *belief in the need to improve an urban transport network*. Such an input could be transformed into an output like a *determination to build an urban motorway*. Defining a transformation process must be done in such a way that Hume's Guillotine is not transgressed. Or in other words, normative inputs can only be transformed into normative outputs so that logical categories remain consistent (Checkland & Scholes 1990, p. 33). In this example a *belief* and a *determination* are both types of human ideas or goals that are non-material.

To begin development of a soft system model, the transformation process is expressed as a *root definition* or statement that takes the form *a system to do X by Y in order to achieve Z* (Checkland & Scholes 1990, p. 36). The root definition selected for the soft system model developed here is: *A system to decide whether or not to give approval for construction of an urban motorway within the rules of a democratic society,* where X is the act of deciding, Y are the rules of a democratic society and Z is approval or rejection of a motorway proposal.

Formulation of a root definition needs to refer to the elements that make up the structure of the soft system. After many years of application in industry, Checkland and his colleagues were able to define a generic list of elements that broadly apply to any case of purposeful activity. They summarised these in the mnemonic CATWOE, as shown in Figure 2.4. (Checkland 2001, p. 74). Working through the CATWOE series establishes the *mechanics* or structure of the model that makes up the Logic-based stream of analysis.

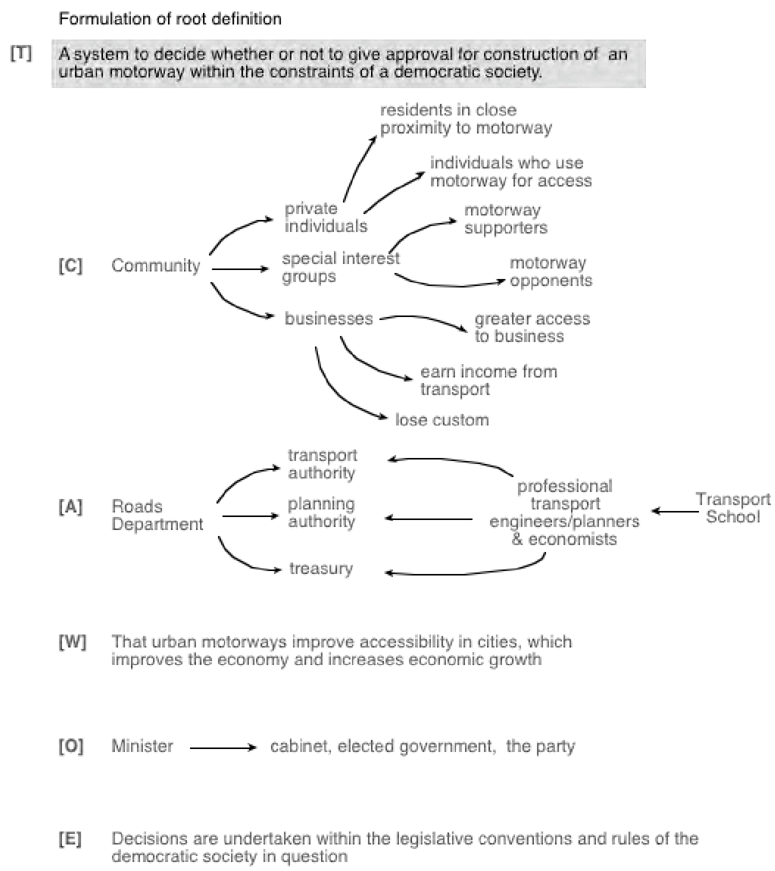
Figure 2.4 CATWOE elements



Source: Checkland, P. B. 2001, 'Soft systems methodology' in Mingers, J. and Rosenhead, J. (eds), *Rational analysis for a problematic world revisited: problem structuring methods for complexity, uncertainty and conflict.* 2nd edition. Wiley, New York, p. 75.

The first element in the CATWOE series is called *customers*. These are individuals or groups that comprise the receivers of the effects of the transformation process. In the case examined here, this group is the general community and so has been called the *community*, as shown in Figure 2.5. Individual views within this group are diverse, comprising a wide range of attitudes towards urban motorway development. Some are supportive while others are hostile. Many maintain positions with qualifiers and some do not care or have a position. The degree to which different positions compete with one another is a key factor that drives the social and political dynamics of this issue-based system.

Figure 2.5 CATWOE elements of a decision-making system for urban motorway constructions



The second element in the CATWOE series is called *actors*. This group comprises the institutions and individuals who carry out the activity in question. Like the community, this group is diverse, comprising a mix of government departments, authorities and corporations. Professional transport engineers, planners and economists, equipped with the knowledge needed to carry out the work, play a critical role in the function of these organisations. In this example this role has been called the *Roads Department.* In practice, many different government departments would have input to and work towards the final decision, but this will be elaborated in later explorations of the model. A related subgroup within the actor element is the educational institutions responsible for training transport professionals and undertaking transport research. This actor group has been called the *Transport School.*

The next crucial element in the CATWOE series is the *owner.* An institution or individual who can stop or start the transformation process in question carries out this role. This element essentially functions like a system controller. In the case examined here, this role has been identified as the *Minister* who ultimately makes the decision to accept, alter or reject a motorway proposal and who oversees the array of government departments that act to implement transport policy. A Minister's decision is influenced by public opinion as expressed by the various groups within the community. How these groups react may alter the Minister's decision, however, they do not stop or start the process officially within the rules of a representational democratic society.

In practice, the system owner role of *Minister* might be more than one person or office. In Sydney and New South Wales, for example, most decisions to accept or reject a motorway proposal are undertaken by Cabinet. The Minister with the specific legislative powers to sign off on such a proposal complies with the wishes of cabinet for reasons concerned with power relations within the political party in government. But to begin, as with all the elements in the CATWOE series, a generic figure has been selected to establish each role. Detail and variation will be articulated later as the dynamics of the model are explored.

There are two further critical elements in the CATWOE series that need to be identified. These are the *weltanschauung*[12] and *environmental constraints*. The core of CATWOE is the pairing of the transformation process *T* with the weltanschauung *W*, as the weltanschauung provides the motivation for undertaking the transformation process in the first place (Checkland & Scholes 1990, p. 35). In this example the weltanschauung is the belief that urban motorway development improves accessibility and increases economic growth (for example RTA 2003a, p. 2). While the weltanschauung does not play a literal role in the model, it is always present thematically, the importance of which can be appreciated when addressing issues that make up the stream of cultural analysis.

Like the weltanschauung, environmental constraints comprise contextual factors and conditions that work to shape the final structure of the transformation process

[12] Weltanschauung comes from the German *Welt* meaning world and *Anschauung* meaning view. The term refers to a comprehensive conception of the world from a particular standpoint. When the weltanschauung for an individual or community changes, their fundamental beliefs shift.

described by the model. These are factors that are not created by the deliberations of the system itself. In the example analysed here, it will be shown that the rules by which a democratic society operates are highly significant to final outcomes, however, those rules are not determined by deliberations over urban motorways directly.

Once the CATWOE elements have been identified and a working root definition constructed, development of what Checkland calls a *rich picture* of the system can begin. Rich pictures map the active relationships between different people, groups and institutions involved in a complex decision-making process. Verbs are used to link the system elements, revealing the whole system structure as well as the role of subsystems. Figure 2.6 shows a rich picture of the political decision-making process for accepting or rejecting an urban motorway proposal.

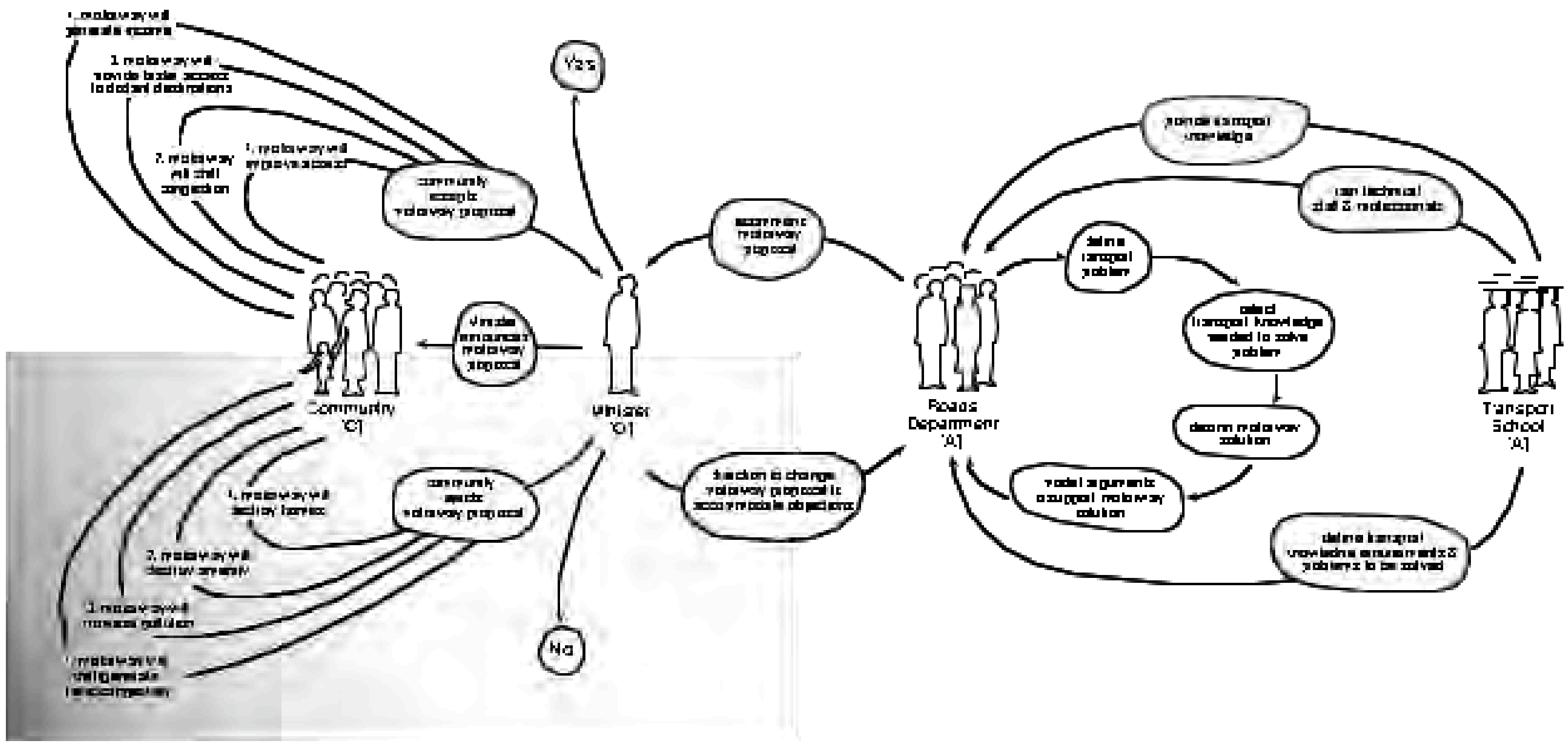
Of key significance in the rich picture model shown in Figure 2.6 is the array of different community responses. These are shown as either supportive — the upper section of the model — showing an array of community reactions fed back to the Minister — or hostile — the lower section of the model. Four different grounds for accepting or rejecting a proposal have been listed as examples in Figure 2.6, but in practice the reasons are various and differ between proposals. The tension between divergent community reactions generates a dynamic in the system that feeds back to the owner and through to the actor elements of the transformation process.

The other side of the model depicts the Roads Department and Transport School. As with the role of Minister, the inner workings and relationships between these institutions are more complex than shown in Figure 2.6. There are also informal relationships between these institutions and subgroups within the community.

Figure 2.6 A soft system model of the political decision-making process for urban motor way proposals

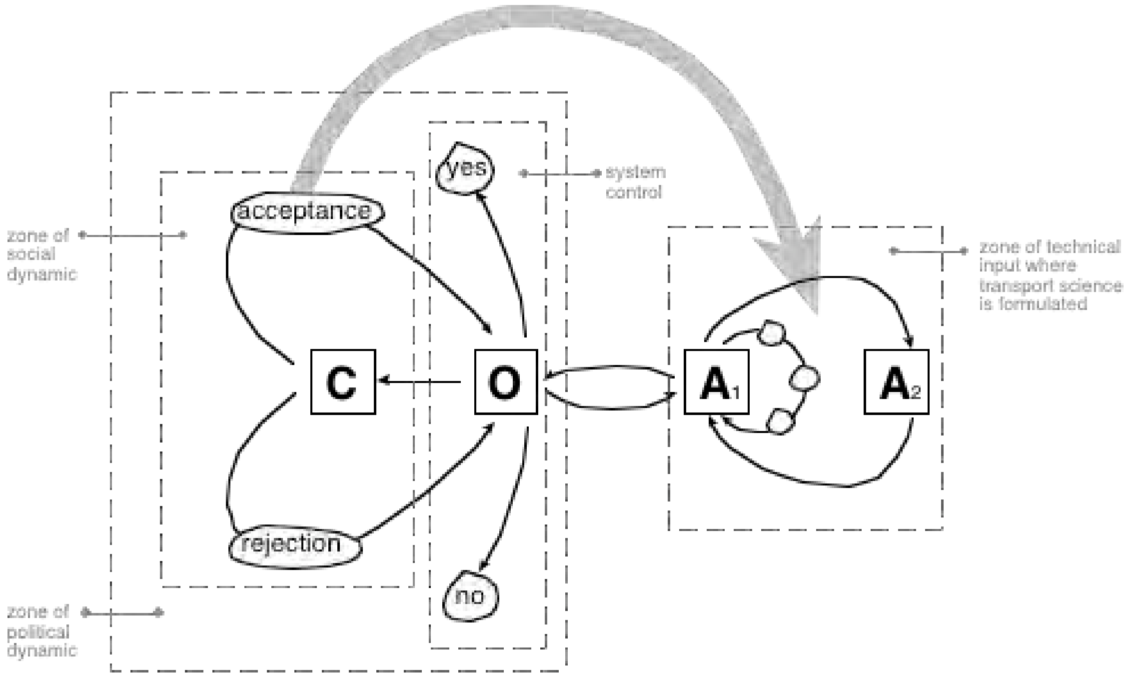
Root definition

A system to decide whether or not to approve construction of an urban motorway within the rules of a democratic society



According to Checkland, rich pictures are preferable to descriptions using linear prose because human affairs involve a multiplicity of relationships that can work in a variety of different combinations. Rich pictures are able to capture this information succinctly, providing an holistic picture without sacrificing much of its complexity (Checkland 2001, p. 74). Rich pictures can become visually complex. More detailed explorations of this model reveal important roles played by additional groups, institutions and individuals. But despite this added complexity, it is possible to generalise in a conceptual way about relationships between subsystems within the wider context of the system. This assists conceptual clarity when drawing conclusions as to why induced traffic growth has been a contested phenomenon.

Figure 2.7 Conceptual overview of soft system model



In this analysis, the model shown in Figure 2.6 has been conceptually simplified into four *activity zones*. These are shown in Figure 2.7. The first of these has been called the *zone of social dynamic*. Precisely why will be explained in more detail in Section 2.2, in which the steps in the cultural analysis will be explained in detail. But in brief, this zone refers to the activity and debate that take place within the community in response to a motorway proposal. As will be shown, the various responses usually occur in accordance with the social position and material interests of different individuals, groups and organisations. For example, local residents whose homes and streets are impacted upon react differently from commercial business groups whose trade and income might be affected. Sometimes conflict develops between these different interests.

Later analysis will identify a second zone that has been called the *system controller,* where arbitration between divergent community views takes place and social stability is maintained through Ministerial decisions and directives. Together, these two activity zones form what is defined here as the *zone of political dynamic,* where different groups in society compete for acceptance of their views in relation to urban motorway proposals and ultimately transport policy generally.

The fourth activity zone is defined here as the *zone of technical input,* where the technical impetus and justification to build an urban motorway is generated within government agencies and associated technical and educational institutions. This is also the zone where transport science is formulated. As will be shown in later comparisons between historical episodes and the model, the political dynamic affects activity within the zone of technical input, by setting broad policy objectives and by changes to the institutional organisation of actor agencies. But the day-to-day work of technical or scientific practice that works to cement the weltanschauung takes place within the zone of technical input which, under some conditions, reveals considerable inertia. The nature of the relationship between the zone of political dynamic and technical input strikes at the heart of what is accepted as transport science and why the existence and significance of induced traffic growth is often contested.

In keeping with the general aims of this part of the literature review, Section 2.2 will now test the model against a variety of historical scenarios to explore the dynamics of the political and social context in which debates about urban motorway development and induced traffic growth have taken place. Details of the relationships within each of the activity zones will change and become more elaborate as the model is run through these cycles, highlighting the role that transport science plays, with a particular focus on identifying what is responsible for the contested nature of induced traffic growth.

2.2 A road through the madding crowd: the structure of urban motorway conflicts

There are many significant examples of community conflict over urban motorway proposals. Indeed, most cities of the industrialised world have played host to such events at one time or another. While each case is unique, there are similar elements and points of debate, as the selection of histories examined here will show. From a soft systems perspective, the conflicts have similar structures — similar protagonists with similar arguments and motivating interests.

As stated in the introduction to this chapter, the most significant document in the induced traffic growth literature is the SACTRA Report from 1994. Two decades of dispute over London motorway proposals and the induced traffic growth they would cause preceded release of the SACTRA Report, shaping the social and political context in which the report was written and received. This episode will be used as the first experience cycle to explore and refine the soft systems model of the decision making process for urban motorways.

The second experience cycle focuses on conflicts over motorway development in Sydney, with particular attention paid to professional cultures within government road-building agencies and their treatment of induced traffic growth when assessing private tollway proposals. This has been made possible by the recent release of material that includes working drafts of technical documents and e-mail correspondence between technical staff responsible for formulating the case for building a motorway project.

The third experience cycle focuses on community reactions to urban motorway building in Zürich. The rules of democratic society in Switzerland are different from those of Britain and Australia. Swiss democracy has direct and deliberative elements to its organisation, giving greater power to aggregate community interests through the exercise of citizen-initiated referenda. As a consequence, the interests that motivate policy decisions often differ from those in Britain and Australia, as do the material outcomes.

The contrast highlights the degree to which interests other than those of citizens are able to determine policy, affect professional culture and ideology and ultimately affect the interpretation of empirical data and the practice of transport science.

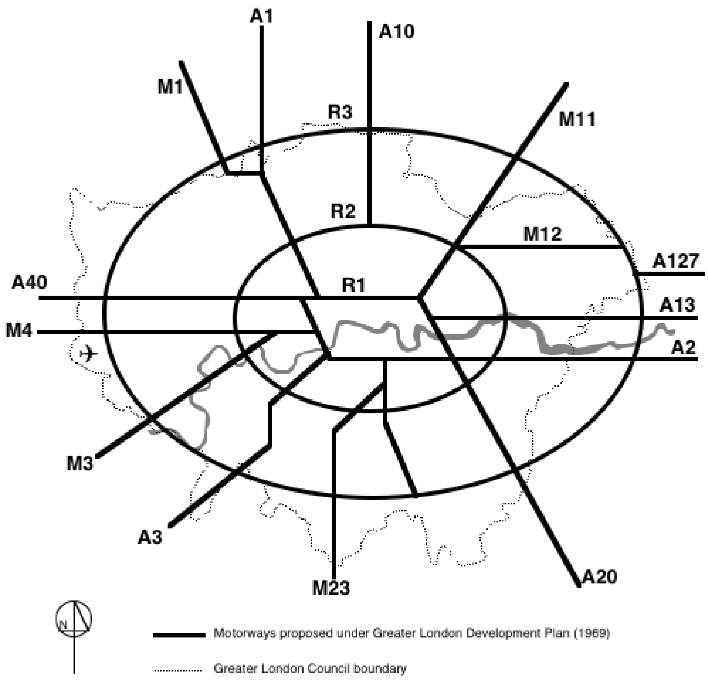
2.2.1 SACTRA, Roads to Prosperity and the last link in London's M25 motorway

Since the 1960s, transport policy for London has oscillated between advocacy of extensive urban motorway development and support for public transport and demand management programs — the latter often motivated by strong opposition to further motorway construction. Episodically, governments have put forward various motorway network schemes that have generated opposition from residential communities that would lose homes and suffer community severance if the proposed motorways were to proceed. While the political consequences of community rejection have brought changes to stated transport policy, real change has been difficult and transient. Over time policy has reverted back to programs that support construction of additional motorway capacity. As will be shown, this oscillation occurs as groups and individuals in support of motorway development are able to gain social and political ascendancy over those opposed to it and vice versa.

This historical pattern became most pronounced after the creation of the Greater London Council (GLC) in 1965, when legislation was passed requiring a legislative plan to be developed for the city. A Conservative National Government identified the need for an agency that could formulate such plans and coordinate large projects on a metropolitan scale (Self 1972, p. 299), key among these being a comprehensive metropolitan program of motorway building (Moore 2006, pers. comm.). In 1969, the GLC released such a motorway plan for the London metropolitan area as part of the *Greater London Development Plan* (GLDP). The motorway plan comprised a network of radial motorways that intersected with three concentric ring roads. Its configuration is shown in Figure 2.8.

Being an old city, corridors of vacant land had not been set aside in London specifically for future motorway constructions. Consequently, many thousands of homes in neighbourhoods located throughout the metropolitan area would have had to be demolished if the proposed motorway network were to proceed.

Figure 2.8 GLDP primary road concept diagram



Source: GLC. 1969, *Greater London Development Plan Statement.* Greater London Council, London, p. 25

There is a long history of theories that articulate the role of self-interest in political life and how conflict between competing self-interests forms the basis of *adversarial democracy* (Mansbridge 1990). Similarly, theorists writing about social movements have drawn attention to the point that when the immediate interests of individuals are threatened — such as their homes — people become more focused and likely to question the merits of a given proposal and attendant world view, and ultimately, actively involved in resisting its implementation, where previously they would not (Doyle 2000, pp. 226–227). Organised opposition to the motorway plan within the London community took two forms. Local neighbourhood societies formed a coalition called the *London Amenity and Transport Association* (LATA), which focused on technical analysis of the plan. This group was chaired by transport economist Michael Thomson — whose theoretical work will be reviewed in Section 2.3. A second London-wide pressure group, called the *London Motorway Action Group* (LMAG), was also formed, led by Douglas Jay — the MP for Battersea. This group focused on political lobbying and media coverage for the *Homes Before Roads* campaign, which was helped by members like Terence Bendixson who had worked as a journalist for *The Guardian* newspaper (Pharoah 2006, pers. comm.).[13]

Because the GLDP affected so many homes, entire communities, not just disparate individuals, took a keen interest in the issue of urban motorway development and actively opposed it. The *inner motorway box* (see Figure 2.8), comprising 30 miles of motorway, 60 per cent of which would have been on an elevated structure, required demolition of thousands of homes through the wealthy suburbs of Hampstead and Greenwich as well as Battersea, Hammersmith, Fulham and a score of other inner London neighbourhoods (Thomson 1969, p. 109). Many of the people directly affected occupied influential positions within society or had technical skills useful to the campaign (Pharoah 2006, pers. comm.).

The LATA coalition group first had to persuade the individual member societies that their best defence against local motorway plans was to call for the abandonment of the entire scheme. In this way, the *not in my backyard* interests were harnessed to the much wider aspiration of fighting the entire urban motorway concept. This greatly strengthened the opposition case underpinned by the technical work of Thomson and his colleagues (Pharoah 2006, pers. comm.).

The transformation from concerns motivated purely by self-interest to concerns motivated by threats to public interests has been noted in many analyses of social movements (Mansbridge 1990, p. 14). Initially motivated by concerns about impacts on personal property, many people became concerned about a wider range of transport issues and their impacts. The argument that bigger roads would generate more traffic was one such concern — the estimated extent of traffic growth is shown in Figure 2.9 (Thomson 1969, pp. 23–35). On the back of this argument, attention was drawn to the problem that if the GLDP motorway scheme were built in its entirety, not only would it be necessary to demolish homes for the motorway network itself, but substantial widening of existing arterial roads would also be needed to distribute the additional

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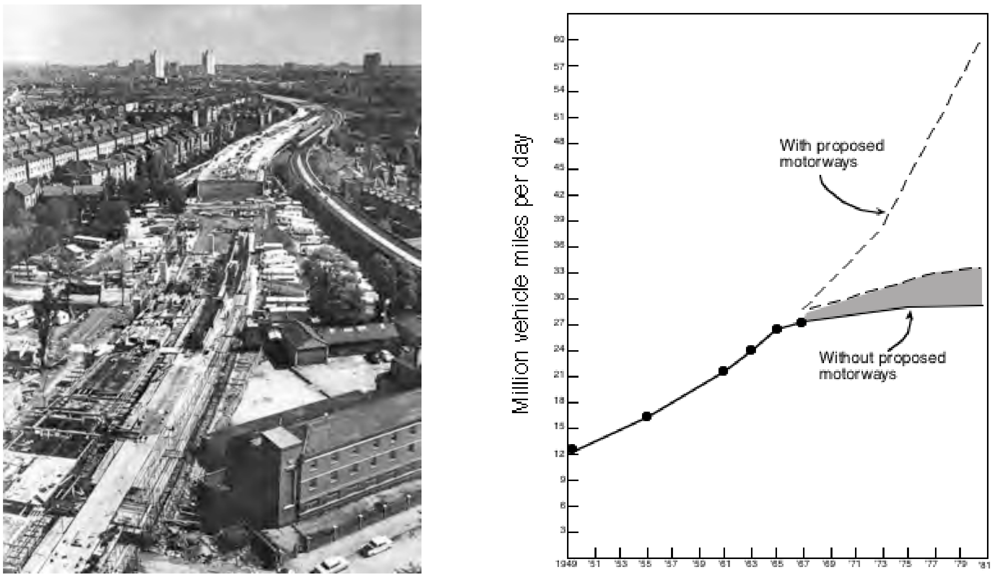
[13] Please see notes in Appendix A on the use of personal communications.

traffic generated by the increase in motorway capacity, requiring demolition of yet more homes (Thomson 1969, pp. 164–165). In view of this problem, many London residents advocated a halt to motorway development, preferring improvements to public transport alternatives that would not require personal losses on the same scale, while at the same time would protect urban amenity (Bendixson 1974; Plowden 1972).

Figure 2.9 Community severance from London motorway construction and projected traffic volumes for the GLDP motorway network



Source: Thomson, M. J. 1969, *Motorways in London: report of a working party led by J Michael Thomson*. Sage Publications, Beverly Hills, pp. 123 and 144.

Just as there were individuals whose immediate interests were threatened by the motorway network, there were groups and individuals who would benefit. Support for the motorway scheme came from organisations like the *British Road Federation* (BRF) — an industry group that received most of its funding from the road construction industry. Like residential community organisations opposed to the motorway plan, the BRF had specialist media and technical assistance. Renowned engineer, Professor Colin Buchanan, was commissioned to produce a report supporting the motorway plan, and professional media personnel were hired to influence public opinion through the popular press (Pharoah 2006, pers. comm.). In addition to industry groups, there were specialist personnel who saw their income and job security as reliant on motorway programs proceeding. It seemed many of the GLC technical staff responsible for devising the scheme were drawn from central government agencies in which the culture and ideology of motorway planning and development was deeply embedded in professional and organisational thinking (Elliott 2006, pers. comm.).

In response to the emerging conflict, a public inquiry headed by Sir Frank Layfield was held to formally investigate the implications of the plan, taking into account arguments both for and against. In support was the argument that given past trends, such as growth in car ownership, traffic volumes would grow by 70 to 100 per cent over the next two decades. If road space were not added to accommodate this growth, traffic congestion would increase, debilitating the city economically (Thomson 1969, p. 165). This is often referred to as the *predict and provide* approach to transport planning (Mogridge 1990b, p. 4). In opposition to the proposed motorway plan was the argument that while the objectives stated in the GLDP were to improve accessibility and environmental amenity, extensive motorway building and demolition of homes would not achieve this. Other transport options like improvements to rail and bus services would, and although mentioned in the GLDP outline, they were not presented as comprehensive proposals in the same way that plans for motorway building were. Further criticism pointed out that construction costs for the motorways — particularly for the inner motorway box — would be far greater than any economic benefits and in addition would leave few resources for improving public transport (Thomson 1969, pp. 166–167).

The *Layfield Inquiry* released its findings in 1972, recommending that the two innermost ring-roads be maintained but that the outer orbital was not necessary. This was precisely the opposite case to that presented by community coalition groups LATA and LMAG at the Inquiry. Layfield also recommended retention of many of the proposed radial motorways, despite the arguments and economic assessment provided by LATA as well as the growing community backlash against the need for any motorway construction at all (Pharoah 2006, pers. comm.).

Many in the community did not accept the Layfield Inquiry findings or the elected politicians committed to pursuing its recommendations. On balance, the electorate rejected the Conservative-led GLC in 1973 by voting for Labour candidates opposed to motorway development and who supported public transport improvements.

Upon election, the Labour-led GLC encountered two obstacles to its general transport policy position. The first came about because responsibility for roads was shared with the Conservative National Government through the Department of Transport. This meant the Council could stop motorway developments that came within its own jurisdiction but could not stop trunk road development for which the Department of Transport had responsibility. When negotiating the transport component of the GLDP, the GLC had to work with the Department of Transport and National Government, which supported urban motorway-building. The second, and perhaps more difficult obstacle, was resistance from GLC staff to the change in policy direction. The GLC transport section was primarily staffed with technicians who had expertise in road network development. Consequently, the minutiae of technical conventions used to guide and structure the everyday work of planning staff were geared towards road-building. For example, GLC staff continued to require development applicants to retain setbacks on new building alignments along proposed motorway routes and existing roads identified for widening, even though it had become GLC policy not to build them. The Labour Councillors did not have an explicit strategy for overcoming or changing these practices (Moore 2006, pers. comm.).

In addition, the case for improving public transport services had to some degree been hampered by two former rail studies. The *Beeching Report* into the national rail network had recommended cuts to services that required high levels of subsidy or where alternate road transport provided a preferred level of service (Beeching 1963, pp. 1–2). In 1974, a group chaired by Sir David Barran produced the *London rail study*, concluding that there was no case for substantial rail investment (Mogridge 1990b, p. 4). This was supported by a widely held professional belief that people generally preferred private transport (Elliott 2006, pers. comm.). While the GLC was responsible for the *Underground* and bus services, the National Government was responsible for suburban heavy rail services. A large portion of the GLC area was reliant on these for longer distance trips by transit. Consequently, any general public transport upgrades across the GLC required the cooperation of the National Government. In this climate, improvements to public transport advocated by communities wanting to stop motorway-building were not forthcoming, and the central question of what to do in light of rising road traffic volumes remained essentially unresolved (Mogridge 1990b, pp. 4–5).

In 1976, a modified GLDP was passed. Ring-roads one and two had been removed, ring-road three — which would later become known as the M25 — was retained, in addition to several of the radial motorways for which the National Government had legislative responsibility. In 1977, a Conservative GLC was elected to office, while the Labour Party gained control of the National Government. During this period, GLC motorway policy was reversed, however, new motorway and road projects for which the GLC had jurisdictional responsibility were approached on a project-by-project basis rather than as a metropolitan-wide scheme. While the policy change brought groups like LATA back to life, community opposition was not as widespread as it had been previously (Pharoah 2006, pers. comm.).

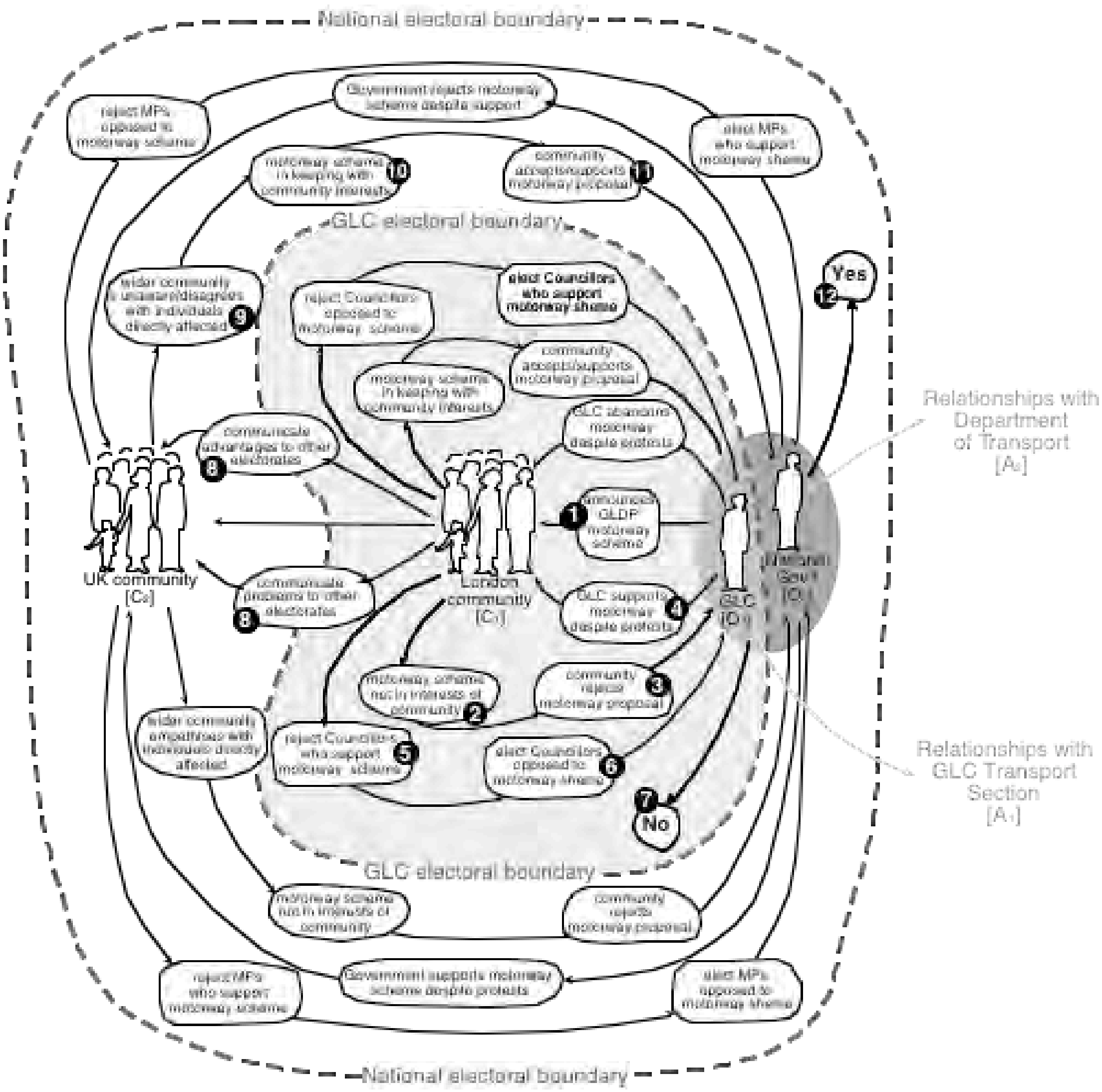
When viewed through the lens of the soft system model outlined in Figure 2.7, the number of individuals with interests in stopping the motorway scheme outnumbered those who would benefit. This majority used their voting power to replace the system owner with an alternate candidate who would use the position to pursue transport policies in keeping with the interests and wishes of the majority of the electorate. But this did not resolve the conflict. Multiple jurisdictions as well as difficulties in the relationship between system owners and actors circumvented the aggregate voting power of individuals within the London community.

Understanding the more complex social relationships that influence system outcomes requires explicit identification of the way that customers are able to exert power over the system owner and actor agencies and vice versa. As Checkland outlines, this is achieved by:

> … [A]sking through what *commodities* power is manifest in the situation, and finding out how these commodities are obtained, used, preserved, passed on … Typical commodities include role-based, sapiential or charismatic authority; privileged access to certain people or information; command of resources etc. (Checkland 2001, pp. 73–74).

In a representational democratic system like the UK, *votes* are the primary commodity of power because these ultimately determine who, with her/his attendant policies, is assigned the role of system owner. Where combinations of local and national jurisdictions exist, multiple system owners are responsible for decision-making. One owner may not be beholden to the community directly affected by an unpopular motorway proposal because her/his electoral boundaries include a large number of unaffected neighbourhoods. If the communities in opposition to a motorway do not have the resources to communicate, or are unable to persuade others to agree with them, they are less likely to influence the multiple system owners, leading to conflict and division. Figure 2.10 shows how the split within the role of system owner came about in terms of the model. The sequence of events that led to the division are numbered, point eight being of critical significance because it is at this point that the voting power of citizens within the GLC electorate is overtaken by powers within the wider community that can only be appealed to through other commodities of power. It is at this point that understanding the workings of the model enters into areas that form the Cultural-based stream of analysis.

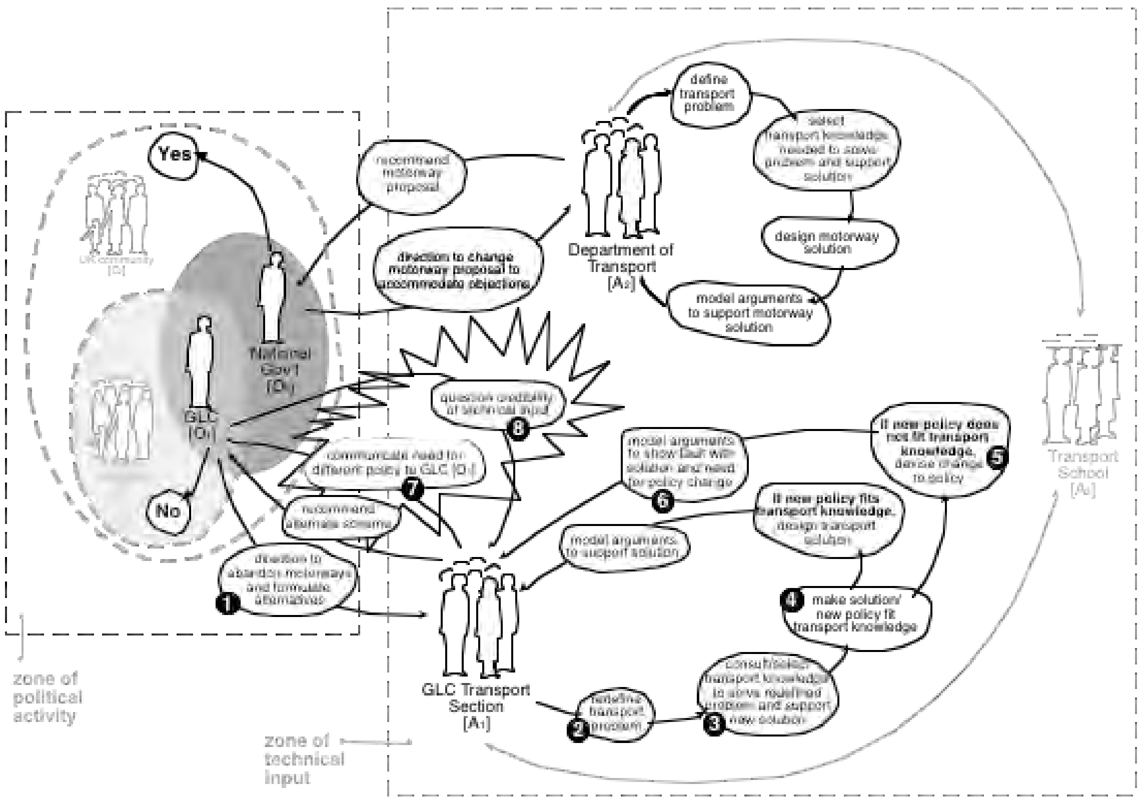
Figure 2.10 Role of votes in the zone of political activity



Note that components relating to system actors have been removed to simplify the diagram.

There are many considerations that people take into account when electing a national government. Transport is only one, and it is not within the scope of this thesis to look beyond conflicts over transport policy. What is significant is that the consequences of the split and conflict within the function of system owner, located within the zone of political activity, sent *signals* to the zone of technical input. These signals clashed with the usual procedures and knowledge base used by individuals working in their capacity as actors, extending the conflict to other parts of the system. While the history of events in London related earlier showed that various motorways were removed from the legislative plan finally passed by government, the problem was not resolved to the extent that conflict within the community stopped. The conduit by which the conflict spread to other parts of the system is shown in Figure 2.11.

Figure 2.11 Impact of political conflict on zone of technical input



Note that components relating to system customers and some system actors have been simplified.

In order to maintain their positions of authority, system owners need to justify their respective policy positions and implement them to the satisfaction of the electorate or system customers. To do this, the relationship between system owners and actors needs to be cooperative and constructive. The nature of this relationship is dependent on a range of what will here be called *secondary commodities of power*, which provide an opening into aspects of behaviour that fall within the Cultural-based stream of analysis.

There are two key secondary commodities of power that are fundamental to the relationship between system customers, owners and actors. The first is *role-based authority*, which refers to the general belief that individuals — like ministers — and groups of people — like governments — can be relied upon to make sound decisions, often for no other reason than that they are in that role (Weber 1962, p. 74). Role-based authority is a less tangible and mechanically more complex commodity of power than votes. A variation of role-based authority is the belief that technical advice provided by professionals must be sound, because it is their job to provide that service (Arendt 1954, pp. 108–109). This latter form of role-based authority, particularly in specialist areas like transport, is dependent on another commodity of power — *access to technical and specialist information.*

When conflict occurs within a decision-making system like that for urban motorway proposals, the problem is often exacerbated by the inability of system owners, and the lay communities that elect them, to question technical advice provided by technicians working in an actor capacity. Without access to specialist knowledge, it becomes difficult to question the authority of an unpopular policy that is the product of a previously compatible relationship between system owners and actors. It also becomes difficult to formulate alternative courses of action. This form of conflict drives at the very heart of specific knowledge structures, for in order to change or overturn them it is not enough to recommend change in a general way. Real change only comes with specific directives that put system actors in a position where they must acknowledge and address the shortcomings of the stock of ideas they rely on to solve problems. Or in other words, directives have to be given that intervene at appropriate points in the scientific research process itself. This is what happened in the next GLC election cycle.

In 1981, Labour candidates led by Ken Livingstone won control of the GLC, and by contrast with their previous term in office, realised that a key task was to change the thinking and responses to problem-solving of the GLC transport bureaucracy. In addition to terminating around three quarters of the proposed road works identified under the previous GLC, changes were made to senior and middle management as well as the structure of the transport bureaucracy. For example, new sections dedicated to the development of cycleway and pedestrian access were created and given some autonomy. These sections and staff, to some extent, acted as a counter to those specialising in road traffic planning and engineering (Moore 2006, pers. comm.).

The GLC maintained its explicit opposition to further urban motorway development. The Vice Chairman of the GLC Transport Committee, Paul Moore, stated that where it was the Department of Transport's policy to anticipate traffic growth and provide sufficient capacity to accommodate it, it was GLC policy to resist any increase in road space precisely because it accommodates traffic growth (Elliott 2006, pers. comm.). It was during this period that John Elliot — a traffic engineer working for the GLC — recalled an unusual increase in traffic volumes on roads in the vicinity of the Westway motorway section after it was opened to traffic in July 1970. He had noticed these when undertaking routine assessment work for that area. He suggested to Moore that they should undertake a detailed analysis that would either work to support Moore and the GLC's policy position or else help to temper their general statements at road inquiries and during negotiations with the Department of Transport (Elliott 2006, pers. comm.).

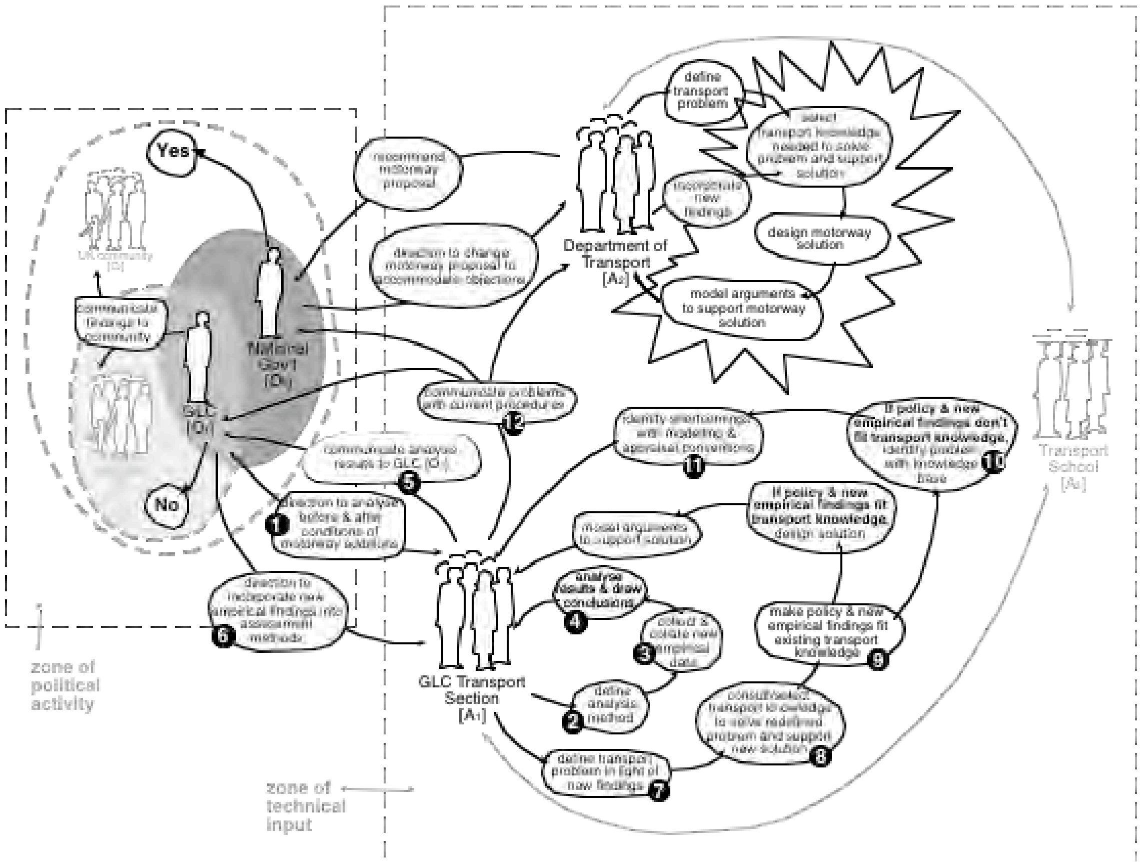
On producing the analysis, the GLC staff found evidence of traffic volumes greater than what could be reasonably attributed to traffic reassignment or growth rates occurring under normal conditions (Beardwood & Elliott 1985; Purnell 1985). The Westway motorway was one of six cases examined by GLC staff. Their analysis will be reviewed in detail in Section 2.3. Up until that time, the Department of Transport had not undertaken any comprehensive before and after analyses of urban motorway development, despite its role as the primary advocate for them (Purnell, Beardwood & Elliott 1999, p. 30). The combination of Moore's persistent policy position on urban motorway construction and technical cooperation of GLC staff produced the necessary material to question more comprehensively the authority of many of the claims made by the Department of Transport. When reflecting on the impact their work had, Elliott observed:

> Several politicians were more perceptive about the counter-productive implications of further motorway capacity than professional traffic engineers like myself (Elliott, 2006 pers. comm.).

Significantly, these analyses later formed a large part of the empirical work cited by SACTRA to support the induced traffic growth hypothesis.

Figure 2.12 the effect that these early induced traffic growth analyses had on the relationships between system owners and actors. Importantly, it shows how the conflict between policy and practice within existing conventions and knowledge boundaries had spread to other parts of the system.

Figure 2.12 Impact of empirical confirmation of induced traffic growth



Note that components relating to system customers and some actors have been simplified.

In political terms, this produced two significant outcomes. First, the Labour Councillors were able to discipline and encourage staff in such a way as to get them to work more cooperatively within the terms of their policy thinking. Second, the GLC was able to show evidence of the merits of its policy platform, both in the theatre of public discussion and in the throes of technical debates with Department of Transport representatives at motorway inquiries[14]. This enhanced the role-based authority of

[14] Elliott made the observation that once results were available of the empirical analysis of before and after conditions for several London motorways, he was required to give evidence at the East London River Crossing Inquiry. He was cross-examined over a period of six days on matters relating to the GLC's evidence. Elliot saw this as an indication of the degree to which induced traffic growth analysis challenged prevailing professional beliefs and road expansion policy at that time (Elliott 2006, pers. comm.).

system owners and actors opposed to urban motorway developments while threatening that of government Ministers and the Department of Transport.

In 1985, the Thatcher Government abolished the GLC, removing the split in the system owner that had restricted easy passage of many motorway proposals. Responsibility for transport and motorway development within the London area was brought under the control of the National Government. Those within the community opposed to motorway development were no longer able to appeal to the resources and jurisdictional authority facilitated by a GLC opposed to additional urban motorway capacity. Where community opposition had previously been expressed as voter backlash and submissions to public inquiries, it was now expressed as protest and bruising civil disobedience campaigns in which individuals attempted to physically stop motorway constructions through blockades (Torrance 2006, pers. comm.).

In 1989 the Thatcher Government released a white paper entitled *Roads to Prosperity*. The paper provided details of a road-building program for the UK designed to accommodate forecast traffic volumes for the year 2025. The program had an estimated cost of 12 billion pounds. When finished, an additional 2,700 miles of motorway would be added to the UK road network (Department of Transport. 1989, paragraphs 20, 28 and 30). During this period, controversial motorway proposals were not confined to urban areas but were initiated throughout the entire country, inflaming rural and regional as well as urban electorates (Torrance 2006, pers. comm.). In London itself, the Thatcher Government commissioned studies into the transport requirements of four key movement *corridors*. Although presented as multi-modal studies, they were expected to produce a case for further road-building (Pharoah 2006 pers. comm.).

Later that year, the last link in London's M25 outer orbital motorway was opened to traffic. After opening, it was clear that traffic volumes on almost every section of the ring-road were greater than on the original road network and much higher than predicted (SACTRA 1994, p. 51).

This commentary has not focused so much on the arguments against induced traffic growth, or on the motivating interests of groups within society in favour of motorway developments. More will be said about these in the following experience cycle that investigates motorway development in Sydney. But briefly, after the release of the GLC analysis, there were attempts to dismiss the significance of problems with the testing method and by generally ignoring the significance of their implications. These will be investigated in Sections 2.2 and 2.3. While these attempts were successful to varying degrees in quashing professional opposition within actor agencies so that the role-based authority of those in support of urban motorway development was not questioned, after opening of the last link in the M25, argument about the veracity of empirical testing methods was lost on a community for which the increased delays and inconvenience were plain to see (Torrance 2006, pers. comm.), and media coverage of the M25 produced images such as that shown in Figure 2.13.

Figure 2.13 Traffic jam on the M25 Motorway after opening of the last link and community protest over the M11 link road in East London

Source: BBC News. 2002, *M25 is worst road 'hotspot'.* www.bbc.co.uk/1/hi/england/2328867.stm 15 October and Brass, E. & Poklewski Koziell, S. 1997, *Gathering force: DIY culture – radical action for those tired of waiting.* The Big Issue Writers, London, p. 43.

It was within this climate that the Secretary of State, John Gummer, instructed SACTRA to investigate the issue of induced traffic growth. He requested the committee:

> To advise the Department [of Transport] on the evidence of the circumstances, nature and magnitude of traffic redistribution, mode choice and generation [resulting from new road schemes], especially on inter-urban roads

> and trunk roads close to conurbations; and to recommend whether and how the Department's methods should be amended, and what if any research or studies could be undertaken (SACTRA 1994, p. i).

The committee decided to approach the Secretary of State's request by asking four basic questions, to which the following answers were:

> 1 **Is induced traffic a real phenomenon?** ... induced traffic can and does occur, probably quite extensively, though its size and significance are likely to vary widely in different circumstances.
>
> 2 **Does induced traffic really matter?** … induced traffic can seriously affect the design, environmental appraisal and economic evaluation of schemes.
>
> 3 **When and where does induced traffic matter most?** … induced traffic will be of greatest importance … where the network is operating or is expected to operate close to capacity; where the elasticity of demand with respect to travel costs is high [and]; where the implementation of a scheme causes large changes in travel costs (SACTRA 1994, p. 205).
>
> 4 **How should the current forecasting and appraisal methods be amended to allow for induced traffic — what needs to be done?** … induced traffic growth needs to be incorporated into all levels of the hierarchical approach to trunk route forecasting and appraisal, a consistent approach be taken to the consistent application of variable matrix demand models and demand models be regularly audited to establish their accuracy (SACTRA 1994, pp. 187, 191 and 196).

While SACTRA's review of the issue provided the opportunity for an *independent* technical assessment of the problem by individuals working within the actor sphere of the decision-making system, but whose work was not directly linked to the Department of Transport, it is important to remember that the investigation was carried out against a backdrop of extraordinary public protest. On the eve of the release of the committee's report, several hundred citizens were refusing to move out of homes earmarked for demolition to make way for construction of the M11 Link Road through London's East. Hundreds camped on roofs while others cemented themselves into basements to stop demolition gangs from moving in. At the height of the campaign, over 600 police in riot gear came on site to remove protesters. Objectors were drawn from a wide spectrum of demographic and ideological interest groups (*The Economist* 1994, p. 57). This made for disturbing imagery on the evening news. Feature articles appeared in magazines questioning the authority of arguments used to justify road-building. These cited evidence to contradict the Department of Transport's claim that motorway construction solves the problem of congestion (for example Tickle 1993, pp. 22–23).

Once SACTRA's findings were published in 1994, the NGO equivalents of LATA and technical officers from government agencies in cities all over the world began to cite the report, leaning on its authoritative stature as a government document as much as its technical contents. While much of the report focuses on specific details concerning traffic modelling procedures used by the Department of Transport, for which induced traffic growth had previously been viewed as a tedious complaint, habitually raised by interest groups opposed to motorway development, it was now a legitimate technical consideration that needed to be included in the assessment of motorway proposals.

The popular interpretation and status granted to the SACTRA Report, however, troubled some members of the professional transport community. In an address to the Chartered Institute of Transport and Logistics entitled *The dangers of nihilism in roads policy*, Foster made the point that the media had misrepresented the actual contents of the SACTRA Report. He argued that the findings were less dramatic than popular news headlines like 'More roads mean congestion' would suggest, and that editorials like 'New roads create extra traffic and to some extent worsen the problem they are supposed to solve' provided a misleading picture of what SACTRA found (Foster 1995, p. 27). On some levels this is true. But the SACTRA Report was released at a time when the very existence of induced traffic growth was denied by key government agencies, as were the policy implications. In such a climate, for many people an understanding of the nuances of changes to modelling procedures seemed less important than the realisation of a general idea that could legitimately challenge the equally general ideas habitually used by road-building agencies to justify urban motorway development.

In the years that followed, SACTRA's recommendations to include consideration of induced traffic growth in assessments impacted on the minutiae of urban transport planning and assessment (SACTRA 1994, pp. 187–202). Reforms were made to COBA, the system of cost–benefit analysis used by the Department of Transport for motorway assessment. Within this arena, the nuances of the phenomenon did matter. The base algorithms in traffic models had to be changed to incorporate induced traffic growth, and transport professionals were compelled to find robust ways of doing this.

In 1997, New Labour was elected to power, heralding a raft of further reforms to the assessment process for motorway developments and stopping the extensive motorway construction program originally introduced by the Thatcher Government. The New Approach to Appraisal (NATA) criteria were established in an attempt to give greater weight to factors that were difficult to represent in terms of microeconomic analysis and traffic modelling[15], replacing the previous EIS process (Prince 1999). But despite these early reforms, current policy has to some extent reverted back to a road-building agenda. Plans to expand capacity on the Thames Gateway Bridge[16] are currently being debated, as is the proposal to increase capacity on the M25.

Irrespective of these apparent retractions, the science did change in the wake of the SACTRA Report. It also changed some of the dynamics of the relationship between different actor agencies involved in the decision-making process for urban motorway proposals. The change in this relationship is the focus of the next experience cycle that investigates the details of a recent motorway proposal for Sydney.

2.2.2 Induced traffic growth in the context of Sydney motorway proposal assessment procedures

The history of urban motorway development in Sydney has run a similar course to events in London. The primary difference, however, has been in the jurisdictional structure of government and supporting technical bureaucracies, as well as the introduction of private tollway operators to the mix of system actors.

The aim of this experience cycle is not to examine the details of public opposition to motorways, which was the primary focus of the London experience cycle. Rather, the aim is to focus on the role and motivations of commercial interest groups that support motorway development. Their involvement is more explicit in Sydney due to the presence of private tollway consortiums, providing a greater opportunity to explore how these groups — which do not have access to primary commodities of power, or votes — are able to influence the decisions of system owners. This experience cycle also

[15] Appraisal of the Newbury By-pass under the NATA 5 assessment criteria led to the rejection of the motorway on the grounds that impacts on natural heritage were insupportable.
[16] This bridge was formerly known as the East London River Crossing and was the subject of an earlier Public Inquiry.

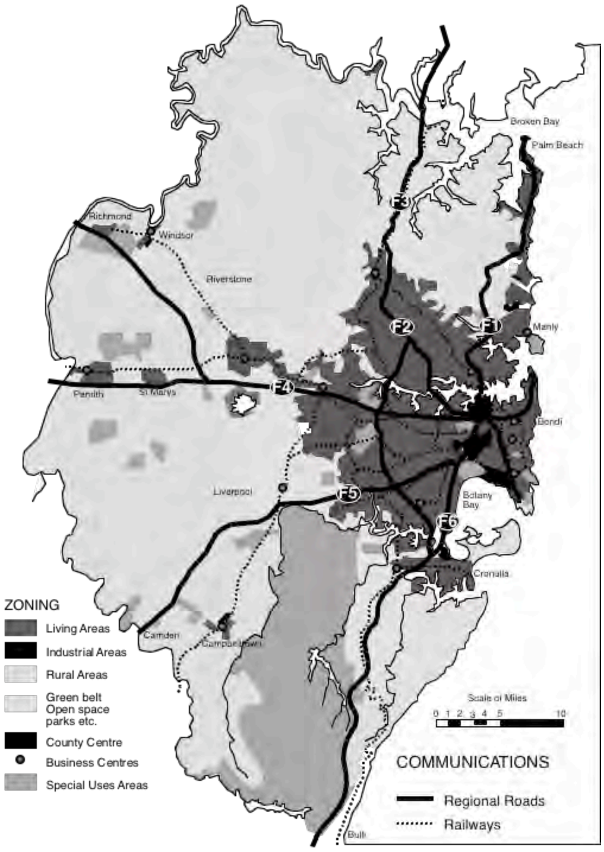
focuses on the interaction between system actors — government transport professionals responsible for the advocacy and planning of motorway proposals and those responsible for assessing their efficacy. As will be shown, the inclusion of induced traffic growth in the assessment of a recent motorway proposal for Sydney — the M4 East — made considerable differences to this process. But to begin, a brief background on motorway development in Sydney is useful to contextualise the discussion.

In 1951, the McGirr Labor Government of New South Wales (NSW), which had jurisdiction over the motorway and arterial road network, passed legislation for the *County of Cumberland Scheme*. The scheme included a proposed motorway network in the same way that a motorway network was proposed as part of the GLDP. The original configuration of the Sydney motorway network proposed as part of the scheme is shown in Figure 2.14 and will be examined in more detail in Section 3.1.

Up until the late 1960s, successive State Governments led by the Coalition[17] had only constructed sections of the radial motorways in unsettled outer-lying areas. Consequently the proposed network remained largely unopposed until 1968–69 when the Askin Coalition Government, under advice from the Department of Main Roads (DMR), proposed to construct motorway sections through inner-city neighbourhoods that would have required the demolition of thousands of homes (*Sun Herald* 1972, p. 3).

[17] In Australia, the *Coalition* is the local idiom for the conservative political parties comprising the *Liberal Party* and the *National Party*. The Liberal Party generally represents urban electorates while the National Party represents rural electorates.

Figure 2.14 County of Cumberland Scheme, 1951



Source: Ashton, P. & Waterson, D. B. 2000, *Sydney takes shape: a history in maps.* Hema Maps Pty Ltd. Brisbane, p. 59.

Like London residents, Sydney residents launched campaigns against the need to demolish homes for motorway constructions. These culminated in blockades that were supported by Trade Unions[18] as well as the opposition Labor Party (Mundy 2006, pers. comm.). In 1976, the Labor Party was elected, bringing with it a change in transport policy. Under the new Wran Government, priority was given to expansion of the rail network in urbanised areas. The government also launched two Commissions of Inquiry into radial motorways proposed under the County of Cumberland Scheme — the F1 and F5. The problem of induced traffic growth was cited in both cases as reason for not proceeding with the motorways (for example see Kirby 1981, pp. 1–2).

After changes to the Labor leadership, in 1986 the Unsworth Labor Government retracted its previous policy to prioritise mass transit development and began

[18] At that time the trade union movement in Sydney had devised a program of *greenbans*, comprising sites that the Builders Labourers Federation had banned any of their members from working on. Initially, the Labor Party prevaricated on the issue of whether to support unions and local residents in their campaign to stop the motorways from going ahead, however, they eventually opposed the motorways (Mundy 2006, pers. comm.).

investigation of ways to involve the private sector in the funding and operation of motorway developments in order to fast-track the construction program (Searle 1999, p. 112). The Sydney Harbour Tunnel (SHT) was the first project undertaken with private-sector financing. After a change of Government in 1988, whereby the Greiner Coalition Government gained power, the program of private tollway construction increased in scale. The M4[19] and M5[20] tollway proposals were approved, with private-sector involvement a key feature in their financing and operations. All three tollways — the SHT, M4 and M5 — were opened to traffic in 1992. In the case of the SHT and M4, traffic volumes appeared to be much higher than before and congestion greater at key points on the surrounding road network, which became a source of public complaint (Hutchings 1992, p. 1; Skinner 1992, p. 12).

Originally, tollway projects were funded within the Build-Own-Operate-and-Transfer, or BOOT Scheme, framework, whereby tollway consortiums comprising financial and construction interests would finance, design and construct a project as well as take on responsibility for operating and maintaining it for an agreed time period. In exchange, the consortium would be allowed to toll traffic using the facility (IIG 2005, p. 14). The financial arrangements for later motorway projects became more elaborate, involving tax breaks from the Federal Government and capital-raising through the listing of projects in the form of infrastructure trusts on the stock exchange (for example, MIIM 1996). These more elaborate financial arrangements came about because the ratio of toll revenue to construction costs and other inputs, could not sustain projects on a purely commercial basis. Problems with commercial viability were compounded by rising construction costs in response to community demands for changes to project configurations.

Like motorways, the construction of tollways attracted strong opposition from resident interest groups representing communities that would be affected by the environmental and amenity impacts from the roads. However, because of its geology, tunnelling is easy

[19] Substantial portions of the M4 Motorway had been built prior to 1992 (see Section 3.2 for more details). A private tollway consortium built the last section between Mays Hill and Prospect.
[20] No sections of the M5 Motorway that pass through urbanised areas had been built up until this period. A private tollway consortium built a section between Liverpool and Bankstown (see Section 3.3 for more details). Unlike the M4 Motorway, the M5 struggled financially until the NSW Government built the remaining sections.

in Sydney. Once a motorway is put underground, opposition from residents who would lose their homes is largely removed and confined to arguments over emissions from tunnel exhaust stacks (Main 2003, p. 29). Most motorway and tollway proposals with alignments through heavily urbanised areas are now built in tunnels to avoid such conflict. While tunnelling makes the politics easier, the drawback is that costs increase significantly.

Private tollway consortiums have confronted the issue of higher construction costs in two ways. The first has been through special tax concessions from the Federal Government. The second has been through a program of capital raising by listing tollways on the stock market and then paying shareholders dividends through debt funding.

Initially, the Federal Government's[21] Development Australia Bond Scheme (DABS) was quite critical to many higher cost infrastructure projects. The DABS comprise *stapled securities* issued to private-sector companies who provide key infrastructures like motorways. The stapled securities entitle recipients to income tax concessions, which can be passed from the tollway consortium to individuals and banks providing capital for the project. Under this scheme, the amount of capital that bond-holders put up for projects is often less than the reduction in income tax they receive. Consequently, the cost to taxpayers was greater than if government had borrowed the money and built the projects itself. Much to the 'dismay' of the Australian Council for Infrastructure Development[22] (ACID 1997), the scheme was subsequently stopped in 1997 once the extent of the revenue loss was realised (Costello 1997). DABS has since been replaced by the Infrastructure Borrowing Taxation Offset Scheme (IBTOS), which, like the previous scheme, provides tax relief for bond-holders, however, this scheme is capped at $75 million per year (Fischer 1998).

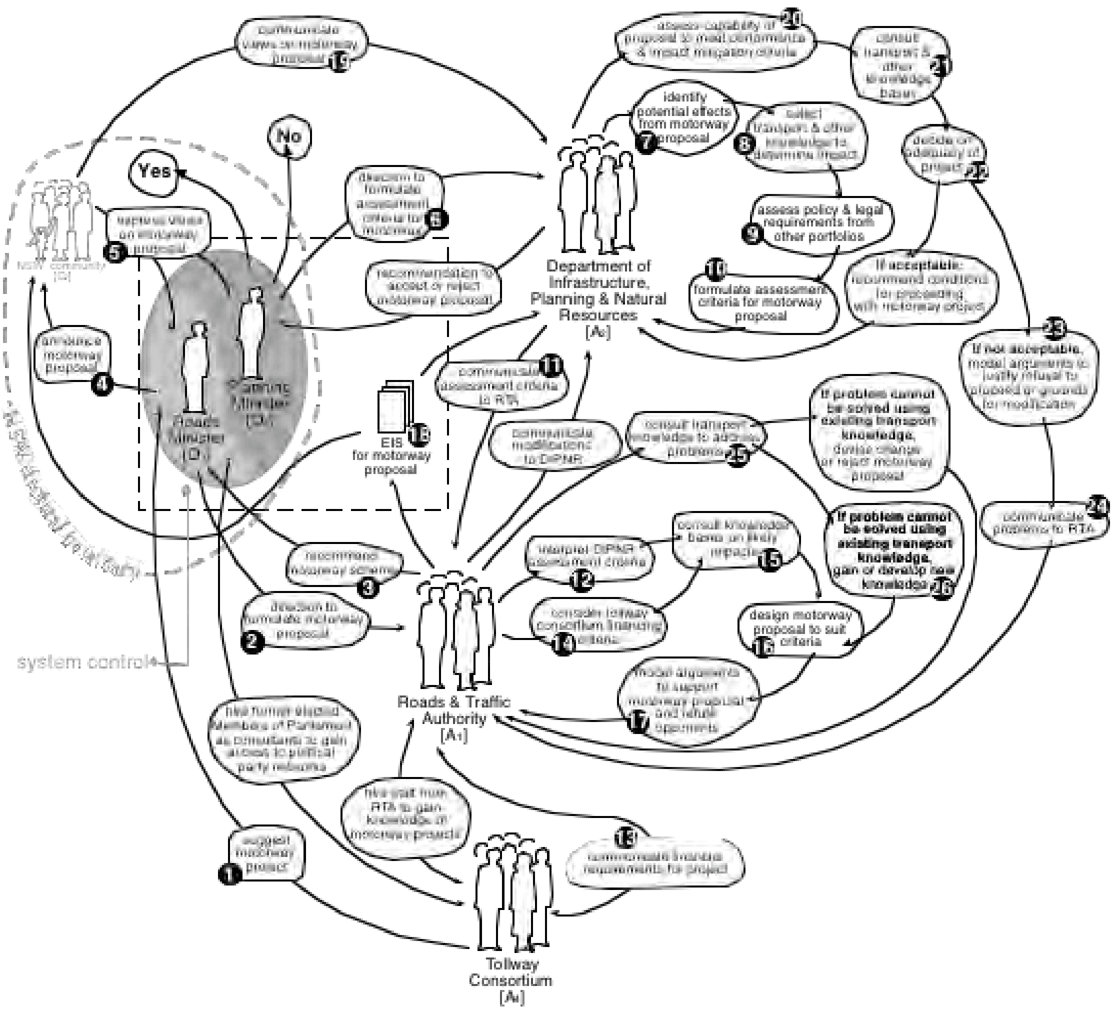
The second conduit through which capital for construction is provided is the listing of infrastructure portfolios on the stock exchange. This enables tollway consortiums to

[21] The Federal Government of Australia is not responsible for the planning and construction of road works throughout the country, but it does play a funding role.
[22] ACID is a commercial body representing private-sector finance and construction interests.

access capital from multiple sources. In the vast majority of cases dividend payments to investors are made through debt funding. The asset value of the infrastructure in question is raised and funds borrowed against the increased value of the asset. There are however many finance industry professionals an commentators who have questioned the sustainability of this form of financing. They point out that distributions cannot be financed by this means forever and that many of the valuations appear to be unsound (Long 2006).

After the Federal Government reduced the amount of available funding to tollway investors through income tax schemes, tollway consortiums had to bear more of the risk themselves. In the case of the Cross City Tunnel — Sydney's most recent tollway — private investors had to bear the full risk if traffic volumes did not produce sufficient revenue to cover project costs. After opening, traffic volumes were around 60 per cent below projections, creating problems for investors (Alberici 2005). The project contract, however, included provisions to manipulate the capacity and signal phasing of traffic lights on the surrounding distribution network in order to redirect traffic into the tollway. The tollway consortium requested the State Government to honour these agreements in an attempt to boost its revenues. Chronic congestion occurred in response, causing widespread public complaint (Goodsir & Moore 2005). This outcome has given rise to further review of finance models for private tollways, with the latest advocating that a greater portion of the risk should be transferred to government. It has been argued that if patronage levels fail to generate sufficient revenue, government should make up the shortfall or else contribute a portion of construction costs, as has been the case with the M7 Motorway. The justification for these measures has been made on the grounds that governments, on behalf of the community, often require roads to be built in such a way as to accommodate community expectations relating to environmental amenity — such as placing motorways in tunnels — and that the community should pay for this and not the tollway consortium (IIG 2005, pp. 14–15). Given that many of the private-sector interests involved in tollway projects receive commissions based on a percentage of construction costs or the asset value of the motorway, higher construction costs are good for business if governments are prepared to pay a portion of them (Rennie 2001).

Figure 2.15 Actor agencies in the Sydney system



Note that the relationships with system customers has been simplified and those with system actors responsible for training profesionals and undertakeing research have not been listed.

Figure 2.15 shows the relationships between the system owner and actor agencies responsible for the planning and assessment of motorway proposals in Sydney up until late 2005. As can be seen, the Roads & Traffic Authority (RTA) is responsible for providing the technical basis for motorway proposals under the direction of the Minister for Roads. The Department of Infrastructure, Planning and Natural Resources (DIPNR) is responsible for setting the criteria on which proposals are assessed, as well as providing advice to the Minister for Planning, who is responsible for the final determination. For infrastructure projects like urban motorways, the formal relationship between the RTA and DIPNR revolves around the preparation of Environmental Impact Statements (EIS) as set out under the *Environmental Planning and Assessment Act and Regulations 1975* (EP&A Act). In terms of the soft system model, the legislation requiring preparation of an EIS functions as an extension of the system controller, providing specific rules about the process, which ultimately leads to acceptance or rejection of a proposal.

One of the more recent motorway proposals to be subjected to the process of assessment as set out under the *EP&A Act* has been the M4 East Motorway — an extension of the existing M4 tollway through the inner suburbs of Sydney linking the outer western metropolitan sector with Port Botany[23] and the motorway network surrounding the CBD (see Figure 2.14 for alignment of the F4, now the M4). As with other recent motorways, most of the M4 East would be built in a tunnel.

The M4 East has been the subject of conflict between residential communities that would be affected by the proposal and the State Labor Government (Mistilis 2004, p. 1). Some local Labor MPs broke with State Government policy and publicly opposed the project in an attempt to retain voter support within their electorates (Ashfield Municipal Council 2004, p. 1). Where State MPs thought local resident communities would benefit, or at least not object to the proposal because it did not affect their homes, they supported it. While residential communities have been divided on the issue, commercial interest groups such as the NSW Roads and Transport Association — which represents road freight haulers — and the National Roads and Motorists Association (NRMA) — which claims to represent the interests of motorists — as well as road finance groups, have all publicly expressed support for construction of the M4 East Motorway (Australian Tunnelling Society 2006; Korporaal 2006; NRMA 2003; NSW Road Transport Association 2004, p. 4). The position of those opposed to the motorway has been helped by technical problems with the project, not least of which has been the revelation that on some segments of the surrounding road network, traffic volumes are estimated to increase rather than decline after the motorway is opened

[23] Port Botany is Sydney's primary seaport and is the primary distribution point for international container traffic to the city and many parts of New South Wales.

(EcoTransit Sydney 2004a; Hale 2004). This contrasts with RTA claims that traffic congestion would be reduced (RTA 2003a, p. 2). Within this ferment of different interests, technical problems and political consequences, the project was put on hold until after the next state election, which was held in March 2007 (Goodsir 2005).

One of the specific requirements for assessment of the M4 East set by the Director General of DIPNR on behalf of the Minister for Planning was for any induced traffic growth that might be generated by the project to be included in the modelling and economic assessment (DIPNR 2004b, p. 4). As will be shown, this stipulation resulted in an outcome that changed the viability of the project.

In late 2005, documentation concerning the M4 East was made available after a call for papers, initiated by the Greens[24], was passed by the State Parliament. The call for papers required all documentation concerning the M4 East to be made available for public inspection. This included internal correspondence between government departments like DIPNR and the RTA, their communications with private consultants commissioned to provide specialist input, as well as drafts of the unpublished EIS.

Draft copies of the EIS show that modelled estimates for the Level of Service[25] (LOS) at several key intersections in the surrounding arterial road network would decline as a result of increased volumes or induced traffic growth (Masson Twiney & Wilson. 2005, p. 74). This would have had the effect of slowing travel times for road trips using nearby feeder routes, as well as for some trips from the western suburbs to the CBD by people using the new facility (Masson Twiney & Wilson. 2005, p. 79).

The RTA's initial response to these findings appears to have been to overlook the impacts, as they were not included in the version of the EIS prepared for public exhibition (RTA 2005b). Instead, the RTA continued to claim that traffic conditions would be improved if the proposed tollway were to proceed (RTA 2005a). Slower travel times for trips on the surrounding road network affected the Benefit Cost Ratio

[24] The Greens are a minor political party that holds three seats in the NSW Legislative Council or Upper House of the NSW Parilament. Legislative Council members are elected via a proportional voting system for the State of NSW. By contrast, members of the Lower House are elected via a preferential voting system. This system favours major parties.
[25] Level of Service (LOS) refers to a description of the general quality of operations on a facility like a motorway or road using a letter scale from A to F (Roess, Prassas & McShane 2004, pp. 292–293).

(BCR) for the project, so that total costs exceeded the total benefits (DIPNR 2005b). In an attempt to overcome the negative BCR, the RTA responded by including the additional tollway revenue generated by the induced traffic growth as a *producer surplus* in the list of benefits for the project, which would have the effect of giving it a positive BCR (RTA 2004a). Correspondence also shows that NSW Treasury found this approach problematic and was not amenable to changing the standard method of economic assessment (RTA 2004b).

On the basis of present documentation, it appears that proceeding with the M4 East Motorway would be unsound on an economic basis. However, if the impact of induced traffic growth is not included, it is possible to calculate a positive BCR for the project.

Internal documents also show that DIPNR technical staff subjected the RTA's traffic modelling to on-going scrutiny during the development of options to be investigated as part of the EIS (DIPNR 2005a, 2005b, 2005c). This on-going scrutiny and their stipulation that induced traffic growth be incorporated into the assessment, appears to have arisen as a result of several converging factors. The first was acknowledgment by DIPNR staff that during previous motorway assessments they had been locked out of negotiating possible improvements to projects because they had agreed to a scope of works before the results of detailed modelling were known. To guard against missing such opportunities, DIPNR only made recommendations as to what it felt needed to be investigated as information became available (DIPNR 2004a). The second was the importance of the arterial road network in the vicinity of the M4 East to land-use development outcomes. DIPNR was overseeing an extensive urban consolidation program in that area and was concerned about impacts from the M4 East on amenity and development within those precincts (DIPNR 2004b, p. 1, 2005b). The third factor was the presence of articulate and well-informed resident interest groups representing communities that would be affected by the motorway. These groups were able to gain access to confidential technical information early in the assessment process, so that the public became aware of potential increases in traffic that the RTA had not made public (EcoTransit Sydney 2004b). This exposure put political pressure on the State Government and may have contributed to a shift in voting patterns for Local

Government, which saw a significant increase in votes for Greens Councillors opposed to the motorway in three Council areas. The fourth factor was strident opposition to the motorway by local councils, once a clear picture of the likely impacts of the project had been made known (Leichhardt Council 2004). These last factors, while not contributing directly to discussions between RTA and DIPNR staff, created a climate in which greater scrutiny could be justified.

Since the decision to put the project on hold, the structure of DIPNR has been changed and key personnel previously responsible for overseeing the evaluation of the proposal have taken up different positions within government. The *EP&A Act* — under which the M4 East was to be assessed — has been changed significantly. Projects deemed *critical infrastructures* are now assessed internally within State Government, requiring no public scrutiny of projects through an EIS process (Allens Arthur Robinson 2005; Knowles 2005).

These changes will no doubt work to reduce the degree of scrutiny to which the M4 East will ultimately be subjected. Nevertheless, the example illustrates the extent to which recognition and inclusion of induced traffic growth can affect the viability of urban motorway projects. It also shows how technical staff can react when confronted by outcomes that do not fit within their expectations or weltanschauung.

The motivation to disregard unfavourable technical analysis appears to come from the relationships that exist between system owners and actors. This is particularly strong in the case of Sydney now that private tollway consortiums have been introduced into the process. As shown in Figure 2.15, staff move between positions in the RTA and tollway consortium where they are able to earn higher incomes. More recently, individuals have moved between positions within elected government and member groups of tollway consortiums. For example, after resigning from his position as Premier of NSW, Bob Carr became a consultant to Macquarie Bank for an annual fee of $500,000 (Dempster 2005; Samuel 2005).

The next experience cycle examines how decisions are made when system customers are able to exert more power over the actions of system owners and actors.

2.2.3 Changes to commodities of power: motorway building in Zürich under the Swiss system of direct democracy

Urban motorway development in Zürich has been the subject of on-going controversy in much the same way that it has in cities like London and Sydney. Since the 1960s, similar interests groups have emerged within society, raising similar arguments to either support or oppose motorway constructions on the basis of similar themes. However, issues like induced traffic growth have not been contested in the same way that they have in other industrialised countries like the UK and Australia. There are two reasons for this. The first is that where communities have objected to urban motorway development on the grounds that additional traffic will be generated, they have been able to enforce the position through legislation so that argument in a policy sense becomes moot. The second is that policy has focused on development and expansion of public transport systems, specifically in many cases, as an alternative to urban motorway development. This difference in policy focus has generated a different set of technical problems for transport engineers and planners to solve. Subsequently, different organisational cultures and forms of transport knowledge have emerged.

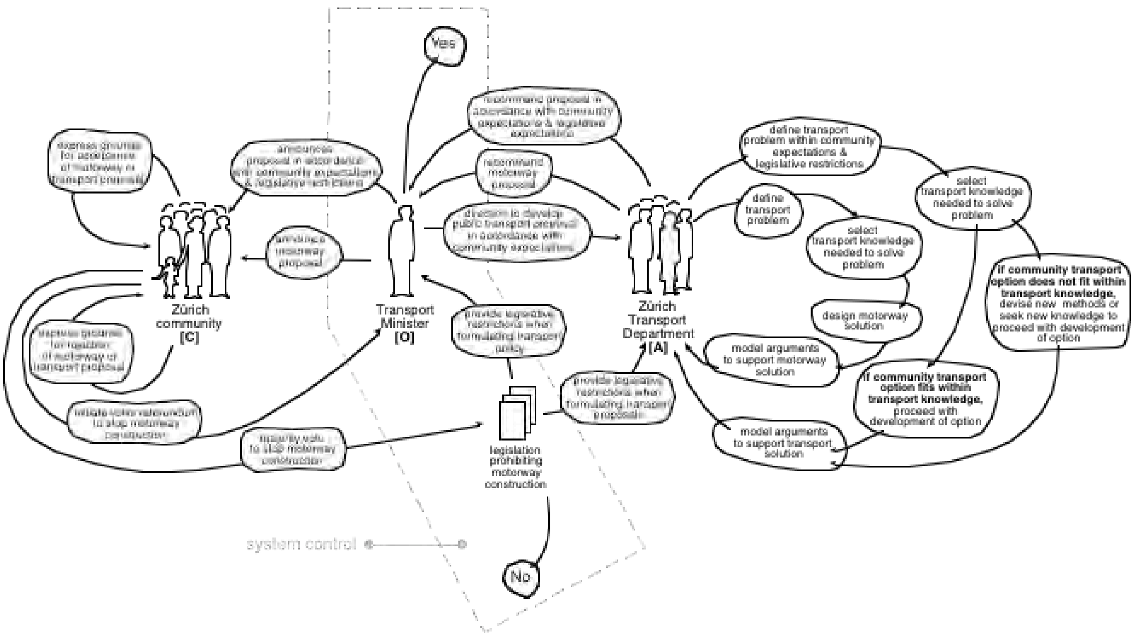
The reason for this stark difference is that the social and political context in which decisions are made about transport is substantially different in Switzerland. When individual citizens cast votes, they do not merely vote for someone to make decisions on their behalf, as is the case in *representational democracies* like Britain and Australia. Swiss citizens also have the option of voting on the specific details of policy. Power is distributed differently as a result, so that the aggregate interests of individual citizens, rather than institutions or corporations, are the primary motivation for decisions. This occurs because of Switzerland's system of *direct democracy.*

Many states in the USA also have direct democracy provisions, however, it is permissible to offer monetary and other material inducements when asking people to sign a petition as part of a citizen-initiated referendum. Such practices are illegal in Switzerland, attracting heavy penalties and gaol sentences. Swiss legislation also requires a minimum time lapse of three months between submission of a petition for a citizen referendum and having the issue put to a vote. This time lapse allows all interested parties to form and a public debate to occur. By contrast, in the US, referenda can be brought to a vote within days of their submission so that public discussion and deliberation is stifled. The deliberation clause means that technically the Swiss system is not only a direct democracy with representational elements, but it is also a *deliberative democracy*. In addition, legislation requires government to explain to voters the arguments of both proponents and opponents to the question as well as provide a reasoned outline of the government's position (Laube 2006, pers. comm.).

Switzerland's present system of direct democracy came into effect in 1874 and operates at all three levels of government — Federal, Canton and Local Council. At the Federal level there are three forms of direct voting. These are *obligatory referenda* that refer questions relating to constitutional amendments and international treaties devised by parliament to the Swiss population. To pass, a double majority of individuals and Cantons is required. Australia also has this form of referendum incorporated within its Federal and State constitutional frameworks. The second is an *optional referendum* whereby most legislation passed by parliament is challengeable if 50,000 citizens indicate rejection by petition within 90 days. The legislation is then put to a popular vote and a simple majority of the people determines whether the bill is passed or rejected. The third is the *volks initiative*, or people's referendum, that allows citizens to initiate their own legislation. This requires 100,000 signatures from Swiss citizens. As with an optional referendum, elected government can present a counter-proposal to be voted on at the same time that a volks initiative is put to the voting population. While this system of direct democracy operates at all three levels of Swiss government, the number of votes required at the Canton and Local Council level differs in accordance with the rules and conventions determined by the electorates (Fossedal 2002, pp. 90–91).

Like many cities in the late 1960s, Zürich was the subject of a general development plan that incorporated an extensive motorway scheme. In the same way that significant sections of the GLDP motorway plan would affect wealthy inner London neighbourhoods, and sections of the County of Cumberland Scheme would affect inner city neighbourhoods in Sydney, the Zürich motorway plan would have affected amenity and many homes in several affluent communities. One particular segment of motorway known as the *Goldcoast Freeway* drew strong opposition. Like local residents in London and Sydney, many of Zürich's local residents objected to and campaigned against the motorway, claiming that it would adversely affect local amenity, would generate additional traffic and that public transport should be improved instead (Laube 2006, pers. comm.).

Figure 2.16 Soft system model of transport decision-making process in Zürich



Note, system actors have been simplified.

Figure 2.16 shows how Zürich residents were able to deploy the power of their votes more quickly and with greater specificity than the people of London, as was shown in Figure 2.10. After the government of the Canton of Zürich announced its motorway plan, the community initiated a referendum to stop it from proceeding. The volks initiative also required that the relatively poor single-track rail service operating along the same urban corridor be upgraded within the confines of existing budgets. As a consequence, transport engineers and planners were compelled by public decision to confront a transport problem in a way that challenged professional conventions and beliefs at that time. In response, for the first time, transport engineers reversed the sequence of transport planning for new mass transit services. In order to accommodate a new clock-face timetable capable of delivering the level of service the community requested within a relatively low budget, engineers planned from *schedule to infrastructure* rather than *infrastructure to schedule*. Where previously expensive infrastructures had been devised and a timetable then developed to use them, engineers now designed timetables that were manipulated to minimise the cost of any necessary hard infrastructure upgrades. This method of manipulating low-cost soft system components in order to reduce expenditure on high-cost hard system components is now standard practice in Switzerland (Laube 2006, pers. comm.).

This outcome stands in stark contrast to the outcome achieved in London, where citizens campaigned for improvements to public transport services instead of motorway development. In both cases, the wishes of individual citizens were largely the same. How the system is controlled is different, however, in Zürich, as there is a mechanism in place to ensure that if decisions of system owners are different from those of the majority of citizens, they can be challenged and overturned.

In Zürich, as in London, transport professionals believed that urban motorways had to be built in order to reduce traffic congestion and keep pace with traffic growth. However, when the community in Zürich examined these proposals and disagreed with the reasons for proceeding with them, elected government and transport professionals had to comply with these wishes, as there was a law in place to ensure it.

At the time of these developments, Zürich did not have the extensive S-Bahn network that it does today. The line in the Goldcoast corridor provided the first link in what would later become a more comprehensive network of suburban rail services for the whole of the Zürich metropolitan area.

The referendum that stopped the Goldcoast motorway section acted as a prompt for a host of other transport reforms. In 1972 a referendum at the Canton level saw the community reject a proposal by the government to replace surface tramway services with an underground metro network — a proposal primarily devised in order to increase the availability of road space for motor vehicle traffic. Capital made available by abandonment of the underground option was subsequently invested in the improvement and expansion of on-street tramway and suburban heavy rail services.

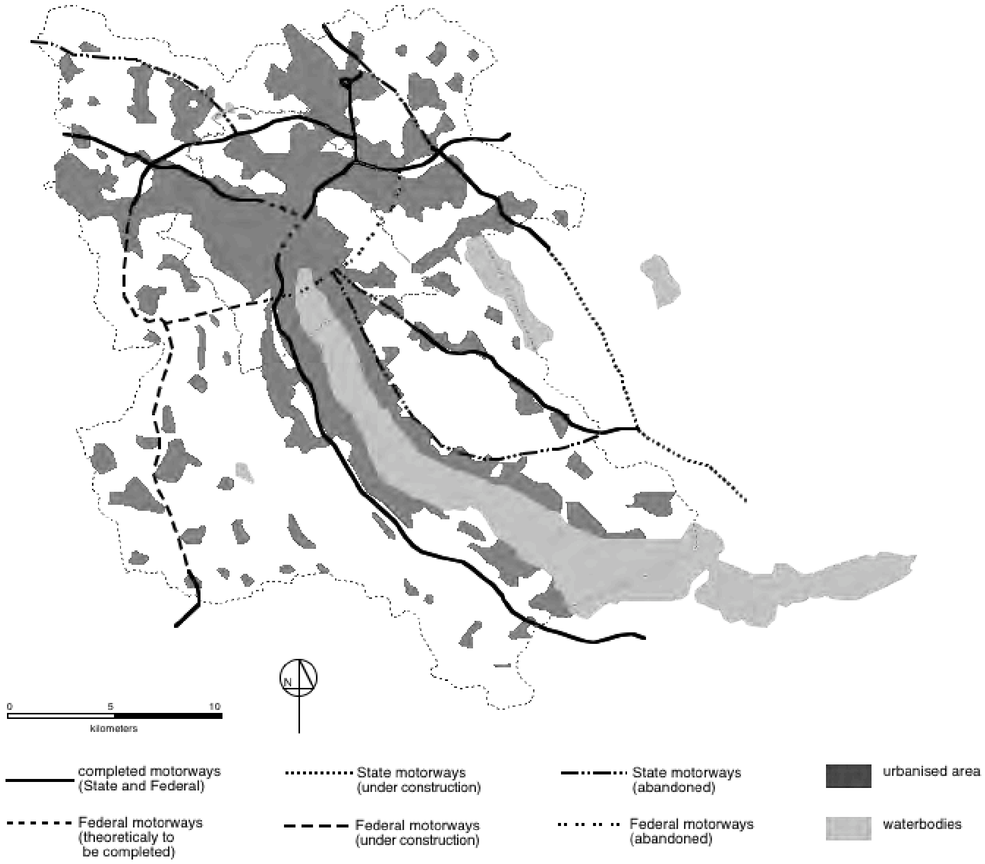
In 1990, the Zürich Verkers Verbund (ZVV) was created — a government agency responsible for the coordination of all mass transit services within the Zürich metropolitan area and surrounding hinterlands. After investment in the development of Zürich Central Station, an elected politician of the day made the decision that unless there was a high level of coordination between different mass transit services so that connection times were minimised, the project was likely to fail in practice. The Government put enabling legislation for creation of the ZVV to a public vote to overcome this problem.

From the outset the ZVV has set itself the goal of working in the interests of the customer rather than operational convenience for operators. Devising ways to maintain and increase operating and interchange speeds of the public transport network is central to their work. Measuring the performance of operators and enforcing compliance with standards is fundamental to this role. Where problems are identified, ZVV makes them public so that their work is highly transparent (Laube 2006, pers. comm.).

While volks initiatives were able to alter the course of motorways proposed by the Canton of Zürich, they were not able to halt motorway sections that formed part of the federal highway system. In 1978, a volks initiative on the need for the Federal Government to obtain permission from the people for each proposed federal highway was put to the federal electorate. But this was narrowly defeated by 51 per cent to 49 and supported by only nine out of 23 Cantons (Fossedal 2002, p. 96). Not all Cantons in Switzerland experience the same problems. Populations living in urban Cantons like those of Zürich and Berne, for instance, have different perceptions of the impact and consequences of motorway development from those of people living high in the Alps in rural Cantons like Uri and Unterwalden. This explains why the vote was close but did not pass at the federal level, whereas similar referenda have passed at Canton levels of government. Once again, the point that people are more inclined to think about problems when they affect their immediate interests is evident in this example (Doyle 2000, pp. 226–227).

Despite community opposition to urban motorway development, several motorway sections have been built, in Zürich. As can be seen in Figure 2.17, the federal motorway plan for Zürich comprised an orbital with three radial motorway sections. Most of the orbital sections have been built but these skirt around communities on the urban perimeter. While the radial sections are still *on the books*, they would impact heavily on densely populated neighbourhoods if they were built and so are unlikely to be completed.

Figure 2.17 Existing and proposed motorway sections in Zürich



Adapted from: Kenworthy, J. R., Laube, F. B., Newman, P. W. G., Barter, P., Raad, T., Poboon, C. and Guia, B. 1999, *International sourcebook of automobile dependence in cities 1960–1990*, University Press of Colorado, Boulder, p. 414.

While the Swiss Federal Government maintains a motorway program, like many Cantons, it too prioritises rail and public transport development over road expansion.

Mass transit companies were able to capture and respond to public requirements at a time when road-building interests could have dominated the transport debate. Because mass transit operators function in a political environment in which specific proposals that benefit the customer/voter are regularly put to a federal vote and these proposals become law, network development cannot be curtailed by a change of government, and road-based interest groups cannot coerce elected government to stop these programs. This has occurred in relation to federal rail services as well as urban mass transit. For example, Swiss Federal Railway (SBB) engineers had originally identified the need for a high-speed rail link between Geneva and Zürich. The project would have cost several billion francs and served only a select few origins and destinations. This proposal was rejected by a public referendum, prompting SBB engineers to develop a proposal that was acceptable to the community. *Rail 2000* was the result — a program of upgrades to existing networks that would allow faster trips to be made right across the federal network at a much lower investment cost than the high-speed rail link. This amounted to a far-reaching reform of the national rail system, involving a long-term commitment to high levels of capital expenditure. When the Federal Government put the program to a national referendum, Rail 2000 was passed by a large majority in all Cantons. Present and future politicians cannot stop the program or reduce its funding base. Similarly, a government initiative in 1998 to ban transalpine trucking was passed by public referendum. The ban was prompted by the need to protect many rural Cantons from erosion caused by deforestation. Localised concentrations of acid rain, thought to be caused by truck exhausts, were killing trees needed to stabilise embankments and stop landslides that threatened the safety of entire villages. When passing through Switzerland, all heavy vehicles will be required to be placed on rail wagons as a consequence. Two extensive rail tunnels are currently under construction to facilitate this policy decision — one 27 and the other 55 kilometres in length, the latter to be expanded to approximately 80 kilometres at a later date (Laube 2006, pers. comm.).

If SSM is used to model the process for assessing urban motorway proposals in Switzerland, activity within the *zone of political dynamic* can be seen to be dramatically different because of the way it is structurally related to control of the system. Votes —

the primary commodity of power — ensure greater control by citizens over decision-making because of the direct and deliberative rules of the Swiss democratic system. Consequently, the majority wish of Swiss citizens usually prevails, as does a greater stability within agencies responsible for infrastructure delivery. As the experience cycles from the UK and Australia have shown, this does not occur in representational democratic systems. More often than not, the wishes and interests of the majority of citizens are ignored in all but exceptional circumstances. Instead, the wishes of minority interests groups are often implemented as policy. By and large, these groups do not vote but have access to secondary commodities of power like money and specialist expertise which they deploy to affect outcomes.

Differences between the representational and direct democratic decision-making systems discussed here highlight how social and political contexts affect transport science in several ways. First, it shows that explanations for material phenomena — like induced traffic growth — are more readily acknowledged when those who have the most power over the decision-making system are served by its acknowledgment. Citizens have the most power in Switzerland. The majority of people in urban communities like Zürich feel that motorway development gives rise to increased levels of motor vehicle use and that this is not in their interests, so that the phenomenon is acknowledged by a majority in a political if not technical sense. By contrast, if the findings of a science do not support the interests of those groups with the most power in society, it will struggle to be acknowledged and incorporated into standard practice. In Britain and Australia, citizens have far less power over decisions made by government than is the case in Switzerland. In these cases, the construction of urban motorways is seen to be in the interests of a select group of commercial bodies and interests. The ability of this group to offer inducements to elected decision-makers through secondary commodities of power ensures that their wishes prevail over those of the general community.

The impact of politics on transport science can also be seen in the way that alternative modes of transport development are approached. In London, improvements to public transport have been difficult to support because of the political dynamic within the general realm of transport decision-making. While it has not been discussed at length in this thesis, public transport services in London and Sydney do not perform as well as those in Zürich. This is because the actor agencies are less capable than those in Switzerland. However, the reason why the provision of mass transit services is superior in Switzerland is because the voting public compelled professionals to develop the requisite expertise. As a result, once again, politics affects transport science.

This raises the third point. The comparisons show that actor agencies can develop cultures and beliefs about their work that are not in keeping with the material behaviour of the systems for which they have operational responsibility. The London and Zürich experience cycles show this especially. In London, the opening of the last link in the M25 Motorway created increases in the general level of traffic that has given rise to chronic congestion and a decline in the performance of the transport system. But despite this experience, there are plans to increase capacity on that motorway. The Zürich experience cycle shows that transport proposals put forward by professional transport planners and engineers are not always the most technically appropriate or optimal solutions The high level of expertise that Swiss public transport engineers and planners now have is as much a product of the country's political decision-making system that enabled citizens to reject the recommendations of professionals, while at the same time requiring them to develop solutions which many may have thought inappropriate or unworkable. All of which demonstrates that political systems have the capacity to both conceal and highlight, retard and advance scientific knowledge of travel behaviour and the operations of urban transport systems.

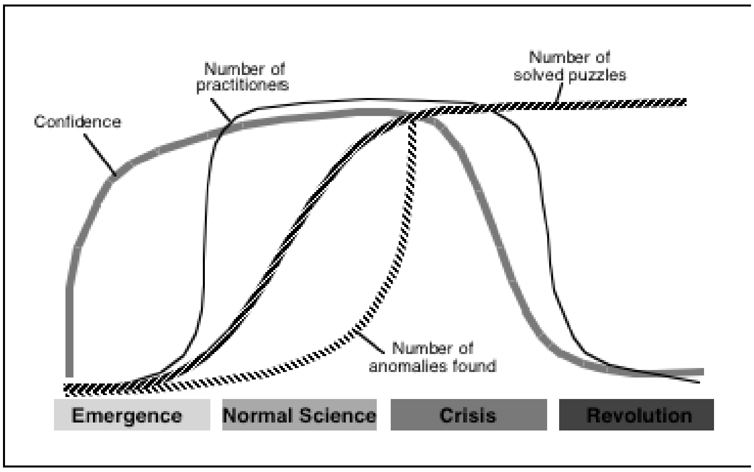
2.3 When governments fall: political crisis as a cause for change in accepted transport science

One of the most influential books in the philosophy of science literature is Thomas Kuhn's *The structure of scientific revolutions* (Kuhn, 1970). Prior to Kuhn, the discussion about what makes science unique, how it works and why it has achieved such authority, was largely confined to abstract points about logic and methodology. By contrast, Kuhn appealed to the history of science, arguing that science progressed as a series of episodes, one superseding another, and that it took place within a social context replete with religious beliefs, moral values and cultural norms.

In a mechanical sense, Kuhn conceived of science as a process of *puzzle-solving*, wherein the great bulk of scientific work involves the expansion, consolidation and reformulation of theory around a small number of key concepts that act to hold the puzzle together. Kuhn called these theories *paradigms*, a term used to engender both a theoretical framework and accompanying world view or weltanschauung (Kuhn 1970, pp. 10–11).

According to Kuhn, most periods in the history of scientific paradigms are characterised by broad agreement between practitioners on fundamental concepts and ideas. Kuhn called these periods *normal science* (Kuhn 1970, p. 24). In the day-to-day work of normal science, new empirical discoveries are constantly being made. In the majority of cases, a scientific theory can accommodate these new findings through adaptation or expansion of the theory, while fundamental ideas remain the same. Periodically, however, the course of normal science is disrupted by an *anomaly* in the empirical record — an event that cannot be explained by altering the predominant paradigm at the margins. The anomaly serves to falsify the foundation concepts of the paradigm by confronting its practitioners with the inability of their theory to solve all of the puzzle (Kuhn 1970, p. 52). By falsifying the universal applicability of scientific paradigms, anomalies create a state of *crisis*. The crisis is only resolved when a new paradigm, able to accommodate the anomaly within its theoretical framework, emerges from the confusion of the old, creating what Kuhn called a *paradigm shift*. This ultimately results in *revolution*, whereby the number of practitioners who believe in the validity of the new paradigm outgrow those who support the old (Kuhn 1970, p. 66). Stevens (1990) provides a depiction of Kuhn's succession of episodes that lead to a paradigm shift and scientific revolution, which has been reproduced in Figure 2.18.

Figure 2.18 Phases in the life-cycle of a paradigm, as proposed by Kuhn



Source: Stevens, G. 1990, *The reasoning architect: mathematics and science in design.* McGraw-Hill Publishing, Sydney, p. 330.

Many of Kuhn's historical examples show how societal and institutional beliefs are aligned with the progress of scientific theories. Kuhn's retelling of the paradigm shift from the Ptolemaic theory of the universe to the Copernican is particularly compelling, highlighting the conflict that takes place around scientific revolutions. The Roman Catholic Church supported the Ptolemaic theory, condemning Galileo's advocacy of the Copernican paradigm and branding him a heretic for defying church doctrine. In contemporary political terms, Galileo's theory was not confined merely to issues of whether the sun revolved around the earth or the earth around the sun. It was also an assault on the world-view espoused by the Church, thereby questioning its authority and power within society. The Copernican theory on the other hand, suited the growing number of humanist leaders of the Renaissance period who were not only interested in how the material world functioned but also in increasing their own secular power within society by reducing that of the Church (Kuhn 1970, pp. 67–69).

A parallel could be drawn between Kuhn's theory of scientific revolutions and the struggles that have taken place between those who support and oppose urban motorway development as a solution to traffic congestion. Within such a framework, induced traffic growth functions as an empirical anomaly that falsifies the central beliefs of the predominant paradigm, heralding a need for the emergence of a new view of urban systems and accompanying transport science.

If the Kuhnian model of scientific progress is accepted — a view that suggests a linear progression of ideas — then as more empirical evidence comes to light and the number of practitioners who understand the phenomenon increases, induced traffic growth should be incorporated within transport science and lasting change should occur. Publication of the SACTRA Report could be seen as evidence of this shift in world view and should have marked a significant turning point. But, as has been shown in the experience cycles explored in Section 2.2, in the case of London's M25 which provided the empirical trigger for such a shift, policy has regressed so that no significant change appears to have taken place.

As many science historians and sociologists have pointed out, closer examination of the history of scientific revolutions does not follow the neat succession of phases espoused by Kuhn. Bowler (1983), for example, points out that Darwin's theory of natural selection proposed in the mid-nineteenth century had lost much of its early acceptance by the turn of the century. Its popularity and ultimate acceptance only came after the discovery of DNA in the 1930s (Bowler 1983, pp. 10–15). Even today, Creationist theories — which Darwin's theory of natural selection *replaced* — appear to be making a comeback. This suggests that the social ascendancy of a scientific theory can wax and wane, falling in and out of favour in keeping with societal trends and priorities.

This raises the question of whether social acceptance or rejection — Kuhn's idea that science is a game based on the number of believers — ultimately determines the validity of a scientific theory. If so, then what implications does this have for acceptance or rejection of the original research contributions presented in Chapters Three and Four?

This thesis takes the position that while the social context in which an area of scientific research is debated clearly influences the uptake and application of ideas, social belief does not determine whether a given theory might be materially true or false. A scientist who believes in phlogiston[26] theory, for example, as opposed to one who believes in atomic theory and quantum mechanics, does not merely have a different world view —

[26] Phlogiston theory is an obsolete chemical theory, which holds that all flammable materials contain phlogiston — a substance without colour, odour, taste or weight that is liberated on burning. Once burnt, the *dephlogisticated* substance is held to be its true form.

the latter has the knowledge necessary to manipulate the material world and produce superconductors and transformers, while the former does not.

The accepted norms of empirical science, or points concerned with logic and methodology that Kuhn's socio-historical theory of scientific revolutions sidelined, are still of central significance to any scientific research program. These will be discussed in Section 2.2, where it will be argued that these norms function because of logistical factors in the material world — space-time conditions that exist independently of social goals and objectives.

But if this is the case, then why bother with a discussion about politics and power relations when presenting results of an empirical case study on induced traffic growth? Surely a simple statement of the results is sufficient? If existence of the phenomenon and accompanying theory are contested socially, it does not mean the results are materially false. It just means that some people don't like them and possibly don't care if there is a mismatch between their stated goals and how they would like the world to be, and how the world materially is.

There are two significant reasons as to why the politics does matter. The first concerns the minutiae of empirical data as these relate to testing for induced traffic growth. Politics can and does affect what is permissible as empirical evidence or proof. As will be shown in the next section, achieving closed boundary conditions during testing is difficult in the case of induced traffic growth analysis. SACTRA found that critics often raise alternate explanations for sudden traffic volume increases that often require data that are simply unavailable (SACTRA 1994, p. 85). Doubt on some points is then used to refute the induced traffic growth hypothesis, retard the progress of further research that logically extends from the theory and bring a halt to any policy changes. The case studies presented in Chapter Three lean heavily on SACTRA's accounts of these criticisms, using the definitions outlined by it to make the analysis more robust and systematic. Fortunately, data are available in some cases to test for these other possibilities, but at times they are fractured and incomplete. Where this occurs, values have been estimated from other points in the time series data, and choices made between higher or lower values. When a phenomenon is uncontested, such estimation would be viewed as perfectly acceptable. But in cases such as this, where controversy has been the norm rather than the exception, some may decide to contest this procedure for reasons that are acceptable to some, but unreasonable to others.

The second reason for reviewing the politics that surround the topic of induced traffic growth is that, despite gaps in the empirical record, decisions to either proceed or not proceed with urban motorway construction in Australian and other world cities have to be made. Or in other words, the existence of induced traffic growth cannot be treated purely as an interesting intellectual problem involving urban systems and transport science. While governments and transport agencies more readily acknowledge induced traffic growth and its attendant problems when public unrest is high, once that opposition recedes, the urgency to address problems exacerbated by the phenomenon also recedes, so that arguments change course, and the problem is repositioned, as are its implications. As problems go, more material factors like oil depletion and global climate change also have the potential to cause crisis within this activity sector. Unlike political interests, these are unlikely to be transitory.

Politics and ideology do not alter the material reality of the effect and nor does our success at measuring it. So from a practitioner’s point of view — or at least one acting within the spirit of he or his professional code of ethics — understanding the politics is vital when drawing conclusions about whether or not the evidence and science is sufficient to warrant a change in policy. Familiarity with the politics and convolutions in the debate helps to distinguish criticisms that are the product of healthy scepticism and honest inquiry from strained counter-arguments that are motivated merely to maintain an ideological position or individual economic advantage.

Nature has always looked like a horrible mess, but as we go along we see patterns and put theories together; a certain clarity comes and things get simpler.

Richard Feynman
QED: the strange theory of light and matter
(1985)

3 Before and after the motorway: empirical analyses of induced traffic growth

This chapter reviews past empirical analyses of the before and after conditions surrounding the opening of new urban motorway sections and the addition of capacity to existing road networks. As preparation for this review, some 30 analyses and critiques were examined. Several of these contained empirical data for cases from around the world. Of these, the majority concluded that their analysis confirmed the induced traffic growth hypothesis. A minority either claimed there was no evidence of induced traffic growth, an inability to access sufficient data or else cited problems with the methodology.

Of the case studies examined, four broadly different transport data types were used, including traffic survey or road volume counts, travel survey data, area-wide VKT data and public transport patronage data. Several different analysis methods were employed to interrogate the data. These ranged from simple before and after comparisons of aggregate travel survey and traffic counts to relatively complex forms of time series regression analysis, using area-wide VKT data.

The purpose of this review is to assess the range of empirical testing methods that have been used in an effort to identify the method most suited to investigating the Sydney case study, which will be presented in Chapter Five. The focus is not to assess in detail all case studies that have ever been undertaken to test for induced traffic growth, or indeed to establish whether the weight of empirical analyses undertaken to date either supports or refutes the induced traffic growth hypothesis, although some sense of this is provided when comparing empirical analysis that support the hypothesis with those that attempt to refute it.

This chapter begins by examining a variety of aspects concerning empirical analyses with an outline in Section 3.1 of the standard norms of empirical science and how they apply to testing for the presence of induced traffic growth. Included in this section is an overview of different data types and the importance of boundary conditions when identifying samples.

This is followed in Section 3.2 by a brief overview of the type of empirical data assessed by SACTRA. The committee considered many submissions containing what they called *commonsense* arguments that relied on general observations of traffic behaviour. SACTRA also paid particular attention to the comparison of traffic counts across appropriate screenlines before and after the addition of motorway capacity. Section 3.3 examines one particular case study that is indicative of this method of analysis.

Section 3.4 focuses on the use of travel survey data when testing for the presence of induced traffic growth. Few studies have been undertaken using this method. Two examples are reviewed in detail and their results compared.

Section 3.5 reviews several analyses, primarily undertaken in the United States, of changes to road capacity and VMT levels on a region-wide basis. These analyses construct models that attempt to account for the degree to which changes in one variable might be responsible for changes in the other, using time series regression analysis.

As stated in the introduction, aside from the case study presented in Chapter Five, there appear to have only been two other empirical analyses of road traffic network conditions that focus on the issue of induced traffic growth after the opening of urban motorways in Australian cities. Of these, one confirmed the induced traffic growth hypothesis in relation to a high-profile addition to the Sydney motorway network, highlighting the presence of mode-shifting from parallel rail services (Mewton 1997, 2005). The other, while providing a lucid explanation of how induced traffic growth could occur, is ambivalent at best, claiming no empirical evidence of the phenomenon in relation to a Melbourne motorway (Luk & Chung 1997). These will be reviewed in some detail in Section 3.6.

3.1 The standard norms of empirical science and their application to testing for induced traffic growth

This section discusses the standard norms of empirical science, their significance to analysis of material phenomena that feature in hard systems and how they should be applied to traffic and transport analysis aimed at testing for the presence of induced traffic growth.

There are three standard norms that form the foundations of empirical science:

- always be sure of *boundary conditions* (Wilson 1952, p. 119),
- always run a *control* (Wilson 1952, pp. 40–43), and
- always ensure the results are *repeatable* (Wilson 1952, pp. 46–52).

These three norms reflect the contention that a material world exists independently of human perception, it is knowable, and while complex, operates on the basis of regular or generic sets of organising principles (Wynn & Wiggins 1997, p. 144). This world-view is referred to as *philosophical materialism* (Flew 1984, pp. 222–223).

The logic of philosophical materialism is based on the argument that in the absence of purposeful thought — or a goal-directed controller that would introduce random signals to a system — similar sets of conditions should function in the same way.[27] Consequently, if the same sequence of events is set in motion, the results should be repeatable, as proposed in the third norm of empirical science. Running controls, or similar experiments with known differences to a key feature of the system, as proposed by the second norm, enables selected aspects of system behaviour to be isolated and the

[27] *Stochastic systems* are common in nature, involve random behaviour and produce probabilistic outcomes. Tossing a coin is an example of a simple stochastic system. Despite the basic components always being the same, the outcome is not always identical but falls within a range of probable outcomes that are known. Stochastic systems, like cities and natural ecosystems, still conform to the basic premises of philosophical materialism, as their outcomes fall within a set of probabilistic outcomes determined by the material conditions that constrain system behaviour (Sandquist 1985, p. 2).

element responsible for the behaviour to be identified. Being sure of boundary conditions — the first norm of empirical science — ensures that all features and changes to the system are accounted for.

The following sections examine the issues of boundary conditions, running controls and the repeatability of results when applied to the particular problem of testing for the presence of induced traffic growth.

When conducting an empirical analysis of any kind, it is necessary to define what phenomenon is being observed and to have some rudimentary idea about what causes it to happen. This information is critical to the appropriate design of testing procedures (Wilson 1952, p. 36).

In the majority of cases, empirical testing of a phenomenon requires observation of a change or movement in some factor. Distinguishing the source of an increase, and place to which a given factor might dissipate, is essential to establishing the nature of the relationships between a set of system components. In empirical science this is undertaken by observing changes that cross a boundary, so that the establishment of *boundary conditions* is critical to the design of any testing method (Wilson 1952, p. 69).

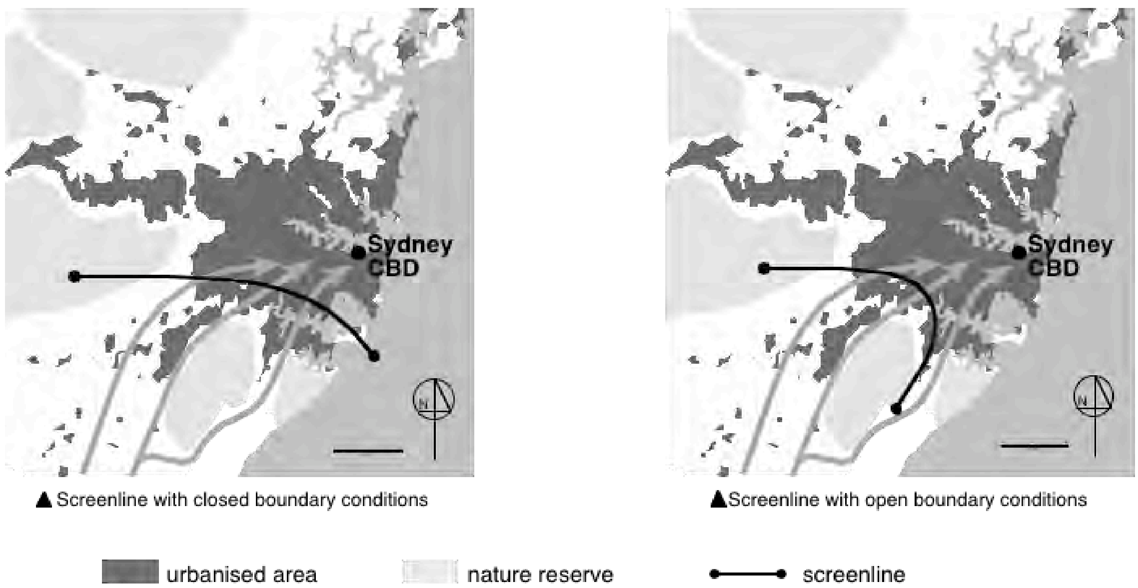
3.1.1 Boundary conditions

When testing for induced traffic growth within a city system using traffic volume counts, boundaries called *screenlines,* or *traffic cordons,* are often used to gauge general changes to movement patterns. A screenline is a conceptual line drawn through a section of the urban transport system that attempts to capture all traffic movements between the same broad set of origins and destinations. Where several different routes could be taken for the same trip, a screenline draws a boundary across all of these, thereby accounting for all the traffic moving in and out of the areas on either side (Roess, Prassas & McShane 2004, pp. 196–200).

The central aim of empirical analysis when testing for the presence of induced traffic growth is to determine whether or not there are increases in traffic volumes that are over and above those that would have occurred if no additional road space had been added to the transport network (Bonsall 1996, p. 19). As stated in Chapter One, traffic reassignment has to be distinguished from traffic redistribution and induced trips. The selection of appropriate screenlines, capable of producing what will here be called *closed boundary conditions*, that are able to account for all possibilities, is critical to achieving this distinction.

Figure 3.1 shows the difference between a screenline with closed and open boundary conditions. The dark shaded areas indicate the extent of the urbanised area of Sydney and grey-hatched areas represent national parks and nature reserves where access for through-movements is restricted. The map on the left shows a screenline that is able to capture all movements from the south and south–west of the conurbation through to the north. Traffic switching between routes would still be picked up at one of the other monitoring stations along the screenline. The map on the right shows a screenline that does not capture all possible traffic reassignment. If a route to the south–west were upgraded, traffic that had been accessing the conurbation via the southernmost route could shift to the south–western route, increasing volumes on the new route, but not increasing traffic volumes overall.

Figure 3.1 Screenlines showing open and closed boundary conditions



In the case of the Sydney system shown above, the seacoast and reserves where motor vehicle access is restricted, work to simplify movement patterns. Consequently, it is easier to establish boundary conditions that are more amenable to testing for the phenomenon, because the number of viable alternate routes is minimised and all options can be accounted for. The geographical distribution of urbanised areas beyond the Sydney metropolitan area is relatively sparse. This further assists analysis because long distance-traffic is unlikely to shift its route when accessing the city, as travel time savings afforded by additional urban motorway capacity would, in most cases, have to be in the order of several hours to make shifting worthwhile.

While analysing changes to traffic volumes can provide an indication of traffic numbers, it does not enable a distinction to be made between traffic redistribution — people making longer trips — or induced trips — people making more trips than they had previously. This is why testing for the effect by conducting travel surveys of the population has also been used by some researchers.

3.1.2 Data types, controlling for variation and the repeatability of results

There are four different types of transport data that have been used to test for the presence of induced traffic growth. Each data type is conducive to a different set of testing methods that generate different problems concerning *boundary conditions, controlling* for variation and the *repeatability* of results.

The first, and most commonly used, data type comes from monitoring changes to traffic volumes at points along a screenline. Most case studies seeking to identify induced traffic growth use this form of data. Good examples of case studies using this data type can be found in analyses by Purnell, Beardwood and Elliot (1999), Wurz (1992) and Evans, Lee and Sriskandon (1986) to name but a few. The two Australian case studies by Luk and Chung (1997) and Mewton (1997, 2005) also use these data.

The advantage of using traffic volume counts is that analysis is able to focus on traffic volumes at specific points in the network and differences in net volumes at those areas directly affected by the capacity change. This enables appraisal of specific schemes.

The drawback to using these data is that the precise nature of any unexplained traffic increases remains unknown, so an assumption needs to be made about its source.

The second data type is travel survey data for a sample population. These data are collected through surveys and questionnaires of individuals and so can document changes in travel origins and destinations, arrival and departure times as well as estimates of trip rates for journeys undertaken before and after a particular development. Studies by Kroes *et al.* (1996) and Wilcock (1988) provide good examples of case studies that use travel survey data.

The benefit of using travel survey data is that information on specific trips enables a distinction to be made between traffic redistribution and induced traffic growth as well as changes in vehicle occupancy rates and trip timing. The drawback is that in isolation this method is poor at gauging estimates of changes in net volumes caused by a particular scheme. As Bonsall has pointed out, the sample size required to achieve even moderate levels of target accuracy is prohibitively large and, given the scale of the effect, analysis using travel survey data alone may be too insensitive to reveal small changes (Bonsall 1996, p. 30). It is also unclear as to how boundary conditions should be drawn to distinguish communities whose travel behaviour may be influenced by changes to road capacity from those whose behaviour would not. Bonsall has argued that ideally a combination of these two data types — traffic volume counts and travel surveys — would need to be analysed to provide near-conclusive empirical proof of the existence and extent of induced traffic growth (Bonsall 1996, p. 32).

The third form of data used in induced traffic growth studies is passenger journey estimates for rail, bus and other public transport services. These data are primarily used in conjunction with road traffic volume data from screenline and cordon counts. By monitoring volume changes on alternate modes it is possible to assess whether or not shifting may have occurred between the two.

The advantage of case studies in which passenger journey estimates can be used is that it may be possible to estimate the mode shift component of induced traffic growth without the use of traffic surveys. The disadvantage is that changes in public transport passenger volumes are also subject to variations in service scheduling and reliability, so that a way needs to be found to account for possible changes in these other variables. Mewton (1997, 2005) provides a good example of a case study that makes use of rail, bus and ferry patronage data in addition to road traffic volume data.

The fourth form of data used to gauge changes to traffic volumes is annual VKT or VMT data. AADT data from designated points within a road network — usually every three to four kilometres — are multiplied by the respective length of road segment to generate these data (Roess, Prassas & McShane 2004, pp. 192–193). Annual VKT and VMT data provide an estimate of the total amount of driving undertaken on particular classes of roads over a year within a designated area, such as a whole metropolitan region. These data are usually examined in conjunction with changes to total road network capacity for that year.

The advantage of these data is that theoretically they can capture net travel increases for an entire region, thereby avoiding the problems associated with open boundary conditions discussed in the previous section. The disadvantage is that it can become difficult to attribute changes to particular road capacity increases, and running controls cannot be undertaken in the way that scientific research usually attempts to where a similar set of system conditions is run and monitored but without the presence of the variable in question. Good examples of analyses that use these data can be found in Hansen and Huang (1997), Noland (2000) and Cervero (2003).

In addition to the data types mentioned here, information is also needed to assess changes to the array of other factors potentially responsible for fluctuations in observed road traffic volumes. These factors include the general level of economic activity, car ownership, fuel prices, income and employment levels as well as demographic and land-use changes. Accounting for these other factors raises the issue of controlling for variation.

When using road traffic volume data, controlling for variation is often achieved through identification of a similar set of road sites that is subject to the same economic, demographic and land-use development influences as the road/s in question but which is unaffected by the capacity increase. Control sites need to be in relatively close proximity to the area where the capacity change has taken place so that economic and demographic factors are the same and yet remain unaffected by the change in capacity. These requirements can make the identification of suitable control sites difficult and in some cases impossible (Bonsall 1996, p. 21).

When using data for entire city systems, it is not possible to run controls in an orthodox sense. The most that can be accomplished is to compare entire urban systems with one another, similar to that shown in Figure 1.16. In such analyses, the nature of causality becomes more difficult to gauge. Such forms of macro-, or whole-system, analysis need to be used in association with other forms of micro-system analysis.

With these introductory points about empirical testing in mind, it now remains to examine the details of a selection of empirical case studies that attempt to test for the presence, and gauge the extent, of induced traffic growth in response to increases in urban motorway capacity.

3.2 SACTRA and the generation of traffic

As discussed in Chapter Two, SACTRA itself did not produce any new material or analysis. Instead, the committee sought submissions from the Department of Transport and other interested parties, and after comparing and contrasting them, worked to synthesise these into a single cohesive position.

SACTRA approached the issue of empirical evidence with the belief that it would be impossible to provide near-conclusive proof of induced traffic growth using empirical evidence alone. The committee attributed this problem to the nature of the phenomenon and the limitations encountered when testing for it (SACTRA 1994, p. 29). Some of these have already been explored in Section 3.1.

To begin, SACTRA appealed to several commonsense arguments about the nature of traffic growth and travel behaviour. The first was in relation to the role of congestion, which is reduced upon the addition of road capacity. If no allowance is made for the suppression of traffic growth by congestion, the application of ordinary forecast growth rates would lead to the prediction of absurdly long queues, which everyone knows does not happen in practice (SACTRA 1994, p. 34).

The second rather bald observation is that if there is no road space, there can be no road users and therefore no induced traffic growth (SACTRA 1994, p. 34).

The third, admittedly exaggerated, argument was that if it were possible to construct a transport link capable of providing five-minute trips between London and Melbourne, the amount of traffic between the two cities would increase greatly (SACTRA 1994, p. 34).

After considering the implications of these ideas, SACTRA then examined some simple cases of what were probably incidents wherein induced traffic growth gave rise to *unexpected* patterns of travel behaviour. In particular they noted records of traffic volumes provided in a highway development survey for Greater London published in 1937. The survey was undertaken to determine what roads would need to be built in the Greater London Traffic Area over the next thirty years to keep pace with traffic growth. The authors of that early report note:

> [A] typical instance may be quoted the new Great West Road which parallels and relieves the old Brentford High Street route. ... [T]he new route, as soon as it was opened, carried 4 1/2 times more vehicles than the old route was carrying; no diminution, however, occurred in the flow of traffic along the old route, and from that day to this the number of vehicles on both routes has steadily increased (Bressey & Lutyens 1937, p. 25).

The data on which Bressey and Lutyens based their observations is shown in Table 3.1.

Table 3.1 Vehicles per day for Brentford High Street and Great West Road London

	Number of vehicles for a day of 16 hours	
Year	**Brent'd High Street**	**Great West Road**
1922	1,404	Not open
1925	1,435	6,440
1928	1,887	9,404
1931	2,238	12,610
1935	3,826	16,903

Source: Bressey, C. & Lutyens, E. 1937, *Highway development survey (Greater London).* HMSO, London, p. 25.

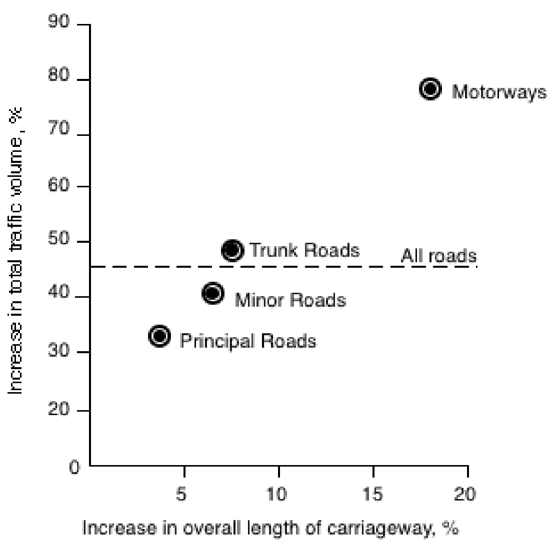
As can be seen, in the years immediately after opening, traffic volumes across the two routes increased by more than 600 per cent. When reviewing these data, SACTRA (1994) also noted comments by Leslie Burgin, then Minister for Transport in 1938:

> [T]he experience of my department is that the construction of a new road tends to result in a great increase in traffic, not only on the new road but also on the old one which it was built to supersede (SACTRA 1994, p. 31).

SACTRA noted that methodologically, the example from Bressey and Lutyens was interesting because it showed traffic volumes on the new route as well as the old route, illustrating that despite some reassignment, traffic volumes rose by a conspicuously greater rate after the addition of new capacity (SACTRA 1994, p. 32).

Another submission from the Institution of Highways and Transportation showed that the classes of roads in Britain with the highest rates of traffic growth are closely associated with those that have experienced the greatest increase in capacity (SACTRA 1994, p. 32). The results from that submission are shown in Figure 3.2.

Figure 3.2 Comparison of road space increases and traffic growth, Great Britain 1980–90



Source: SACTRA. 1994, *Trunk roads and the generation of traffic.* HMSO, p. 32.

As part of its more detailed appraisal of empirical evidence, SACTRA placed particular significance on the examination of changes to traffic flows for specific schemes. The committee acquired these from four general sources. The first was the Department of Transport's review of road traffic growth on the M25, which compared traffic forecasts with actual traffic volumes. The results from this analysis showed that at the 19 points along the perimeter of the orbital for which traffic forecasts were made, actual traffic volumes were higher by margins of between 13 and 155 per cent (SACTRA 1994, p. 52). The second was the Department's routine monitoring of road traffic flows, which, like the analysis for the M25, compared traffic forecasts with actual volumes for some 151 road projects. The findings of this analysis showed that the mean result for all schemes studied is that flows were underestimated by 12 per cent (SACTRA 1994, pp. 55–67). The third and fourth were literature reviews of case studies on the subject of induced traffic growth carried out by Pells (1989) and by Howard, Humphreys and Partners (1993). Both literature reviews were commissioned by the Department of Transport (SACTRA 1994, p. 54). Some of the submissions made independently to SACTRA contained material that was covered in these literature reviews. SACTRA examined these in some detail and was able to gain an insight into the divergent ways in which the same data sets were being interpreted by different analysts working either as private technical consultants or else as technical staff for government agencies.(Howard Humphreys & Partners 1993)

Howard Humphreys and Partners (1993) cited 12 case studies in their review and concluded that apparent increases in traffic volumes occurring after road capacity expansion could be attributed to area wide traffic reassignment and that there was no evidence of increases due to trip retiming, redistribution, traffic generation or mode shifting. Pells (1989) cited 78 published and unpublished studies, reporting a wide range of views. He concluded that while traffic reassignment was an obvious source of much of the increases in traffic volumes reported, trip retiming could be important as well, and that while weak in terms of overall volumes, there was also evidence of traffic redistribution, mode-shifting and generated traffic (SACTRA 1994, p. 54).

During the course of SACTRA's investigations, the Department of Transport generally held a view consistent with the conclusions drawn by Howard Humphrey and Partners rather than results from the earlier review it commissioned from Pells (for example, SACTRA 1994, p. 55).

According to Pells (1989), up until the late 1980s the number of detailed studies examining user responses to motorway developments was ‘very limited’ (Pells 1989, p. 2). Purnell, Beardwood and Elliot (1999) also note the paucity of before and after studies of motorway developments. They identify analyses of London’s Westway motorway section opened in 1970, the Blackwall Tunnel and approach roads opened in 1969 as well as a series of before and after studies carried out by Hertforshire Council to gauge the effects of new road schemes (Purnell, Beardwood & Elliott 1999, p. 30).

The next section provides an overview of a relatively detailed analysis of road network conditions before and after the opening of the Westway motorway section in London’s inner west. This analysis is typical of several reviewed by SACTRA as part of its detailed investigations of specific case studies (SACTRA 1994, pp. 67–85).

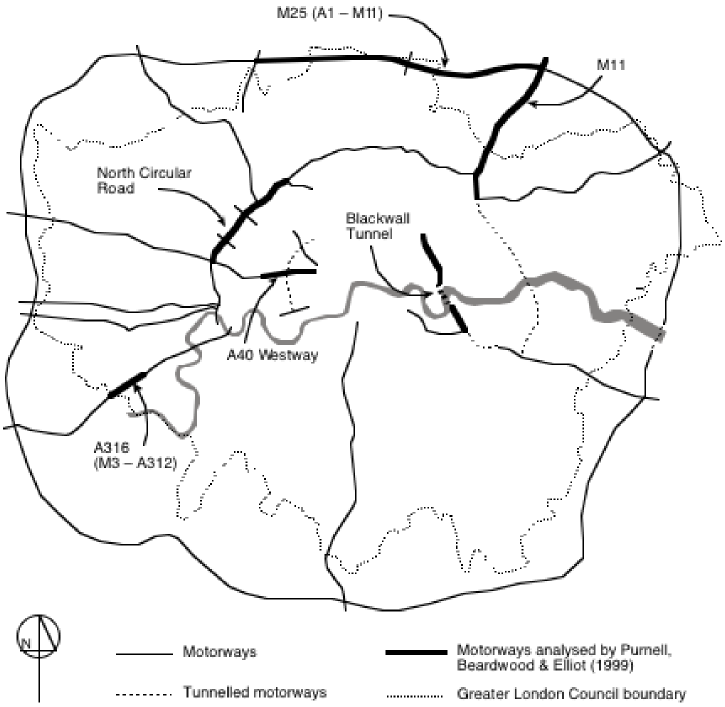
3.3 Testing for induced traffic by observing changes to traffic volumes across screenlines

As discussed in Section 2.1.2, during the early 1980s GLC staff undertook a series of studies of the before and after conditions of several motorway projects. The results of these empirical studies are summarised in a paper by Purnell, Beardwood and Elliot that was later published in 1999.

3.3.1 Purnell, Beardwood and Elliott’s studies of London motorways

Purnell, Beardwood and Elliott (1999) summarised analyses of six different motorway projects within the Greater London Area. The location of these is shown in Figure 3.3.

Figure 3.3 Location of road schemes analysed by Purnell, Beardwood and Elliott



Source: Purnell, S., Bearwood, J. & Elliot, J. 1999, 'The effects of strategic network changes on traffic' in *World Transportation Policy and Practice,* Vol. 5, No. 2, p. 29.

The first motorway development examined by Purnell, Bearwood and Elliott was the Westway link — a 4-km elevated motorway section in London's inner west that was opened to traffic in July 1970 (Purnell, Beardwood & Elliott 1999, pp. 32–36). As can be seen in Table 3.2, the Westway link was carrying some 46,900 average daily vehicle movements two months after opening. The authors also examined before and after counts for several roads along a screenline they called the *Westway corridor,* which comprised a mix of arterial and local streets that could be considered as potential alternate routes for traffic using the Westway motorway. Traffic movements on these alternate routes, before and after the motorway opening, show an aggregate decline of 29,400 — 63 per cent of total Westway traffic. This suggests that traffic shifted from these other roads on the screenline to take advantage of the faster travel times afforded by the new Westway motorway section. This left an overall increase of 17,500, or 14 per cent of aggregate counts along the screenline, over the two-month period, that could not be accounted for in this way.

Table 3.2 24 Hour two-way traffic flows before and after opening of Westway

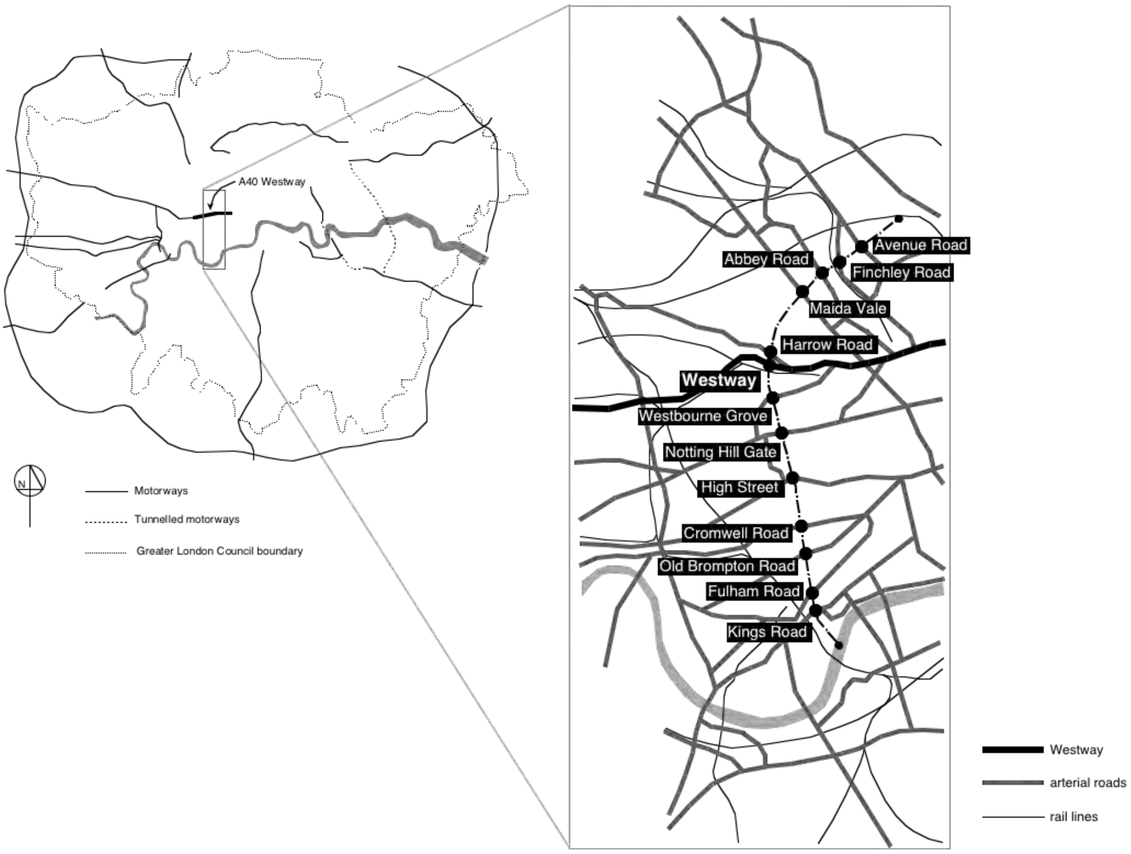
Westway corridor*	*Before*	*After*	*% Change*
Notting Hill Gate	52,300	44,700	-15
Moscow Road	7,800	5,000	-36
Dawson Place	7,900	3,500	-56
Westbourne Grove	19,900	15,100	-24
Talbot Road	11,400	4,300	-62
St Stephen's Gardens	1,500	1,900	+27
Westway	-	46,900	-
Harrow Road	22,700	19,600	-14
Total	**123,500**	**141,000**	**+14**
Finchley Road corridor			
Maida Vale	26,200	27,800	+6
Hamilton Terrace	11,800	12,800	+8
Abbey Road	21,100	19,600	-7
Loudoun Road	5,000	4,700	-6
Marlborough Road	1,300	900	-31
Finchley Road	34,000	34,600	+2
St John's Wood Park	6,400	6,500	+2
Avenue Road	21,000	22,300	+4
Total	**127,200**	**129,200**	**+2**

* Westbourne Park Road was not included, as the results were found to be inaccurate.

Source: Purnell, S., Bearwood, J. & Elliott, J. 1999, 'The effects of strategic network changes on traffic' in *World Transportation Policy and Practice,* Vol. 5, No. 2, p. 34.

The authors identified a control corridor along the lines advocated by Bonsall (Bonsall 1996, p. 32), which comprised a set of eight roads they called the *Finchley Road corridor* (Purnell, Beardwood & Elliott 1999, pp. 33–34). The locations of these roads relative to those in the Westway corridor are shown in Figure 3.4.

Figure 3.4 Screenlines for Westway, Finchley Road and Old Brompton Road corridors



The locations of Moscow Road, Dawson Place, Talbot Road and St Stephen's Gardens on the Westway corridor and Hamilton Terrace, Loudoun Road, Marlborough Road and St John's Wood Park on the Finchley Road corridor have not been shown but are located between the routes in the order in which they are listed in Table 3.2.

Adapted from: Purnell, S., Bearwood, J. & Elliott, J. 1999, 'The effects of strategic network changes on traffic' in *World Transportation Policy and Practice,* Vol. 5, No. 2, pp. 33 and 34.

As can be seen, the Finchley Road corridor is directly to the north of the Westway corridor. Where the Westway corridor roads generally have an east–west orientation, those in the Finchley Road corridor have a north–west orientation. It can be argued that because of the differences in orientation, reassignment from the routes on the Finchley Road screenline would be unlikely because the two sets of roads essentially connect different OD pairs. However the close proximity of the two corridors ensures that other potential reasons for changes in traffic volumes, such as seasonal variations, fluctuations in the general level of economic activity and other changes due to the demographic characteristics of the population, would not be widely different, thereby ruling out sudden increases that could be attributed to these other causes.

As can be seen in Table 3.2, aggregate volumes for roads in the Finchley Road corridor increased by 2,000 average daily vehicle movements, or two per cent, over the same period. If an increase of two per cent is attributed to other background variables in the Westway corridor, an increase in the order of 15,000 average daily vehicle movements over and above what could be expected still remains.

In an effort to identify the source of the remaining 32 per cent increase, Purnell, Beardwood and Elliot also examined the longer-term effects on road traffic volumes across the screenlines for the period 1969 to 1984. The authors decided the Finchley Road corridor was an inappropriate control group for longer-term comparisons because road works had taken place within that set during 1967 and 1974. Another control corridor referred to as the *Old Brompton Road corridor* was identified, comprising a set of four arterial roads located to the south of the Westway corridor. The position of these roads is also shown in Figure 3.4 in addition to the position of High Street, which was a road for which the authors were unable to obtain data.

As can be seen in Figure 3.4, Cromwell Road has a similar orientation to the Westway motorway section, as does High Street — for which no data were available. Cromwell Road does not appear to have experienced any dramatic long-term declines in traffic volumes; neither do the other roads on the Old Brompton Road screenline. If any of these roads did experience short-term declines, traffic volumes soon grew, returning to levels experienced before the Westway motorway opening.

Table 3.3 24-hour two-way flows in Westway, Finchley Road and Old Brompton Road corridors

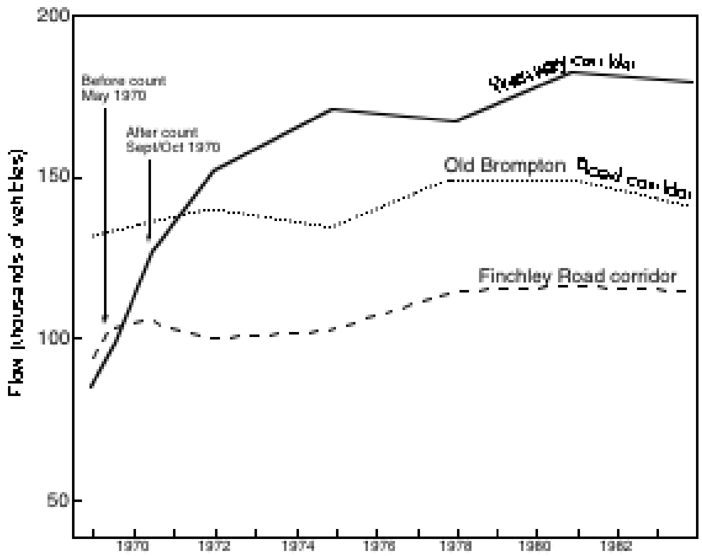
'000s of vehicles	1969	1970 Before	1970 After	1972	1975	1978	1981	1984
Westway corridor								
Notting Hill Gate	53.7	52.3	44.7	44.4	50.0	46.3	51.8	50.0
Westbourne Grove	16.7	19.9	15.1	14.8	14.8	16.7	16.7	13.0
Westway	-	-	46.9	75.9	85.1	81.4	88.8	90.7
Harrow Road	14.8	22.7	19.6	16.7	20.4	22.2	24.1	24.1
Total	**85.2**	**94.9**	**126.3**	**151.8**	**170.3**	**166.6**	**181.4**	**177.8**
Finchley Road corridor								
Maida Vale	25.9	26.2	27.8	25.9	25.9	25.9	25.9	27.8
Abbey Road	16.7	21.2	19.6	18.5	18.5	22.2	20.4	22.2
Finchley Road	29.6	34.0	34.6	35.3	37.0	40.7	42.6	40.7
Avenue Road	18.5	21.4	22.3	22.2	20.4	24.1	25.9	22.2
Total	**90.7**	**102.8**	**104.3**	**99.9**	**101.8**	**112.9**	**114.8**	**112.9**
Old Brompton Road corridor								
Cromwell Road	61.1	-	-	61.1	61.1	68.5	67.8	61.1
Old Brompton Road	20.3	-	-	20.4	20.4	20.4	22.2	22.2
Fulham Road	22.2	-	-	22.2	22.2	24.1	27.8	24.1
Kings Road	27.8	-	-	35.2	29.6	35.2	33.3	31.5
Total	**131.4**			**138.9**	**133.3**	**148.2**	**148.1**	**138.9**

Source: Purnell, S., Bearwood, J. & Elliott, J. 1999, 'The effects of strategic network changes on traffic' in *World Transportation Policy and Practice,* Vol. 5, No. 2, p. 35.

Available data for roads in each of the three corridors from 1969 through to 1984 are shown in Table 3.3. In the period from 1969 to 1984, aggregate traffic volumes for the Westway corridor increased by 109 per cent. In the Finchley Road and Old Brompton Road corridors it was 24 and 6 per cent respectively. The marked difference can be clearly seen in Figure 3.5.

Despite slight peaks and troughs, average daily traffic volumes for both the Finchley and Old Brompton Road corridors did not experience dramatic declines that could be used to explain the sharp increase in traffic on the Westway motorway section from 46,900 at opening to just over 85,000 — an 81 per cent increase — in the five-year period after opening of the motorway. Even taking into account the lack of data for High Street, and the possibility that traffic could have been reassigned from this route, there does not appear to be requisite reductions in traffic volumes on other roads to offset the increases for roads in the Westway corridor, nor is there any explanation for the comparatively higher growth rates that took place in the corridor.

Figure 3.5 Traffic growth in Westway, Finchley Road and Old Brompton Road corridors



Source: Purnell, S., Bearwood, J. & Elliott, J. 1999, 'The effects of strategic network changes on traffic' in *World Transportation Policy and Practice,* Vol. 5, No. 2, p. 35.

On the basis of these observations, the authors concluded that the empirical data showed evidence of unusual traffic volume increases and that:

> Volumes of traffic using the Westway corridor increased dramatically for a five-year period after which it adjusted to normal trends. A large proportion of traffic using Westway has not originated from within the corridor. It can only be concluded that this traffic has been generated by the construction of the road (Purnell, Beardwood & Elliott 1999, p. 36).

At this point it is useful to reflect on the issues concerning boundary conditions that were raised previously in Section 3.1 and to review some of the criticisms of studies like the one reviewed here that were submitted to SACTRA. The key arguments were summarised by SACTRA in the following way:

> These studies are not suitable for judging the relative importance of the different potential components of induced traffic. This leaves open alternative interpretations of the source of the extra traffic, including the possibility (suggested by the Department of Transport) that road improvements may cause rerouting of trips, over quite wide areas, in which case some or all of the observed extra traffic on the improved road could be drawn from other routes so far away that reductions in their traffic level have not been detected in counts. While no evidence has been submitted in support of this suggestion, we cannot dismiss the possibility (SACTRA 1994, p. 85).

The screenlines chosen by the authors raise two critical questions often directed at case studies of this kind. First, the screenlines are relatively short. Because they only include roads within a few kilometres of each other, the possibility of reassignment from key regional routes over a wide area could not be gauged. Second, changes to traffic volumes were not accounted for on all roads relevant to the new motorway section. Or in other words, the boundary conditions were *open* owing to the fact that data for High Street were not available. This raises the possibility that much of the short-term discrepancy could have been due to reassignment from High Street. Trends in the longer-term time series data for all three corridors suggest that this was probably not significant. If it was, it would appear that the reduction in traffic on alternate routes set in motion a process of second-order induced traffic growth effects. In which case the authors' conclusion — that the higher rate of traffic growth was attributable to the increase in capacity — could still be valid.

In relation to the key complaint — that traffic reassignment from a large number of routes over a much wider area than that considered in the study took place — Purnell, Beardwood and Elliott attempted to control for this possibility by comparing the longer-term growth rates on the three corridors with national growth rates for the same time period. They showed that national growth rates were generally less than half that of the Westway corridor (Purnell, Beardwood & Elliott 1999, p. 36).

Purnell, Beardwood and Elliott investigated several other motorways. The trends revealed in these studies are generally similar to that of the Westway case study and have been summarised in Table 3.4. Control groups were not analysed in association with the A406 North Circular Road and M25(A1(M)–M11). This is because their orbital orientation and function cannot be replicated. The relative proximity of a road to the city centre is a key determinant of traffic patterns using the facility. Using another orbital route located at a different distance from the city centre would not replicate key features of the road and would therefore fail to provide a useful control.

Table 3.4 Summary of before and after studies by Purnell, Beardwood and Elliott

Motorway section	Opened to traffic	% change on motorway	% change in m'way corridor	% change in control corridor
M11	1978 Section 1 1980 Section 2	+ 131% (1977 – 1983)	+ 38% (1974 – 1983)	+29% (1974 – 1983)
A316	1975/6	+159% (1974 – 1983)	+ 84% (1971–1983)	+66% (1971–1983)
Blackwall Tunnels	1969	+242% (1962 – 1982)	+91% (1962 – 1982)	+64% (1962 – 1982)
A406 North Circular Road	1973 Section 1 1976 Section 2	+18, +34 and +16% (1972/3 – 1981/2)	+16, +24 and +16% (1972/3 – 1981/2)	Not available
M25 (A1(M) – M11)	1975	+242% (1976 – 1984)	+27% (1976 – 1984)	Not available

Source: Purnell, S., Bearwood, J. & Elliot, J. 1999, 'The effects of strategic network changes on traffic' in *World Transportation Policy and Practice,* Vol. 5, No. 2, pp. 37, 39, 42, 45 and 48.

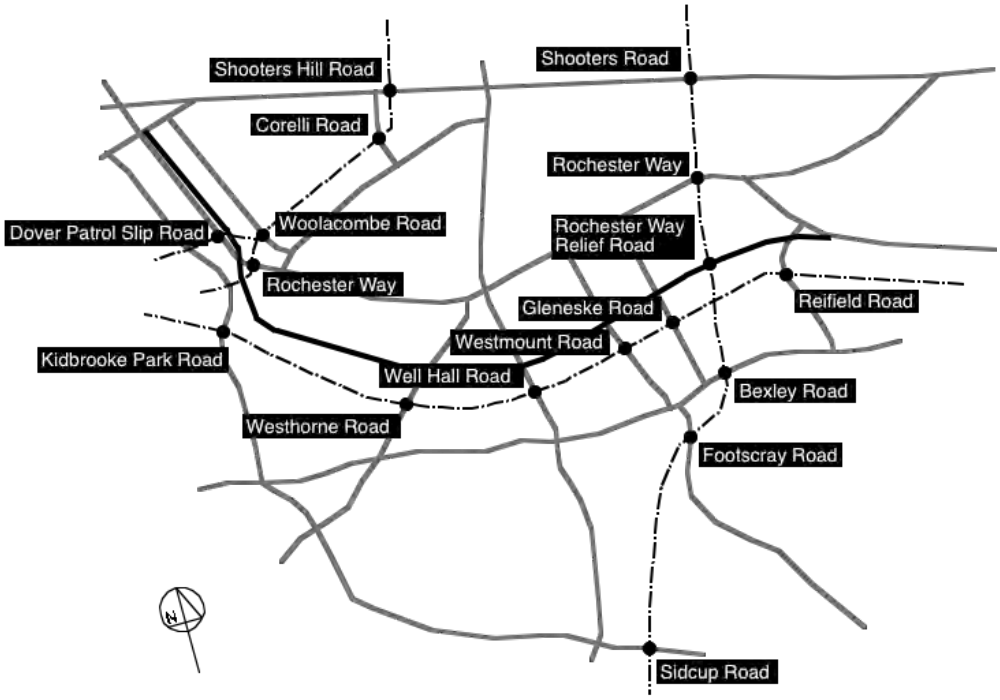
There have been several other empirical studies of before and after conditions of motorway developments in the UK. These include a study by Crow and Younes of the Rochester Way Relief Road (RWRR), in which the authors concluded that traffic counts showed no evidence of induced traffic growth (Crow & Younes 1990, pp. 60–61). On closer inspection of the data, SACTRA concluded there was evidence of the phenomenon (SACTRA 1994, pp. 78–80).

The next section briefly examines this study, which was sponsored by the British Road Federation, which played a key role in providing support for the GLDP motorway scheme discussed in Section 2.2.

3.3.2 Crow and Younes study of the Rochester Way Relief Road

The RWRR was opened to traffic in late March 1988. Its primary objective was to divert through traffic from Rochester Way — a bottleneck in the regional road network — that connects the Blackwell Tunnel southern approach road with the M2 Motorway. The road is 5.5 kilometres of dual carriageway with two lanes in each direction. Figure 3.6 shows the configuration of the RWRR in relation to the surrounding network.

Figure 3.6 Rochester Way Relief Road and surrounding network



Adapted from: Crow, G. & Younes, B. 1990, *The Rochester Way Relief Road: an appraisal of the operationsl, environmental and economic impacts.* Imperial College of Science Technology and Medicine, London, p. 23.

The appraisal of the RWRR undertaken by Crow and Younes (1990) examines a range of different impacts from the motorway, not just changes to traffic volumes. For all the factors considered, the authors found that the road improved local conditions. In relation to traffic volumes and the issue of induced traffic growth, the authors concluded:

> These figures give us the first indication that the Relief Road has NOT generated or induced any more traffic within the corridor than might have been the case had it not been built (Crow & Younes 1990, p. 25).

The authors based this conclusion on traffic volume data for the years 1978, 1988 and 1990 that were recorded across three key screenlines. The position of these is indicated in Figure 3.6.

Table 3.5 shows traffic volumes for roads along the western screenline. Crow and Younes cited data from the Department of Transport's Statistics Bulletin that indicates that traffic volumes on the outer cordon of London grew around 2.3 per cent per year. In the inner London area, traffic grew by an annual rate of around one per cent. The authors argued that the RWRR lies between these two cordons and that it would be reasonable to expect the annual rate of growth to be in the margin of two to 2.5 per cent per year. Between 1978 and 1990, traffic volumes on the western screenline increased by around 26 per cent. When this figure is averaged out over 12 years, a growth rate of around 2.2 per cent is achieved. The calculation forms the empirical basis of the claim noted above.

Table 3.5 Traffic counts for western screenline, Rochester Way Relief Road (18-hour, two-way veh/day)

	1978	1990	change
RWRR (West)	-	68,400	+68,400
Other roads*	87,200	41,739	-45,461
Total	87,200	110,139	+22,939

*Shooters Hill Road, Corelli Road, Woolacombe Road, Rochester Way, Dover Patrol Slip Road, Kidbrooke Park Road.

Source: SACTRA. 1994, *Trunk roads and the generation of traffic*. HMSO, p. 78.

When data for the eastern screenline are assessed, however, a somewhat different picture emerges. These data are shown in Table 3.6.

Table 3.6 Traffic counts for eastern screenline, Rochester Way Relief Road (18-hour, two-way veh/day)

	1978	1988	1990	change
RWRR (East)	-	52,200	60,400	+60,400
Other roads*	144,300	104,600	118,000	-26,300
Total	144,300	161,800	178,400	+34,100

*Shooters Hill Road, Rochester Way, Bexley Road, Footscray Road, Sidcup Road.

Adapted from: Crow, G. & Younes, B. 1990, *The Rochester Way Relief Road: an appraisal of the operationsl, environmental and economic impacts.* Imperial College of Science Technology and Medicine, London, p. 26.

The data show that between 1978 and 1988 traffic volumes increased by 17,500 vehicle movements on average per day over 18 hours. This amounts to a 12 per cent increase. Between 1988 and 1990, traffic increased by a further 16,600 vehicle movements on average per day over the 18-hour period, or 10 per cent. If these are averaged out over the respective time periods, traffic before the opening of the road was increasing at a rate of 1.2 per cent per year before the RWRR was opened and then by 5 per cent per year after the road opened.

This pattern of growth is similar to that revealed in the analysis examined in the previous section, where, steep growth rates were shown to occur after the addition of motorway capacity.

Table 3.7 Traffic counts for transverse roads crossing the Rochester Way Relief Road (18-hour, two-way veh/day)

	1978	1988	1990	change
Transverse roads*	77,700	92,100	100,7000	+23,000

* Kidbrooke Park Road, Westhorne Avenue, Well Hall Road, Westmount Road, Glesk Road (the only one to show a reduction), Reilfield Road.

Adapted from: Crow, G. & Younes, B. 1990, *The Rochester Way Relief Road: an appraisal of the operationsl, environmental and economic impacts.* Imperial College of Science Technology and Medicine, London, p. 30.

On examining changes to traffic volumes for roads running in a transverse direction to the RWRR, a similar result was found. In the 12 years before opening, traffic volumes increased by an average of 14,400 vehicle movements per day over an 18-hour period, or 19 per cent. In the two years after opening, volumes increased by an average of 8,600 vehicle movements per day over an 18-hour period, or nine per cent. That is, traffic grew at a rate of 1.9 per cent per year before opening and 4.5 per cent after opening of the additional capacity.

After considering the submissions made by Crow and Younes, SACTRA concluded:

> Overall, the pattern of changes shown in this study is similar to those shown in the GLC studies. We had expected this study to be one of the more persuasive pieces of evidence against the existence of important induced traffic effects, since this is how it is often quoted. [The Tables] above do not seem to support this interpretation (SACTRA 1994, pp. 79–80).

After examination of case studies like the Westway motorway section and the RWRR, SACTRA found that the empirical evidence was '… more consistent with the existence of induced traffic than its absence', concluding that:

> We consider that the results are consistent with the expectation that in urban areas where there are many alternative destinations, modes and activities, induced traffic may be an appreciable consequence of major road building schemes. Its extent, however, will be influenced by the availability of capacity on surrounding and downstream roads, and by the effectiveness of any prevailing policies of traffic restraint (SACTRA 1994, p. 80).

While there are many analyses of the before and after conditions relating to specific urban motorway projects, like the two examined here, it is not necessary to review all of them. These examples reveal many of the issues and problems concerning methodology and interpretation of results that confront all analyses of this kind. The next section provides a case study on the impact of road closures that reveals additional issues.

3.3.3 Cairns, Hass-Klau and Goodwin's analyses of induced traffic growth in reverse and the closure of Hammersmith Bridge

This section examines a single example from the literature on the effects of reducing road capacity. Many of the characteristics observed in this example appear to be repeated in others, pointing to an underlying set of generic organising principles.

Empirical science emphasises the merits of devising alternate ways of testing the empirical veracity of hypotheses (Wilson 1952, p. 27). This can be achieved by drawing logical extensions about behaviour from an hypothesis. For example, if adding road capacity induces traffic growth, then logically, reducing capacity should induce travel reductions.

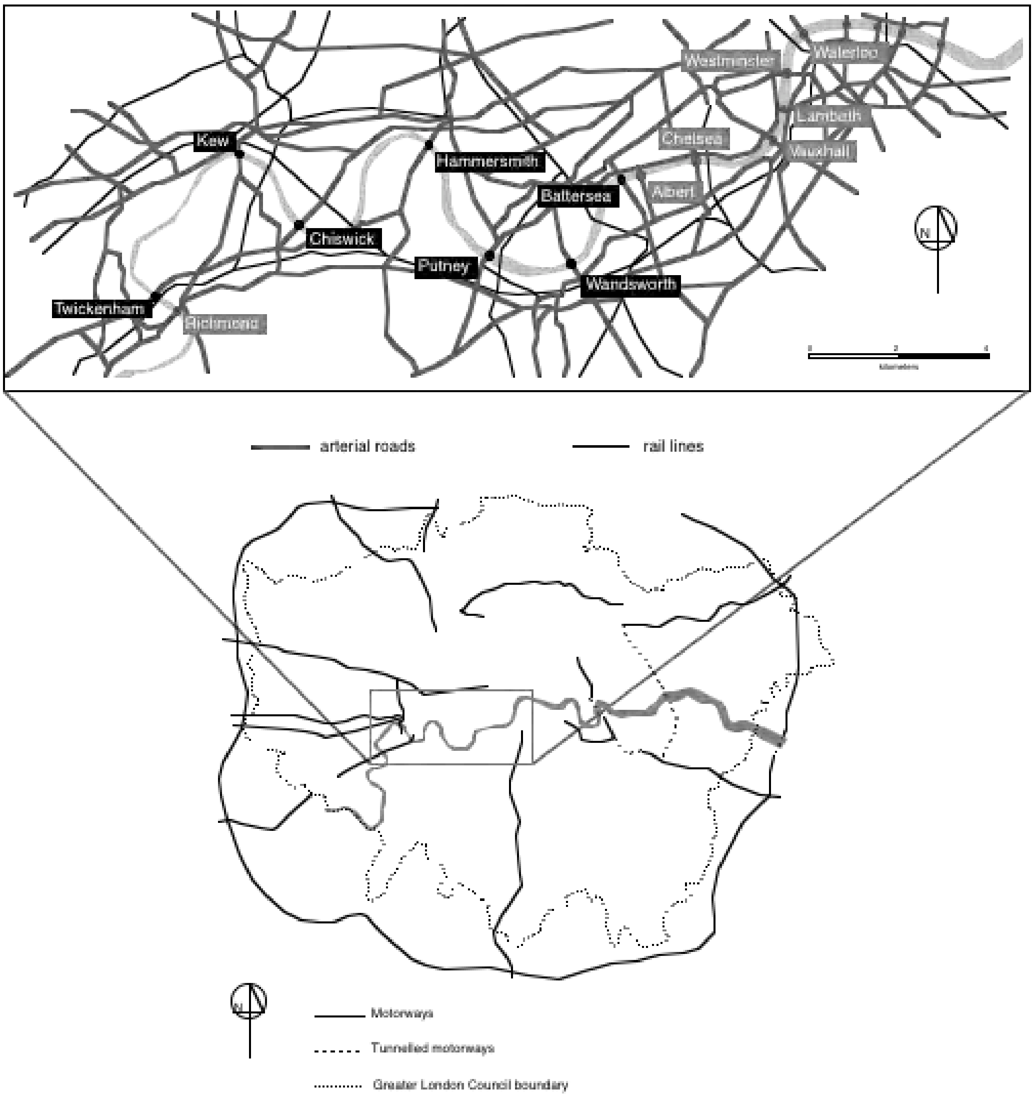
This line of thinking was pursued after release of the SACTRA Report. In the late 1990s, London Transport and the Department of Transport (later called the Department of Environment, Transport and the Regions) commissioned a research team to investigate '… a practical and authoritative means of estimating the likely effect on traffic flows of selective reduction of highway capacity for certain classes of vehicles' (Cairns, Hass-Klau & Goodwin 1998, p. 2). Cairns, Hass-Klau and Goodwin (1998) examined empirical data for more than 60 case studies wherein road capacity had been reduced as a result of road closures, through accident or safety concerns, or dedication of former road space to public transport services, cycleways or pedestrian-only access (Cairns, Hass-Klau & Goodwin 1998, p. 3).

Cairns, Hass-Klau and Goodwin found that in 50 per cent of the cases for which they were able to obtain relatively complete data, overall reductions in traffic volumes of more than 14 per cent were recorded. There were exceptions. Two cases recorded a reduction in traffic that was greater than the amount using the original route where capacity was taken away. In seven cases there was an overall increase in traffic volumes. When these nine outliers were removed from the set, reductions of more than 16 per cent were recorded (Cairns, Hass-Klau & Goodwin 1998, p. 14). Further analysis put median estimates of traffic reduction at around 11 per cent of volumes using the route in question (Cairns, Atkins & Goodwin 2001, p. 16).

There was a great deal of diversity in the cases examined. One particular example — closure of the Hammersmith Bridge in London — provides a useful overview of the results and kind of factors involved when capacity on trunk routes is reduced.

Hammersmith Bridge was closed to private motor vehicle and truck traffic on 2 February 1997, due to structural weaknesses in the bridge. Access for scheduled bus services, motorcycles, bicycles and pedestrians was continued (Cairns, Hass-Klau & Goodwin 1998, p. 128). The Bridge was re-opened to general traffic on 21 December 1999. The location of Hammersmith Bridge relative to other crossings of the River Thames is shown in Figure 3.7. The position of these districts within the Greater London Area is also shown. The River Thames provides a good *screenline* for analysis, limiting the number of possible routes to which traffic may be reassigned. Data were available for bridges highlighted in black, while other crossings within general proximity are highlighted in grey.

Figure 3.7 Hammersmith Bridge and other crossings along the River Thames



Adapted from: Cairns, S., Hass-Klau, C. & Goodwin, P. B. 1998, *Traffic impact of highway capacity reductions: assessment of the evidence,* Landor Publishing, London, p. 127.

In their analysis, Cairns, Hass-Klau and Goodwin stated that many people typically expect road closures to generate traffic chaos and gridlock in the period immediately after a reduction in capacity. While anecdotal evidence of increased congestion at some intersections was reported, in the case of the Hammersmith Bridge closure, abject chaos failed to materialise (Cairns, Hass-Klau & Goodwin 1998, p. 128). While some of the traffic that was crossing the River Thames at Hammersmith Bridge appeared to divert to other routes, it also appears that some people responded by reducing the number of car trips they made.

Cairns, Hass-Klau and Goodwin summarised traffic count data for before and after closure of the Hammersmith Bridge to through traffic, as shown in Table 3.8.

Table 3.8 Traffic before and after closure of the Hammersmith Bridge in February 1997

		Putney, Hammersmith and Chiswick Bridges	All bridges*
Oct.1994		135,396	311,505
Mar. 1997		125,106	330,075
Oct. 1997		100,955	293,592
After 1 month	Overall change	-10,290 (-7.6%)	+18,570 (+6%)
	Change as percentage of traffic over Hammersmith Bridge	-33.5%	+60.5%
After 8 months	Overall change	-34,441 (-25.4%)	-17,913 (-5.8%)
	Change as percentage of traffic over Hammersmith Bridge	-112.2%	-58.4%

* These include Battersea, Wandsworth, Putney, Hammersmith, Chiswick, Kew and Twickenham.

Source: Cairns, S., Hass-Klau, C. & Goodwin, P. B. 1998, *Traffic impact of highway capacity reductions: assessment of the evidence,* Landor Publishing, London, p. 132.

As can be seen, the authors reported a decline of 10,290 vehicle trips on average per day from the Hammersmith, Putney and Chiswick Bridges one month after closure. For the seven bridges highlighted in Figure 3.7, a net increase of 18,570 was recorded. This overall increase could be attributed to several factors. As the authors pointed out, it is important to note that the data are monthly averages and so are subject to seasonal fluctuations (Cairns, Hass-Klau & Goodwin 1998, p. 133). Between October 1994 and March 1997, traffic volumes may well have grown or fluctuated to a degree that could make comparisons between the two misleading. It is also unclear as to whether or not the bridges form entirely discrete alternate crossings. Some people may have *zig-zagged* between Twickenham and other bridges while accessing various destinations in the area (Cairns, Hass-Klau & Goodwin 1998, p. 133).

Comparisons between data for March and October of 1997, however, show a dramatic decline of 34,441 average daily vehicle trips for the group of three bridges and 17,913 for the group of seven. Unfortunately, no data for a control corridor were provided to gauge how much of this difference could be attributed to seasonal fluctuations. But with this reservation in mind, the comparison suggests that the number of car trips made using Hammersmith Bridge were not all reassigned to alternate routes. It is possible that some drivers had responded to the new conditions by changing their origin and destination patterns so that crossing the River Thames was not necessary, using a different mode of transport, or by reducing the number of trips they were undertaking.

At the time of the Hammersmith Bridge closure, Transport for London commissioned a survey of people using the bridge. A reported 12,000 survey cards were distributed to individuals on the Friday before closure and about 10 per cent of people responded (1,246) with 973 usable telephone interviews carried out between 14–28 February (Cairns, Hass-Klau & Goodwin 1998, p. 128).

The results showed that, prior to the bridge closure, 71 per cent of respondents reported using the bridge for the journey-to-work at an average of four trips per week, while 68 per cent reported using the bridge for non-work trips (all other purposes) at an average rate of 1.8 trips per week. The survey found that, after closure, 16 per cent of respondents had changed mode from car use to either the Underground, bus, train, cycling or walking. For those still using their car, 44 per cent reported diverting to Putney Bridge, 47 per cent to Chiswick, 23 per cent to Battersea, Wandsworth, Kew or Twickenham, 6 per cent to Chelsea, Richmond, Albert, Vauxhall or Lambeth and a further 4 per cent to bridges beyond those. Overall, the number of car trips made per week dropped from an average of 4.1 to 2.9 (Cairns, Hass-Klau & Goodwin 1998, p. 129).

A key feature of this case study is that both traffic and travel survey data were available along the lines recommended by Bonsall (1996), as discussed in Section 3.1. The results of the travel survey are broadly consistent with those of the road traffic counts. However, other traffic volume data have become available since publication of the overview of case studies by Cairns, Hass-Klau and Goodwin. These data are shown in

Table 3.9, and unlike the previous data, are average daily traffic volumes for the same month of March, thereby reducing some of the differences due to seasonal fluctuations.

Table 3.9 Average daily traffic volumes for seven bridges

	1994 March	1997 March	1998 March	2000 March	2001 March
Battersea	25,087	36,034	25,803	27,268	37,392
Wandsworth	56,840	55,001	46,325	45,675	35,675
Putney	55,003	70,754	68,958	55,255	59,867
Hammersmith	30,678	3,000*	3,000*	22,638	24,457
Chiswick	49,715	51,352	48,313	-	41,123
Kew	44,587	63,742	51,733	-	41,482
Twickenham	49,595	50,192	40,610	-	46,222
Total	**311,505**	**330,075**	**284,742**	**-**	**286,218**

* Estimated figure

Source: Street Management 2005, Average two way weekday flows (24 hours) across *Hammersmith and surrounding Bridges*. Transport for London, London. http://www.lotag.com/bridge/24.htm.

As can be seen, aggregate traffic volumes for March 1998 are below those for 1997. Generally, traffic volumes crossing Putney and Kew Bridges increased, suggesting traffic reassignment. Traffic volumes for Wandsworth and Twickenham appear to have undergone reductions, while volumes crossing at Battersea and Chiswick experienced an increase in the month after closure, but then appeared to undergo significant reductions a year out from the closure. This suggests that just as adding capacity can generate changes to traffic patterns across an entire network while the system undergoes a *ramp-up period*, the same may occur in the form of a *ramp-down period*, in which traffic flows can change significantly and unexpectedly as a succession of different travel responses impact on the system. The later data also show that once the road space on Hammersmith Bridge was reopened for regular use, road traffic volumes began to return to the levels they experienced prior to closure.

This literature review has been unable to identify any concerted attempts to empirically refute the general findings of Cairns, Hass-Klau and Goodwin. In broad terms, the case studies they present suggest that just as people respond to increases in average travel speeds by travelling more after increases in road capacity, they also respond to decreases in average speeds by travelling less after capacity reductions.

Conclusions

This literature review of case studies using comparisons of traffic counts across screenlines to test for induced traffic growth has highlighted several advantages and disadvantages of the method. The advantages are:

- Where data and control sites are available, the method is able to broadly distinguish traffic reassignment from other sources of traffic increase, thereby identifying the presence of general traffic growth that is above what would be expected if the capacity had not been added to the network.

The disadvantages to using this method are:

- If data for sites across screenlines are incomplete, then traffic reassignment in the immediate vicinity of the capacity increases cannot be reasonably accounted for.
- If data are unavailable for reasonably small time periods before and after the addition of motorway capacity — that is every few years — then the real rate of increase is difficult to gauge and results can be interpreted in a way that is misleading.
- While an increase may be identified, the actual source of the increase is unknown, so that an assumption must be made that the increase comes from one of the sources defined as induced traffic growth.

There are other methods available to identify the source of potential increases. The next section considers the use of travel surveys to investigate induced traffic growth.

3.4 Induced traffic growth studies using travel survey data

There have been comparatively few case studies of induced traffic growth that use travel survey data, or surveys of individuals and their travel behaviour, as the basis for testing. However analyses undertaken by Wilcock (1988) and Kroes *et al.* (1996) provide notable examples.

Wilcock's (1988) case study of the Rochester Way Relief Road employed direct surveys of drivers using the new road. Kroes *et al.*'s (1996) case study of completion of the Amsterdam Ring Road utilised a random sample of households in regions assumed to be affected by the new motorway sections.

The primary advantage of analysis using travel survey data is that the origin and destination of trips can be identified and questions asked about whether people had changed their travel behaviour to include longer or additional trips. The primary drawback appears to be the prohibitive cost of conducting such surveys. If a random sample is used, as in Kroes *et al.* (1996), the sample needs to be quite large to generate a signal big enough to overcome problems with sampling errors. Problems concerned with cost and sample size can be reduced if a survey targets motorists and passengers from the specific traffic stream in question, as in Wilcock (1988). But this method can invite other problems related to sample bias, as will be explained.

The next two sections examine both these studies in some detail, noting both negative and positive aspects of the data-collection and analysis methods.

3.4.1 Wilcock's survey of the Rochester Way Relief Road near London

According to Pells (1988), Wilcock (1988) used a pre-paid mail-back questionnaire to survey drivers using the new Rochester Way Relief Road (RWRR) near London that was the subject of the analysis by Crow and Younes (1990) discussed in the previous section. The road was opened to traffic in late March 1988. A total of 770 questionnaires were issued to drivers in July — some four months after opening. A total of 184 were returned — a response rate of 24 per cent (Pells 1989, p. 14).

The questionnaire was distributed between 14:00 and 17:00 hours and focused on the trip that drivers were making at the time when given the questionnaire, asking how the new road had affected that trip and if indeed it had been previously undertaken at all (Pells 1989, p. 14). Responses were sorted into different categories, the results of which are summarised in Table 3.10.

Table 3.10 User responses to the Rochester Way Relief Road

Classification	Number	Per cent
Reassignment	178	96.7
Redistribution	6	3.3
Modal diversion	5	2.7
Trip rescheduled — total	44	23.9
Trip rescheduled — earlier	3	1.6
Trip rescheduled — later	41	22.2
Induced trips	18	9.8

Source: Pells, S. R. 1989, *User response to new road capacity: a review of published evidence*. Working Paper 283, Institute for Transport Studies, University of Leeds, p. 14.

As can be seen, close to 97 per cent of survey respondents had changed routes, with almost 24 per cent rescheduling their trip. Only 2.7 per cent claimed to have switched from using public transport, while 13.1 per cent claimed to be making longer and/or additional trips compared to before the opening of the RWRR. If the survey provides an indicative sample, then almost 16 per cent (15.8) of the traffic for the time period surveyed comprised induced traffic growth — longer trips, additional trips and mode-shifting.

While Wilcock's relatively simply survey appears to provide evidence of induced traffic growth, the veracity of the sampling method is unknown.[28] Questionnaires that ask people what their travel behaviour might be — such as whether or not an individual is making a trip more often than she or he had before, so that the data is reliant on people's perceptions and memories rather than a comparison of purely descriptive records — raises the possibility of introducing a *sampling bias* through *self-selection* that could unduly skew survey results (Bonsall 1996, p. 28; Stevens 1986, p. 78). This is especially so in cases wherein motorway projects have been controversial with local communities. It is also unknown whether the composition of trips undertaken at the time of the survey is similar to trips undertaken at other time periods of the day, and to what degree the sample is indicative of the entire statistical population for a typical day (Stevens 1986, p. 77).

[28] It was not possible to access a copy of the original thesis by Wilcock (1988) for the purposes of this literature review.

While the veracity of Wilcock's study is difficult to gauge, it demonstrates many of the problems encountered when surveying traffic streams.

3.4.2 Kroes, Daly, Gunn and van der Hoorn's study of the Amsterdam Ring Road

Kroes *et al.* (1996) undertook a survey of households in districts affected by additions to the Amsterdam Ring Road (ARR). Figure 3.8 shows a schematic diagram of the ARR, highlighting the new sections that were opened to traffic in September 1990. As can be seen, a waterway, the North Sea Canal, separates areas to the north of the Amsterdam Metropolitan Area from the Central Business District located on the southern bank of the river. Prior to the additional road capacity, most traffic travelling between the two areas used the Coentunnel, which was heavily congested during the morning peak period. Addition of the Zeeburgertunnel and approach roads effectively doubled capacity across this corridor.

Figure 3.8 Amsterdam Ring Road

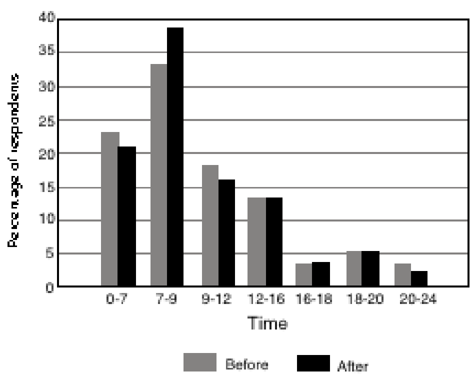
Adapted from: Kenworthy, J. R., Laube, F. B., Newman, P. W. G., Barter, P., Raad, T., Poboon, C. and Guia, B. 1999, *International sourcebook of automobile dependence in cities 1960-1990*, University Press of Colorado, Boulder, pp. 71 and 73 and Kroes, E., Daly, A., Gunn, H. and van der Hoorn, T. 1996, 'The opening of the Amsterdam Ring Road: a case study on short term effects of removing a bottleneck' in *Transportation* No. 23, p. 73.

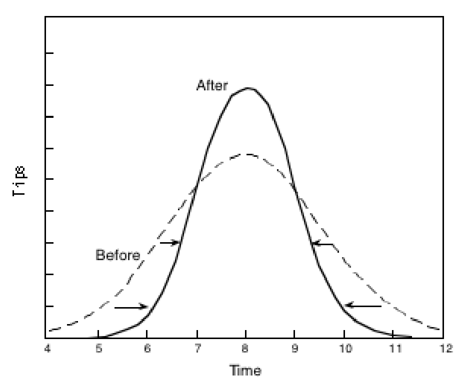
The survey undertaken by Kroes *et al.* was funded by The Netherlands Ministry of Transport. A telephone survey of around 5,000 households drawn from areas north of the waterway was undertaken. Participating households were interviewed in May — four months before the ARR additions were opened — and again in November — two months after opening. The same contact person from each of the households was used in both before and after interviews using essentially the same questionnaire, and because professional survey staff completed all survey forms, there was a high degree of consistency throughout the survey records (Kroes et al. 1996, p. 73).

Two of the authors had previously undertaken a similar study (van der Hoorn *et al.* 1984), reporting that tests had shown this method compared well with other more expensive travel survey methods, however, the study of the ARR was more comprehensive than the 1984 study, incorporating analysis of changes in trip numbers, destinations, choice of mode including travel as car driver or passenger, trip-scheduling and route choice (Kroes et al. 1996, p. 72 and 74).

Like Wilcock (1988), the primary travel behaviour changes observed by Kroes *et al.* were trip reassignment and trip-rescheduling. A total of 29 per cent of survey participants reported they had changed their time of departure after opening of the new ARR sections while 25 per cent claimed to have changed routes. Survey results for trip departure times before and after the motorway additions are shown in Figure 3.9.

Figure 3.9 Observed changes in crossing time of the North Sea Canal





Source: Kroes, E., Daly, A., Gunn, H. and van der Hoorn, T. 1996, ‘The opening of the Amsterdam Ring Road: a case study on short term effects of removing a bottleneck’ in *Transportation* No. 23, p. 76.

As can be seen in Figure 3.9, the 25 per cent of survey participants who changed their departure times either left earlier or later than the peak period between 07:00 and 09:00 hours, thereby reducing the spread of the peak period. This stands in stark contrast to the findings reported in the literature review by Howard Humphrey and Partners, cited by the Department of Transport and conveyed to SACTRA that there was no evidence of trip retiming (SACTRA 1994, p. 54). Kroes *et al.* calculated the savings in travel time resulting from the shift to be 3,800 hours per day (Kroes et al. 1996, p. 77).

There was also evidence of extensive traffic reassignment. Around 19 per cent of total car movements across the North Sea Canal used the Zeeburgertunnel, with around 33 per cent coming from the Coentunnel. Around 8 per cent of traffic came from the Velsertunnel (located 15 kilometres west of the Coentunnel), all of which resulted in a 4 per cent reduction in traffic volumes in the CBD and a 13 per cent increase on roads skirting the CBD (Kroes et al. 1996, p. 77).

There was little evidence of mode-shifting after opening of the Zeeburgertunnel. Survey data showed around 5 per cent of participants had changed modes, but this was no larger than the portion that would normally switch in the absence of a change in capacity. Switches from car use to public transport were of a similar magnitude and not significantly above the scale of the sampling error (Kroes et al. 1996, pp. 77–78).

In relation to induced traffic growth attributable to people undertaking longer and additional trips, an increase of three per cent was observed. However, once expected seasonal changes of two per cent were taken into account, a one per cent increase resulted but was not viewed as significant by the authors (Kroes et al. 1996, pp. 78–79). On this basis, the authors concluded they had found no evidence of induced traffic growth in their survey. They emphasised that the survey was only able to provide an indication of the short-term system feedback effects and that a survey conducted several months further out from the opening of the new ARR sections may have produced different results, raising the issue of whether induced traffic growth is a short- or long-term response (Kroes et al. 1996, pp. 79–80).

As with the RWRR, SACTRA also examined road traffic counts for the ARR, which are summarised in Table 3.11. As can be seen, the aggregate volumes for total crossings of the North Sea Canal show an increase of 23,100 vehicles per day.

Table 3.11 Traffic counts across the North Sea Canal in Amsterdam (24-hour flows, vehicles per day)

	Before (April 1990)	After (November 1990)	Change (April to November)
Zeeburgertunnel	-	57,700	+57,700
Other routes	294,200	259,600	-34,600
Total crossing	294,200	317,300	+23,100

Source: SACTRA. 1994, *Trunk roads and the generation of traffic.* HMSO, London, p. 84.

Once seasonal fluctuations in traffic volumes between the months of April and November are taken into account — estimated to be in the order of a 3.5 per cent increase — the data suggest that traffic reductions on other routes was in the order of 45,000 vehicles on average per day, compared with the increase of 57,700 in the Zeeburgertunnel. The 24-hour measured traffic flows accordingly suggest there is evidence of induced traffic growth of around 12,700 vehicle movements per day (SACTRA 1994, p. 84). Kroes *et al.* did not point this out in their 1996 paper, even though these data were part of the same study commissioned by The Netherlands Ministry of Transport.

Conclusions

The literature review of case studies using travel survey data reveals several problems and advantages with the use of this method to test for induced traffic growth. The advantages include:

- Qualification and quantification of traffic stream composition, that is, whether traffic is reassigned, redistributed or induced as well as percentage share.

The disadvantages of travel surveys include:

- Potential problems with self-selection and sample bias if using a targeted survey sampling method, as in the case of Wilcock (1988).

- Prohibitive costs if using a random sample survey method, as in the case of Kroes *et al.* (1996). Depending on the scale of the selected survey area as well as the capacity increase of the motorway project in question, the sample size may need to be exceptionally large to generate a detectable signal.

While the results of the two case studies reviewed here are to a large degree ambiguous — one reports confirmation of induced traffic growth but the veracity of the sampling method is unknown, while the other reports no confirmation but acknowledges problems with the survey timing — there are potential benefits to be gained by using travel survey data in conjunction with analysis based on traffic counts. Bonsall (1996) recommends that travel surveys should be used in conjunction with a comprehensive program of traffic surveys so that the composition of traffic can be gauged, otherwise the source of any increases that may be observed remains unknown. Surveys undertaken before a motorway section opening need to ensure that they are not affected by disruption due to construction (Bonsall 1996, p. 20). In relation to surveys after the opening of new road or motorway capacity, Bonsall recommends they be undertaken at least nine months after opening but no more than 18 months. If two after-studies are possible, he recommends surveys at 12 and 24 months after opening (Bonsall 1996, pp. 21–22).

3.5 Induced traffic growth studies using aggregate VKT data and time series regression

While many European researchers continued their analysis of individual motorway expansion projects in the post-SACTRA period, researchers in the United States had begun the first of what would become a series of studies that analyse whole urban transport systems rather than single motorway developments, using time series regression analysis. This form of analysis is easier in the US due to data availability and collection conventions. Time series regression analyses have been undertaken by Hansen *et al.* (1993) and Hansen and Huang (1997), Noland 2001) and Cervero (2003). This section will focus on the studies by Hansen and Huang (1997) and Cervero (2003), as well as an analysis using regression modelling by Prakash, Oliver and Balcombe (2001) that attempts to refute the induced traffic growth hypothesis.

At the outset, it is useful to make some broad observations that relate to this form of analysis, for unlike the previous case studies, this form does not use simple descriptive statistics. Instead, this form of analysis involves the development of *models* that attempt to imitate behaviour. That there are differences between models and reality may seem an obvious point to make, however, it is important because it is easy to become so involved in the modelling process that its outputs seem real and unchallengeable.

Analyses using time series regression essentially try to track fluctuations in a *dependent variable* against other *independent variables* that are assumed to cause the fluctuations. The conclusions that can reasonably be drawn from this form of analysis are that when one particular variable is increased (or decreased), then changes in another variable occur in a particular way within a specified time frame. However, this does not mean that a causal relationship exists between the two variables under examination. This is because a statistical regression model does not articulate the structure of a given phenomenon or the mechanism that relates different functions of a given set of components towards one another. From a systems perspective, it could be said that a regression relationship does not articulate a specific path by which a given sequence of events takes place. These points will be explored in more detail in Chapters Four and Six.

3.5.1 Hansen and Huang’s time series regression analysis of changes to highway capacity and VMT in California

Hansen and Huang (1997) sought to test the induced traffic growth hypothesis by examining the relationship between highway capacity — measured in State Highway Lane Miles (SHLM) — and traffic volumes on state highways — measured in Vehicle Miles Travelled (VMT). Their study examined these data for a set of urban counties and metropolitan aggregations in California for the years 1973 to 1990. In particular, they wanted to gain some insight into the extent of induced traffic growth by calculation of a VMT elasticity for capacity increases (Hansen & Huang 1997, p. 206).

The primary finding from the modelling undertaken by Hansen and Huang was their estimate of a lane-mile elasticity of 0.9 for metropolitan areas with the full impact of VMT increases materialising within five years of opening the additional capacity to traffic. Or in other words, with every ten per cent increase in highway lane-miles, the capacity itself was responsible for inducing a nine per cent increase in VMT.

Analysis of this kind has both benefits and limitations. A key benefit arising from this method of modelling is that it is able to overcome the difficulties created by traffic reassignment over wide areas, which was discussed in Section 3.3. By analysing the relationship between total road space and VMT, possible problems with open boundary conditions, as discussed in Section 3.1.1, are overcome. A drawback occurs, however, in that while the method is able to capture the central tendency of the effect resulting from a collection of road projects, it cannot estimate the traffic generation effects due to a single project. As Hansen and Huang point out:

> Simple models of the kind presented here cannot supplant the detailed analyses needed to evaluate specific projects. It should not be assumed that the aggregate elasticities obtained in our analysis apply equally to every urban region, let alone to any particular project. They do, however, support important generalisations about supply-demand relationships for urban roads. Ideally, these generalisations will eventually be reconciled with the more detailed predictions of disaggregate, activity-based models that are the focus of so much ongoing research (Hansen & Huang 1997, p. 218).

Clearly, adding capacity to a highly congested inner-city section of road network will affect traffic volumes differently from capacity added to a lightly trafficked section of road located on the urban fringe (Cervero 2003, p. 146). Because aggregate models contain no information about network geometry, they are not able to reveal much other than that as capacity increases, VMT has also increased. While this outcome supports the induced traffic growth hypothesis, it does not shed any light on the nature of the mechanism that causes it.

When carrying out their analysis, Hansen and Huang generated a set of time series regression models. Data were aggregated in two different formats — by administrational jurisdiction and physical agglomeration, the latter producing higher R^2 values (Hansen & Huang 1997, p. 208). The models also controlled for other factors including changes to population, personal income levels, gasoline prices and stochastic effects (Hansen &

Huang 1997, pp. 209–210), which in combination were estimated to account for the majority of VKT increases (Hansen & Huang 1997, p. 216). A distributed lag function was employed to account for increases in traffic volumes over time. Such a function enables the model to recognise that responses to the increase in road capacity may not occur instantaneously but rather over an extended time period. In and of itself such a proposition makes sense, however, it raises questions about the potential for increases in VMT levels to affect increases in road capacity. This is because as the effects from multiple projects in turn affect the system, increases in VMT — presumed to have been caused by previous increases in capacity — occur before the opening of other projects, raising the question of how the two can be disentangled statistically. This inturn raises the problem of *simultaneity bias*.

Hansen and Huang approached the problem of simultaneity bias by controlling for fixed effects in the model, which they claim substantially reduces potential distortion. The authors note, however, that:

> Such bias will occur if traffic affects road supply, or more generally, when the error term in a regression equation is correlated with an independent variable. In the long run, the causality between VMT and SHLM does in fact run in both directions. However, the protracted nature of the highway expansion project development and delivery process, the lumpy and durable nature of the projects, and politicised manner in which they are chosen, make it impossible for highway supply to respond to changes in traffic level on a year-to-year basis. In other words, while it is probably true that Los Angeles has a lot of SHLM in part because it has a lot of traffic, it is far less likely that SHLM in the LA region would increase from one year to the next in response to (or anticipation of) a traffic increase there (Hansen & Huang 1997, pp. 209–210).

Other researchers have interpreted this issue differently. In particular, proponents of the *predict and provide* approach to transport planning — which was discussed briefly in Section 2.1 — have argued that induced traffic growth is not a product of additional capacity but rather a product of other factors to which governments are merely responding. That traffic grows in the immediate aftermath of a motorway addition is due to the foresight of road building agencies that have anticipated the potential growth and catered for it. SACTRA acknowledges this point, but also stresses that if capacity is insufficient, then higher traffic growth — anticipated or not — simply cannot be accommodated because of capacity restrictions (SACTRA 1994, p. 33).

The two induced traffic growth studies that follow both highlight this point in their analyses, but in different ways.

3.5.2 Prakash, Oliver and Balcombe's arguments against the induced traffic growth hypothesis

Prakash, Oliver and Balcombe (2001) approached the issue of induced traffic growth by examining national road expenditure and VKT data for the UK using *Granger causality* testing.

Granger causality tests were originally developed as a way of using one economic variable to predict the behaviour of another. The example often used to illustrate application of the test is to show how fluctuations in the price of petrol precede fluctuations in GDP. Testing for causality in the Granger sense uses F-tests to establish whether lagged data on a particular variable provides statistically significant information about another (SAS Institute 2006).

In their analysis, Prakash, Oliver and Balcombe assumed that road expenditure and road capacity are aligned. Or in other words, when road expenditure is increased, capacity similarly increases. On applying Granger causality testing, Prakash, Oliver and Balcombe concluded that road expenditure does not cause road traffic but rather that road traffic causes road traffic expenditure in the Granger sense:

> The results appear consistent with a government long-term strategy of predicting the growth in road traffic and providing the necessary level of expenditure to maintain a stable 'equilibrium' between the two variables (Prakash, Oliver & Balcombe 2001, p. 1583).

Prakash, Oliver and Balcombe also found that road expenditure in the shortrun is upwardly 'sticky', meaning that if road traffic volumes are less than anticipated, expenditure is reduced at a faster rate than if road traffic is above predicted levels and expenditure needs to be increased to meet this (Prakash, Oliver & Balcombe 2001, p. 1584).

Goodwin and Noland (2003) responded to Prakash, Oliver and Balcombe with the primary argument that road expenditure data is not a good measure of road capacity increases. This is because national road expenditure also includes maintenance and operation outlays, with the largest portion spent on maintenance. They showed that in the time series data used by Prakash, Oliver and Balcombe, the percentage of capital expenditure spent on adding capacity, either in the form of new roads or lanes added to existing roads, varies widely from between 70 to 45 per cent. They also showed that there is no correlation between total road expenditure and additional road length or motorway length (Goodwin & Noland 2003, p. 1455). In conclusion, they defined Prakash, Oliver and Balcombe's work as a mis-specification of the problem.

Goodwin and Noland (2003) did review past literature in some detail, pointing out that Hansen and Huang (1999) had used a similar time-lag method of analysis, however, their model acknowledged the behavioural complexity under investigation, incorporating several other key variables that affect traffic growth while using changes in lane-miles as the independent variable as a measure of capacity (Goodwin & Noland 2003, p. 1454).

Goodwin and Noland (2003) also made the point that if Prakash, Oliver and Balcombe's thesis is correct, they are in effect claiming that the elasticity of vehicle kilometres with regard to increases in lane kilometres is zero. This contradicts the general consensus that Goodwin and Noland (2003) claimed has been reached of an elasticity estimate of between 0.3 and 0.5 for the relationship in the short term, and somewhat higher in the longer term (Goodwin & Noland 2003, pp. 1452–1453).

Dispute over the issue of cause has been explored by many scholars researching in this area. One of the more creative attempts to address the problem has been produced by Cervero (2003).

3.5.3 Cervero's path analysis

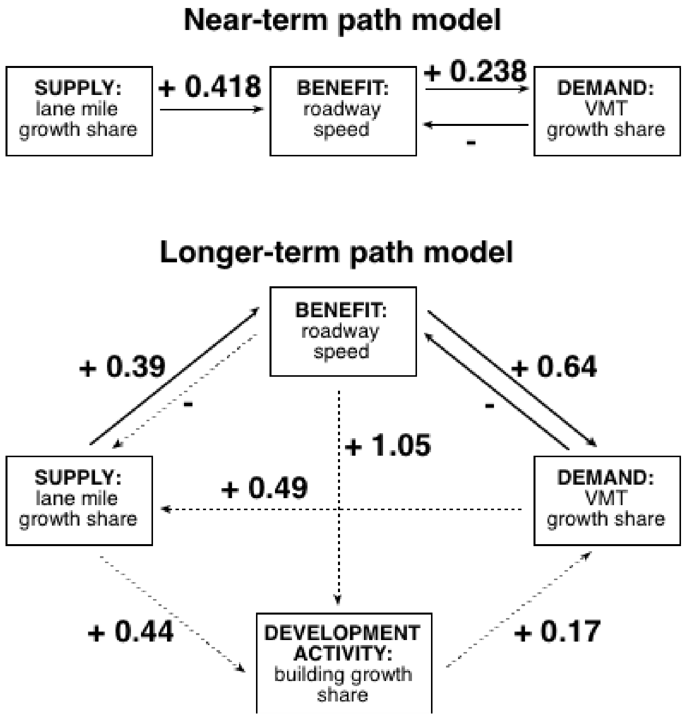
The model developed by Cervero (2003) is the most recent in what has been a series of time series regression analyses. As was shown in the brief overview of studies by Hansen & Huang (1997) and Prakash, Oliver and Balcombe (2001), the need to clarify issues concerning causality has undermined the confidence that can reasonably be invested in analyses that use this method.

Previously, DeCorla-Souza and Cohen (1999) and Pickrell (2002) had criticised models like that produced by Hansen and Huang (1997) on the basis that the method did not take into account intermediate steps between the addition of road capacity and traffic growth. Cervero sought to counter these criticisms by undertaking what he called a *path analysis*, which articulated in more detail changes to the relationships between a variety of elements in the urban system that work together to change the relationship between the supply of road space and demand as expressed in VKT/VMT.

First and foremost, Cervero stressed that it was changes to travel speeds that induced changes in travel behaviour and not simply the increase in capacity (Cervero 2003, p. 146). In the past, most models had sought to find correlations between capacity changes and VMT levels. Cervero calculated changes to travel speeds that occurred as a result of capacity changes and used this as an independent variable instead.

Figure 3.10 shows the relationship between the various systems elements that Cervero considered when articulating the sequence of events that give rise to induced traffic growth. The solid lines represent near-instantaneous responses while the dotted lines represent responses involving a time lag. For example, after a new motorway is opened, some time may pass while land-use developers secure the rezoning and building permits for new developments that will generate more traffic. The elasticities that Cervero calculated for each of the sequences in the path analysis are also shown in Figure 3.10.

Figure 3.10 Elasticity results of near- and longer-term path model analyses



Source: Cervero, R. 2003, 'Road expansion, urban growth and induced traffic: a path analysis' in *Journal of the American Planning Association,* Vol. 69, No. 2, pp. 156 and 160.

As can be seen, at 0.2 in the near term and 0.6 in the longer term, the elasticities calculated by Cervero to be indicative of the volume of induced traffic growth arising from new road and motorway developments are lower than those estimated by Goodwin and Noland (2003). Significantly, Cervero also calculated elasticities for the effect that growth in demand would have for road supply. The argument used to explain and rationalise such a relationship is that as congestion is moved to new points in the network it generates the perceived need to add further road space to the system (Cervero 2003, p. 148). In this way the predict and provide approach to transport planning is not supported, as increases in capacity are seen to be a response to congestion generated by previous capacity increases. This is how Cervero accounts for the problem of simultaneity bias that often features in this form of aggregated analysis.

The lower elasticities calculated by Cervero led him to conclude that:

> Whether new roads are on balance beneficial to society cannot be informed by studies of induced demand, but rather only through a full accounting and weighing of social costs and benefits. Induced-demand research can, without question, help us better measure the net benefits of road improvements;

> however, by itself, it cannot inform policy making on whether or not to build or expand roads.
>
> Critics of any and all highway investments, even those backed by credible benefit–cost analyses, should more carefully choose their battles. Energies might be better directed at curbing mispricing in the highway sector and managing land use changes spawned by road investments (Cervero 2003, pp. 160–161).

It is important to recognise, however, that the data on which these conclusions are based are for a set of highway capacity increases that were selected for specific reasons concerned with the design of the analysis. Because Cervero wanted to include the effects that highway expansion had on land-use development, he had to find a way of generating a land-use data set that was compatible with the traffic data he used in the time series regression. This was accomplished by only including data for highways that passed through counties where urbanised areas within two miles of the highway alignment made up a minimum of 40 per cent of the urbanised area within the counties for which land-use data were extracted (Cervero 2003, p. 149). This requirement meant that highway capacity additions located in mature and heavily urbanised areas would be excluded in favour of newly developing areas where urbanisation was more confined to areas within the immediate vicinity of the highway alignment. It is possible that this may have affected the results in such a way that the elasticities were lower. After all, it is generally believed that induced traffic growth is more likely to occur where congestion is high and this in turn is more likely to occur in the centre of heavily urbanised areas (SACTRA 1994, p. iii). Consequently, Cervero could be overstating the degree to which his results are able to support particular policy conclusions.

Despite these potential problems, Cervero’s path analysis begins to take induced traffic growth studies into the realm of systems theory, as it tracks a sequence of events that occur in response to changes in motorway capacity. These sequences are discussed as feedback loops, however, they are not articulated using the formal rules of General Systems Theory and so are not presented with the structural discipline and intricacy that comes with such analysis. Nevertheless, the idea of a path that moves through phase space in response to a trigger is broached in a way that many other studies do not utilise. In this way, Cervero’s paper attempts to draw together theory and observation in a way that tries to identify a causal mechanism for the phenomenon.

Conclusions

The literature review of induced traffic growth studies using time series regression to analyse the relationship between VKT/VMT levels and road space on an area-wide basis has shown:

- That broad generalisations can be drawn from such analyses, however, these cannot be used to draw conclusions about specific projects.

- If modelling is to be used, then it is useful to first articulate the relationships between different system elements that form part of the process responsible for induced traffic growth, as demonstrated by Cervero (2003). This thesis contends that such an articulation should be undertaken within the formal strictures of General Systems Theory.

It now remains to examine the two empirical case studies of network conditions relating to before and after motorway constructions in Australian cities.

3.6 Induced traffic growth studies in Australia

Of the two Australian case studies, Luk and Chung's (1997) has been the most widely, and generally the only, paper cited on induced traffic growth. The other case study by Mewton (1997, 2005) — originally a Master's Dissertation and more recently a journal article — has rarely been cited.

In their case study of the South Eastern Arterial in Melbourne's south-eastern corridor, Luk and Chung report no evidence of induced traffic growth (Luk & Chung 1997, p. 27). By contrast, in his case study of the Sydney Harbour Tunnel and Gore Hill Freeway, Mewton reports statistically significant differences between before and after traffic counts that could be viewed as evidence of induced traffic growth, highlighting mode-shifting from parallel rail services (Mewton 1997, p. 16).

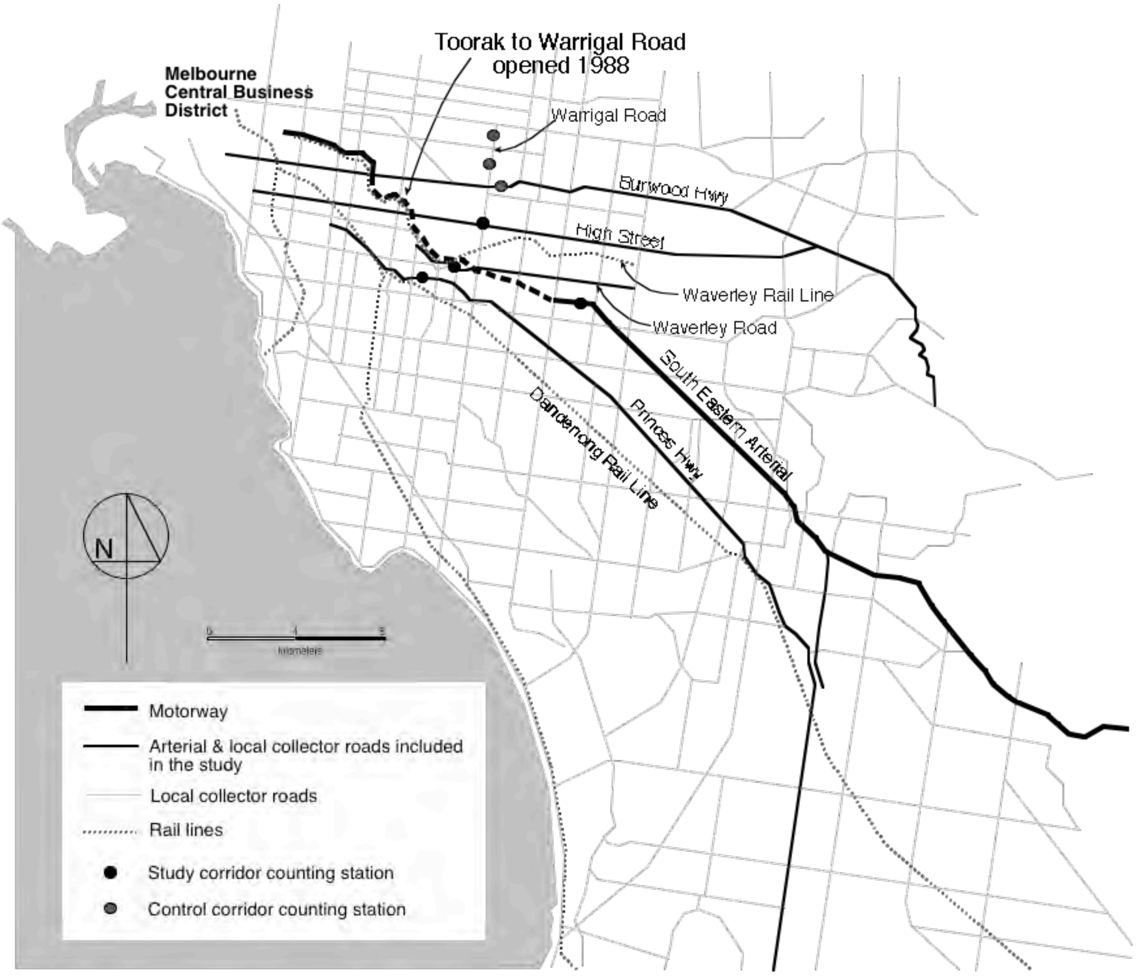
A significant feature of these studies is the stark differences in the quality and availability of data, particularly rail and public transport data. Luk and Chung (1997) were only able to access limited road and rail data. The methodology and extent of their analysis is similar to many of the early studies that examined changes to road traffic volumes across screenlines.

Mewton (1997, 2005) was able to access more comprehensive road traffic and public transport records. Like Luk and Chung, Mewton examined road traffic and public transport patronage data across specific screenlines. But because Mewton had access to more detailed data sets, he was also able to subject his data to a more sophisticated form of statistical analysis, using time series regression.

3.6.1 Luk and Chung's analysis of Melbourne's South Eastern Arterial

Melboune's South Eastern Arterial (SEA), previously known as the Mulgrave Freeway, and now the Monash Freeway, was built in several stages during the late 1970s and 1980s, with those stages closest to the CBD built first. Figure 3.11 shows the alignment of the motorway as well as the alignments of alternate road and rail routes throughout the corridor.

Figure 3.11 Melbourne's south-eastern metropolitan area



Note: this map is more detailed than the map provided by Luk and Chung and has used verbal descriptions provided by the authors to locate the position of counting stations (Luk & Chung 1997, pp. 17 and 19).

As can be seen in Figure 3.11, the SEA is a radial motorway that connects the Melbourne CBD with the outer-lying suburbs of the south-eastern metropolitan area. The Princes Highway runs parallel to the SEA, as do the Dandenong and Glen Waverley Rail Lines. The motorway section that was of particular interest in the study was a link between Toorak and Warrigal Road that was opened to traffic in 1988. Congestion on several roads in the area was reported to have increased after the opening, giving rise to speculation that traffic volumes had increased in response to the quicker speeds made possible by the additional capacity. Luk and Chung's study sought to ascertain whether this could be attributed to induced traffic growth by analysing fluctuations in road traffic and public transport patronage data over the 20-year period from 1975 to 1995 (Luk & Chung 1997, p. 16).

Luk and Chung defined induced traffic growth as increases attributable to mode-shifting, additional road traffic from new developments built to take advantage of the greater accessibility afforded by the increase in motorway capacity and the release of *latent demand.* Traffic reassignment and trip-rescheduling were not considered to be induced traffic growth and nor were increases that could be attributed to what they call *natural growth*. The authors defined natural growth as increases in traffic volumes due to population, employment and car-ownership increases, which were estimated by measuring traffic growth on a control corridor comprising road traffic counts taken at three points on surrounding roads (Luk & Chung 1997, p. 20).

The key empirical findings from Luk and Chung's study are summarised in Table 3.12, which shows the differences in average growth rates between roads in the designated study corridor and those on roads selected as part of a control group. The primary conclusion drawn from the data listed in the table is that there is no evidence of induced traffic growth, because the average growth rates in the study corridor for the periods 1985–90 and 1990–95 were lower than the equivalent growth rates in the control corridor.

Table 3.12 Growth rate (per year) for arterial roads in Melbourne's south-east corridor (1985–1995)

Road	Growth rate per year 1985-90 (%)	Growth rate per year 1990-95 (%)	Growth rate per year 1985-95 (%)
Study corridor			
South Eastern Arterial	5.0	4.0	4.5
Princes Highway	1.0	0.0	0.5
Waverley Road	-1.6	1.7	0.0
High Street Road	-4.4	2.6	-1.0
Corridor total	**1.2**	**2.2**	**1.7**
Control			
Warrigal Road North of Burwood Hwy	2.0	1.0	1.5
Warrigal Road South of Canterbury Road	3.0	4.4	3.7
Burwood Hwy East of Warrigal Road	2.8	3.8	3.3
Control total	**2.5**	**2.9**	**2.7**

Source: Luk, J. & Chung, E. 1997, *Induced demand and road investment — an initial appraisal.* Report No. 299, Australian Road Research Board, Vermont South, p. 22.

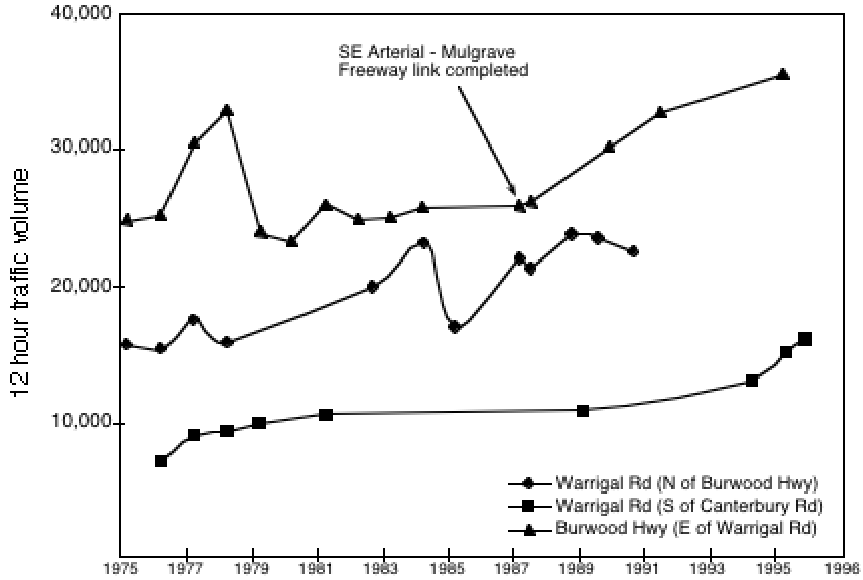
Unfortunately, Luk and Chung only provided a table of percentage differences for the various roads used in their analysis and they provided no clear indication of the configuration of screenlines used. This stands in stark contrast to the reporting standards observed by researchers like Purnell, Beardwood and Elliott (1999).

On close inspection, there are several problems with the collation of empirical data used by Luk and Chung. First, examining empirical data on the basis of percentage differences alone is problematic, because roads with smaller volumes experience fluctuation rates that are generally much greater than is the case for larger roads. Or in other words, small changes can appear to be big and big changes small when estimated only in terms of percentages. While the apparent proportion of increase relative to starting figures is consistent, the comparison of high-volume trunk roads, which carry a high proportion of long-distance through traffic, with lower-volume roads, distributing local traffic, does not provide a good control.

The other problem with this standard of reporting is that Luk and Chung averaged increases over five-year time periods. In many of the other studies it is clear that growth rates in the first few years after opening of a motorway section are steep, but flatten out once the road begins to reach its ceiling capacity.

While Luk and Chung did not provide comprehensive AADT data for roads within the study and control corridors, they did provide a graph of 12-hour volumes for the control corridor. This is shown in Figure 3.12. As can be seen, two of the control sites are not high-capacity roads and volumes at one site appear to fluctuate substantially, suggesting that there may have been road works in the immediate area.

Figure 3.12 12-hour traffic volumes for control sites



Source: Luk, J. & Chung, E. 1997, Induced demand and road investment — an initial appraisal. Report No. 299, Australian Road Research Board, Vermont South, p. 25.

The second and more significant problem with the sites selected for the control corridor is that volumes for the Burwood Hwy appear to undergo a ramp-up period directly after the opening of the Toorak to Warrigal Road section of the SEA. This is evident in the steady increase in volumes occurring after the opening, as shown in Figure 3.12, suggesting that there may have been other roadworks in the area, or that traffic reassignment in response to the SEA changes may have affected traffic volumes on the Burwood Hwy, in which case a more appropriate control site needs to be found.

A third problem with the data for the control corridor is that it incorporates measurements of traffic volumes on the same road at different points along its length. The alignment of Warrigal Road runs transverse to the SEA and has an entry ramp between it and the motorway. This breaks with the standard procedure of using a set of measurements for a *screenline* that enables comparisons between aggregate traffic volumes between comparable corridors.

A fourth potential problem is that, given the distribution of data points indicated in Figure 3.12, it is unclear as to whether the data are annual average 12-hour counts or whether they may be averages for different periods in the same year. If the latter is the case, seasonal fluctuations may be affecting the time series collation so that the counts are not strictly comparable.

Luk and Chung also provide 12-hour counts for 1985 and 1995 for roads in the study corridor. These are shown in Table 3.13 and reveal an aggregate increase of 18 per cent. Unfortunately it is not possible to compare these data with 12-hour counts for the control corridor because data are only available for one road in 1985 and two of the three roads in 1995.

Table 3.13 Corridor counts and growth rate (1985–1995)

Route	1985 (veh per 12 hour)	1995 (veh per 12 hour)	Percentage change
South Eastern Arterial	49,473	76,742	55%
Princes Highway	52,390	55,035	5.0%
Waverley Road	27,424	27,537	0.4%
High street Road	24,361	22,113	-9.2%
Total	**153,648**	**181,428**	**18%**

Source: Luk, J. & Chung, E. 1997, *Induced demand and road investment — an initial appraisal.* Report No.299, Australian Road Research Board, Vermont South, p. 27.

In relation to Luk and Chung's examination of road data, the data collations are confusing and less consistent than other studies in which a much clearer picture is provided of changes and conditions on the network. The three sites they identified for use as a control corridor seem unsound.

Luk and Chung also make reference to rail patronage data. They identified two lines that could have been affected by the opening of the SEA — the Dandenong and Glen Waverley lines. The authors were unable to access any data for the Glen Waverley Line but were able to access limited data for average daily trips by train for three years, two before the opening of the SEA section from Toorak to Warrigal Road — 1982–83 and 1986–87 — and for one year after opening in 1993–94. They note that a decline of 14 per cent between 1986–87 and 1993–94 on the Dandenong Rail Line is greater than the decline of 4 per cent for the whole Melbourne rail network, but conclude that the data are too incomplete to draw a firm conclusion and that economic factors could also be the reason for the drop in rail patronage (Luk & Chung 1997, pp. 26–27).

While the authors do not refer to the Glen Waverley line in any detail, it is perhaps worth noting that approximately 400 homes directly alongside the Glen Waverley Line were demolished in order to accommodate construction of the SEA motorway section from Toorak to Warrigal Road. These homes were all within the walking catchment areas of stations located on the Glen Waverley Line and so patronage levels would more than likely have been affected (Mees 2005, pers. comm.).

In their conclusions, Luk and Chung make the following points:

> The Melbourne case study suggests, however, that the level of unexplained traffic growth due to the linking of the Mulgrave Freeway and the South Eastern Arterial was only 1.7 per cent per year over a 10-year period after allowing for route diversions. The natural growth rate at control sites near the Arterial was 2.7 per cent per year over the same period. Therefore, there was no induced demand from this initial assessment, assuming also that there is no significant mode shift from public transport (otherwise the level of induced demand is even less or more negative). The key reasons for the lack of induced demand are the radial nature of the arterial and the current prevailing high level of congestion. This case study therefore could be treated as a representative case of all cases of new road construction or expansion (Luk & Chung 1997, p. 30).

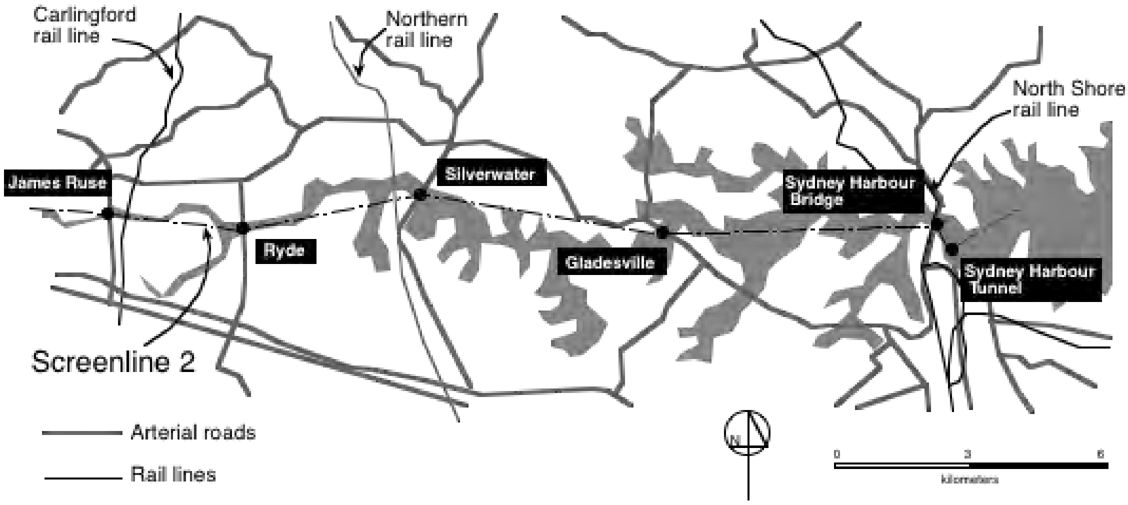
In light of the problems and inconsistencies in the data presented, however, it is unreasonable to conclude that evidence of induced traffic growth has been provided either way.

The next Australian case study was able to access far more extensive and complete data sets, and has been able to provide a much clearer picture of changes to the transport network that took place after the addition of motorway capacity in Sydney.

3.6.2 Mewton's analysis of the Sydney Harbour Tunnel and Gore Hill Freeway

The Sydney Harbour Tunnel (SHT) sits at the centre of the Sydney transport network. The Gore Hill Freeway (GHF) is a stretch of restricted access carriageway that functions as a feeder route to the north of the SHT. Figure 3.13 shows details of the SHT relative to other crossings along the harbour and Parramatta River. These crossing points form part of a traffic cordon identified by the RTA as Screenline 2, which runs along an east–west axis from Sydney Harbour to Penrith in Sydney's outer west.

Figure 3.13 Sydney Harbour Tunnel and other bridge crossings of Sydney Harbour



Mewton's analysis of road traffic data is restricted to counts at the SHT, the Sydney Harbour Bridge (SHB) and the Gladesville Bridge, which is located approximately six kilometres to the west of the SHT and Bridge. Crossings further west from the Gladesville Bridge provide potential alternate routes for long-distance trips, especially traffic with origins and destinations to the south and north of the Sydney conurbation.

Comprehensive data for rail, bus and ferry patronage levels was also available for services that cross Screenline 2 in the near vicinity of the SHT. These are estimated from ticket sales on the basis of their point of sale.

Mewton conducted his analysis by developing discrete time series regression models that attempt to explain fluctuations in road traffic, rail patronage, bus patronage and ferry patronage data respectively. The explanatory variables used to describe fluctuations in road traffic and other public transport patronage data were changes over time in the level of economic activity, which was measured by the Gross Domestic Product (GDP) of Australia at constant prices per quarter year, seasonal fluctuations and the existence or otherwise of the SHT which was represented as a dummy variable (Mewton 2005, p. 26). The results from each of the regressions are shown in Table 3.14.

Table 3.14 Results from Mewton's regression analyses

	Significance	Confidence interval (95%)	Coefficient of determination (R^2)
Road traffic	9,295	6,651 to 11,939 (+/- 28%)	0.9927
Train patronage	-22,141	-12,764 to -31,518 (+/- 42%)	0.7646
Bus patronage	-	-	-
Ferry patronage	-8,782	-14,218 to -3,347 (+/- 62%)	0.8513

Source: Mewton, R. 2005, 'Induced traffic from the Sydney Harbour Tunnel and Gore Hill Freeway' in *Road & Transport Research*, Vol. 14, No. 3, pp. 28–29.

The regression model found significant differences in road traffic, train patronage and ferry patronage data after opening of the Sydney Harbour Tunnel. The model found no significant changes to bus patronage. After the opening of the SHT, one road lane on the deck of the SHB was dedicated to buses. This would in part explain why there had been no apparent mode-shifting from bus to private car use, or if there had been, it was negated by possible shifting from other public transport modes to bus use because the average speed for bus services, like that for trips by car, was increased.

Mewton did not identify a control corridor as has been done in other case studies. This is in part due to his assumption that fluctuations and increases in road traffic volumes — where there are no changes to capacity or service levels — are due to fluctuations in economic activity. The use of Australian GDP data appears to be a blunt way of incorporating this assumption, however. Mewton did not report test runs with any other forms of economic data used to account for fluctuations in road traffic and public transport passenger volumes.

Mewton's concluding remarks are more cautious than Luk and Chung's. He stated that the opening of the SHT was an event that provided:

> … a statistically significant explanatory variable in traffic volume, associated with an increase in vehicular traffic of most likely 3.4 per cent (95 per cent confidence interval 2.45 and 4.35 per cent) of total harbour crossing traffic (Mewton 2005, p. 29).

Mewton observed that his results are broadly consistent with the elasticities found by Cervero (2003) and Fröhlich (2003).

Conclusions

This literature review of Australian analyses of induced traffic growth case studies has revealed the following:

- It is difficult to draw robust conclusions when time series data are incomplete. The position of screenlines and monitoring sites needs to be clearly indicated and careful attention needs to be paid to other roadworks in the vicinity of study and control corridors.
- How data are aggregated can influence conclusions.
- Data collection by transport agencies in Sydney is of a high standard, enabling relatively complete sets to be collated in accordance with many of the considerations raised by researchers such as Bonsall (1996) when testing for induced traffic growth.
- Analysis methods that examine changes to traffic volume counts across screenlines can be subjected to time series regression analysis to estimate statistically significant changes when detailed data exist. This method provides another way of potentially controlling for variation when appropriate economic and other explanatory variable data can be accessed.

This concludes the examination of empirical case studies of induced traffic growth.

I hold that the chief merit of a theory is that it shall guide experiment without impeding the progress of the true theory when it appears.

James Clerk Maxwell
On Faraday's lines of force
(1856)

4 Theoretical explanations of induced traffic growth

This chapter examines the theoretical explanations that have been used to account for induced traffic growth. Where Chapter Two sought to outline the social and political context in which transport knowledge has been generated, and Chapter Three the empirical investigations prompted by that social and political context, this chapter seeks to draw these two together by outlining how the causal mechanism responsible for induced traffic growth has been articulated in light of the politics and empirical experience.

As stated in Section 3.1, theories developed through the process of scientific investigation are grounded in the belief that the world operates on the basis of regular or generic sets of organising principles. The goal of science is to articulate these. Consequently, a robust *scientific* theory aimed at explaining why induced traffic growth takes place would identify the generic elements of the relevant system and how they combine to form the mechanism that causes the phenomenon.

As will be shown, the predominant theoretical accounts for why induced traffic growth occurs have their origins in project evaluation. In these explanations, there is usually no comprehensive description of why some people choose to travel more, beyond the notion that as travel speeds for roads increase, the cost of travel is reduced, so more people take the opportunity to travel further or travel more often. The structural role that induced traffic growth plays within the operations of a whole urban system is generally not explained. There are some exceptions and these will be reviewed with an eye to informing the theoretical work presented in Chapter Five.

At the outset it is useful to acknowledge a distinction between what might be called *engineering knowledge* and *scientific knowledge*. The distinction is important because explanations derived from assessment methods used in engineering disciplines are only intended to provide approximations for behaviour, while theories that arise out of scientific investigations aim to describe causal mechanisms. Johnston, Gostelow and King account for these subtle differences in the following way:

> [T]he thrust of science has been towards understanding the nature of things and the causes of their behaviour. Its basic question has been 'Why?' Engineering is about innovation, the production of commercially viable products, processes, or systems. Its central focus has been 'How?' (Johnston, Costelow & King 2000, p. 534).

Engineering is a form of knowledge that is applications focused, being very much influenced by the institutional and commercial framework in which it operates. By contrast, science, with its suite of reductionist methods of investigation, isolates and socially decontextualises its subject matter. Science is a body of knowledge that attempts to know how something works without necessarily having an explicit application in mind. If a robust answer to a particular problem does not come readily to hand, or the workings of a particular system evade comprehension, then scientific conventions necessitate that the inability to provide an explanation be declared, in the hope that one day an answer will be found. Engineering, on the other hand, continues irrespective of ambiguities or shortcomings in available knowledge. Engineering practice even explicitly tries to reduce the amount of information needed to make a decision or produce a design so that the engineering process is more efficient.

Acknowledging the readiness to proceed on the basis of imperfect knowledge is unhelpful in a social and political sense, however. The authority of government, the credibility of its supporting institutions and the power of those groups within society who have organised themselves around such institutions is at stake, as discussed in Section 2.2. To acknowledge that the understanding on which vital decisions are based is incomplete, undermines such authority. Consequently, there is a high degree of resistance to admitting past failures and instigating significant reform.

The engineering approach to knowledge fails in practice when outcomes from its methods are widely different from the actual behaviour of the system in question. It is possible that no other branch of engineering has suffered this particular problem more than traffic engineering and, before reviewing explanations for what causes induced traffic growth, it is useful to understand why.

In relation to capacity provisions for urban road and motorway networks, Jacobs expresses the following view:

> In what traffic engineers have chosen to do and have recommended, they abandoned and betrayed science as it is understood. … It is popularly assumed that when universities give science degrees in traffic engineering, as they do, they are recognising aboveboard expert knowledge. But they aren't. They are perpetrating a fraud upon students and upon the public when they award credentials in this supposed expertise (Jacobs 2004, p. 72).

While polemical, it is probably the case that the general community has the same expectations of traffic engineering that Jacobs does, but are unaware of the differences between engineering and a purely scientific approach to knowledge production. Jacobs goes on to describe a set of experiences she had in relation to traffic and motorway development issues in New York and Toronto:

> In the mid-1950s, I was one among thousands of New York citizens trying to save Washington Square, the major Greenwich Village community park, from bisection by a limited access expressway … After staving off [the] threat …, our community movement discarded its defensive stance and insisted aggressively that a two-lane carriageway road bisecting the square be closed to all but emergency traffic …
>
> When a test closing of the carriage road became imminent, the traffic commissioner told us that traffic is like water: if it is dammed up or diverted from its course in one place, it will find other outlets where it meets less resistance. To close off the carriage road without providing a new road would, he predicted, inundate all the narrow streets in the park's vicinity with thwarted traffic and belching fumes … He predicted that we would come back to him on our knees, begging for a road.
>
> His dire predictions did not come true. … Indeed, traffic counts were slightly down.
>
> Where did the vanished traffic go? This was a new question that emerged unexpectedly. But it was not pursued. It was ignored in favour of a vague notion that some drivers must have chosen less frustrating routes, or else switched to public transit; or maybe some oddballs walked (Jacobs 2004, pp. 72–73).

Jacobs then describes a similar meeting over the closure of a road in Toronto, where the traffic engineers relayed the same explanation and prediction of failure by the road commissioner in New York 30 years before. She reflects on the event:

> I thought sadly, ‘Here they are, another generation of nice, miseducated young men, about to waste their careers in a fake science that cares nothing about evidence; that doesn’t ask a fruitful question in the first place and that, when unexpected evidence turns up anyhow, doesn’t pursue it; a science that hasn’t been building up a coherent body of knowledge that organises its own direction by grace of the succession of questions it opens’ (Jacobs 2004, p. 74).

The subtle differences and tensions that exist between *implementing a solution quickly* — engineering knowledge — and understanding *how the system functions in practice* — scientific knowledge — are reflected in the calibre of the theoretical explanations for the phenomenon of induced traffic growth. Understanding the workings of an unknown phenomenon, by making analogies between it and a known phenomenon, is common in the early developmental stages of many scientific theories. But as observation and testing become more sophisticated, crude analogies can be seen to be misleading and so get replaced by more cogent descriptions of causal mechanisms unique to the phenomenon in question (for example, Gould 1989, p. 213). Or at least this is the usual course of science.

Explanations for behaviour drawn solely from engineering disciplines do not provide explanations of causation in the same way that scientific theories attempt, and nor do they pretend to. Significantly, many engineering disciplines appear to perform with greater skill than traffic engineering. For example, electrical and chemical engineers appear to have far greater command over their subject matter than traffic engineers. This is because they both work in tandem with *companion sciences*. In the case of electrical engineering, the body of scientific knowledge comprising electro-magnetic field theory informs the work of engineers when designing electricity grids and power-plants. Similarly, chemical engineers draw on the extensive theory of organic and inorganic chemistry when designing the production processes of chemical manufacturing plants. By contrast, traffic engineers have no companion science to draw on when attempting to solve traffic problems. While various behavioural theories have been consulted from time to time, the predominant views that attempt to explain behaviour and its causes rely largely on analogies with physical phenomena as relayed in Jacobs' polemic.

Current theoretical explanations for induced traffic growth — and travel behaviour more generally — suffer from this legacy. *Theory* arises out of two critical tasks that make up the technical input to the transport planning and assessment process for motorway developments. The first is the need to predict and model changes to travel behaviour via demand models. The second task is the economic evaluation of transport projects and programs.

Both theories arise from the need to evaluate projects and not from the desire to identify the cause of changes to travel behaviour. It will be argued that this is one of the key difficulties with theories that attempt to explain why induced traffic growth occurs. Because they have evaluative rather than descriptive origins, they fall short in the face of the more demanding social expectations usually levelled at scientific theories, as demonstrated in the polemic by Jane Jacobs.

This chapter reviews the theoretical concepts used in both these applications, while paying particular attention to how they have been adapted in order to take into account the effects of induced traffic growth. These two approaches — modelling and economic evaluation — were integrated in the 1970s to form unified frameworks for demand modelling that were compatible with microeconomic theory (Bates 2000, p. 11). In this overview, however, they will be reviewed separately.

Section 4.1 begins the review of the theoretical accounts of induced traffic growth by examining the concepts and procedures generally used to construct demand models. It discusses how induced traffic growth has been incorporated into these models, while at the same time highlighting how the inherent difficulties involved in such a procedure have served to influence views about the phenomenon.

Section 4.2 examines how induced traffic growth features in the microeconomic evaluations of infrastructure changes like the addition of urban motorway capacity. This section also reviews utility theory and ideas about utility transfer that play a critical role in microeconomic theory and analysis.

Section 4.3 focuses on a body of work referred to as the *Mogridge conjecture*. The Mogridge conjecture relies heavily on both observations made during the compilation of travel survey data used in demand models and the logic of microeconomic theory. Unlike most microeconomic analyses, the Mogridge conjecture attempts to situate these relationships within a whole urban system.

4.1 Calculation procedures for demand modelling

As part of its investigations, SACTRA reviewed the degree to which allowance for induced traffic growth is incorporated into traffic and transport modelling. At the outset the committee cautioned:

> Transportation models can only tell us about the relationships actually built into them. They cannot inform us about drivers' reactions for which mathematical relationships or procedures have not been developed … (SACTRA 1994, p. 135).

These qualifications are similar to those that apply to the time series regression modelling reviewed in Section 3.5. Despite these qualifications, demand models, and the underlying theories that comprise their logical structures, are often granted a status similar to that of the results of empirical analyses. Such a status is undermined, however, when large disparities are incurred between modelled results and real outcomes, as SACTRA found when comparing the two for 151 road schemes in the UK (SACTRA 1994, pp. 55–67). In light of this experience, SACTRA added to its qualification of demand models that:

> A model must calibrate — that is, it must explain the relationships displayed by observations. It must also validate — that is, it must replicate observed conditions, such as the pattern of traffic flows on roads (SACTRA 1994, p. 135).

Viewed in a prudential light, the calibration and validation of models provide an opportunity to test theories and highlight the complexity of travel behaviour responses to changes in travel conditions. An examination of the concepts and procedures that make up the structure of such models also provides an opportunity to gain some insight into the theories used to account for changes. While it is important to recognise that there are difficulties when trying to pin down a robust theory of causation through the examination of modelling procedures, the exercise is useful, if for no other reason than that it helps to highlight what is not known about travel behaviour responses to capacity additions and consequent changes to service levels.

4.1.1 Traffic is like water: an overview of four-step and assignment modelling

The most widely used demand model is a form of calculation known as *four-step modelling*. The name of such models is derived from the four broad procedures that sit at the core of the modelling process, which are:

1. *Trip generation*: identification of origins and destinations

2. *Trip distribution*: description of transport link characteristics

3. *Mode choice*: allocation of modes to array of trip OD combinations

4. *Trip assignment*: allocation of trips to routes according to optimum travel time (Van den Boss 2006, pers. comm.).

The first three steps in the four-step modelling process serve to describe what is referred to as the *trip matrix*, or the general parameters of the system and array of trips to be undertaken on it. The last step in the process — trip assignment — assigns trips across the network using an equilibrium function that serves to distribute trips in such a way that travel times are reduced to an optimum. The algorithms used to calculate such assignment processes were pioneered in the 1950s by traffic researchers like Wardrop (1952) in the UK, and Mitchell and Rapkin (1954) in the US. These functions are largely responsible for the analogy 'traffic is like water', so often used to conceptualise the underlying dynamic responsible for observed travel behaviour.

In more recent years, a variation of four-step modelling known as *assignment modelling* has been widely used in many parts of the world. Assignment models differ from four-step models in that they do not calculate a trip matrix. Instead, the trip matrix is devised independently and loaded onto the model with the primary focus of the modelling exercise being on the way in which traffic is assigned across the network rather than descriptions of trip origin and destinations. In brief, assignment modelling focuses on four aspects of the assignment process:

1. Choice of route

2. Aggregating flows on links of chosen paths

3. Dealing with supply side-effects, such as capacity constraints

4. Obtaining the resulting cost of each combination (Bates 2000, p. 18).

When calculating the assignment of trips across a transport network, four-step and assignment models can be made to reiterate earlier steps in light of outcomes from later steps in the calculation. Indeed, reiteration is an important aspect of the equilibrium function. During assignment, a variety of different feedback functions can be incorporated into the calculation, and many of these can feed back to earlier steps, such as the step that sets the mode choice for particular trips so that mode shifting may be incorporated into the model (Williams 2004, p. 7).

From a theory perspective, four-step models conceptualise travel behaviour in a way that describes behaviour using two different sets of ideas. The first set seeks to describe specific details of trips and transport paths — the trip matrix. The second set attempts to describe the essential dynamic of the system. Assignment models also divide the conceptualisation of the system along these lines but with far less emphasis on trying to replicate specific details of trips, as is the case with a trip matrix. As discussed in Section 1.3.1, induced traffic growth occurs as a result of several different travel behaviour responses. To replicate these, some responses — like mode-shifting — require variation to the algorithms that attempt to describe the dynamics of the system. Others — like trip redistribution and additional, or induced, trips — require changes to the trip matrix. Sources of induced traffic growth that bring about changes to the trip matrix raise an entirely different set of questions about travel behaviour and require an altogether different form of algorithm, or calculation process, in order to capture the changes that take place. Why and how change takes place to these aspects of the system is unclear in terms of a mechanism for change. So that while an equilibrium mechanism is clearly at play, there is another mechanism responsible for organisation on the trip description side of the system that is still unclear. Assignment models can by-pass this problem, as the volume of trips is, to some degree, arbitrary and can be set at a range of different levels in order to assess the sensitivity to potential impacts of induced traffic growth.

Changes to the calculation process that deal with dynamic aspects of travel behaviour are relatively easy to accommodate, as these are presumed to arise from changes to travel times which can be easily calculated. The logic that underscores changes to the trip matrix, that is, changes to OD combinations, however, is not so straight forward. The basis for why people might choose to travel further or more often has been relatively difficult to pin down from a calculation perspective. Very general explanations for why people might do this can be envisaged — and some of these will be discussed later — but generally it is difficult to have these reasons manifest themselves in a numerical form so that they can be incorporated into a model.

Bates (2000) has argued that the enduring appeal of four-step models is that they reflect the logic people use when deciding how they might travel (Bates 2000, p. 17). Other researchers, like McNally (2000), maintain a very different view, arguing that while transport is acknowledged as a *derived demand* — an activity whose consumption is dependent on other activities — conceptually, four-step and assignment models divorce travel from the activities from which it is derived and consequently provide a poor means of replicating many of the processes and factors critical to generating observed travel behaviour (McNally 2000a, p. 55). McNally attributes the endurance of four-step modelling to the institutionalisation of the practice, rather than its ability to reflect travel behaviour or the real decision-making processes of commuters (McNally 2000b, p. 51).

This shortcoming — that most demand models divorce travel from its activity base — has been cited as the primary reason for why many of the sources of induced traffic growth cannot be readily accounted for in such models (McNally 2000a, p. 55). In which case, while the assignment functions may be able to replicate some aspects of real travel behaviour — like trip reassignment — this form of modelling is not well suited to understanding the reasons for traffic *growth.* As a consequence of this realisation, many researchers have turned their attention to activity modelling.

4.1.2 Activity models

While most demand models constitute a variation of the four-step or assignment model format, there are other models that approach the replication of travel behaviour from a radically different perspective and so attribute a different underlying dynamic to it. These models are referred to as *activity-based* models, however, they are not widely used by government transport institutions.

The primary difference between activity and assignment-based models is that travel is treated as part of a series of linked activities, whereas assignment models treat trips as individual and isolated units (McNally 2000a, p. 57). Consequently, the way in which travel is treated remains deeply embedded in the activities from which it is derived. The degree to which trip purposes are linked within the same trip, for example, is important in activity-based models, as are the activities that intersperse periods of travel.

There is no universal theory or algorithm that guides the work of activity-based models. The inability to standardise procedures is possibly one of the reasons why activity-based models have not been more widely used in practice, as the nature of government administration usually requires the standardisation of procedures rather than constant adaptation. Despite these drawbacks, a survey of transport professionals working in private practice, government and academia showed that activity-modelling was rated as a high priority area for research and development over and above more traditional forms of demand modelling (Hensher & Button 2000, pp. 5–6).

There is currently a debate in progress about whether attention should be focused at this early stage in the development of activity-modelling on identifying calculation procedures, or alternately, on the collation of data so that a greater empirical understanding of travel behaviour within an activity-based format can be achieved (McNally 2006, pers. comm.).

4.1.3 Incorporating induced traffic growth in demand models

As outlined in Section 1.3.1, induced traffic growth manifests as several different responses to changes in network conditions, including mode-shifting, trip redistribution, induced trips and trip rescheduling. From a modelling perspective, if using standard four-step and assignment models, accommodating each of these responses would require a change to different parts of the modelling process. For example, the way that mode-shifting features in a model, when origin and destination points remain the same, is different from the way that trip redistribution and induced trips appear when origin and destination pairs change.

Incorporating induced traffic growth into four-step models broadly requires the use of *variable trip matrices* over conventional fixed trip matrix approaches, wherein many of the parameters used to describe trips need to change while the model is run through its various iterations. Incorporating induced traffic growth into assignment models is potentially easier in that a single or array of different demand elasticities may be applied to volumes assigned by the model. The effects of increased volumes along a particular axis on travel and waiting times for traffic travelling in a transverse direction can be accommodated in such models and its effects evaluated, however, the fundamental cause for why demand might increase remains unknown.

From a causal theory perspective, such calculation functions do not outline what causes travel behaviour to change. However, the implications of such a feature can best be appreciated by examining how induced traffic growth might be explained within the terms of microeconomic theory.

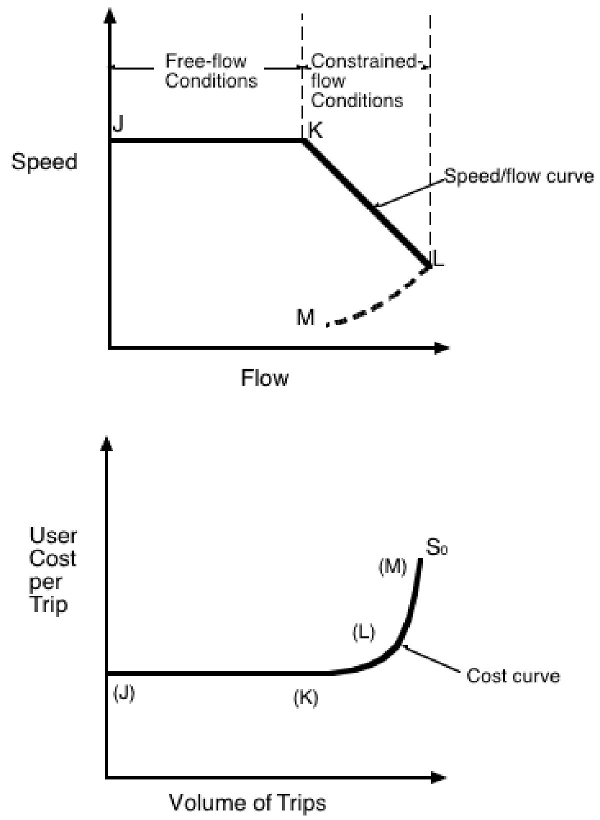
4.2 Explanations for induced traffic growth using microeconomic evaluation

When viewed through the lens of microeconomic theory, the key question concerning induced traffic growth is whether the demand curve is flat and therefore inelastic, or whether it is sloped and therefore elastic (Goodwin & Noland 2003, p. 1452). If flat, then induced traffic growth does not occur. If sloped, then it can occur and should be incorporated in the assessment of motorway projects because it has the potential to undermine the significance of benefits relative to costs.

4.2.1 Microeconomic evaluation of speed–flow–cost relationships

When evaluating the economic credentials of road and transport projects, the process begins by identifying the benefits of a project so that they can be offset against the cost of constructing it. This is undertaken within a Cost–Benefit Analysis (CBA) framework, wherein the estimated benefits are divided by the costs and the corresponding value ranked against other projects (for example, NSW Treasury 1997, p. 56). But to do this, a way of estimating benefits relative to costs has to be found. How induced traffic can affect this relationship can be demonstrated within the terms of a microeconomic theory framework (SACTRA 1994, pp. 123–128).

Figure 4.1 The Speed–Flow–Cost relationship



Source: SACTRA. 1994, *Trunk roads and the generation of traffic*. HMSO, London, p. 116.

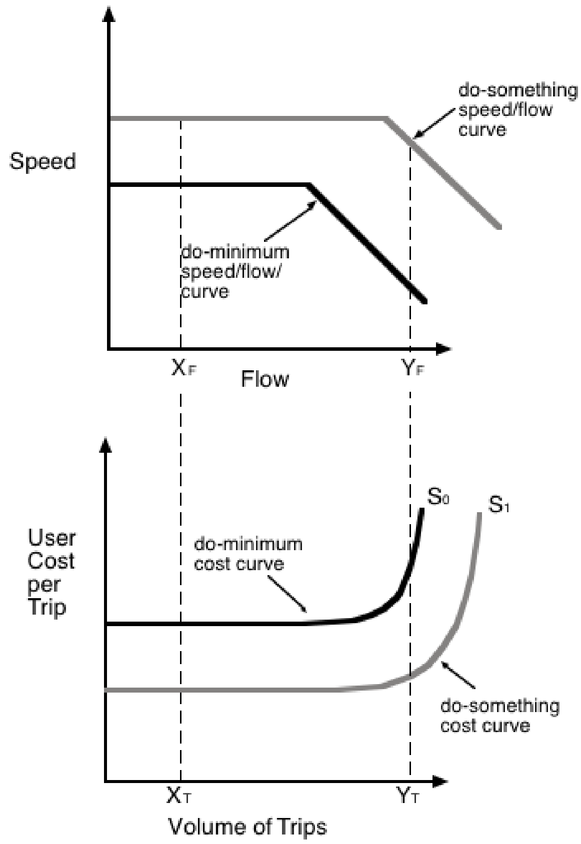
For roads and motorways, the basic characteristics of the infrastructure — or supply curve — are set alongside behavioural responses of the people using it, as represented by the demand curve. To derive the supply curve, the relationship is defined between the speed at which people are able to travel and another critical factor known as flow, or the number of vehicles able to pass a given point. Figure 4.1 shows the form of this relationship.

When only a few vehicles are using a road facility, the speed at which they travel is set by a legal speed limit or the *design speed* of the road. The number of vehicles able to travel at this speed can vary, which is why section JK of the speed/flow curve remains flat. But once vehicles reach a critical number, as indicated at point K, the speed begins to fall. This occurs because the stopping distances, or necessary headways between vehicles, begin to encroach on one another. When this happens, drivers travel at slower speeds to reduce headways so that they can stop if necessary for safety reasons. As the number of vehicles increases, headways become very small and speeds low. Queues form, congestion occurs and delays accumulate rapidly throughout section LM as traffic flow deteriorates and becomes unstable (SACTRA 1994, p. 116).

The speed/flow curve shown in Figure 4.1 is equated with a cost curve. Costs for a trip remain the same between JK, irrespective of how many vehicles are on the road. These costs are defined as the operating cost of vehicles and people’s travel time. For most road appraisals, the value of travel-time savings is a critical factor comprising most of the monetised cost benefits (Goodwin 1981, p. 99; Rayner 2003, p. 1). As conditions become congested, costs begin to rise, as shown at KL. Where roads begin to reach saturation levels, costs rise more steeply, primarily because of increases in journey times, as indicated at LM. If a new motorway is built or a road is widened so that operating and travel time costs are reduced, the speed–flow relationship changes, as does the cost.

When new motorway capacity is added to a congested road network — shown in grey as the do-something scenario — the speed–flow relationship for traffic is changed, as is the cost curve. This is illustrated in Figure 4.2, where it can be seen that when capacity is increased, the volumes for which the facility is able to provide free flow conditions is greater and the point at which flow-rates deteriorate is higher (SACTRA 1994, p. 117).

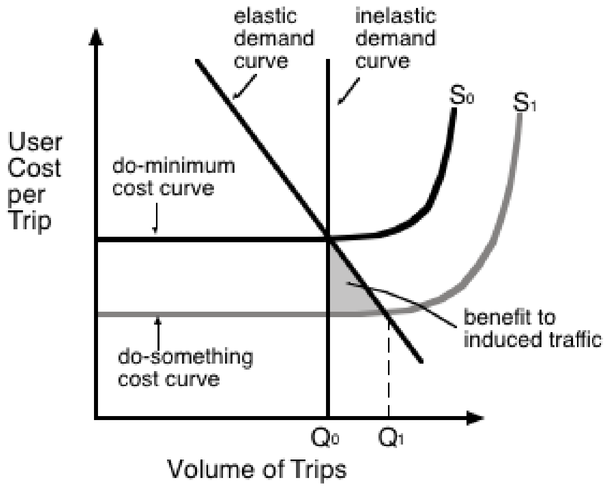
Figure 4.2 The effect of User Costs on road improvements



Source: SACTRA. 1994, *Trunk roads and the generation of traffic*. HMSO, London, p. 117.

There are broadly two ways in which additional road space can affect the speed–flow relationship and hence costs. The first refers to cases wherein a motorway by-pass might be built, for example, enabling people to travel at 110 km/h instead of 70 km/h. In this way the travel time component of the User Cost is reduced and shown as Case X in Figure 4.3. The second occurs when the addition of capacity enables vehicles to increase the amount of headway between them so that they can travel at higher speeds, reducing travel times in that way. In this case congestion is reduced and vehicles are able to travel at improved service levels.

Figure 4.3 Addition of road space in uncongested conditions

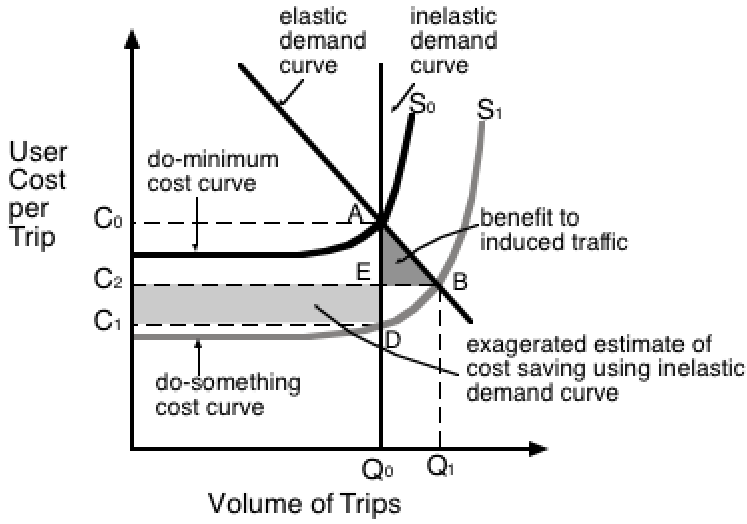


(Case X: increasing free-flow speed)

Source: Source: SACTRA. 1994, *Trunk roads and the generation of traffic*. HMSO, London, p. 118.

Figure 4.4 considers the changes in User Costs as a result of a project that increases the free-flow speed of traffic, such as a by-pass. Because the trip is quicker, people may make that trip more often. The elastic demand curve shows this change and the section indicated with the dark-grey hatching reveals the benefits to induced traffic growth. Because this increase in demand does not adversely impact on the flow of vehicles, any evaluation that did not include the possibility of induced traffic growth — one based on an inelastic demand curve — would return an underestimation of the benefits. But if the addition of road capacity is introduced under congested conditions, a different result is achieved (SACTRA 1994, p. 118).

Figure 4.4 Addition of road space under congested conditions



(Case Y: increasing capacity and free-flow range)

Source: SACTRA. 1994, *Trunk roads and the generation of traffic.* HMSO, London, p. 119.

When an inelastic demand curve is used as shown in Figure 4.4, costs are reduced from C_0 to C_1. But when an elastic demand curve is used, User Costs are only reduced to C_2. The key difference between Case X and Y is the point at which the demand curve intersects the supply curve. The more elastic the curve is, the greater the degree to which estimated benefits are eroded. In Case Y, the benefits are exaggerated if an inelastic demand curve is used. In these cases the critical question becomes: are the cost differences between C_1 and C_2 such that estimated benefits are not large enough to off-set construction costs? (SACTRA 1994, pp. 119–120).

While such a framework provides a means of evaluation changes to road networks, it does not provide an explanation as to why in fundamental terms individuals might choose to change their travel behaviour in such a way that they travel further or more often when travel speeds increase. For this explanation, microeconomic theory relies on the concept of utility, as outlined in marginal utility theory.

4.2.2 Marginal utility theory and economic happiness

Surprisingly, microeconomics and utility theory have their origins in the evaluation of transport proposals. This is surprising because contemporary explanations of the key ideas that form the basis of microeconomic theory usually rely on examples that involve the production of easily traded goods that can be consumed in discrete units, like ice, creams (for example, Samuelson et al. 1992, p. 124). Consumption of an infrastructure service, like transport, is widely viewed as a special case. Most commentaries acknowledge that transport networks have a physical form that makes them physical monopolies and so significantly different from products that are consumed in discrete units. In addition, transport infrastructure is a public good whose performance is generally optimised through tight regulation and an absence of competition (for example, Samuelson, Hancock & Wallace 1970, pp. 99–100).

Recent research by economic historians Ekelund and Hérbert (1999) has found that the methods of analysis used by French engineers working for the Corps des Ingénieurs des Ponts et Chaussées — and in particular that of nineteenth century transport engineer Jules Dupuit — show a working familiarity with concepts like marginal utility theory and the construction of demand schedules.[29] These engineering origins are significant in light of the earlier discussion about the difference between engineering and scientific knowledge. The origins are also significant because many of the debates that currently surround marginal utility theory, and its application to transport problems, also took place during development of these concepts in the nineteenth century. Some of these debates will be discussed later in this section. But before doing so, it is useful to recount the basic definition of utility and the auxiliary ideas that constitute marginal utility theory.

Samuelson defines utility in the following way:

> Utility denotes satisfaction. More precisely, it refers to the subjective pleasure or usefulness that a person expects to derive from a good or service (Samuelson et al. 1992, p. 124).

[29] The development of marginal utility theory is usually attributed to Menger, Jevons, Walras and Marshall. The reasons for Dupuit's relative obscurity have been variously attributed to language differences, that his primary concern was application rather than theoretical development and that, unlike better known theorists, Dupuit did not articulate his ideas in one great thesis. Instead, his contributions were recorded in a series of essays and government inquiries (Ekelund & Hérbert 1999, p. 3).

Samuelson describes utility as an *expository concept* — unable to be described in and of itself, but rather an idea that needs to be understood within the context of a range of other ideas.

When placed within the context of the dynamic relationship between the supply and demand for a particular good or service, utility — as a goal of consumers — provides the rationale for the downward slope of the demand curve. As more units of a good are consumed, the marginal utility, or additional satisfaction, becomes less with the consumption of each additional unit (Samuelson et al. 1992, pp. 124–128). Likewise, the shape of the supply curve changes with the production of additional units depending on the particular conditions that pertain to the supply of that good or service (Samuelson et al. 1992, pp. 184–187). Importantly, where the supply and demand curves intersect, utility is thought to be maximised for any given market.

The maximisation of utility, and how it sits within the corresponding framework of supply and demand profiles, transforms the concept of utility, so that it becomes more than a generally vague notion about individual satisfaction, but one involving a form of optimisation. Ultimately, it is the prospect of optimisation that gives the concept and attendant framework its credibility and authority.

But what is utility in a transport context and what can it tell us about the causes of induced traffic growth?

The value of the utility that consumers place on a particular good or service is manifest in the price they are willing to pay for it. In transport analysis, demand curves are usually conceived in terms of the *generalised cost* of transport, which includes the various fixed and variable costs associated with fuels, vehicles and infrastructure — to which a price can be assigned. The generalised cost of transport also includes a person's travel time. Travel time is significant because, as discussed briefly in Section 1.3.2, most of the benefits, or reductions to the generalised cost of transport, that are attributed to the installation of additional road space, are realised as travel-time savings. In some cases, this is as much as 80 per cent of total benefits. So that at the very least, microeconomics tells us that the inclusion of travel time is often critical to realising benefits on a sufficient scale to offset the high cost of urban motorway construction.

There is considerable debate within the professional transport community, however, about the practice of assigning hourly wage-rate equivalents, or any money value in some cases, to travel-time savings for the evaluation of urban motorway proposals. This is because the travel-time savings are relatively small on a trip-by-trip basis, but when added together, can produce a large monetary value. Those who doubt the validity of such a practice argue that there is little in the way of productive or satisfying activity that could be undertaken with the small time savings, so that viewing the value of time saved as a proxy for the utility of time spent on alternate activities is undermined, because the time periods involved do not represent benefits that are tangible. The robustness of utility transfers in such cases is doubtful, because time does not have the same transferability characteristics of the other factors that comprise the generalised cost of transport. For example, if a small volume of fuel is saved on a standard trip, multiple fuel savings can be materially combined so that an entire trip could be fuelled with those savings. By contrast, small time savings cannot be materially combined in the same way. This is because time moves forward as a specific and unbreakable sequence, consequently, its transferability is not as straight forward as that of other material factors.

Those who support the procedure have argued that, when combined, small travel-time savings for urban motorway segments that work to form a network, do amount to meaningful time savings (for a summary of the debate, see Welch & Williams 1997). But if this is the case, then evaluation should really compare the costs and benefits of entire urban motorway networks with entire rail networks, for example. If this is done, the generalised cost of transport for cities that are largely mass-transit based is shown to be lower on a per capita basis than it is for cities that are private-car and motorway based (see, for example, Figure 1.19 and Figure 1.20).

But if these criticisms and empirical evidence are valid, then what is microeconomic theory and evaluation really telling us?

There are three key issues that arise in relation to these criticisms and empirical observations. The first relates to whether or not all the utility transfers — including significant disutilities — are captured in the analysis, and if not, to what degree might the absence of these factors be skewing results? The second issue relates to the theoretical robustness of such a form of micro-analysis. Or in other words, is an analysis framework that approaches the problem from a part-system perspective as robust as one that approaches it from a whole-system perspective? Does the concept of utility change when viewed from a whole-system perspective? The third issue relates to the way that time features within such a framework. By translating time into a money value, whereby changes in price control system feedback responses, are the important structural relationships responsible for the way in which urban systems behave being faithfully represented? Or is the control mechanism that relates to time more complicated, so that optimisation takes place in a different way?

As discussed in previous sections, when motorway capacity is added to an urban road network the change in service levels triggers a raft of different responses. Some of these can be construed as having positive outcomes, while others are negative. Many of these outcomes are not incorporated into the analysis, either because they are difficult to quantify, or because there is controversy surrounding their relationship to the capacity increase. For example, when a new motorway is opened to traffic, the change in service levels that it affords can attract commuters away from other routes and public transport services that had been the focal point for particular patterns of land-use development. Changes to movement patterns may alter the commercial viability of businesses orientated around these alternate routes. The volume of traffic supporting these land uses may be reduced to a point where such businesses are not viable. Travellers who did not change their route or mode in response to the motorway may have to change their travel patterns, despite this being inconvenient and a disutility for them. These outcomes, however, were not included in the evaluation. If they were, the general cost of transport may have increased rather than decreased.

In such a scenario, the conception of utility and the microeconomic theory used to calculate costs and benefits is not at fault, but rather, the way the analysis is executed.

However, if the qualifier *all other things being equal* is incorrect and the addition of urban road space triggers complex structural changes to the urban system, then the theoretical robustness of such an analysis framework may be at fault, which raises the second issue.

The second problem — analysis of the whole system versus analysis of a selected part — questions the application of microeconomic theory at a more essential level. The nature of the problem can perhaps best be understood firstly through an analogy. Standard surveying techniques use Euclidean geometry to measure and stake out points in real space in order to map the shape of an object. Such methods assume that all lines and planes are flat. If used to record the contours of a landform, or locate key points for construction of a building, these assumptions do not jeopardise the task at hand. However, if the same assumptions are used to survey the world, section by section, such an incremental approach would encounter difficulties, because it assumes all planes to be ultimately flat.

If a similar problem is occurring in relation to the microeconomic evaluation of urban motorways, a question that must be asked is what critical characteristics of the system have been left out of the analysis and how is the method doing this?

There are critical differences between the notion of an individual travelling on an urban transport system, for a purpose specific to her or him, and that of a large group of people, where its purpose is conceived in terms of a common goal. The first difference is that, in a group setting, the relationships between individuals and other system elements are taken into account in a way that goes unacknowledged when examining motivation from an individual perspective. For example, if various individuals were asked why it is that they live in a city, a wide variety of disparate reasons would be given. From a group perspective, however, the reason for living in an urban system is to facilitate the division of labour and complex industrial activity, as outlined in Chapter One. An urban transport system contributes to this by *providing access* to a wide diversity of destinations, as was outlined in Section 1.1.5. The individual reasons cited for travel can all be seen as related sub-sets of this group motivation. When defined in this way, however, the concept of accessibility raises a different set of relationship questions from those that arise when the problem is framed in terms of reductions to the generalised cost of transport. Indeed, the way in which access would be measured is different from how utility is measured.

The second difference relates to the way in which goals, or the needs of such a group, are communicated to those making decisions about the supply of transport services. When communication of purpose is conceived in terms of increasing private utility and market forces, goal definition is approached differently. For example, when the DMR was questioned by the Commissioner during an Inquiry into the F5 freeway in Sydney on whether or not urban motorway development, and the induced traffic growth to which it gives rise, were in the best interests of the community, the DMR explained that:

> The Department's view in this respect is that it is the road authority's [responsibility] to provide for arterial roads; it is not its business to tell people … what they should and should not do in respect of travel. It endeavours to, or aims to cater for the demand as it appears … (Kirby 1981a, p. xi).

Or in other words, if capacity is added to a road network, and the number of individuals using it increases, it is assumed that a legitimate, albeit unspecified, need is being fulfilled by building the road. The implications such travel behaviour changes might have for the sorts of goals a whole community might set are not considered, for communication of these is made through a political decision-making process, as outlined in Chapter Two. From an optimisation perspective, viewing the goal of such a development from a group perspective transforms concepts of what may have the greatest utility in a public sense.

Systems theorists account for such *transformations* through the concept of *emergence*, as outlined in Section 2.1.1. If a system element is considered in isolation, properties that it acquires when working in conjunction with other parts of a system go undetected, as these only emerge when the system is viewed as a working whole. The same could be said for the notion of utility and how it applies to infrastructures. Infrastructures exist primarily for the purposes of enabling large numbers of people to work as a group. Consequently, the utility of an infrastructure needs to be viewed in terms of its benefit to a group of people — its public utility — rather than how it might benefit people as isolated individuals. If analysis is pursued on the basis of private utility, it is possible that key characteristics of the system may be excluded from the analysis, so that a sub-optimal outcome is created.

Social scientists commonly refer to such situations as *social dilemmas*. Social dilemmas arise when the behaviour of an individual may seem rational if viewed purely from the perspective of that individual, but counter-productive when viewed from the perspective of the whole system of which an individual's behaviour is an integral part (for example, VanVugt 1997).

Both current and late twentieth century and nineteenth century researchers have argued that there is a substantial difference between private utility and public utility (Ekelund & Hérbert 1999, pp. 76–77). While a new transport infrastructure may enable an individual to gain satisfaction from being able to undertake a particular trip more quickly so that her or his private utility is enhanced, such an investment may not add to general productivity, or public utility, through net efficiency gains which can be gauged when the system is analysed as a whole.

The third problem area relates to the issue of whether or not the mechanics of microeconomic analysis are able to faithfully render the way in which time features structurally within an urban system. If the relationship between supply and demand is conceived in system terms, where changes to one create feedback responses from the other, then control of the feedback relationship is enacted through changes to prices. In this way, pricing is treated as the control mechanism. However, when systems theory is applied to problems in the material world, the concept of control, and a control mechanism, can manifest in many different ways. This raises the prospect that perhaps the unique features of time, and the relationship it has with other elements in the urban system, cannot be faithfully represented as a form of system feedback, where, price acts as the system controller. These aspects of travel behaviour will be discussed in more detail in Chapter Six.

There are several theorists who have attempted to articulate significantly different approaches to the evaluation of transport projects and theoretical accounts of induced traffic growth. Some of these theories are fundamentally different from those used to construct transport demand models and microeconomic evaluation frameworks. Others have augmented these concepts in such a way that essential ideas can still be recognised, but the outcomes are wildly different. One of the more widely known theories of this kind is the theory put forward by Martin Mogridge.

4.3 The Mogridge conjecture and the Downs/Thomson paradox

The *Mogridge conjecture* focuses on an equilibrium mechanism responsible for the component of induced traffic growth that can be attributed to mode-shifting. In light of the previous discussion in this chapter, such a theory would not appear to move away from conventional thinking. However, its central thesis — that average road speeds are set by the average speed of a city's mass transit network — is a significant departure from conventional thinking, not least because its implications are that in order to improve the road network, service levels on the public transport system need to be maintained at a commensurate level.

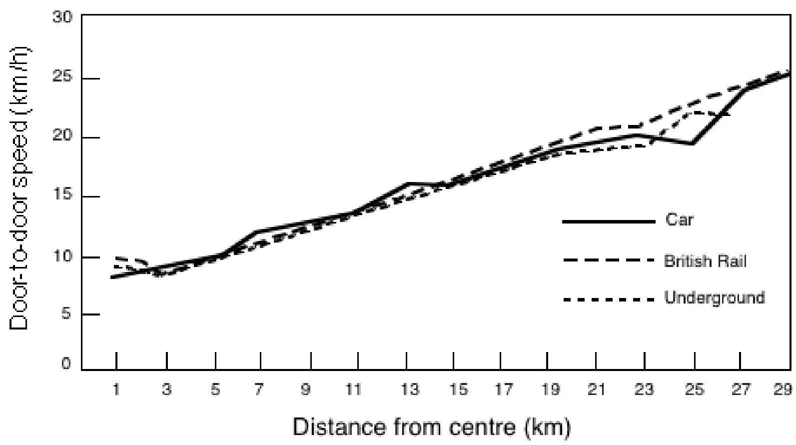
Unwittingly perhaps, the Mogridge conjecture also attempts to account for changes to urban travel behaviour from a whole-system perspective rather than a bit-part perspective. It does this because it begins to conceive of urban transport as competing networks.

The Mogridge conjecture was prompted by the empirical observation that average travel speeds across different modes in London appear to have remained much the same for almost five decades (Mogridge et al. 1987, p. 283). As later research by Mogridge explained:

> A comparison of two surveys in 1936 and 1986 shows … how little has changed. Three 20 km routes across the city from approximately the north to the South Circular roads, and one 37 km route around North Circular, were measured fifty years apart; the speeds across the city were 20 km/h and that around the orbital was 37 km/h in both surveys. And this is with a ten-fold increase in car ownership in the period (Mogridge 1990a, pp. 12–13)

Figure 4.5 shows average morning peak travel speeds for travel by car, suburban rail and the London underground system. As can be seen, speeds across modes are similar at the same distance from the city centre, progressively slowing with closer proximity to the centre.

Figure 4.5 Average direct speeds of morning peak-hour journeys to the centre of London



Source: Mogridge, M. J. H., Holden, D. J., Bird, J. and Terzis, G. C. 1987, *The Downs/Thomson paradox and the transportation planning process* in International Journal of Transport Economics p. 289.

In their search for an explanation, Mogridge and his collaborators Holden, Bird and Terzis drew on theoretical contributions from several other transport researchers, but primarily on the work of Downs (1962) and Thomson (1977). Both Downs and Thomson proposed the existence of an equilibrium relationship between road and mass transit networks that Mogridge *et al.* (1987) referred to as the *Downs/Thomson paradox.* The paradox arises because under some conditions the marginal cost of trips before investment in urban motorways may be less than after investment. This is particularly the case if demand modelling and economic evaluation methods do not incorporate mode-shifting into their assessment.

Before considering the central argument of the Mogridge conjecture, and the debate that has taken place around it, it is useful to examine the theories of Downs and Thomson in some detail.

4.3.1 Downs' law of peak-hour traffic congestion

The first explicit attempt to provide a theoretical account for why traffic volumes appear to increase and traffic jams continue after the addition of new motorway capacity appears in a paper by Downs, entitled 'The law of peak-hour expressway congestion' (Downs 1962). The paper focused on the inability to reduce congestion in cities purely through urban expressway development. Downs saw this failure as the result of something he called *traffic equilibrium* (Downs 1962, p. 393).

Downs begins by outlining four axioms concerning commuter behaviour (Downs 1962, pp. 393–394 and 408). The first states that all commuters try to minimise travel times to and from work within four constraints — *income*, which determines what mode of transport is affordable; changes to the *money cost of transport*, which includes factors like fuel and fares; *residential location*, which determines the modes and options available, and; *personal comfort*, which relates to personal preferences like avoiding contact with crowds and fixed schedules. The second axiom states that most commuters have a low inertia to changing routes. Once a mode is selected, an individual will stick to a route that appears quickest until conditions change in such a way that pushes her or him over her or his *route-decision threshold*. The third axiom states that commuters will change their route, or mode of transport, if travel time can be reduced. The fourth axiom distinguishes commuters according to their decision-making threshold, describing them as either *explorers* or *sheep*. Explorers have a low route-decision threshold and change routes quickly in response to ephemeral obstacles to reduce travel times. Sheep, on the other hand, have a high route-decision threshold and stick to a regular route, only changing when confronted by significant obstacles and changes to travel times.

When these four axioms of commuter behaviour are put into play, they work to generate a state that Downs called *traffic equilibrium* (Downs 1962, p. 395). Through a process of trial and error, individual commuters attempt to reduce their travel times. Confronted by multiple route options, most commuters — *sheep* — will settle into a travel pattern that seems quickest. However, commuters who regularly shift between different route options — explorers — will keep doing so until no further travel time-savings can be gained and the system settles into a state in which all routes move at a typical speed.

This happens because sheep outnumber explorers, their inertia keeping network speeds stable. This is how the system reaches a point of traffic equilibrium, at which speeds remain roughly the same.

Downs described how traffic equilibrium operates in relation to three different transport scenarios — one with roads only, a second with road and bus options and a third with road and segregated carriageways for public transport (Downs 1962, pp. 396–406).

In the roads-only scenario, Downs explained that new expressway capacity between a city's outer suburbs and CBD generates a *disequilibrium*. Initially, travel speeds on the new expressway route are vastly quicker than alternate routes. Explorers soon shift to the faster route. As word of the travel-time savings spreads, more commuters — many of them sheep — shift to the quicker route too, reducing travel speeds for commuters on the new and old routes. However, as more commuters shift to the expressway, congestion rises so that the expressway operates below its optimum speed during peak hour.

Despite congestion, travel times on the expressway are still quicker because it is less circuitous and has no traffic lights or intersections to slow traffic. Consequently, commuters continue to be attracted to it even though average travel speeds are slower. Shifting between the expressway and alternate routes stops and the system reaches a new equilibrium when travel times between origins and destinations are roughly the same for all routes.

The same outcome occurs in relation to trip timing. Where roads had been highly congested before the expressway opening, some commuters departed either before or after the peak to avoid congestion. Faster road speeds might encourage some commuters to leave later than previously, and so reduce the spread of peak-period traffic. These convergences in scheduling and route choices tend to force levels of congestion upwards to the maximum capacity of the expressway (Downs 1962, p. 398).

In summary, Downs foresaw three outcomes. First, a reduction of traffic on more circuitous alternate routes would reduce journey times for commuters wanting to access destinations not served by the new expressway. Second, the expressway would carry heavy traffic loads during peak hour and the speed would be lower than the optimum, but journey times would be shorter as the route is more direct. Third, the duration of the peak period would be reduced (Downs 1962, p. 399). Downs, however, did not explicitly anticipate any increase in trip numbers or average journey distances in response to the new expressway capacity.

In the roads-and-bus service scenario, Downs reasoned that as traffic levels on alternate routes fell and speeds increased, journey times for both buses and cars would be reduced. The time savings for bus trips would be less than for car trips, as fixed costs remain much the same and buses simply must stop to pick up and put down passengers, so time savings would be less. As a result, some bus commuters would shift to driving their cars, adding to road traffic congestion and reducing some of the time savings (Downs 1962, p. 400).

What becomes critical is the number of bus commuters who might shift modes. This is dependent on several factors such as income levels, the cost of parking at destinations and the configuration of bus services — local as opposed to express. If the number of commuters who leave bus services to drive is large, declines in bus revenue could force operators to increase fares or reduce service levels. The latter would increase journey times for bus commuters. Such an outcome would create a further disequilibrium, encouraging more commuters to leave the bus system.

Once the system has reached its ultimate equilibrium, and provided bus services are still in operation, Downs envisaged four outcomes. First, commuting times would be less for all commuters. Second, a smaller proportion would catch the bus. Third, operating costs per passenger would rise, leading to possible service cuts. Fourth, because of mode-shifting from bus services, travel time reductions for motorists would be less (Downs 1962, p. 401).

In Downs' third scenario the crucial difference was the presence of segregated carriageways for public transport. Unlike buses and on-street tramcars, when public transport operates on a segregated carriageway its speed is independent of road traffic levels. The effects of opening a new expressway are the same for the previous scenarios except that commuters using public transport services experience no reductions in travel times. Consequently, the disequilibrium between the desirability of travel by cars and public transport is sharper, so many commuters who formerly used public transport services shift to using the road and expressway network. Downs notes:

> As more and more commuters start using their automobiles to reach work, the level of traffic congestion begins to return to the level existing before the expressway improved traffic conditions. Theoretically, such shifting could continue until the original automobile commuting time was re-established in spite of the added capacity introduced by the expressway (Downs 1962, p. 404).

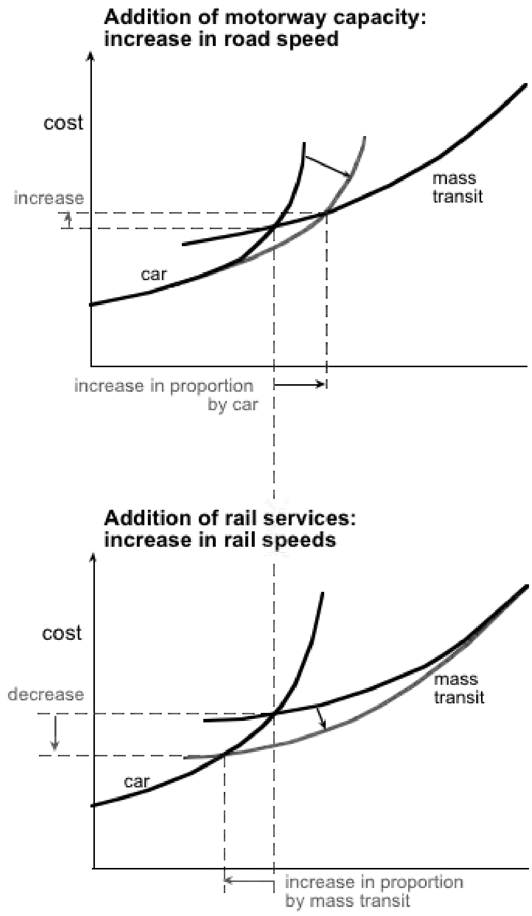
Downs also notes that:

> In any city where the number of non-automobile commuters is relatively large, the shift from other means of commuting to automobiles may become extremely significant, especially if a whole network of expressways is built converging on the downtown area (Downs 1962, p. 404).

Mogridge illustrates this point in a diagram, an adaptation of which is presented in Figure 4.6. In his review of Downs' contribution, Mogridge notes that:

> Downs (1962) seems to have been the first to argue through the consequences of the allocation of the space of the city between car users and public transport users … but it seemed to have no impact on the transportation planning profession for the next two decades (Mogridge 1990b, p. 190).

Figure 4.6. The Downs/Thomson paradox: increasing road capacity vs. improving collective transport



Adapted from: Mogridge, M. J. H. 1997, 'The self-defeating nature of urban road capacity policy: a review of theories, disputes and available evidence' in *Transport Policy* Vol. 4, No. 1, p. 9.

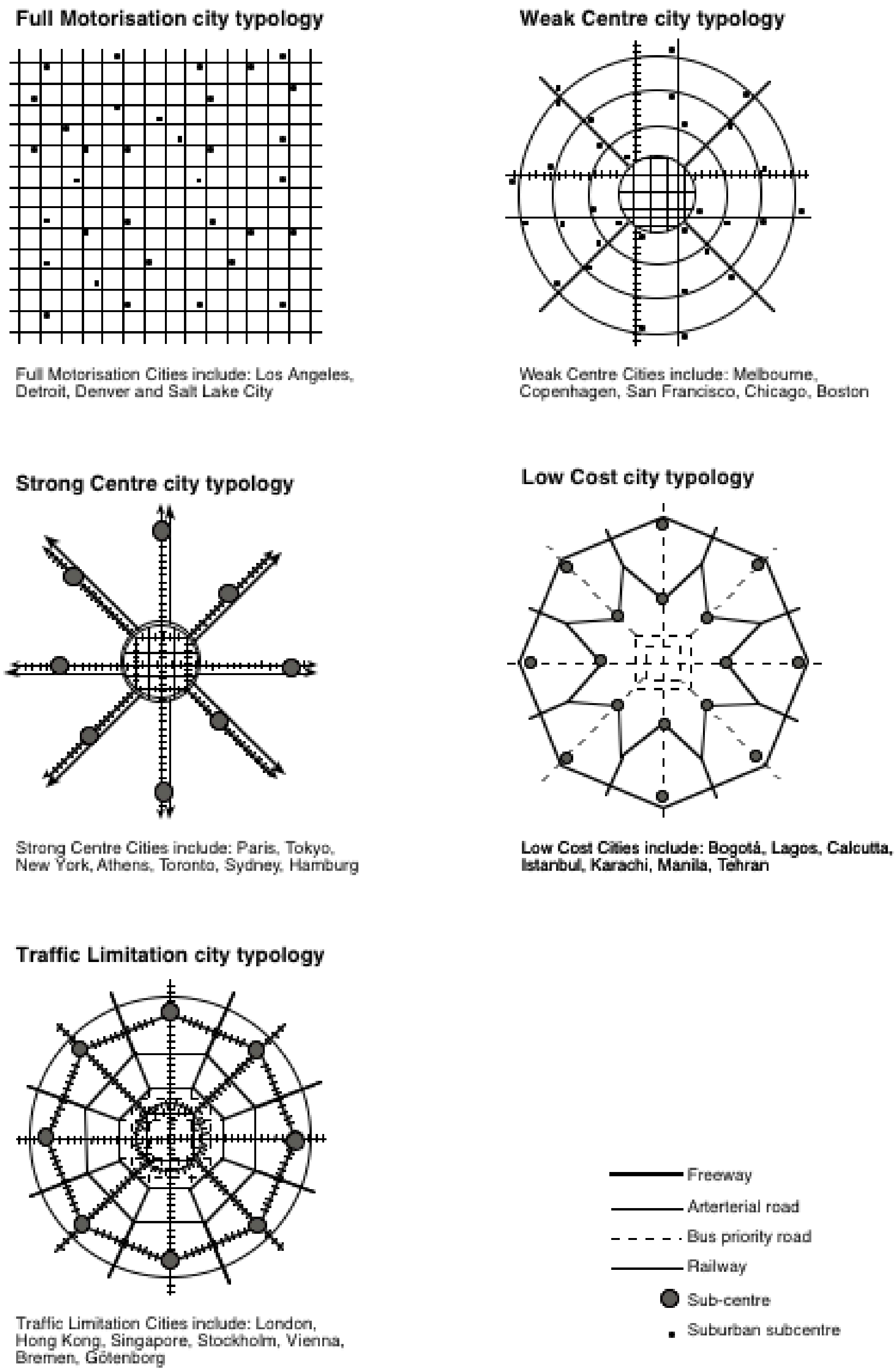
The second author to the Downs/Thomson paradox is transport economist Michael Thomson. As discussed in Section 2.2.1, Thomson had been instrumental in public campaigns against proposed motorway developments in London during the 1970s.

4.3.2 Thomson's great cities and their traffic

Like Downs, Thomson believed that an equilibrium mechanism was at play (Thomson 1977, p. 96). However, Thomson's thesis was much broader. Where Downs's was conceived in terms of individuals moving between alternate routes in search of faster travel times, Thomson conceived of an equilibrium balance between people choosing between different *types of networks* and accompanying patterns of land-use development. The geometry and relative dominance of different transport modes, as well as corresponding forms of building and patterns of land-use development, were all of critical significance when establishing a balance between providing easy access for people and combating the congestion that necessarily arises when large numbers of people are attracted to the great diversity of activities found in large cities. In short, where Downs thought about the implications of induced traffic growth in terms of a part of the urban system, and trips as relatively isolated activities, Thomson thought in terms of whole urban systems, contiguous activities, the urban amenity that different system types afford their resident population and the businesses of cities, economic vitality and safety.

Thomson identified five archetypical city typologies to encapsulate these ideas and presented them in a book entitled *Great cities and their traffic*, which was published in 1977. The five archetypes are shown in Figure 4.7.

Figure 4.7. Thomson's five city topologies



Adapted from: Thomson, J. M. 1977, *Great cities and their traffi,* Gollancz, Harmondsworth, pp. 100, 131, 163, 226 and 267.

Each of the archetypes is dominated by a particular network geometry and set of logistical properties determined by different transport modes. Thomson wrote about each of the typologies in terms of strategies, or transport policy choices made by government transport institutions. When doing this, Thomson acknowledged that the success of transport policies was dependent on the types of decision-making systems used to determine policy. Each of the strategies constitutes a different way of resolving the inherent conflict between the need for people to congregate close together in order to make large numbers of exchanges, and the need to overcome the congestion that obstructs such congregation.

The *Full Motorisation* city typology recognises that intense points of activity like CBDs cannot be accommodated if networks are predominantly road based and the private car is the primary means of access. This is because high concentrations of activities would generate heavy congestion. Abandoning CBDs means that radial transport networks are not necessary, so that development can proceed on the basis of a grid structure with low land-use densities. The primary drawback of this pattern of development is that individuals without access to a car are disadvantaged (Thomson 1977, pp. 99–101).

The *Weak Centre* city typology maintains a relatively small CBD, but balances this against a series of urban centres accessed by a series of orbital roads. A tension necessarily develops between the strength of the CBD and alternate suburban sub-centres. As Thomson explains:

> The problem with the weak-centre strategy is that it does not consist of a natural equilibrium: it does not reflect a position towards which market forces tend to move: it is not a self-regulating strategy but rather one that can easily overbalance in the direction of an overgrown centre or just another sub-centre (Thomson 1977, p. 132).

In addition to an extensive road network, a mass-transit service is necessary to serve the CBD during peak hour when congestion is potentially high, but it is comparatively expensive to maintain (Thomson 1977, pp. 130–133).

Thomson’s next city archetype is the *Strong Centre* city typology, which is dominated by its CBD, so that it must be made highly accessible via a predominantly radial network. The strength of the city centre means that a local distribution network within the centre is necessary to achieve high levels of accessibility.

The ideas embodied in the Mogridge conjecture attributed to the Thomson half of the Downs/Thomson paradox arise in recognition of the pursuit of two conflicting types of transport development in a Strong Centre city typology, namely the development of radial motorways against radial mass transit links:

> Hence we derive one of the golden rules of urban transport: the quality of peak-hour travel by car tends to equal that of public transport … The important conclusion to be drawn is that all attempts to improve peak-hour travel conditions by car will fail unless public transport is also improved. Unhappily, attempts to improve traffic conditions by providing more capacity *can* lead to a deterioration in public transport if, by drawing paying customers away from the latter, they force an increase in fares and a reduction in services. In this case the balance of traffic may shift from public to private transport until a new equilibrium is reached where each system is of lower quality than before (Thomson 1977, p. 165).

The *Low Cost* city typology differs from the previous three archetypes in that it would invest less in its transport networks — no extensive freeway network to serve a low-density metropolis or high-capacity mass-transit system to support a high concentration of development in the CBD. Instead, a high-density CBD that is relatively modest in scale by comparison with that of Strong Centre cities, would be served by a network of arterial roads providing access for road-based forms of mass transit. But because such transit systems are limited to relatively low capacities, a series of strong sub-centres accessible by ring roads and road-based mass transit would also be necessary. All would be maintained at high densities. Such a city, in Thomson's view, would need to be highly regulated in order to resist the tendency towards low-density single-use development that usually accompanies road-based networks (Thomson 1977, pp. 224–227).

When describing the Low Cost city typology, Thomson was conscious of this being a strategic ideal suited to cities located in developing economies. At the time when Thomson was writing, he acknowledged that such a strategy would be difficult to maintain at high Levels of Service. In later decades, the transport and land-use development realised in Curitiba could be seen to provide a good example of this city archetype working at an equilibrium (Parasram 2003) .

The *Traffic Limitation* city typology, like the low cost-city type, is the product of a deliberate strategy. While recognising that people will use their cars for some trips, it attempts to deliberately minimise use by providing a structure that reduces the need for extensive travel, with the aim of reducing congestion while at the same time maximising accessibility. Unlike the Weak and Strong Centre typologies, the Traffic Limitation city provides radial mass transit links between outer lying sub-centres. In order to maintain the necessary equilibrium between private-car and public-transport use, deliberate strategies that restrict the flow of private cars to the CBD would need to be pursued in addition to strategies aimed at ensuring a diverse mix of land-use activities located within close proximity to people's homes (Thomson 1977, pp. 263–268).

When viewing the issue of urban motorway development using Thomson's framework of city typologies, the addition of motorway capacity to a *Full Motorisation* city typology may bring about improvements in travel times and therefore accessibility, however, the social and economic dynamic of dense mixed-use centres is forgone in order to achieve this. The same strategy pursued in a city with a structure like that described in the third, fourth and fifth archetypes — the Strong Centre, Low Cost and Traffic Limitation city typologies — would likely retard, rather than enhance, accessibility.

Thomson's was the first extensive empirical analysis that compared whole city systems with one another (Thomson 1977, pp. 22–90). This same approach featured in the later empirical analysis by Newman and Kenworthy (1989), some of which was briefly examined in Section 1.1.2. In their analysis, Newman and Kenworthy focus on alternate transport modes but largely overlook the critical issue of network geometry. Consequently, while similar, their discussion of urban structure is less detailed than that of Thomson.

4.3.3 Criticism of the Mogridge conjecture

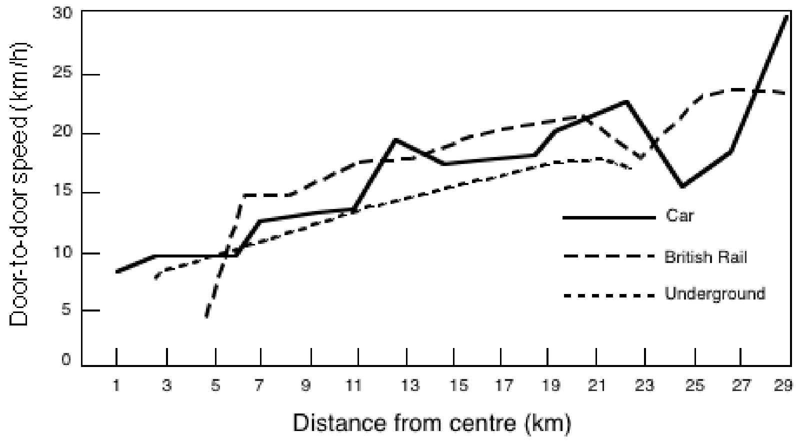
The theoretical proposition central to the Mogridge conjecture goes further than the theoretical work by Downs and Thomson in that it proposes that road speeds are set by public transport speeds and that this can be supported empirically. As outlined by

Bly, Johnston and Webster (1987), if this were true, ‘the implications for urban transport planning would be far reaching’ (Bly, Johnston & Webster 1987, p. 8). The reason for such far-reaching implications relates to transport evaluation conventions at that time. While the prospect of mode-shifting in response to changes to Levels of Service on the road network is not inconceivable today, at the time when this debate was taking place, conventional practice did not incorporate such responses into demand models and economic evaluation. It is quite possible that this was as much a product of different institutions being responsible for different modes as much as it may have been the product of ideology or expectation in the absence of empirical analysis.

Bly, Johnston and Webster, however, were not convinced that the Mogridge conjecture was sound. They criticised the theory on several grounds. First, they showed that data for average travel speeds for different modes in London was not as similar as portrayed by Mogridge. As shown in Figure 4.8, there is far greater variation between door-to-door speeds when data are disaggregated and analysed as sectors, rather than whole annuli, as was the case in Figure 4.5. In response to this criticism, Mogridge and Holden point out that the Mogridge conjecture is about journey speed and not traffic speed. The data on which average journey speeds is based come from disparate sources such that the coefficient of variation is not known, and the sample sizes are in many cases small. Because journey speeds and not travel speeds are the central concern, in the case of car travel, parking time had to be included. Data for this were not directly available and so, in many cases, were estimated. Consequently, variation may be a product of the calculation and collection methods and so the hypothesis should not be discarded (Mogridge & Holden 1987, pp. 14–15).

But despite the greater variation, Bly, Johnston and Webster conceded that there was some relationship between different modes, as average road travel speeds were higher in those sectors where average public transport speeds were also higher (Bly, Johnston & Webster 1987, p. 9).

Figure 4.8 Average direct speeds of morning peak-hour journeys to the centre of London



Source: Bly, P. H., Johnston, R. H. and Webster, F. V. 1987, 'A panacea for road congestion?' in *Traffic Engineering and Control*, January, pp. 9–12.

After concluding that data alone could not provide sufficient evidence to support the Mogridge conjecture, Bly, Johnston and Webster sought to identify whether the conjecture was theoretically sound. Their exploration of the conjecture focused on the applicability of Wardrop's first principle — that travel times between two points on a road network, where multiple routes exist, will equalise (Wardrop 1952). Mogridge *et al.* claimed that a similar outcome would occur if the same principle were extended to traffic on multiple modes (Mogridge *et al.* 1987).

Bly, Johnston and Webster canvassed other explanations for why road and public transport speeds might remain stable and similar over time. On the supply side, they felt the response of road agencies — to increase capacity as average road speeds fell below *acceptable* levels — could be an important factor. Mogridge and Holden dismissed this claim by pointing out that engineers and transport authorities could not realistically close and pedestrianise streets, to the extent that they have been in London, and achieve the same speed. Instead, they argued:

> We do not claim that improving public transport is a panacea for road congestion …What we do claim is that, if Mogridge's hypothesis and its corollary are valid, then improving road capacity in central cities does not improve traffic speed, and may actually reduce it (Mogridge & Holden 1987, p. 18).

Mogridge and Holden reject this explanation, arguing that it is no explanation at all. They noted that on the demand side, Bly, Johnston and Webster argued that average speeds in the central areas of London were lower because walking was a viable option for many trips, as origins and destinations were located very close together. Consequently, in outer areas, average speeds were higher because the average trip distances were greater (Bly, Johnston & Webster 1987, pp. 10–11).

Mogridge and Holden countered that, like the Modgridge conjecture, this explanation also points to an equilibrium mechanism, only with the speed of walking as the default speed for the system generally. In which case Bly, Johnston and Webster were citing arguments that in essence supported the Mogridge conjecture (Mogridge & Holden 1987, p. 16).

Bly, Johnston and Webster also thought that the stark disequilibrium outlined in Mogridge's theory was not plausible in practice, and that rail commuters would not shift modes so easily or in sufficient numbers to dramatically effect the financial viability of service provision. They argued that such a conception of the transport system would, in practice, be overly sensitive to changes and inherently unstable to the point where slight changes that regularly occur on rail services would be affecting people's travel choices, encouraging them to use their cars to the point where rail patronage would deteriorate rapidly. In practice, they pointed out, this does not happen. Bly, Johnston and Webster reasoned that this was because of a wide range of factors that contribute to the generalised cost of transport, but most importantly, they argued that the structure of catchment areas — or patterns of land-use development at both origins and destinations — predisposed particular trips to particular modes. The upshot of this was that a high degree of inertia was an inherent part of travel behaviour, so that mode-shifting was not as likely as advocated by the Mogridge conjecture (Bly, Johnston & Webster 1987, p. 11).

To substantiate these points, Bly, Johnston and Webster relied on results from a modal split model. Mogridge and Holden countered these claims by first pointing out that without details of the model, it is difficult to refute their argument, however, conventional modal-split models are usually calibrated at the zonal level. Such models stand in contrast to those that are calibrated at the individual level, where the parameters derived from such models are quite different. In particular, the model split function will be sharper and so better placed to gauge changes in travel behaviour due to speed changes on trunk routes (Mogridge & Holden 1987, p. 17).

While the Mogridge conjecture focuses on induced traffic growth attributable to mode-shifting, its concepts, and the debate that has taken place around it, highlight several important points about the veracity of such theories. The first is that a causal theory should be able to describe a mechanism that can account for the whole raft of different travel behaviour responses triggered by changes in service levels after urban motorway capacity is added to a network. If the responses are all related temporally, then it follows that a core set of relationships are responsible, with the various forms of induced traffic growth manifesting as variations of the core relationships.

The second point relates to the inherent limitations of theories that rely solely on equilibrium relationships or mechanisms. In many theories, articulating the underlying dynamic of a system also requires reference to *behavioural constants*. In systems theory, for example, this is accomplished through the identification of what is called a *system controller*. Empirically, the presence of controllers is revealed through a variable that returns to a particular value in response to changes to a system — the essential structure of feedback loops, which will be discussed in detail in Chapter Six. While an equilibrium relationship may explain some aspects of a system's dynamic attributes, it does not explain the essential dynamic contained in a feedback loop. In microeconomics, the qualification 'all other things being equal' is tacit recognition of the inability of microeconomic analysis to easily account for changes that occur in systems where multiple feedback loops exist.

The third point is that from a theoretical perspective, the notion of causal mechanisms is only likely to be understood if the system is viewed holistically rather than as a part in isolation from the rest of the system. While such forms of analysis may be appropriate for tradeable goods, in the case of a service fixture like transport infrastructure, conceptually isolating it in the evaluation process may obscure its actual workings.

The final point relates to notions of *competition*. In most expositions of travel behaviour, competition is construed in terms of different transport modes competing with one another. In practice, however, it would appear that it is more appropriate to think of composite transport and land-use systems as competing with one another. The articulation of a causal mechanism should therefore address these composite structures. An equilibrium mechanism, in and of itself, does not appear to be able to do this.

4.4 Conclusions

In conclusion, explanations for induced traffic growth have generally tended to come from engineering traditions motivated by the need to provide evaluation of motorway schemes in a standardised format that is acceptable to government institutions. The results from such models and their structure are at odds however with empirical results and the motivation of scientific research that attempts to articulate causal mechanisms. It is for this reason that further attempts need to be made to investigate and address the processes that cause induced traffic growth if the phenomenon is to be fully understood and its real economic implications identified.

These theoretical considerations will be addressed in more detail in Chapter Six, where theoretical explanations for induced traffic growth will be addressed again. But before doing that, a detailed examination of the conditions before and after the opening of a section of motorway in Sydney will be discussed in the next chapter.

There's two possible outcomes: if the results confirm the hypothesis, then you've made a discovery. If the result is contrary to the hypothesis, then you've made a discovery.

Enrico Fermi
(1901–1954)

5 Before and after the motorway: an empirical analysis of Sydney's M4 Motorway

This chapter presents the results of an empirical case study of the before and after conditions surrounding the section of the M4 Motorway from Mays Hill to Prospect in Sydney's west that was opened to traffic on 15 May 1992. The case-study results confirm the induced traffic growth hypothesis. The analysis attempted to test for mode-shifting from the rail network to the road network using time series regression analysis, as used by Mewton (1997, 2005). However, on the basis of work carried out to date, it is not possible to confirm or reject the possibility of mode-shifting in this case.

This chapter begins (Section 5.1), with a general description of the road and public transport network in Sydney. It briefly tracks the historical development of the transport system for the purposes of identifying appropriate and robust screenlines. It also identifies different phases in the development of Sydney that have given rise to different patterns of transport and land-use development.

The next section (Section 5.2.1), examines the road network within Sydney's western sector. The M4 Motorway is the primary arterial road within that sector. Road traffic counts for the sector before and after the opening of the M4 Motorway section from Mays Hill to Prospect are analysed in detail. Traffic-volume increases across the sector are shown to be higher after the opening of the motorway section than for other periods. This section also analyses fluctuations in estimated passenger journeys on the rail network in an attempt to identify any traces of mode-shifting that could be responsible for the increases in road traffic.

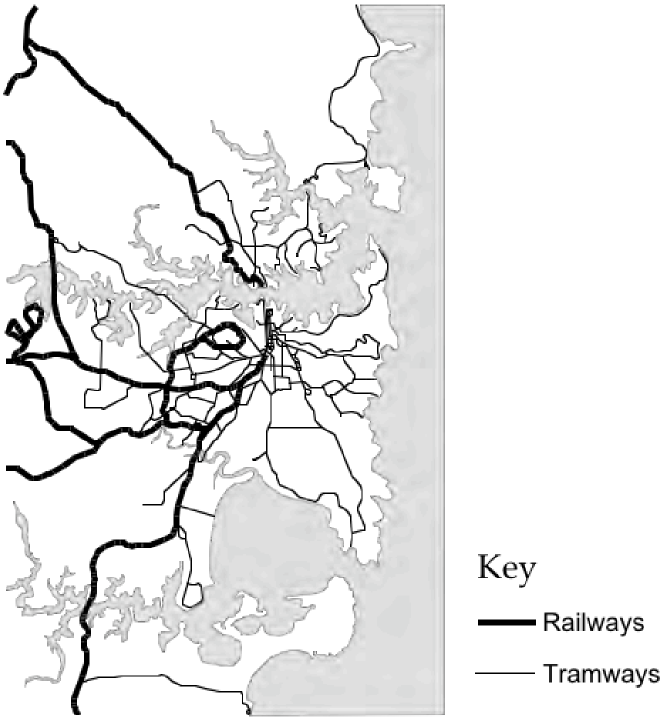
In addition to the analysis of increases in traffic volumes in the M4 corridor, the calibre of available road traffic data has provided an opportunity to investigate in some detail the nature of the *ramp-up period* in the months immediately after the opening of a motorway. Conditions after the opening of both the M4 Motorway section from Mays Hill to Prospect and the Sydney Harbour Tunnel are examined. These data are analysed in Section 5.3 and provide an insight into what takes place during the critical period immediately after a change in network conditions when dramatic changes to travel behaviour occur. It suggests that the array of different travel behaviour responses may follow a sequence.

5.1 Typology of the Sydney transport network

Sydney is a young city. At almost 220 years of age, the city has undergone relatively rapid periods of change during its development. These occurred when the logistical characteristics of the transport network were transformed by the uptake of mass transit services such as suburban heavy rail and tramcar sets in the late nineteenth and early twentieth centuries, and then private motor vehicles and urban motorway development in the mid-twentieth century.

Broadly, there have been three phases in Sydney’s development. The first is directed by the logistical properties of walking. Few remaining areas have a purely walking-based pattern of development along the lines described in Section 1.2.1 and typified in Figure 1.8. These are confined to small pockets located near the CBD and were quickly superseded by a second phase of tram- and railway-based network development. The pattern of building form and street structure that developed around these trunk routes is characterised by relatively high-density buildings with a high proportion of mixed uses. Lot sizes are small. Local streets are narrow and block structures arrayed in highly permeable grids that maximise pedestrian access to tramcars that were located on wider arterial routes. Mixed-use commercial development dominates street frontages along these arterials where pedestrian traffic volumes were highest. Where suburban heavy rail stations are present, development clusters and concentrates around these points in the network, as typified in Figure 1.10 and discussed in Section 1.2.1.

Figure 5.1 Sydney's tram and railway network in 1923



Adapted from: Ashton, P. & Waterson, D. B. 2000, *Sydney takes shape: a history in maps*. Hema Maps Pty Ltd. Brisbane, p. 53.

Figure 5.1 shows the extent of Sydney's rail and tramcar network in 1923. The heavy rail loop servicing the CBD had not been built, but the radial geometry of the network with its strong focus on the CBD was firmly established, giving rise to the strong-centre structure outlined by Thomson in Section 4.3.2. At that time, tram and rail services accommodated more than 90 per cent of all motorised trips within the metropolitan region.

The third phase in Sydney's development began in the late 1940s and early 50s with the advent of widespread private motor-vehicle use and construction of a more extensive arterial road network. Land-use development responded to the logistical properties of the private motor vehicle to produce a different type of building form in Sydney's middle- and outer-ring suburbs. This was characterised by low-density, single-use detached dwellings with wider local streets, as typified in Figure 1.12. The tramway system was removed between 1948 and 1961 and replaced by bus services. While the network is no longer there, the pattern of land use generated by the tramcar network within Sydney's inner suburbs largely remains (Spearritt & DeMarco 1988, p. 19).

As shown in Table 5.1, by 1960, mode splits for motorised trips had changed dramatically. Almost half were undertaken by private motor vehicle. This trend has continued, although, as will be seen in later data sets, the mode splits for inner-ring suburbs where development was shaped by the logistical properties of mass transit show that a high proportion of motorised trips are still undertaken on public transport. The result is a composite pattern of development, one nested inside the other.

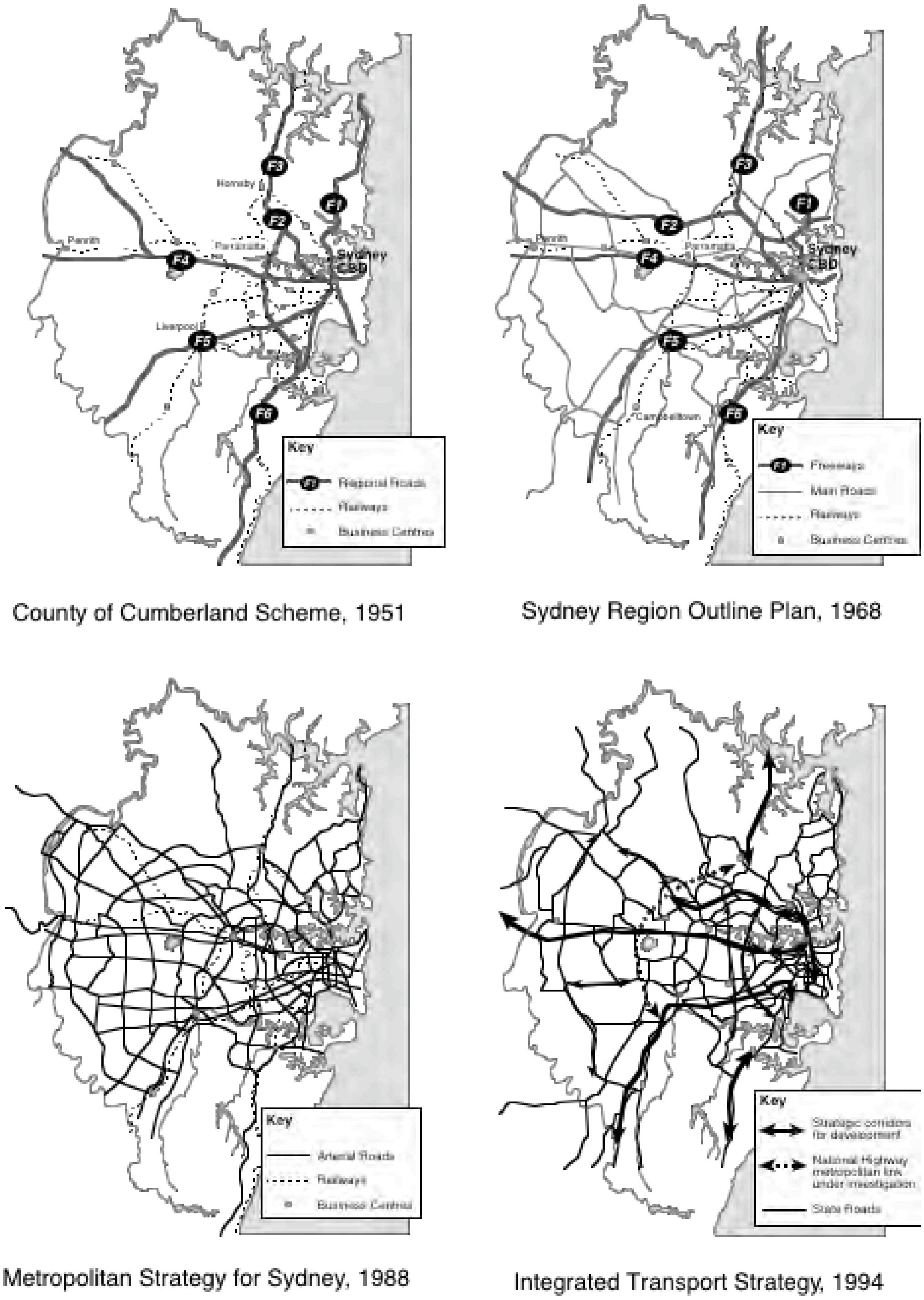
Table 5.1 Annual passenger trips in the Sydney Region 1946–1981

Year	Trips per private vehicle	Proportion of all trips by private vehicle (%)	Public transport trips (in millions)
1946–7	780	13	850
1960	1000	47	586
1971	1220	72	571
1981	2381	87	457

Source: Spearritt, P. & DeMarco, C. 1988, *Planning Sydney's Future.* Allen & Unwin, Sydney, p.48.

The M4 Motorway was originally devised as part of the *County of Cumberland Scheme.* Put on public exhibition in 1948, it was the first metropolitan plan to become a statutory document in Australia and was passed by the NSW Parliament in 1951 (Spearritt 1978, p. 187). Originally called the F4 Freeway, the relative alignment of the M4 and other restricted access roads reveals a network geometry with a radial structure focused on the CBD in the same way that tram and rail networks had been. Its transformation over time is shown in Figure 5.2.

Figure 5.2 Successive strategic plans for the Sydney Metropolitan Region, 1951 – 1995



Adapted from: Ashton, P., Waterson, D. B. & Kelly, M. 2000, *Sydney takes shape: a history in maps*. Hema Maps Pty Ltd. Brisbane, pp. 53 and 59. Spearritt, P. & DeMarco, C. 1988, *Planning Sydney's Future*. Allen & Unwin, Sydney, p. 55. State Planning Authority of NSW. 1968, *Sydney region outline plan 1970–2000 AD: a strategy for development*. State Planning Authority of NSW. Appendix: Map 1. NSW Department of Planning. 1988,*Sydney into its third century: Metropolitan Strategy for the Sydney Region*. Department of Planning, Sydney, p. 50. RTA. 1994b, *State road network strategy*. Roads & Traffic Authority of NSW, Sydney, p. 32.

A key feature of the Cumberland Scheme was its proposed hierarchy of roads. Increasing numbers of private motor vehicles on trunk routes devised for tramcars clashed with pedestrian streetscapes typical of development before the Cumberland

Scheme. The Cumberland planners declared that ‘contact between pedestrian and road vehicle streams must be eliminated’ and so devised a hierarchy of restricted-access carriageways, arterial and local roads to accomplish this. Restricted-access roads were intended to provide alternate routes for road traffic currently using local streets (Spearritt & DeMarco 1988, pp. 17–19).

The other key feature of the Cumberland Scheme was its objective of containing sprawl. This was to be accomplished by the controlled release of land on the fringe. Urbanised areas would be surrounded by a *greenbelt* of parks and reserves. The operating characteristics of the emerging transport system were not controlled, however. Unlike tram and railcars, individuals could drive their own motor vehicles, selecting their own routes and schedules, placing greenbelt areas well within easy access of the emerging transport system. The greenbelt was incrementally given over to suburban residential development.

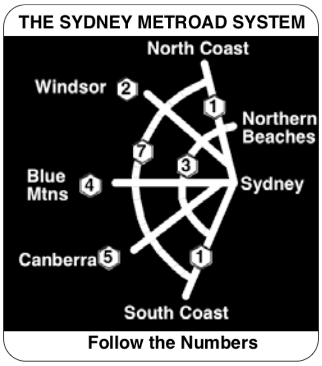
In 1968 the NSW Government released the *Sydney Region Outline Plan*. The plan maintained the essential network geometry of the County of Cumberland Scheme but modified the north-western radial, or F2 alignment, to accommodate further development within that sector. It was envisaged that housing densities would not increase and detached dwelling construction would continue (State Planning Authority of NSW. 1968, p. 9). The radial motorway network was further entrenched by the Sydney Region Development Fund (SRDF), which was used to purchase land in the designated motorway corridors, ensuring the plan’s implementation (Searle 1999, p. 113). Emphasis was placed on the development of the western sector where much of the greenbelt had been developed. Several stages of the F4 were built soon afterwards, reinforcing the low-density pattern of development within these mid-western districts (State Planning Authority of NSW. 1968, p. Appendix: Map 2).

The next plan devised to guide Sydney’s development was the *Sydney Metropolitan Plan*, released in 1988. It did not highlight a network hierarchy of roads but advocated a ‘comprehensive road system’, comprising a grid of arterial roads at three- to four-kilometre spacings that would include the current and proposed freeway network (NSW

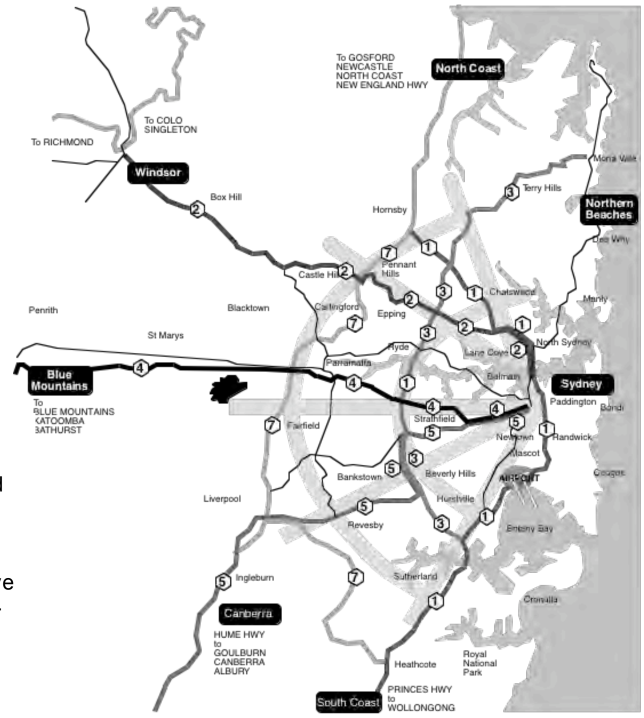
Department of Environment and Planning. 1988, p. 52). Different land-use objectives were adopted, with urban consolidation highlighted as a priority, due to the increasing cost of infrastructure provision for development on the fringe (NSW Department of Environment and Planning. 1988, p. 11). New release areas were still a part of the plan, however, and as with its two predecessors, there was no metropolitan-wide scheme for mass-transit development to new release areas, although some corridor space was set aside to connect Liverpool and Parramatta. This was used for a bus transit way that was opened in 2003 (Audit Office of NSW. 2005, pp. 12–13).

The Sydney Metropolitan Plan was revised in 1995. The *Integrated Transport Strategy* was released in tandem with *Cities for the 21st Century* — a companion plan that focused on land use development strategies. The essential radial network geometry of the County of Cumberland Scheme can still be discerned in this strategy. The Roads & Traffic Authority's schema for its Metroad System makes this explicit, as shown in Figure 5.3.

Figure 5.3 Sydney Metroad System



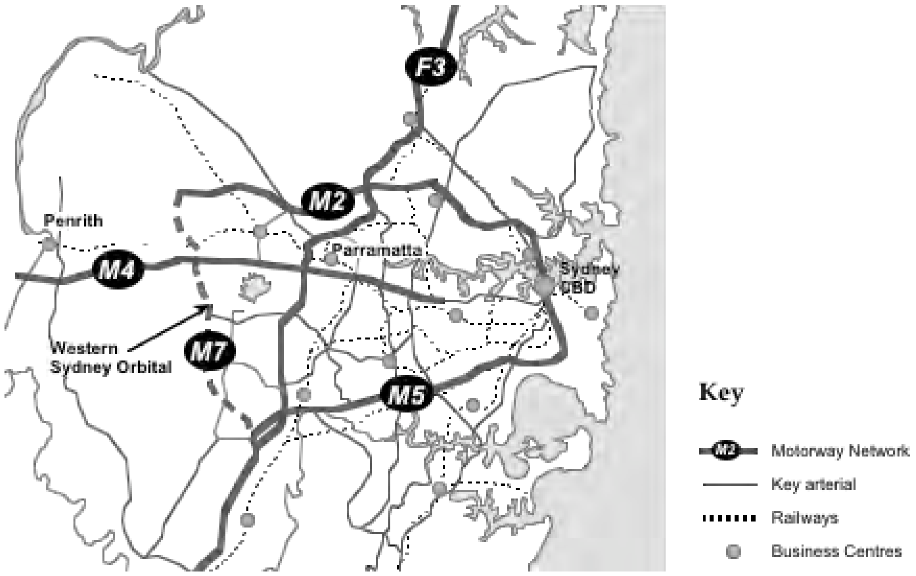
"The Sydney Metroad System was introduced as an aid to motorists. The 6 numbered routes (numbers 1 to 7 – Metroad 6 has been reserved for future use) form a radial and ring pattern across the Sydney metropolitan area. To emphasise the broad purpose of the routes, several Metroads have been given generalised destinations, eg. M4 Blue Mountains, M3 Northern Beaches. Previous route numbers will be superseded by Metroad numbers" (RTA. 1994, p.8).



Source: RTA. 1994a, *Moving NSW forward: directions for 1994–95 and beyond.* Roads & Traffic Authority of NSW, p. 8.

In 2000, not long after the Integrated Transport Strategy, the NSW Government released *Transport 2010*. The language used to describe what was viewed as the primary feature of the network geometry for motorway trunk routes was changed. What had previously been classified as a radial system was now being called an orbital, giving rise to the *Sydney Orbital*, as shown in Figure 5.4. The only significant change was the addition of the M7, or *Western Sydney Orbital*, as it was called. Key motorways in the network such as the M2 and M5 were still essentially radial, despite their being part of the ring-road. Parramatta was designated as the centre of the system, despite the continuing dominance of the Sydney CBD as the city's operational centre.

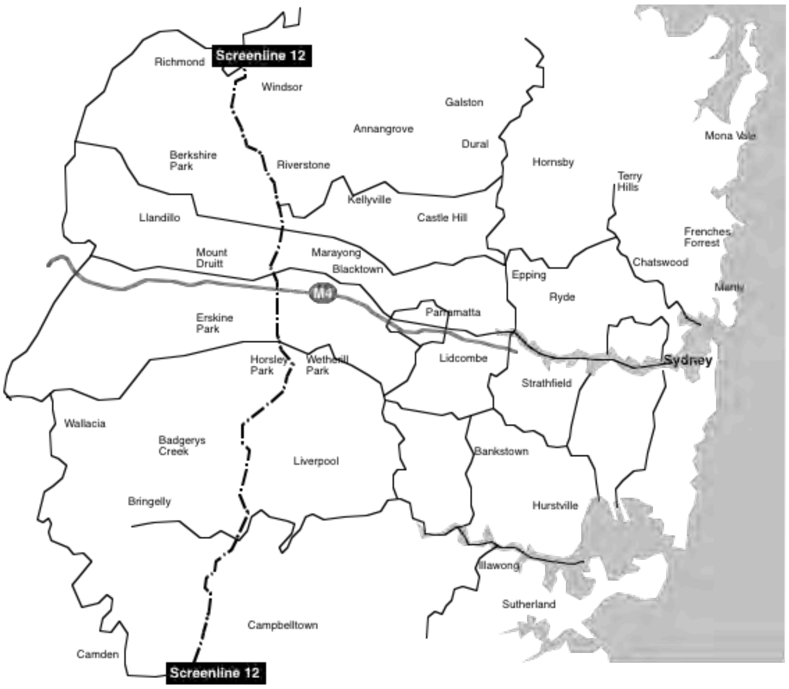
Figure 5.4 Motorway plans for Sydney featuring the Sydney Orbital, 2000



Source: TransportNSW. 1998, *Action for Transport 2010: an integrated transport plan for Sydney.* NSW Department of Transport, Sydney, p. 30.

Figure 5.5 shows the series of screenlines devised by the Roads & Traffic Authority of NSW to monitor the flow of traffic throughout the Sydney Metropolitan Region. The key screenline to be used in this analysis is Screenline 12, which captures all east-west traffic movements across the western sector of Sydney, as shown in Figure 5.5.

Figure 5.5 Screenlines for the Sydney Road Network



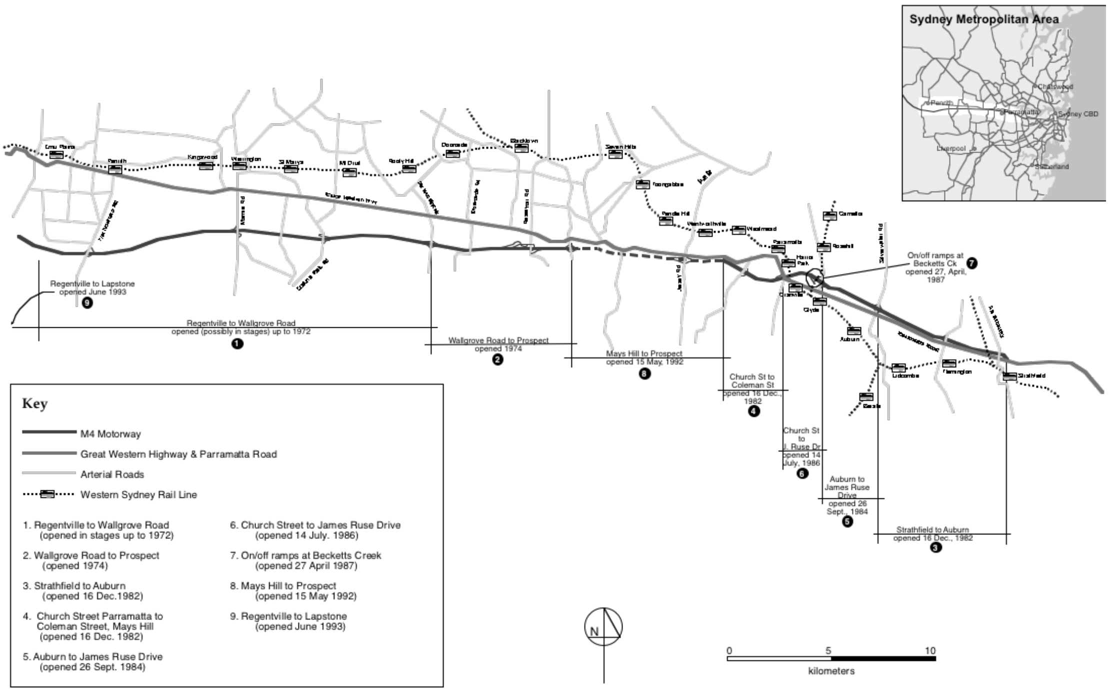
Source: RTA. 2003b, *Traffic volume data 2002: Sydney Region*. Roads & Traffic Authority of NSW, Sydney, Screenline Map.

Given the network geometry of the Sydney system, the sceenline configuration captures all possible routes that traffic might use when moving along the radial sectors in question. As will be shown in the following sections, many of these streets are small local streets and comprehensive data throughout the time series are not available for all of them. But traffic volumes for all key arterials can provide a picture of the degree of traffic reassignment, as discussed in Section 3.1.1, under conditions wherein all options are accounted for.

5.2 Sydney's M4 corridor

The M4 Motorway was constructed in several stages beginning in 1972. The last section of urban motorway was opened to traffic on 15 May 1992. This last urban section is the focus of this analysis. While the section between Regentville and Lapstone was opened to traffic in June 1993, this section sits outside the urbanised area.

Figure 5.6 Sequence of M4 Motorway section constructions



The sequence of construction is shown in Figure 5.6. There have been subsequent widenings of sections between Parramatta and Coleman Street, Mays Hill, which were opened in June 1998, and widenings between Prospect and Penrith, which were opened to traffic in August 1998.

The analysis of conditions before and after the last motorway section opening is presented in two parts. Section 5.2.1 examines changes in road traffic volumes, while Section 5.2.2 examines changes to rail passenger journeys on parallel rail services.

5.2.1 Analysis of the M4 Motorway and Western Sydney road network

The method of analysis used in this section is relatively straightforward, involving a simple comparison of traffic volumes across Screenline 12, which was shown in Figure 5.5. The method is essentially the same as that used by Purnell, Bearwood and Elliot (1999), reviewed in Section 3.3.1. While the methodology is simple, difficulties have been encountered in collating the time series data for particular points in the network.

Traffic counts were unavailable due to counter malfunctions at some sites and so have had to be estimated from traffic volumes from surrounding sites.

As outlined previously, one of the chief criticisms of assessments of this kind is that unusually high traffic volumes on new motorways could be due to traffic reassignment over exceptionally long distances, rather than induced traffic growth. The extent of the screenlines used by Purnell, Beardwood and Elliot are relatively short, for example, and it is conceivable that small volumes of traffic over a much wider area may have been reassigned so that the increase is not due to induced traffic growth generated by the additional motorway capacity. In this analysis of the M4, the screenline used to assess traffic increases is over 40 kilometres in length and encompasses all of the urbanised area to either side of the motorway, thereby closing the boundaries of the system to be tested, as described in Section 3.1.1.

To begin the analysis, details of how data have been collected and collated are provided. A brief outline of the method, results and conclusions follows.

Data: annual average daily traffic volumes

Data for road traffic volumes along Screenline 12 were collected from the RTA's regular traffic-monitoring program, as well as special reports containing traffic counts specifically carried out to assess the impacts of the M4 Motorway section after its opening.

Most of the data compiled in this section comes from the RTA's regular traffic-monitoring program that records traffic volumes at a series of road sites known as *traffic stations*. Two different types of traffic station are used to monitor vehicle numbers at various points across the Sydney Metropolitan road network. These are *permanent stations* and *sample stations*.

Permanent stations provide data on the basis of a continuous survey period. The counting devices record the number of road vehicles that cross that point over an entire 24-hour period for all days of the year. The device used to measure these volumes comprises an induction loop that is embedded in the road surface. These counting devices can malfunction. For example, the loop in one lane of a three-lane road may be subjected to water damage and so return counts that are higher or lower than the actual number of vehicles crossing the lane over that time period. Sometimes these problems are identified and rectified quickly. If there is an extended time delay between the recording of the traffic volumes and inspection of data, a permanent station that is malfunctioning may continue to miscount for several months before being detected. As will be shown, it is important to inspect data for irregularities caused by mechanical malfunctions at the traffic stations, as these can skew results. An Annual Average Daily Traffic (AADT) volume calculated from data generated by a permanent station is based on an average calculated from real counts, consequently unusual changes are captured in this data.

By contrast, *sample stations* provide data on the basis of a short survey period, which means that counting devices are only in place for a few weeks of any given year. Moveable pneumatic tube counters are used to measure traffic at these stations. Unlike induction loops, pneumatic tube counters are unable to distinguish vehicles from one another. Instead, they count the number of times a set of tyres crosses them. Consequently, data from these sites record numbers of axle pairs. Where vehicles have more than one axle pair — as is the case with heavy vehicles — they are recorded as several counts. For example an articulated truck with six axles is recorded as a count of three.

Once traffic counts for a sample period — which is usually about a month — have been taken, an Annual Average Daily Traffic (AADT) figure is calculated. The time of year when the sample was recorded, relative to seasonal fluctuations, is taken into account when making this calculation. The calculation is assisted by referring to fluctuations in counts taken at permanent stations in the vicinity of the sample station.

Figure 5.7 Seasonal fluctuations in Average Daily Traffic volumes over 13 (four-week) periods for the Great Western Hwy (70.001) during 1985

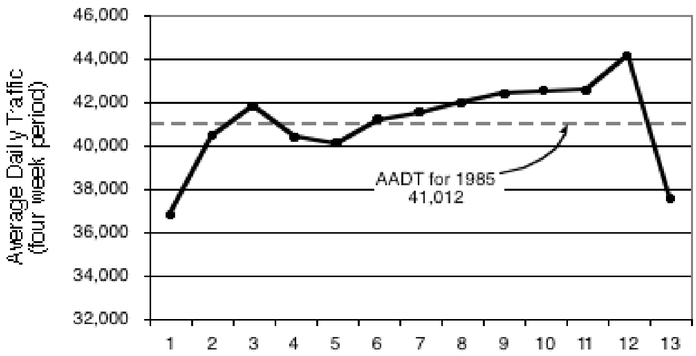


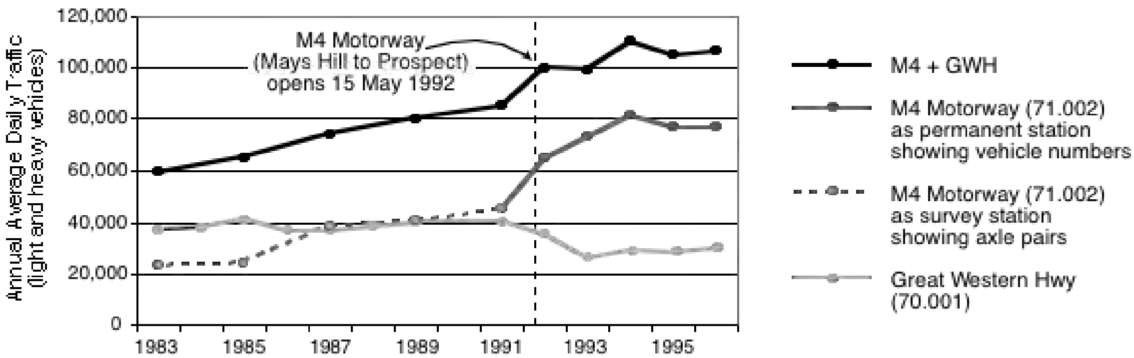
Figure 5.7 shows Average Daily Traffic (ADT) volumes for sequential four-week periods from a permanent traffic station on the Great Western Highway (GWH) during 1985. These reveal a pattern caused by seasonal fluctuations in traffic volumes. Traffic during the Christmas and New Year periods are distinctly lower than for other times of the year. Similarly, after increases through February and March, traffic volumes decline during Easter before rising again over the period leading up to Christmas. A similar pattern can be seen in traffic volume counts from other permanent traffic stations across the RTA's traffic monitoring network.

Differences between traffic stations and the types of data they generate mean that data from sample stations have to be adjusted if they are to be compared with data from permanent stations. To do this, the percentage of heavy vehicles in the traffic stream at locations monitored by sample stations needs to be identified and the average number of axle pairs taken into account. A factor then needs to be calculated to reduce the counts at sample stations so that they are indicative of vehicle numbers, as is the case with counts from permanent stations.

Converting all road traffic data to vehicle number counts

Of all the roads and trunk routes affected by the last M4 Motorway section opening, changes to traffic volumes on the GWH are the most dramatic. Figure 5.8 shows AADT counts for the M4 Motorway and the GWH at key positions on Screenline 12.

Figure 5.8 Incomparable AADT counts for the M4 Motorway and Great Western Hwy (1983–1996)



As can be seen in Figure 5.8, there is a distinct increase in combined traffic volumes for these two roads after the opening of the last M4 Motorway section. There are two other distinct shifts that can be seen in Figure 5.8. The first coincides with earlier additions to the M4 Motorway that took place during the early 1980s, culminating in the section from Church Street to James Ruse Drive that was opened in July 1986. There is also an unusual increase in 1994. After discussions with RTA staff, and inspection of differences between quarter-hour fluctuations, it was decided that there was more than likely a counter malfunction at traffic station 70.002 during 1994, so that volumes read unrealistically high. RTA staff opinion is that the AADT from the M4 traffic station would have been in the vicinity of 76,000, as was the case in 1995 and 1996 (Armstrong 2005, pers. comm.).

The more critical aspect of the data, however, is the adjustment of the AADTs for traffic station 71.002 for the years 1983 to 1991. This is necessary because 71.002 was a sample station before being upgraded to a permanent station in early 1992. This means that heavy vehicles passing the traffic stations were counted as axle pairs and not as vehicle numbers. If data from the sample station is brought into line with counts from permanent stations, the AADT counts for these sites will drop and the difference between AADT counts before and after the opening of the M4 Motorway section from Mays Hill to Prospect will increase in magnitude. The difference in AADT counts is 14,834 without adjustment for the heavy-vehicle component in the traffic stream. Table

5.2 shows the actual AADT volumes for both the GWH and M4 Motorway, including the adjusted figures.

Table 5.2 AADT counts for the M4 Motorway and Great Western Hwy showing values from permanent and sample traffic stations from 1983 to 1996

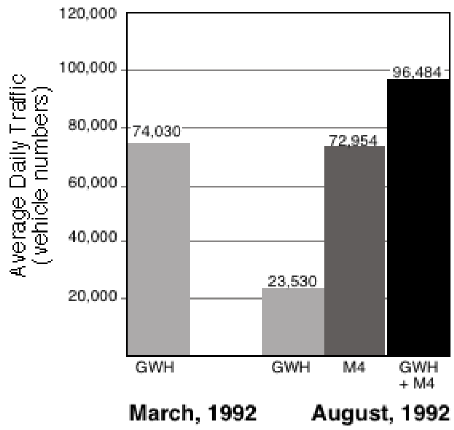
	Great Western Highway 70.001	**M4 Motorway 71.002 (axle pairs)**	**M4 Motorway 71.002 (veh. nos)**	**GWH + M4**
1983	36,920	***22,680***	21,092	58,012
1984	37,757			
1985	41,012	***23,976***	22,298	63,310
1986	36,508			
1987	36,499	***37,864***	35,214	71,713
1988	37,952			
1989	39,641	***40,527***	37,690	77,331
1990				
1991	40,023	***44,896***	41,753	81,776
1992	35,237		64,516	99,753
1993	26,007		73,005	99,012
1994	28,619		81,419	110,038
1995	28,382		76,259	104,641
1996	29,685		76,460	106,145

Note: AADT counts shown in ***bold italics*** are counts of axle pairs, as recorded by a sample station, and not vehicle numbers, as recorded by a permanent station.

Source: RTA, 1997, *Traffic volume data for the Sydney Region 1996*. Roads & Traffic Authority of NSW, Sydney.

Supplementary data for the M4 corridor were found in a special report commissioned by the RTA to monitor road network conditions in the immediate vicinity of the M4 Motorway before and after the opening of the section from Mays Hill to Prospect. The TEC Consulting group authored the special report. The TEC data provide the only known measure of heavy vehicles in the corridor at the time of the motorway opening and have been used to estimate the factor by which counts from sample stations need to be reduced. The TEC data for the M4 Motorway and GWH are shown in Figure 5.9.

Figure 5.9 Comparison of ADT volumes for March and August for the Great Western Hwy during 1992 (TEC traffic stations)



	March 1992				August 1992			
	light	rigid	artic.	total	light	rigid	artic.	total
Great Western Hwy	69,204 93%	2,720 4%	2,106 3%	74,030 100%	22,862 97%	418 2%	250 1%	23,530 11%
M4 Motorway	-	-	-	-	68,119 93%	2,648 4%	2,187 3%	72,954 100%
Total	69,204	2,720	2,106	74,030	90,981	3,066	2,437	96,484

Source: TEC Consulting. 1992, *Traffic changes associated with new M4 Motorway works.* NSW Roads & Traffic Authority, Table 3.1.

As can be seen, there is a marked difference in combined traffic volumes for the M4 and GWH between March and August — a difference of around 22,000 ADT. The M4 Motorway was opened not long after the TEC counts were taken in March. The data shown in Figure 5.9 are based on a week-long sample (TEC Consulting 1992).

The following method was used to adjust the AADT volumes that count axle pairs to vehicle numbers. First, an estimation of the average number of axle pairs on rigid and articulated heavy vehicles was established. In light of there being no reliable registration data prior to 1995, discussions with DOTARS[30] personnel recommended that at that time, on average, rigid heavy vehicles would have had three axles, and articulated heavy vehicles would have had six axles (Coonan 2004, pers. comm.). These averages were used to calculate an ADT equivalent for axle pairs for the March TEC ADT vehicle number counts:

30 The *Department of Transport and Regional Services* is a federal government department.

ADTap = ADTvn – (ADTrig.vn + ADTart.vn) + ((ADTrig.vn x 1.5) + (ADTart.vn x 3))

where ADTap = Average Daily Traffic in axle pairs

ADTvn = Average Daily Traffic in vehicle numbers

ADTrig.vn = Average Daily Traffic in rigid vehicle numbers

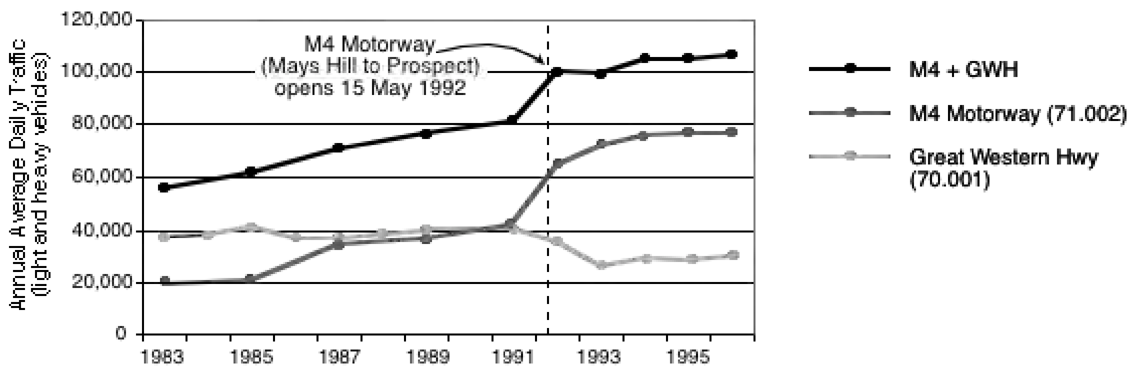
ADTart.vn = Average Daily Traffic in articulated vehicle numbers

The ratio between ADT vehicle number and axle pair counts was then calculated. It was assumed that this ratio would be similar to the ratio between AADT axle pairs and vehicle numbers for the RTA station at 71.002:

ADTvn / ADTap = AADTvn / AADTap

This method was used to produce the AADT counts for the M4 Motorway shown in the third column in Table 5.2. This means that the difference in combined AADTs for the M4 and GWH at 71.002 and 70.001, before and after the opening of the section from Mays Hill to Prospect, was 17,977 vehicles.

Figure 5.10 AADT counts for the M4 Motorway (71.002) and Great Western Hwy (70.001) from 1983 to 1996 with comparable data types



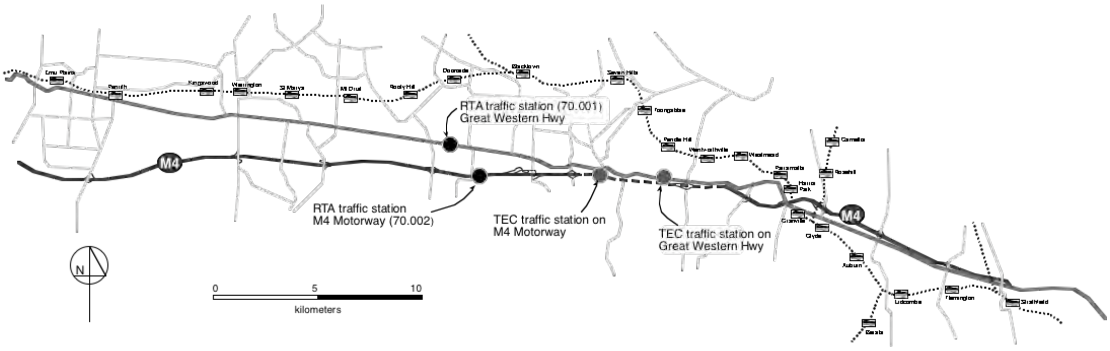
There are several assumptions implicit in the method used to adjust the AADT figures from sample station 70.002:

- The percentage of rigid and articulated heavy vehicles in the total traffic stream has always been four and three per cent respectively.

- The percentage of heavy vehicles is the same, irrespective of the season.

- The percentage of heavy vehicles is the same at the position of the RTA counting stations and TEC sample stations, despite their being 7 km apart. Figure 5.11 shows the relative locations of the stations.

Figure 5.11 Location of RTA and TEC traffic stations on M4 Motorway and Great Western Hwy



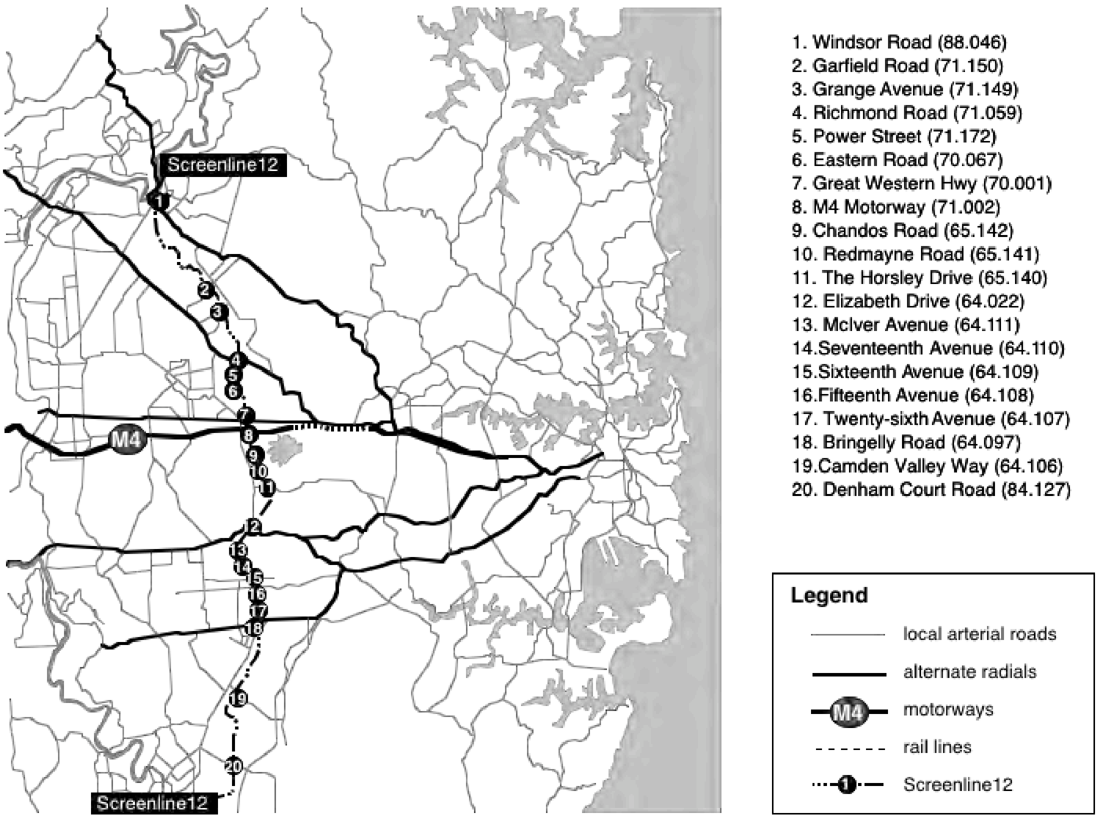
Annual Average Daily Traffic counts for roads along Screenline 12 in the Western Sydney Corridor

This section examines each of the roads on Screenline 12. It assesses their topological characteristics as well as time series AADT data and, where necessary, adjusts AADTs that record axle pairs to vehicle counts.

A detailed map of the roads along Screenline 12 is provided in Figure 5.12. As can be seen, there are 20 roads in total that cross Screenline 12, however, only the M4, GWH, Windsor Road, Richmond Road, Elizabeth Drive and Bringelly Road provide comprehensive east–west access, so consequently only the latter provide potential alternate routes to the M4 Motorway.

The topological features of each road on Screenline 12 varys. For example, some roads have a radial geometry while others have an orbital, or ring-road, geometry. It is important to distinguish these when assessing fluctuations in traffic volumes, because some of these roads record an increase in traffic volumes that coincides with the opening of the motorway section. This is because roads with a ring-road geometry in some cases act as feeder roads to the motorway. Including traffic volumes from these routes would amount to double-counting and ultimately increase the amount of traffic that could be interpreted as induced traffic growth.

Figure 5.12 Roads on Screenline12 in Western Sydney Region



1. Windsor Road (88.046)

Windsor Road is a trunk route that connects the north-western metropolitan districts of Sydney to the rural hinterlands beyond the Hawkesbury River. This route is a potential truck route and alternate route for long-distance commuter and freight traffic travelling to Sydney from the Blue Mountains. The urbanised areas in the near vicinity of Windsor Road contain new release areas that were developed during the study period.

Traffic station 88.046 is a sample station that records axle pairs. It was upgraded to a permanent station in 2001. The AADT data have been adjusted to represent vehicle numbers. The factor used to adjust the data is different from that used to adjust the M4 volumes and was obtained from the Transport and Population Data Centre (TPDC).[31] Data for the proportion of heavy vehicles in the traffic stream at several road sites across Sydney are shown in Table 5.3.

Table 5.3 Rigid and articulated truck traffic composition (2002)

Classified Vehicle Counts: Rigid Trucks, 2002		Classified Vehicle Counts: Articulated Trucks, 2002	
Road	Total Rigid Share	Road	Total Articulated Share
Canterbury Rd Bankstown	8.1%	Canterbury Rd Bankstown	2.0%
General Holmes Dr Botany	5.1%	General Holmes Dr Botany	2.2%
Great Western Hwy Eastern Creek	5.3%	Great Western Hwy Eastern Creek	2.0%
Great Western Hwy Minchinbury	2.7%	Great Western Hwy Minchinbury	1.0%
Hume Highway Ingleburn	5.0%	Hume Highway Ingleburn	5.9%
King Georges Rd Blakehurst	4.8%	King Georges Rd Blakehurst	0.9%
Sth Western Fwy M5 Prestons	5.3%	Sth Western Fwy M5 Prestons	3.9%
Western Fwy Eastern Creek	5.8%	Western Fwy Eastern Creek	3.3%
Western Motorway Homebush	4.6%	Western Motorway Homebush	1.8%
Western Mwy Merrylands	6.8%	Western Mwy Merrylands	3.3%
Windsor Rd Kellyville	5.1%	Windsor Rd Kellyville	1.2%

Source: TPDC. 2002, *Rigid and articulated vehicle counts for eleven road sites in Sydney metropolitan area*. Transport and Population Data Centre, Sydney.

While these are for 2002, percentage-wise, the values for the M4 Motorway from the TPDC data are similar to those recorded in the TEC survey for 1992. The heavy-vehicle composition for Windsor Road at Kellyville was 5.1 per cent for rigid, and 1.2 per cent for articulated vehicles. As with the M4 Motorway data, it is assumed that on average rigid vehicles have 1.5 axle pairs and articulated vehicles three axle pairs. AADT counts for 88.046 are shown in Table 3.2.

[31] The Transport and Population Data Centre is a special data unit contained within the NSW Department of Infrastructure, Planning and Natural Resources.

Table 5.4 AADT counts for Windsor Road (88.046) from 1983 to 1996

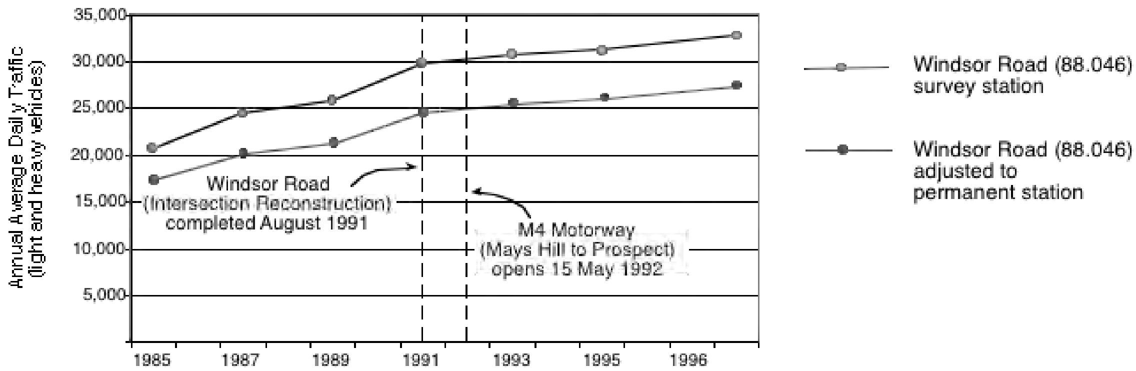
	Windsor Road 88.046 (axle pairs)	Windsor Road 88.046 (veh. nos)	Windsor Road (rigid truck nos)	Windsor Road (artic'd truck nos)
1983	***20,820***	17,404	888	209
1984				
1985	***24,424***	20,417	1,041	245
1986				
1987	***25,769***	21,542	1,098	258
1988				
1989	***29,808***	24,917	1,270	299
1990				
1991	***30,797***	25,746	1,313	309
1992				
1993	***31,232***	26,110	1,332	313
1994				
1995				
1996	***32,726***	27,357	1,395	328

Note: AADT counts shown in ***bold italics*** are counts of axle pairs, as recorded by a sample station, and not vehicle numbers, as recorded by a permanent station.

Source: RTA, 1997, *Traffic volume data for the Sydney Region 1996*. Roads & Traffic Authority of NSW, Sydney.

An AADT value for 1992 was not available. Table 5.4 shows time series AADTs for axle pairs as recorded by the sample station at 88.046, as well as adjusted AADTs to show vehicle numbers. As can be seen, there is a ramping-up of the AADT between 1987 and 1989. There were road works at several locations in the near vicinity of Windsor Road in the years prior to the opening of the M4 Motorway. This included the progressive expansion of Old Windsor Road from two to six lanes, construction of a new roundabout at the intersection of Seven Hills and Kings Langley Road to relieve congestion, as well as pavement reconstruction and intersection upgrades at numerous points along Windsor Road (RTA 1985, p. 41). These works are likely to have been responsible for the ramp-up between 1983 and 1985. The other ramp-up that can be seen in the data between 1987 and 1989 was facilitated by other road works in the area that opened prior to December 1989.

Figure 5.13 AADT counts for Windsor Road (88.046) from 1985 to 1996 showing axle pairs and vehicle numbers



No sample counts were recorded during 1992. It is possible that a decline in traffic volumes took place during that period caused by traffic reassignment to the M4 Motorway. This is certainly the case for Richmond Road, which will be reviewed below. Volumes had recovered to previous levels by 1993, however. In light of this, two possibilities arise. First, traffic was reassigned from Windsor Road to the M4 Motorway, reducing congestion and travel times on Windsor Road, thereby making it more attractive for other trips within the area. Second, traffic was growing in the vicinity of Windsor Road due to new release areas. If the second possibility is the case, there would have been a discernible drop in traffic volumes for 1993, however, new growth masked this trend.

Traffic counts for Windsor Road have been included in the aggregate AADT for Screenline 12.

2. Garfield Road (71.150)

Garfield Road is a ring-road that links Windsor and Richmond Roads. Long-distance traffic movements passing 71.150 on Screenline 12 also pass the traffic station on Richmond Road if travelling east towards the centre of the city, raising the problem of double-counting.

Traffic station 71.150 is a sample station. Counts for this site began in 1993 and have been recorded every three years up to 2002. In 1993 the AADT count was 10,468 axle pairs and 11,785 axle pairs in 1996. In 1999, the AADT count was 12,535, and for 2002 it was 12,881 axle pairs.

Traffic counts for Garfield Road have not been included in the aggregate AADT for Screenline 12.

3. Grange Avenue (71.149)

Grange Avenue has a ring-road configuration and runs parallel to Garfield Road, connecting Windsor with Richmond Roads. Like Garfield Road, including counts from this site raises the problem of double-counting.

Traffic station 71.149 is a sample station that has only recorded one AADT count of 3,568 axle pairs in 1993.

Traffic counts for Grange Avenue have not been included in the aggregate AADT for Screenline 12.

4. Richmond Road (71.059)

Richmond Road is a radial trunk route like Windsor Road and connects the north-western metropolitan districts of Sydney to the rural hinterlands beyond the Hawkesbury River. Richmond Road is a potential truck route and alternate route for long-distance commuter and freight traffic travelling to Sydney from the Blue Mountains. Urban areas in the near vicinity of Richmond Road contain new release areas that were developed during the study period.

Table 5.5 AADT counts for Richmond Road (71.059) from 1983 to 1996

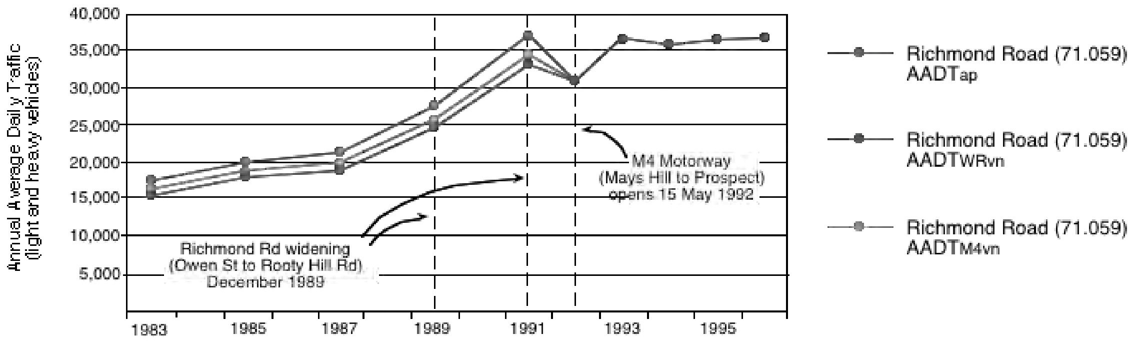
		AADT using M4 Motorway heavy vehicle composition			AADT using Windsor Road heavy vehicle composition		
	Rich'd Rd 71.059 *(axle pairs)*	Rich'd Rd 71.059 (veh. nos)	Rich'd Rd (rigid truck nos)	Rich'd Rd (artic'd truck nos)	Rich'd Rd 71.059 (veh. nos)	Rich'd Rd (rigid truck nos)	Rich'd Rd (artic'd truck nos)
1983	***17,850***	16,601	664	498	16,045	818	193
1984							
1985	***20,323***	18,900	756	567	18,267	932	219
1986							
1987	***21,635***	20,121	805	604	19,447	992	233
1988							
1989	***27,896***	25,943	1,038	778	25,075	1,279	301
1990							
1991	***37,301***	34,691	1,388	1,041	33,529	1,710	402
1992	31,174	31,174	1,247	935	31,174	1,590	374
1993	34,194	34,194	1,368	1,026	34,194	1,744	410
1994	34,304	34,304	1,372	1,029	34,304	1,750	411
1995	36,710	36,710	1,360	1,020	36,710	1,872	440
1996	37,017	37,017	1,371	1,029	37,017	1,888	444

Note: AADT counts shown in ***bold italics*** are counts of axle pairs, as recorded by a sample station, and not vehicle numbers, as recorded by a permanent station.

Source: RTA, 1997, *Traffic volume data for the Sydney Region 1996*. Roads & Traffic Authority of NSW, Sydney.

Traffic station 71.059 was upgraded from a sample station to a permanent station in 1992. Table 5.5 shows AADTs for axle pairs and vehicle numbers. AADT vehicle numbers for the years 1983 to 1991 were calculated using two different conversion factors to take account of heavy vehicles. First, axle-pair counts were converted to vehicle numbers using the same percentage values for rigid and articulated heavy vehicle numbers that were used for the M4 Motorway. A conversion was also undertaken using the values for Windsor Road. As can be seen in Figure 5.14, the volumes calculated using the TPDC data reduce the extent of the traffic redistribution after the opening of the M4 Motorway. The counts for both conversions are shown in Table 5.5.

Figure 5.14 AADT counts for Richmond Road (71.059) from 1985 to 1996 showing axle pairs and vehicle numbers



In the months after opening, according to the TEC data the M4 motorway attracted an additional 346 rigid and 431 articulated vehicles. The drop in rigid and articulated vehicles for Richmond Road was 141 and 106 respectively, using the M4 heavy-vehicle composition data from TEC and 120 and 28, respectively, using the TPDC heavy-vehicle composition data. Which of the two conversion factors is more appropriate will be gauged when analysing traffic and heavy-vehicle reassignment across Screenline 12 in the results section.

Traffic counts for Richmond Road have been included in the aggregate AADT for Screenline 12.

5. Power Street (71.172)

Power Street is a local collector road that crosses Eastern Creek to the north of Nurragingy Reserve. It has an alignment with a similar geometry to Richmond Road and joins the suburbs of Glendenning and Doonside.

Until 1996 Power Street was a sample station (71.172). After that time it was upgraded to a permanent station (71.172) and its location was moved about one kilometre east. As a counting station for the purposes of Screenline 12, the two sites are comparable. There are no measurements available between 1992 and 1995.

Table 5.6 AADT counts for Power Street (71.096 and 71.172) from 1985 to 1996 showing axle pairs and vehicle numbers

	Power Street 71.096 (axle pairs)	Power Street 71.172 (vehicle nos)
1983	***4,550***	-
1984		-
1985	***5,377***	-
1986		-
1987	***5,914***	-
1988		-
1989	***6,441***	-
1990		-
1991	***7,501***	-
1992		-
1993		-
1994		-
1995		-
1996		12,002

Note: AADT counts shown in ***bold italics*** are counts of axle pairs, as recorded by a sample station, and not vehicle numbers, as recorded by a permanent station.

Source: RTA, 1997, *Traffic volume data for the Sydney Region 1996*. Roads & Traffic Authority of NSW, Sydney.

Table 5.6 shows counts for axle pairs at 71.096 up until 1991 and vehicle numbers for 71.172 in 1996. While it is conceivable that traffic may have been redistributed from Power Street to the M4 Motorway, volumes are relatively small, suggesting that it is not a popular rat-run. Consequently, any redistribution would have been small.

Traffic counts for Power Street have not been included in the aggregate AADT for Screenline 12.

6. Eastern Road (70.067)

Eastern Road adjoins Rooty Hill Road, which is a feeder road to the M4 Motorway at Eastern Creek. As can be seen in Table 5.7, traffic volumes on Eastern Road increased significantly after the opening of the M4 Motorway section from Mays Hill to Prospect. The counting site was a sample station until 1994. It was then upgraded to a permanent counting station. The heavy-vehicle composition values of three and four per cent from the TEC data were used to convert the axle-pair data from the sample station.

The AADT count for 1999 is 16,454, which suggests that the road reached its ceiling capacity in 1993 after the M4 link was opened.

Table 5.7 AADT counts for Eastern Road (71.067) from 1983 to 1996

	Eastern Road 70.067 (axle pairs)	Eastern Road 70.067 (vehicle nos)
1983	***10,960***	10,193
1984		
1985	***10,949***	10,183
1986		
1987	***13,378***	12,442
1988		
1989	***14,737***	13,705
1990		
1991	***14,366***	13,360
1992		
1993	***18,375***	17,088
1994		16,924
1995		16,784
1996		16,935

Note: AADT counts shown in ***bold italics*** are counts of axle pairs, as recorded by a sample station, and not vehicle numbers, as recorded by a permanent station.

Source: RTA, 1997, *Traffic volume data for the Sydney Region 1996*. Roads & Traffic Authority of NSW, Sydney.

The data show an increase in vehicle numbers after the opening of the M4, confirming its feeder route status. It is unlikely that traffic was reassigned from this road to the motorway. Including volumes from this site would negate the losses from traffic reassigned on other roads.

Traffic counts for Eastern Road have not been included in the aggregate AADT for Screenline 12.

7. Great Western Highway (70.001)

Data for the Great Western Hwy were documented in the previous section.

8. M4 Motorway (70.002)

Data for the M4 Motorway were documented in the previous section.

9. Chandos Road (65.142)

There is only a single AADT count of 1,771 for traffic station 65.142, which was taken in 1993. Chandos Road is a local road that does not provide a comprehensive through-route for traffic travelling in an east–west direction. Therefore, traffic counts for Chandos Road have not been included in the aggregate AADT for Screenline 12.

10. Redmayne Road (65.141)

Redmayne Road, like Chandos Road, is a local road that does not provide a comprehensive through-route for traffic travelling in an east–west direction. There is only a single AADT count of 253 for traffic station 65.141, which was taken in 1993.

Traffic counts for Redmayne Road have not been included in the aggregate AADT for Screenline 12.

11. The Horsley Drive (65.140)

The Horsley Drive has an east–west orientation that connects it to the Hume Hwy at Villawood. The position of traffic station 65.140 is at the far western end of The Horsley Drive. But as can be seen in Figure 5.15, The Horsley Drive is not a comprehensive east–west through-route. Unlike other arterials further south, it ends at Walgrove Road.

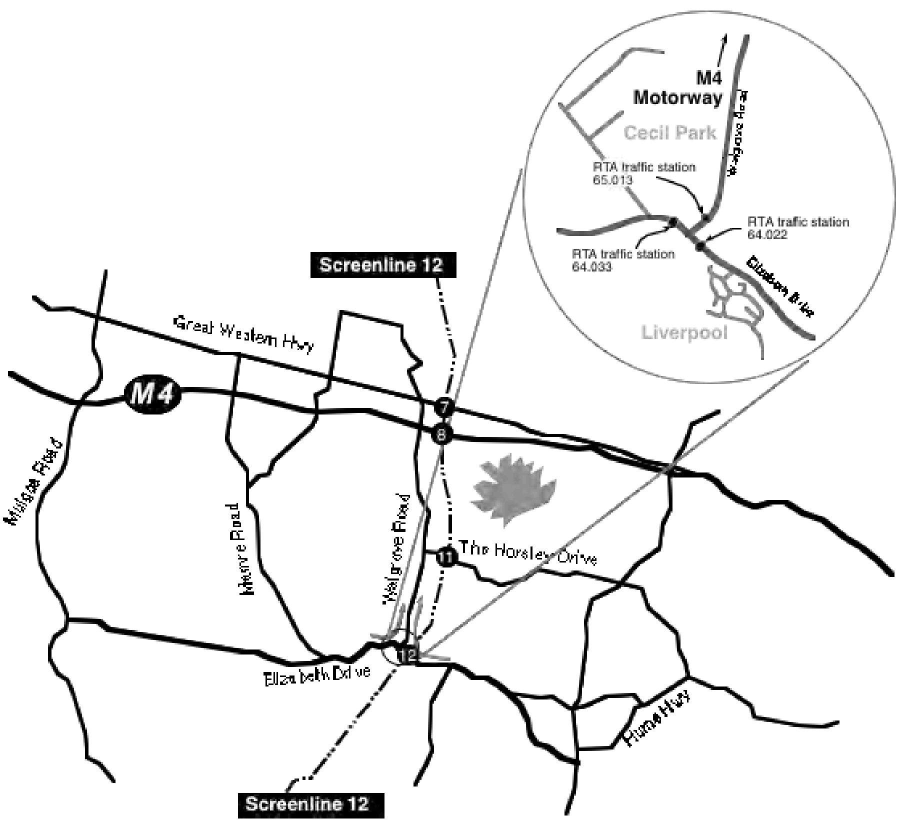
Given its geometry, traffic reassignment from The Horsley Drive to the M4 Motorway would be measured at sites further east of Screenline 1 2. In addition, AADT volumes for The Horsley Drive were only available for the survey years after 1993. These volumes start at 17,627, increasing to 18,833 in 1996 and 19,376 by 1999. Consequently, traffic counts for The Horsley Drive have not been included in the aggregate AADT for Screenline 12.

12. Elizabeth Drive (64.022)

Elizabeth Drive, in combination with the Hume Highway, provides comprehensive east–west access 10 km to the south of the M4 Motorway and so constitutes a key alternative route from which traffic reassignment may have taken place.

Traffic station 64.022 is the point at which Screenline 12 crosses Elizabeth Drive. The site was a sample station until 1991. In 1994 it was upgraded to a permanent station. Unfortunately, sample data were not recorded at 64.022 during 1993. However, two stations in the near vicinity of 64.022 did record traffic counts for 1993. These are station 64.033 — a second sample station located on Elizabeth Drive — and station 65.013, which is a sample station located on Walgrove Road. Figure 5.15 shows the alignment of Elizabeth Drive relative to the M4 Motorway and highlights the intersection of Elizabeth Drive with Walgrove Road where traffic stations 64.022, 64.033 and 65.013 are located.

Figure 5.15 Intersection configuration of Elizabeth Drive and Walgrove Road on Screenline 12



Traffic volumes at 64.033 and 65.013 are shown in Table 5.8 and Table 5.9 respectively. Both stations are sample stations and record traffic volumes as axle pairs. An indication of the heavy vehicle composition of traffic using Elizabeth Drive has been obtained from the TPDC's heavy vehicle survey from 2002, which was shown in Table 5.3. Elizabeth Drive connects directly with the Hume Hwy, which was shown to have five per cent rigid and 5.9 per cent articulated heavy vehicles in its traffic stream in 2002.

Table 5.8 AADT counts for Elizabeth Drive (64.033) from 1983 to 1996

	Elizabeth Drive 64.033 (axle pairs)	Elizabeth Drive 64.033 (veh. nos)	Rigid vehicles 5%	Artic'd vehicles 5.9%
1983	***12,010***	9,593	480	566
1984				
1985	***15,510***	12,388	619	731
1986				
1987	***16,070***	12,835	642	757
1988				
1989	***16,527***	13,200	660	779
1990				
1991	***16,980***	13,562	678	800
1992				
1993	***15,906***	12,704	635	750
1994				
1995				
1996	***17,274***	13,797	690	814

Note: AADT counts shown in ***bold italics*** are counts of axle pairs, as recorded by a sample station, and not vehicle numbers, as recorded by a permanent station.

Source: RTA, 1997, *Traffic volume data for the Sydney Region 1996.* Roads & Traffic Authority of NSW, Sydney.

As can be seen in Table 5.8, there was a decline in vehicle numbers at 64.033 between 1991 and 1992. The decline could be due to traffic reassignment from Elizabeth Drive, which would have used routes on the western end of Elizabeth Drive, such as Mulgoa and Mamre Roads, to access the M4 Motorway.

Table 5.9 AADT counts for Walgrove Road (65.013) from 1983 to 1996

	Walgrove Road 65.013 (axle pairs)	Walgrove Road 65.013 (veh. nos)	Rigid vehicles 5%	Artic'd vehicles 5.9%
1983	***8,990***	7,180	359	424
1984				
1985	***8,866***	7,081	354	418
1986				
1987	***8,585***	6,857	343	405
1988				
1989	***9,671***	7,724	386	456
1990				
1991	***9,019***	7,204	360	425
1992				
1993	***13,977***	11,164	558	659
1994				
1995				
1996	***15,121***	12,077	604	713

Note: AADT counts shown in ***bold italics*** are counts of axle pairs, as recorded by a sample station, and not vehicle numbers, as recorded by a permanent station.

Source: RTA, 1997, *Traffic volume data for the Sydney Region 1996*. Roads & Traffic Authority of NSW, Sydney.

Vehicle numbers at station 65.013 increased between 1991 and 1993. The increase could have been caused by traffic using Walgrove Road as a route by which to access the M4 Motorway if reassigning from journeys with origins to the east of the intersection of Elizabeth Drive and Walgrove Road.

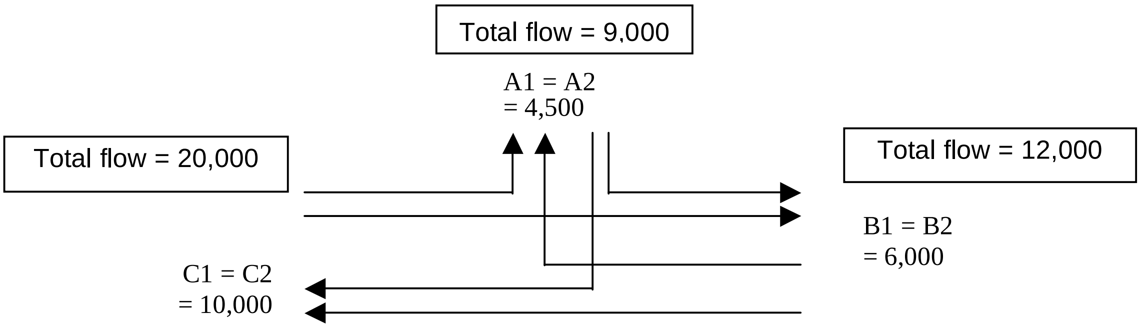
To gauge whether this may have been the case, AADT volumes from both sample and permanent stations to the east of 64.022 were inspected. Traffic volumes at site 65.011 — a sample station to the east of 64.022 — showed an increase between 1991 and 1993 from 23,770 to 25,621 AADT movements.

It is perhaps significant that a few months after the opening of the last section of the M4 Motorway, the first section of what would become the M5 Motorway was opened to traffic in August 1992. It is conceivable that traffic may have been reassigned from Elizabeth Drive to the M5 radial motorway to the south.

To calculate the AADT measured in axle pairs for 64.022, a set of simultaneous equations were used. The method used to devise these is shown in Figure 5.6.

Figure 5.16 Estimation of missing data at Elizabeth Drive intersection

Assume total traffic is split equally in each direction



Equation 1: 10,000 = Proportion_A x 4,500 + Proportion_B x 6,000
Equation 2: 6,000 = (1 - Proportion_A) x 4,500 + Proportion_C x 10,000
Equation 3: 4,500 = (1 - Proportion_B) x 6,000 + (1 - Proportion_C) x 10,000

These three equations will give the unknowns: Proportion_A, Proportion_B, and Proportion_C

Source: van den Bos, P. 2005, *Elizabeth Drive intersection data*. Personal communication, 4 August.

Table 5.10 shows the results achieved when using the simultaneous equations to generate AADT counts for axle pairs at sample station 64.022 from counts for stations 64.033 and 65.013 for the years 1983 to 1991. The columns on the left show the actual counts, while the cells highlighted in the right set of columns show the counts estimated for that year using the simultaneous equations. As can be seen, with the exception of the volume recorded at station 64.022 for 1989, the estimates are very close to the measured counts. By using the coefficients from 1991, a figure of 25,121 is generated for 64.022. Given the time series trends, however, a figure of 25,500 appears more appropriate (van den Bos 2005, pers. comm.).

Table 5.10 Calculation of AADT for 64.022 for 1993

	64.022	64.033	65.013	Using coefficients for the different years Year 83	Year 85	Year 87	Year 89	Year 91
1983	19,530	12,010	8,990	19,524	18,269	16,230	17,039	17,670
1985	20,872	15,510	8,866	21,784	20,986	18,902	19,590	20,542
1987	19,200	16,070	8,685	21,945	21,267	19,209	19,856	20,868
1989	20,970	16,527	9,671	23,492	22,574	20,310	21,071	22,075
1991	21,890	16,980	9,019	22,990	22,322	20,178	20,842	21,919
1993		15,906	13,977	28,446	26,162	23,048	24,388	25,121

Source: van den Bos, P. 2005, *Elizabeth Drive intersection data*. Personal communication, 4 August.

Table 5.11 shows the AADT figures for 64.022 on Screenline 12, including the estimate for 1993. As with the other traffic stations, five and 5.9 per cent rigid and articulated heavy vehicles were used in the estimates to convert counts of axle pairs to vehicle numbers.

Table 5.11 AADT counts for Elizabeth Drive (64.022) from 1983 to 1996

	Elizabeth Drive 64.022 (axle pairs)	Elizabeth Drive 64.022 (veh. nos)	Rigid Vehicles 5%	Artic'd vehicles 5.9%
1983	***19,530***	15,599	780	920
1984				
1985	***20,872***	16,670	833	984
1986				
1987	***19,200***	15,335	767	905
1988				
1989	***20,970***	16,749	837	988
1990				
1991	***21,890***	17,484	874	1,032
1992				
1993	**(25,500)**	19,404	970	1,145
1994		22,201	1,110	1,310
1995		22,005	1,100	1,298
1996		19,755	988	1,166

Note: AADT counts shown in ***bold italics*** are counts of axle pairs, as recorded by a sample station, and not vehicle numbers, as recorded by a permanent station. AADT counts shown in **(bold)** are estimated from counts measured at other sample stations.

Source: RTA, 1997, *Traffic volume data for the Sydney Region 1996*. Roads & Traffic Authority of NSW, Sydney.

The AADT for 1999 is 23,669 and the AADT for 2002 is 23,303. These volumes suggest two things. First, the 1996 figure of 19,755 could be the product of a counter malfunction. Second, the road was operating at close to its ceiling capacity by the late 1990s. A close inspection of the surrounding network and intersection configurations would be necessary to identify precisely why.

Traffic counts for Elizabeth Drive have been included in the aggregate AADT for Screenline 12.

13. McIver Avenue (64.111)

McIver Avenue is a local suburban street that does not provide a comprehensive east–west through-route for traffic. Portions of McIver Avenue are unsealed. In 1993 an AADT count of 63 was measured at traffic station 64.111.

Traffic counts for McIver Avenue have not been included in the aggregate AADT for Screenline 12.

14. Seventeenth Avenue (64.110)1983

Seventeenth Avenue, like McIver Avenue, is a local suburban street. It does connect with other streets that provide through access, however, its status is not that of a major through-route. In 1993 an AADT count of 144 was measured at traffic station 64.110.

Traffic counts for Seventeenth Avenue have not been included in the aggregate AADT for Screenline 12.

15. Sixteenth Avenue (64.109)

Sixteenth Avenue, like Seventeenth Avenue, is a local suburban street that connects with other streets to provide through access. Its status, however, is not that of a major through-route. In 1993 an AADT count of 63 was measured at traffic station 64.109.

Traffic counts for Sixteenth Avenue have not been included in the aggregate AADT for Screenline 12.

16. Fifteenth Avenue (64.108)

Fifteenth Avenue is a local suburban street that functions as a local collector street for other suburban streets before connecting with Hoxton Park and Cowpasture Roads which are the primary trunk routes in the area. Like the previous suburban streets, Fifteenth Avenue does not provide comprehensive through access, nor is its alignment able to provide a rat-run alternative to travel along east–west trunk routes. In 1993 an AADT count of 8,249 was measured at traffic station 64.108.

Traffic counts for Fifteenth Avenue have not been included in the aggregate AADT for Screenline 12.

17. Twenty-sixth Avenue (64.107)

Twenty-sixth Avenue is a local suburban street that does not provide comprehensive through access in an east–west direction. In 1993 an AADT count of 248 was measured at traffic station 64.107.

Traffic counts for Twenty-sixth Avenue have not been included in the aggregate AADT for Screenline 12.

18. Bringelly Road (64.097)

Bringelly Road is located to the far south of the M4 Motorway alignment. The geometry of this road is such that it potentially provides an alternate route for traffic moving from the far south-western districts of Sydney to destinations in the east.

Unlike Windsor and Richmond Roads, there is no longer distance route connecting Elizabeth Drive and Bringelly Road to the far western regions beyond the Sydney Metropolitan region. Consequently, the opportunity for the reassignment of traffic travelling long distances is limited, so that a drop in traffic volumes during 1992 would not be expected to be as great as it was on Richmond Road, for example.

The heavy-vehicle composition of the traffic stream at this point in the network is unknown. Of the eleven sites listed in Table 5.3 that show the percentage of heavy vehicles in the traffic streams, the site at the Hume Hwy near Ingleburn is the closest.

While Bringelly Road is a key trunk route, the volumes are not particularly high. This is because urban development within the far south-west sector at the time of the opening of the last link in the M4 Motorway was not substantial. A value of three per cent for rigid heavy vehicles and one per cent for articulated heavy vehicles was used.

Table 5.12 AADT counts for Bringelly Road (64.097) from 1983 to 1996

	Bringelly Road 64.097 (axle pairs)	Bringelly Road 64.097 (veh. nos)	Rigid vehicles 3%	Artic'd vehicles 1%
1983	***6,630***	6,166	185	61
1984				
1985	***7,211***	6,706	201	67
1986				
1987	***8,946***	8,320	249	83
1988				
1989	***9,906***	9,213	276	92
1990				
1991	***12,412***	11,543	346	115
1992				
1993	***12,348***	11,484	345	115
1994				
1995				
1996	***14,554***	13,535	406	135

Note: AADT counts shown in ***bold italics*** are counts of axle pairs, as recorded by a sample station, and not vehicle numbers, as recorded by a permanent station.

Source: RTA, 1997, *Traffic volume data for the Sydney Region 1996*. Roads & Traffic Authority of NSW, Sydney.

Later AADT volumes for Bringelly Road at station site 64.097 are not substantially higher than they were in 1996. The volume for 1999 is 15,399 and for 2002 it is 9,363. The drop in the latter is possibly due to traffic reassignment after opening of the M5 East Motorway, which was the last link in the south-western sector motorway.

Traffic counts for Bringelly Road have been included in the aggregate AADT for Screenline 12.

19. Camden Valley Way (64.106)

Camden Valley Way has a ring-road alignment, connecting Cowpasture Road to Campbelltown Road, which both have south–west radial alignments Therefore, traffic counts for Camden Valley Way have not been included in the aggregate AADT for Screenline 12.

20. Denham Court Road (84.127)

Like Camden Valley Way, Denham Court Road has a ring-road alignment that connects the southernmost end of Camden Valley Way — where the road has a south–west alignment — to Campbelltown Road. Therefore, traffic counts for Denham Court Road have not been included in the aggregate AADT for Screenline 12.

Method: comparative traffic counts on Screenline 12

This section examines the changes to road traffic volumes on the six key east–west trunk routes that cross Screenline 12.

Table 5.13 shows the AADTs for the various routes that could conceivably provide alternate paths for traffic moving in an east–west direction across Screenline 12. The vehicle numbers for Richmond Road were calculated from counts of axle pairs using the same percentage of heavy vehicles recorded on the M4 Motorway. This conversion factor produces a greater disparity between traffic volumes before and after the opening of the last section of M4 Motorway, which suggests that traffic reassignment from Richmond Road was greater.

As can be seen in Table 5.13, the increase from 1991 to 1993 is the largest between any of the biannual periods for which data were available for all routes. Increases from 1987 to 1989, and again from 1989 to 1991, are also high at roughly 17,000 AADT. During these periods, the road capacity was increased on Richmond and Windsor Roads, so that the same factors that gave rise to induced traffic growth after the opening of the last section of the M4 Motorway were also at play.

Table 5.13 AADT for six key trunk routes along Screenline 12

	Windsor Rd (88.046)	Richmond Rd (71.059)	Great Western Hwy (70.001)	M4 Motorway (70.002)	Elizabeth Drive (64.022)	Bringelly Road (64.097)	Total
1983	17,404	16,601	36,920	21,092	15,599	6,166	**113,782**
1984			37,757				
1985	20,417	18,900	41,012	22,298	16,670	6,706	**126,003 (+12,221)**
1986			36,508				
1987	21,542	20,121	36,499	35,214	15,335	8,320	**137,031 (+11,028)**
1988			37,952				
1989	24,917	25,943	39,641	37,690	16,749	9,213	**154,153 (+17,122)**
1990							
1991	25,746	34,691	40,023	41,753	17,484	11,543	**171,240 (+17,087)**
1992		31,174	35,237	64,516			
1993	26,110	34,194	26,007	73,005	20,367	11,484	**191,167 (+19,927)**
1994		34,304	28,619	(81,419)	22,201		
1995		36,710	28,382	76,259	22,005		
1996	27,357	37,017	29,685	76,460	(19,755)	13,535	**203,809 (+12,642)**

Note: AADT counts in this table are for vehicle numbers only. Volumes that have been (bracketed) were probably subject to counter malfunctions. Volumes shown in **(bold)** show differences in total volumes.

Source: RTA, 1997, *Traffic volume data for the Sydney Region 1996*. Roads & Traffic Authority of NSW, Sydney.

By contrast, growth across Screenline 12 during the period, 1983 to 1985, 1985 to 1987 and 1993 to 1996 gave rise to lower increases in traffic volumes. During these periods, the network was not subject to substantial changes or capacity increases that could have acted as a trigger for wide-scale travel behaviour changes that give rise to induced traffic growth. During these periods, biannual increases appear to be just over 11,000 AADT.

Fluctuations in rigid and articulated heavy vehicles across Screenline 12 were also examined. These results are summarised in Table 5.14.

Table 5.14 AADT counts for rigid and articulated heavy vehicles on trunk routes along Screenline 12 using M4 conversion rates for Richmond Road

	Windsor Road (88.046)		Rich'd Road (71.059)		GWH (70.001)		M4 Motorway (70.002)		Elizabeth Drive (64.022)		Bringelly Road (64.097)		Total	
1983	888	209	664	498	1,477	1,108	844	633	780	920	185	61	**4,838**	**3,429**
1984					1,510	1,133								
1985	1,041	245	756	567	1,640	1,230	892	669	833	984	201	67	**5,363 (+525)**	**3,762 (+333)**
1986					1,460	1,095								
1987	1,098	258	805	604	1,460	1,095	1,409	1,056	767	905	249	83	**5,788 (+425)**	**4,001 (+239)**
1988					1,518	1,139								
1989	1,270	299	1,038	778	1,586	1,189	1,508	1,131	837	988	276	92	**6,515 (+727)**	**4,477 (+476)**
1990														
1991	1,313	309	1,388	1,041	1,601	1,201	1,670	1,253	874	1,032	346	115	**7,192 (+677)**	**4,951 (+474)**
1992			1,247	935	705	352	2,581	1,935						
1993	1,432	337	1,368	1,026	520	260	2,920	2,190	970	1,145	345	115	**7,555 (+363)**	**5,073 (+122)**
1994			1,372	1,029	572	286	(3,257)	(2,443)	1,110	1,310				
1995			1,360	1,020	568	284	3,050	2,288	1,100	1,298				
1996	1,395	328	1,371	1,029	594	297	3,058	2,294	(988)	(1,166)	406	135	**7,812 (+257)**	**5,249 (+176)**

Note: AADT counts in this table are for rigid and articulated heavy vehicles only. Volumes that have been (bracketed) were probably subject to counter malfunctions. Volumes shown in **(bold)** show differences in total volumes.

As can be seen in Table 5.14, growth rates in both classes of heavy vehicles were higher during the 1980s and early 1990s. The increases do not appear to coincide in a consistent way with roadworks across Screenline 12. There are two possible reasons for this. First, the growth in heavy-vehicle numbers may not be subject to changes in the Level of Service in the same way that commuter and light traffic is. Second, there could be problems with the percentage estimates for heavy vehicles that have been used to convert axle pair counts to vehicle number counts. If the composition of heavy vehicles has changed over time, then this may have affected the fluctuations in heavy-vehicle numbers shown in Table 5.14. If the estimates are widely inaccurate, such an effect would have been greater on higher volume roads. The two roads for which there are more detailed heavy-vehicle data are the M4 Motorway and GWH. Heavy-vehicle estimates for these roads were available for 1992 and 2002 and show relatively little difference. The conversion factor used for Richmond Road may be too high. In practice, the composition of heavy-vehicles may have been more like that on Windsor Road. To gauge the difference this might make, heavy vehicle volumes across Screenline 12 were recalculated. The results of this are shown in Table 5.15.

Table 5.15 AADT counts for rigid and articulated heavy vehicles on trunk routes along Screenline 12 using Windsor Road conversion rates for Richmond Road

	Windsor Road (88.046)		Rich'd Road (71.059)		GWH (70.001)		M4 Motorway (70.002)		Elizabeth Drive (64.022)		Bringelly Road (64.097)		Total	
1983	888	209	818	193	1,477	1,108	844	633	780	920	185	61	**4,992**	**3,124**
1984					1,510	1,133								
1985	1,041	245	932	219	1,640	1,230	892	669	833	984	201	67	**5,539 (+547)**	**3,414 (+290)**
1986					1,460	1,095								
1987	1,098	258	992	233	1,460	1,095	1,409	1,056	767	905	249	83	**5,975 (+436)**	**3,630 (+216)**
1988					1,518	1,139								
1989	1,270	299	1,279	301	1,586	1,189	1,508	1,131	837	988	276	92	**6,756 (+781)**	**4,000 (+370)**
1990														
1991	1,313	309	1,710	402	1,601	1,201	1,670	1,253	874	1,032	346	115	**7,514 (+758)**	**4,312 (+312)**
1992			1,590	374	705	352	2,581	1,935						
1993	1,432	337	1,744	410	520	260	2,920	2,190	970	1,145	345	115	**7,931 (+417)**	**4,457 (+145)**
1994			1,750	411	572	286	(3,257)	(2,443)	1,110	1,310				
1995			1,872	440	568	284	3,050	2,288	1,100	1,298				
1996	1,395	328	1,888	444	594	297	3,058	2,294	(988)	(1,166)	406	135	**8,329 (+398)**	**4,664 (+207)**

Note: AADT counts in this table are for rigid and articulated heavy vehicles only. Volumes that have been (bracketed) were probably subject to counter malfunctions. Volumes shown in **(bold)** show differences in total volumes.

As can be seen in Table 5.15, if the heavy-vehicle composition rates at Windsor Road are used to convert the axle-pair data to vehicle counts, the fluctuation in heavy vehicles is less erratic. In particular, the fluctuation in articulated heavy vehicles is more in keeping with fluctuations in economic activity. This will be discussed in the next section, which examines fluctuations in rail passenger journeys (Section 5.2.2).

If these heavy-vehicle volumes on Richmond Road are used, then the number of vehicles crossing Screenline 12 over the period changes. These results are shown in Table 5.16.

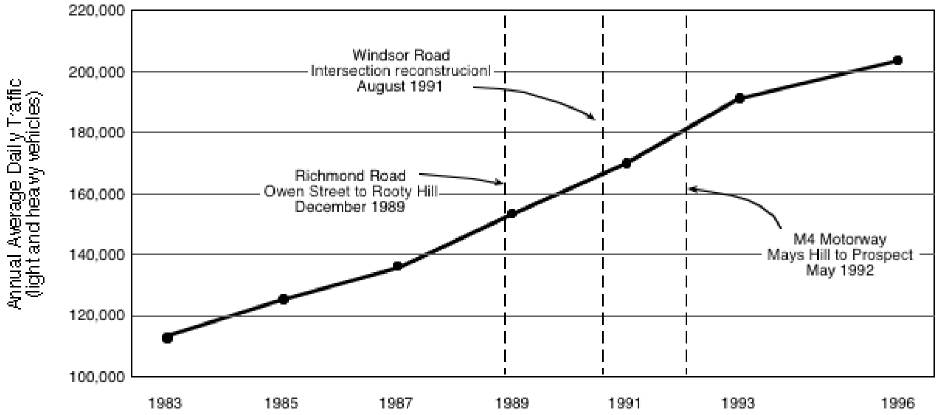
Table 5.16 AADT for six key trunk routes along Screenline 12 (using Windsor Road heavy-vehicle conversion rates)

	Windsor Rd (88.046)	Richmond Rd (71.059)	Great Western Hwy (70.001)	M4 Motorway (70.002)	Elizabeth Drive (64.022)	Bringelly Road (64.097)	Total
1983	17,404	16,045	36,920	21,092	15,599	6,166	**113,226**
1984			37,757				
1985	20,417	18,267	41,012	22,298	16,670	6,706	**125,370 (+12,144)**
1986			36,508				
1987	21,542	19,447	36,499	35,214	15,335	8,320	**136,357 (+10,987)**
1988			37,952				
1989	24,917	25,075	39,641	37,690	16,749	9,213	**153,285 (+16,928)**
1990							
1991	25,746	33,529	40,023	41,753	17,484	11,543	**170,078 (+16,793)**
1992		31,174	35,237	64,516			
1993	26,110	34,194	26,007	73,005	20,367	11,484	**191,167 (+21,089)**
1994		34,304	28,619	(81,419)	22,201		
1995		36,710	28,382	76,259	22,005		
1996	27,357	37,017	29,685	76,460	(19,755)	13,535	**203,809 (+12,642)**

Note: AADT counts in this table are for vehicle numbers only. Volumes that have been (bracketed) were probably subject to counter malfunctions. Volumes shown in **(bold)** show differences in total volumes.

As can be seen in Table 5.16 and in Figure 5.17, the early biannual differences between 1983–1985 and 1985–1987, when there were no significant roadworks taking place, are smaller — around 11,000 to 12,000 average vehicle movements per day. The differences between 1987–1989 and 1989–1991, when there were roadworks taking place on Windsor and Richmond Roads, is slightly higher, at around 17,000 average vehicle movements per day. The difference between 1991 and 1993, when the last section of the M4 Motorway was opened, is greater than in previous years, at just over 21,000 vehicle movements on average per day. In the three years that followed, traffic increased by over 12,000 vehicle movements per day — an increase similar in magnitude to those in earlier periods when there were no increases in capacity.

Figure 5.17 AADT counts for six key trunk routes along Screenline 12



From a testing perspective, it would have been better if there had not been other capacity increases on arterial roads across the Screenline 12 during the study period. But given the necessary length of a comprehensive screenline, such conditions are difficult to locate.

Results: confirmation of the induced traffic growth hypothesis

Generally, the results of this analysis support the induced traffic growth hypothesis. The increase in traffic across Screenline 12 is higher between 1991–1993, when the M4 Motorway section was opened to traffic, than for any other period.

As shown in the previous section on method, when other roadworks were taking place, there were also larger increases in traffic volumes across Screenline 12. While Bonsall has recommended that case studies should be restricted to examples where no other roadworks are taking place in the near vicinity (Bonsall 1996, pp. 19–20), the coincidence between traffic-volume increases and roadworks is consistent throughout the study period. For example, the results clearly show that roadworks on Richmond and Windsor Roads, in the years prior to the opening of the last section of the M4 Motorway, were responsible for relatively high levels of traffic growth on those roads. By contrast, growth on these trunk routes was relatively low in the years 1983 to 1985 and 1985 to 1987. At this time there were no substantial changes to road capacity, so that service levels did not change dramatically.

In terms of magnitude, two scenarios can be drawn from the data. The first, using heavy-vehicle counts for the M4 to estimate those on Richmond Road, suggests that traffic increased by around 7,000 AADT over and above the increases that would have taken place if there had been no increases in road capacity and change in service levels. This is calculated on the basis that AADT volumes for Screenline 12 increased by roughly 20,000 in the period after the motorway section opening, when the increase is usually around 12,000. If a further 1,000 subtracted to offset potential traffic reassignment from Elizabeth Drive, then a volume of 7,000 AADT results.

The second scenario would put the surplus volume at around 8,000 AADT. This result is derived when the vehicle counts for Richmond Road are calculated using the same percentage of heavy vehicles that occur on Windsor Road. As shown in Table 5.15, AADT volumes across Screenline 12 increased by roughly 21,000 in the period after the motorway section opening, when the increase is usually around 11,500 to 12,000. If a further 1,000 are subtracted to offset potential traffic reassignment from Elizabeth Drive, then a volume of 8,000 to 8,500 AADT results if normal growth is estimated as being 12,000 to 11,500.

The analysis has not been able to identify the source of this increase, however, analysis of rail data has the potential to identify potential increases that may be due to mode-shifting.

5.2.2 Analysis of the Western Sydney rail network[32]

In this section, time series regression modelling is used in an attempt to quantify the number of road trips that may have been generated by people shifting from the rail network to the road network because of opportunities to save travel time.

As discussed previously in Sections 3.5 and 4.1, models cannot resolutely identify causality, and time series regression models can only show the degree to which fluctuations in a set of variables coincide with one another, which is consistent with a

[32] Time series regression modelling in this section was carried out as part of an ongoing collaborative research program with Associate Professor Peter Petocz from the Department of Statistics at Macquarie University. The early work in this program was documented in: Zeibots, M. E. and Petocz, P. 2005, 'The relationship between increases in motorway capacity and declines in urban rail passenger journeys: a case study of Sydney's M4 Motorway and Western Sydney Rail Lines' in *28th Australasian Transport Research Forum*, Sydney, September 19.

causal relationship. On this basis, such analysis then necessarily makes assumptions about how the two might be related and what may cause a particular variable to fluctuate. The degree to which other variables are able to account for the degree of fluctuation is also considered in such models.

In the case of rail network analysis, as will be shown, difficulties can arise in relation to the ability to find and collate appropriate data for the raft of factors that affect rail passenger journey volumes.

By subjecting rail passenger journey volumes for the rail line parallel to the M4 to time series regression analysis, it is possible to see whether or not a corresponding reduction in rail journeys coincides with the opening of the M4 Motorway. If there is, then potentially such a reduction could have occurred because of mode-shifting. While such a method cannot show with complete certainty that mode-shifting has taken place, it can indicate whether or not there have been changes that are consistent with that hypothesis. The only way in which mode-shifting could be irrefutably identified would be through a survey of motorists, as reviewed in Section 3.4.

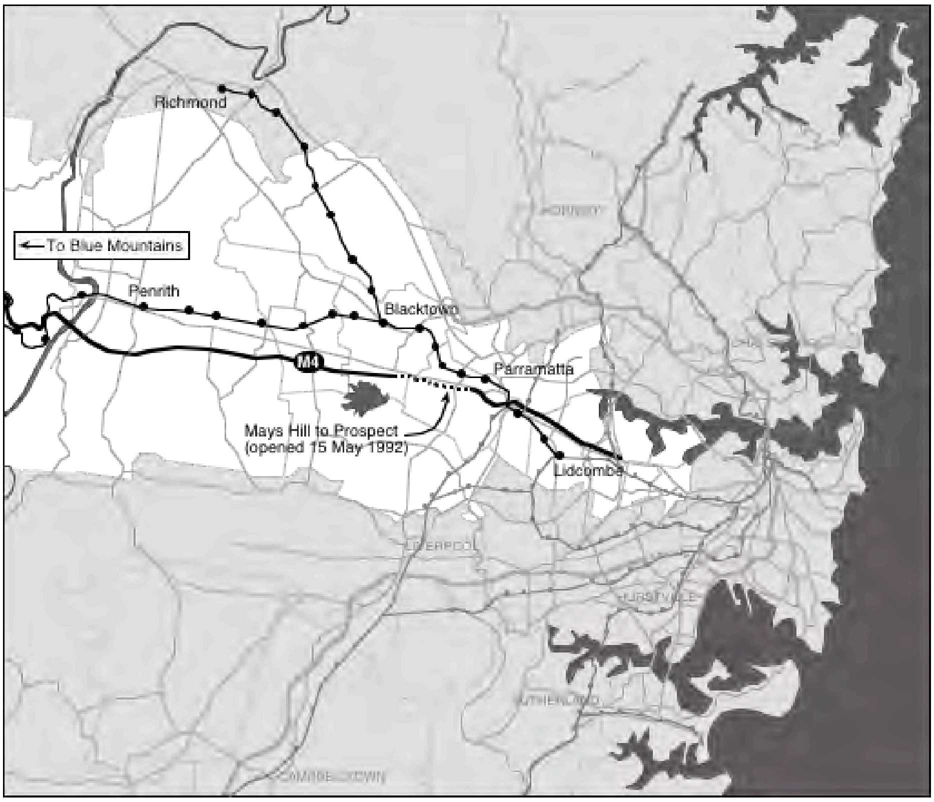
As with the previous section that analysed fluctuations in road data before and after the opening of the M4 Motorway section, this section will first discuss the data used in the analysis followed by the method, results and conclusions.

Data: passenger journeys on the Sydney CityRail network

The primary data used in this analysis are time series *estimated passenger journeys*. These have been calculated from records of rail ticket sales provided by CityRail. Ticket sales are listed by their type and grouped according to their point of purchase. The point of purchase is assumed to be the station at which a passenger enters the CityRail network.

Passenger journeys can be disaggregated into individual rail lines and sections of rail lines. Figure 5.18 shows the route alignments of the Western Sydney and Richmond Rail Lines relative to the position of the M4 Motorway section from Mays Hill to Prospect opened on May 1992. Rail stations highlighted in black indicate stations from which data were collected for inclusion in this study. Rail stations further to the west on the Blue Mountains rail line were also included, but are not shown in Figure 5.18.

Figure 5.18 Rail and motorway trunk routes in Sydney's western sector



Western Sydney Rail Line stations include: Lidcombe, Auburn, Clyde, Granville, Harris Park, Parramatta, Westmead, Wentworthville, Pendle Hill, Toongabbie, Seven Hills, Blacktown, Doonside, Rooty Hill, Mt Druitt, St Marys, Werrington, Kingswood, Penrith, Emu Plains.

Blue Mountains Rail Line stations include: Lapstone, Glenbrook, Blaxland, Warrimoo, Valley Heights, Springwood, Faulconbridge, Linden, Woodford, Hazelbrook, Lawson, Wentworth Falls, Leura, Katoomba, Blackheath, Mt Victoria, Lithgow.

Richmond Rail Line stations include: Marayong, Quakers Hill, Schofields, Riverstone, Mulgrave, Windsor, Clarendon, East Richmond, Richmond.

Ticket types conform to six generic categories: single, return, weekly, monthly, quarterly and yearly. The number of trips generated by single and return tickets is clear. In the case of periodical tickets, whereby ticket holders can undertake as many trips as they like within the nominated timeperiod, the average number of trips has been estimated through surveys carried out by RailCorp.

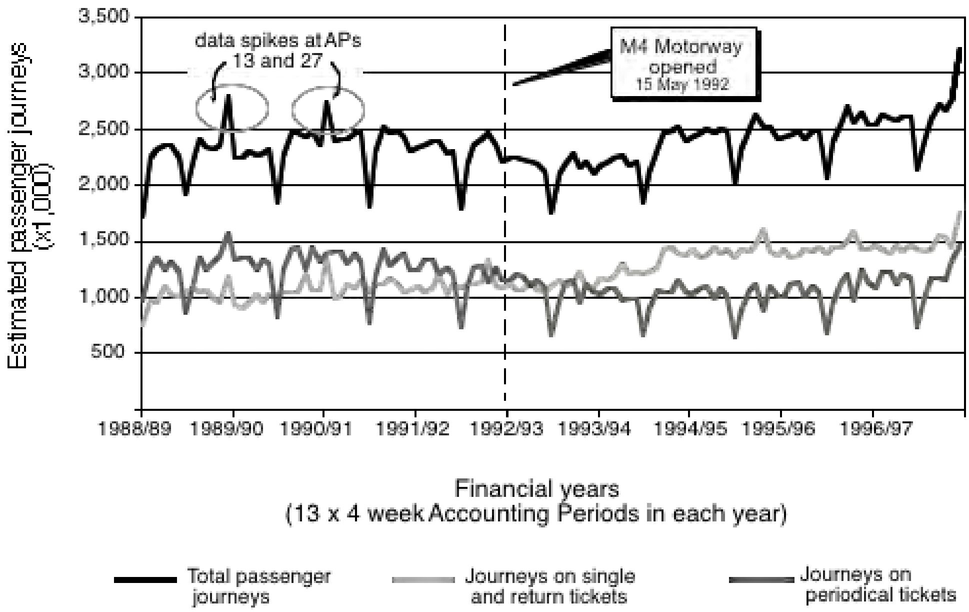
Table 5.17 sets out the number of trips attributed to each ticket type, as per RailCorp's survey findings.

Table 5.17. Trip rates for rail ticket types

Ticket type	Trip rate
Single	1
Return	2
Weekly	11
Monthly	45
Quarterly	115
Yearly	585

Table 5.1 shows total estimated passenger journeys for Western Sydney Rail Line (WSRL) services. Estimated passenger journeys using single and return tickets, and journeys using periodical tickets, are also shown, as is the point at which additional capacity on the M4 Motorway was opened.

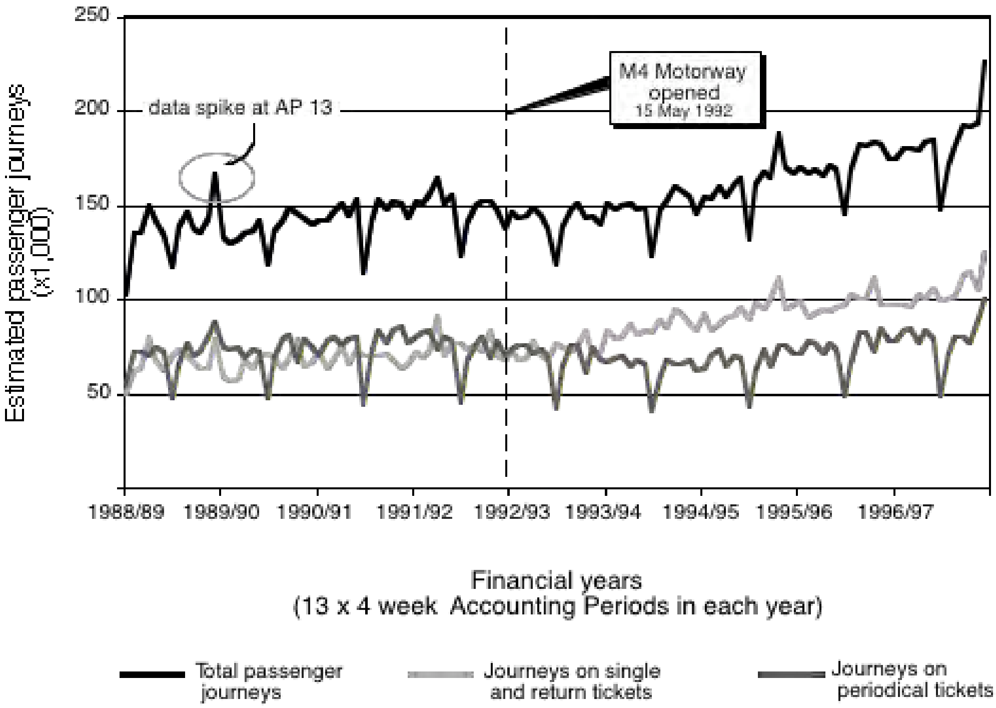
Figure 5.19 Estimated passenger journeys for Western Sydney and Blue Mountains rail services (1988/89 – 1996/97)



Source: Zeibots, M. E. and Petocz, P. 2005, 'The relationship between increases in motorway capacity and declines in urban rail passenger journeys: a case study of Sydney's M4 Motorway and Western Sydney Rail Lines' in *28th Australasian Transport Research Forum*, Sydney, September 19, p. 6.

Prior to 1996–97, RailCorp collated rail ticket sales data according to 13 four-week periods, or Accounting Periods (APs). In this formation, regular seasonal and yearly, as well as long-term cyclical, fluctuations can be seen. Each annual period for total and periodical tickets is characterised by a sharp decline in passenger journey numbers that coincides with the Christmas and summer holiday period. A longer-term trend can also be discerned for total trips, where a slight rise and then decline can be seen before the opening of the motorway section, followed by an increase during the later part of the study period. For singles, trends appear relatively flat before the motorway opening, increasing slightly after opening, while the trend for periodical tickets appears to be the reverse of this trend, increasing before the motorway opening but declining after opening. These trends do not correspond to regular yearly cycles and so their cause is not as immediately obvious. Two irregular data spikes appear at APs 13 and 27 in the time series. There is no explanation for these, but it is possible that they could be the product of data-collation anomalies. There are also unusually low values at the start of the data series and unusually high values at the end.

Figure 5.20 Estimated passenger journeys for Richmond rail services (1988/89 – 1996/97)



Source: Zeibots, M. E. and Petocz, P. 2005, ‘The relationship between increases in motorway capacity and declines in urban rail passenger journeys: a case study of Sydney’s M4 Motorway and Western Sydney Rail Lines’ in *28th Australasian Transport Research Forum*, Sydney, September 19, p. 7.

Figure 5.20 shows total estimated passenger journeys for Richmond Rail Line (RRL) services. Estimated passenger journeys using single and return tickets and journeys using periodical tickets are shown as for Figure 5.19. As with data for the WSRL, regular yearly fluctuations can be seen in addition to a long-term trend that does not conform to yearly cycles. The data spike at AP 13 can be seen, however, the data spike occurring at AP 27 is not as prevalent in the RRL time series. As with the data for the WSRL, there are unusually low values at the start of the data series and unusually high values at the end.

As will be shown in the following sections that detail the method and results, estimated passenger journey data for other sections were also used. These data have been collated in the same way as described here for the WSRL and RRL.

In addition to estimated rail passenger journey data, time series data for other variables that have an effect on passenger journey volumes were also collated. These include data for economic activity and employment levels. At the time of opening the M4 Motorway from Mays Hill to Prospect, there was a downturn in general economic activity. There were declines in rail passenger journeys on all lines in the rail network at this time and so it is necessary to incorporate these other changes into the model. To accomplish this, economic production data for the state of NSW were collated for incorporation in the analysis, as per Mewton (1997, 2005). Later, employment data for the Sydney Statistical Division (SSD) were used. These data were obtained from the Australian Bureau of Statistics (ABS) and were calculated according to quarterly time periods.

Method: time series regression

The data for estimated passenger journeys were collated in parallel time series for 117 four-week APs between July 1988 and May 1997. This was carried out for total journeys on both the WSRL and RRL, as well as for journeys undertaken on periodical tickets and single and return tickets. Testing by different ticket types was undertaken to assess whether the motorway attracted committed rail users who buy periodical tickets, or infrequent users who are more likely to purchase single and return tickets. It is also assumed that a higher portion of journey-to-work trips would be undertaken on periodical tickets.

State Domestic Product (SDP) and employment data were also collated as parallel series. Values for each quarter were repeated and listed in accordance with corresponding APs. Where APs did not correspond directly with quarterly periods, economic production values were used from the quarter whose time span most closely equated with the AP. Consequently, there are three groups of APs with the same SDP value in the time series and one group of four APs with the same SDP value for each year.

The opening of the M4 Motorway section from Mays Hill to Prospect to traffic was represented by an indicator variable that changed from 0 to 1 at the time of opening. This approach models the opening as having an instantaneous effect, although it is quite possible, particularly with periodical tickets, that passengers attracted off the rail and onto the road network did so over a time period around the opening.

As noted earlier, all passenger journey time series showed unusually low values in the first Accounting Period — July 1988 — and unusually high values in the last — May 1997. Upon investigation, these were attributed to *end effects* of the construction of the time series and removed from further analysis.

The analysis started by removing the strong seasonal — annual — effect of period 13 in the data. Investigation of preliminary analyses showed that there were some isolated high values — particularly in June 1989 — but since no specific cause for them could be identified, they were allowed for by applying exponential smoothing to the series — single exponential smoothing with optimal ARIMA 0,0,1 model. Initially, linear regression was used to analyse the data. However, it was clear in many of the series that longer-term non-linear trends were present over and above the seasonal components. The seasonally adjusted and smoothed data were then analysed using a polynomial — cubic — multiple regression with predictor variables *SDP*, *month*, *month-squared*, *month-cubed* and *M4*. This model was found to follow the trend more closely.

The smoothed time series was checked for autocorrelation using the Durbin-Watson test: in each case there was no evidence of autocorrelation.

Analysis was undertaken with the primary aim of gauging two features of the time series. The first was whether the opening of the motorway section had a significant effect on passenger volumes on the WSRL and RRL by drawing passengers away from rail services. Significance was gauged by p-values. The second feature to be gauged was the likely scale of mode-shifting. This volume was estimated by the coefficient of the indicator variable *M4* representing the change caused by the opening of the expressway.

Results: method too insensitive to isolate a signal

Regressions for all coefficients of M4 are significant and negative. This indicates that the opening of the M4 Motorway section from Mays Hill to Prospect did correspond to a significant decline in the number of rail passenger journeys on the WSRL and the RRL, although of course it does not prove a causal link.

Table 5.18 shows the P-values — significance of each coefficient — from the regressions, as well as the R-square values — indicating the percentage of variability explained by the explanatory variables. It reveals that M4 is significant in all models, and estimates the amount of decline in thousands of journeys, for each line and ticket type.

Table 5.18 P-values, R-square values and coefficients of M4 from cubic regressions

	RRLtot	*RRLsing*	*RRLper*	*WSRLtot*	*WSRLsing*	*WSRLper*
SDP	0.15	0.25	0.57	<0.001	0.002	<0.001
month	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
month^2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
month^3	0.94	<0.001	<0.001	0.70	<0.001	<0.001
M4	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
R^2	96%	97%	75%	79%	95%	97%
Coeff of M4 (x1000)	–12.5	–7.9	–4.7	–199	–132	–60

According to these regression models, the loss of passenger journeys in the AP immediately after opening of the motorway section was in the order of 200,000 for the WSRL and 12,500 for the RRL, as shown in Table 5.18. This equates to just under 6,000 car trips per day from the WSRL if an average vehicle occupancy rate of 1.2 is used. The drop for the RRL is around 370.

As discussed in Section 3.1, it is important to run a control in order to substantiate the robustness of the methodology and resulting models. In this case, a control ascertains whether or not the method has been able to isolate the signal of interest in the data by making a similar set of observations, only without the parameter of interest.

For the purposes of this analysis, a control was run by collating a data set for passenger journeys undertaken on the Illawarra Rail Line (IRL) over the same time period. The IRL is a radial rail line that serves the southern sector of Sydney. The F6 motorway corridor runs parallel to this rail line in the same way that the M4 runs parallel to the WSRL, however, the F6 motorway has not been built and there were no substantial increases in road capacity in that corridor at the time of the M4 Motorway section opening. The position of the IRL relative to the rest of Sydney is shown in Figure 5.21.

Figure 5.21 Rail trunk routes in Sydney's southern sector

Illawarra Rail Line stations include: Rockdale, Kogarah, Carlton, Allawah, Hurstville, Penshurst, Mortdale, Oatley, Como, Jannali, Sutherland, Loftus, Engadine, Heathcote, Kirrawee, Gymea, Miranda, Caringbah, Woolooware, Cronulla.

The IRL data were then subjected to the same method of testing used for the WSRL and RRL, where a dummy variable was used to indicate the M4 motorway section opening and so, test for any significant variation in passenger journey numbers after that time. The results are shown in Table 5.19. As can be seen, a significant result for the M4 variable was returned for total and periodical trips on the WSRL and IRL, despite the reasonable expectation that there would be no substantial effects from the M4 on IRL passenger volumes and trips in the southern sector.

Table 5.19 P-values, R-square values and coefficients of M4 from regressions with lagged variables for the WSRL and IRL

	WSRLtot	*WSRLsing*	*WSRLper*	*IRLtot*	*IRLsing*	*IRLper*
emp	0.310	<0.001	<0.001	0.910	0.002	<0.001
month	0.920	0.610	0.100	0.349	0.157	0.656
Lagged variable	<0.001	<0.001	<0.001	<0.001	<0.001	0.011
mon x M4	<0.001	<0.001	0.050	<0.001	<0.001	0.326
M4	<0.001	0.003	<0.001	<0.001	0.032	<0.001
R^2	84%	95%	85%	68%	86%	87%
Coeff of M4 (x1000)	–113	–55	–91	–89	–26	–63

If the hypothesis is correct — that a significant drop in passenger journeys on the WSRL should have taken place after the opening of the M4 Motorway due to mode-shifting —then the same statistical result should not be returned for the IRL. As can be seen in Table 5.19, the P-values for total passenger journeys on both the WSRL and IRL are significant for the M4 variable. This means that the results in Table 5.18 should be rejected. However, it does not mean that the hypothesis should be rejected. This is because there are several other possible explanations that could account for the result. First, there may have been other factors at play at the time of the M4 Motorway opening that were influencing rail passenger journey numbers generally across the CityRail network. These factors could include changes to service speeds and service frequencies. There may also have been changes to ticket prices and fare structures at the time of the opening that could have affected passenger journey numbers. Such factors were noted in CityRail reports around the time of the motorway opening (Kearnes 1994, pp. 2–3).

In an attempt to control for these factors, passenger journey data for another line — the Bankstown Rail Line (BRL) — was added to the regression model for both the WSRL and IRL, to act as a control for general changes to service levels. This was done on the assumption that any general fluctuations in passenger journey volumes due to service levels changes would be relatively uniform. Like the IRL, the BRL should not be affected by the opening of the M4 Motorway. Results from these further regression runs are shown in Table 5.20.

Table 5.20 P-values, R-square values and coefficients of M4 from regressions with lagged variables for the WSRL and IRL using Bankstown data to control for service level changes

	WSRLtot	*IRLtot*
emp	<0.001	<0.001
month	0.008	0.677
M4	0.034	0.003
mon x M4	0.015	<0.001
Lagged variable	<0.001	<0.001
Bankstown	<0.001	<0.001
R^2	88%	84%
Coeff of M4 (x1000)	-52.18	14.15

As can be seen, the M4 variable is not significant for either the regression run on the WSRL or the IRL once a control for changes to service levels is introduced. It is interesting, however, to note that the coefficient for M4 is negative in the case of the WSRL and positive in the case of the IRL. On the basis of these further regression models, it is still not possible to comprehensively reject the hypothesis. This is because differences in service levels may not be even across the rail lines for which data have been collated.

To date, the time series regression analysis method used here has been unable to satisfactorily isolate any significant signal that would indicate a reduction in passenger journey numbers brought about by mode-shifting. Consequently, the analysis has been unable to confirm or reject the hypothesis that people using the rail system were attracted to the road network by faster travel speeds made possible after the opening of the M4 Motorway section from Mays Hill to Prospect.

Additional data would be required to substantially conclude whether any mode-shifting took place. This data would need to include indicators for changes to ticket prices, relative travel times — including travel speeds of services and service frequencies — as well as data for service reliability. These data would need to be for the specific services on the WSRL, RRL and the IRL.

It may also be the case that mode-shifting was confined to a small number of stations on the WSRL, in which case it may be appropriate to disaggregate the data into groups of stations in accordance with service patterns to gauge which services — especially those offering slower speeds — may have been more likely to be a source of mode-shifting.

Further comparative analysis could include an examination of the relevant road speeds on the M4 Motorway and GWH that run parallel to the WSRL to see whether or not there were sufficient differences in speeds across both modes to induce mode-shifting.

5.2.3 Conclusions

The empirical analysis of before and after road traffic volumes that apply to the opening of the last section of the M4 Motorway from Mays Hill to Prospect supports the induced traffic growth hypothesis. However, the analysis of rail data has not been able to confirm or reject the hypothesis that some commuters using the rail network were attracted to car travel, owing to quicker travel times made possible by the addition of capacity to the M4 Motorway.

The analysis has not been able to clarify the specific sources of the traffic volume increase across Screenline 12, such as mode-shifting, traffic redistribution or traffic generation. This is due to limitations in the data. However, further analysis of the ramp-up period could provide a way of differentiating different travel behaviour responses from one another. For example, traffic reassignment could reasonably be expected to occur quickly, whereas other responses such as traffic redistribution and generation might be expected to occur over a much longer period of time. This analysis will be conducted in the next section.

In relation to specific case studies of induced traffic growth under Australian conditions, this case study can claim to be the first, and only documented case study to incorporate comprehensive coverage of a relevant screenline into its method of analysis. While the work undertaken here in relation to rail passenger journey data has cast doubt on the analysis of the Sydney Harbour Tunnel and parallel rail services undertaken by Mewton (2006), further work may be able to help refine his testing method, enabling further analysis that is more robust. Similarly, it may be possible to extend the number of sites on the screenline used by Mewton to analyse road traffic volumes. This would improve the veracity of empirical analysis on this issue under Australian conditions.

5.3 Anatomy of a motorway ramp-up period

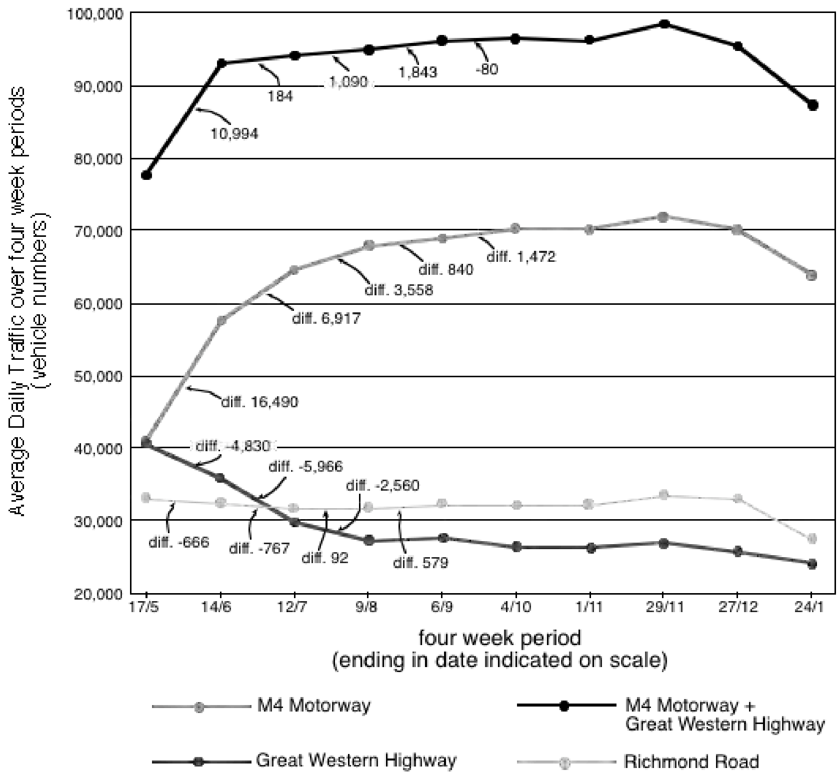
This section examines the changes to traffic volumes in the months immediately after the opening of a new motorway section, known as the *ramp-up period*. Data for the M4 is examined in some detail in addition to data for the period after the opening of the Sydney Harbour Tunnel.

The aim of this section is to examine the period of time when the most dramatic changes to traffic volumes appear to occur, in the hope of identifying from where that traffic might come. As will be shown, sharp increases in traffic volumes on a new route, in concert with steep declines on existing alternate routes, appear to occur primarily within the first three months of opening. The degree to which these changes coincide suggests that most of the *traffic reassignment* associated with a new development is taking place within that time period. This effectively provides a new and different way of gauging the source of traffic volume increases attributed to the addition of motorway capacity. For if the dramatic changes that occur within the first three months of opening can be attributed to traffic reassignment, then it may be the case that sharper than usual increases that take place in the months after that are primarily attributable to traffic redistribution, generated traffic and mode-shifting.

5.3.1 The ramp-up period for the M4 Motorway section from Mays Hill to Prospect

Daily traffic volume data were collected for the GWH at the position on Screenline 12 that was examined in the previous section. Daily traffic volume data were also available for the M4 Motorway, but only after the opening of the new section when induction loop counters were installed in the new pavement. These are shown in Figure 5.22.

Figure 5.22 Daily traffic counts for the GWH and M4 Motorway on Screenline 12



As can be seen, in the 12 weeks immediately after the opening of the additional motorway capacity, daily traffic volumes on the M4 Motorway increased steeply, while those on the GWH declined steeply. Daily traffic volumes for Richmond Road were also available for the period immediately after the opening of the M4 Motorway section, but unlike the M4 and GWH, traffic declines were not as steep and reassignment appears to have ceased within eight weeks after opening rather than 12, as was the case for the GWH .

Significantly, the steepest increases appear to have taken place in the first four weeks after the opening. While traffic reassignment from the GWH to the M4 Motorway was clearly still taking place 12 weeks after the opening, the increases in M4 Motorway traffic and declines in GWH traffic more closely match one another by weeks eight and 12. By week 20, the growth appears to have flattened.

If daily traffic volumes counts were available for all other arterials on Screenline 12 — like Richmond Road — the bulk of the traffic reassignment to the M4 Motorway would have taken place in the first eight weeks. This would partly explain the large increase in volumes over the first four weeks. However, it is important to note that after week four, the aggregate volumes for the GWH and M4 Motorway were not increasing by large amounts. Indeed, it could be said that growth had largely flattened out and the increases could be easily due to seasonal fluctuations.

These observations raise several questions about the array of travel behaviour responses that follow in the wake of a capacity increase. In particular, it raises questions about short-term and long-term responses during the ramp-up period.

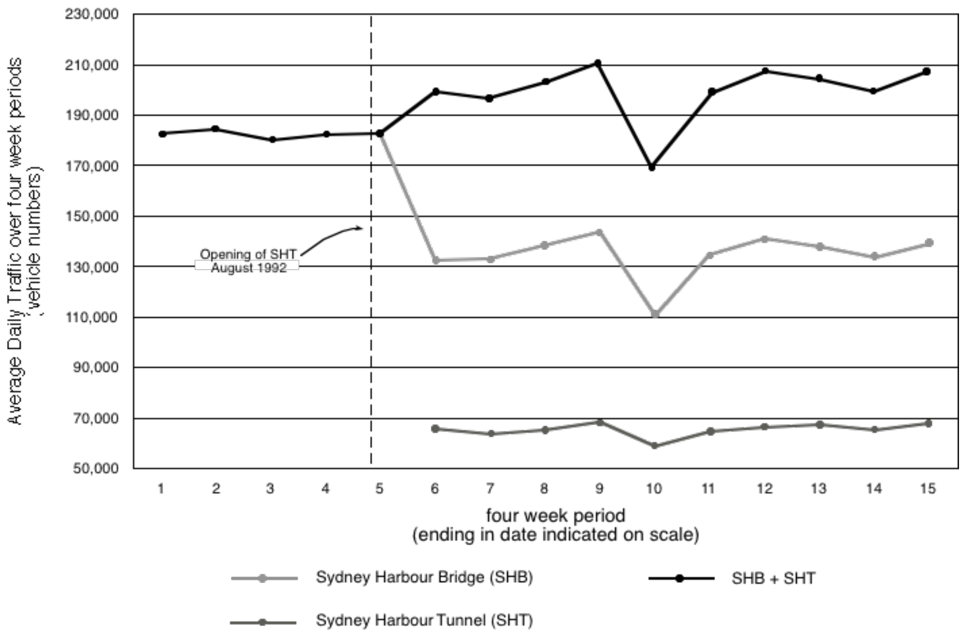
Data from the M4 case study suggests two things. First, most traffic reassignment is over within three months. If this is the case, then increases that may be greater than previous increases could be identified as induced traffic growth. Second, it suggests that there could be a substantial disparity between the more obvious indications of traffic reassignment and total volumes for the M4 corridor. In which case, the responses primarily defined as induced traffic growth — mode-shifting, traffic redistribution and generation — constitute a sizeable portion of the growth that occurs in the first four weeks immediately after opening.

But are these structural features of the ramp-up period consistent, or generic, to all motorway capacity increases? Examining ADT volumes for other projects and comparing the results with those from the M4 case study can in part answer this last question.

5.3.2 The Sydney Harbour Tunnel

In this section, daily traffic volumes for the Sydney Harbour Tunnel (SHT) and Sydney Harbour Bridge are inspected for the period immediately after the opening of the tunnel on 15 August 1992. This project was the focus of the study undertaken by Mewton (1997, 2006) that was reviewed in Section 3.6.2.

Figure 5.23 Daily traffic volumes for the Sydney Harbour Tunnel and Sydney Harbour Bridge



As can be seen in Figure 5.23, a period of sharp decline on the Sydney Harbour Bridge occurred in the four weeks immediately after opening of the SHT. This pattern is similar to what can be observed after the opening of the M4 Motorway section from Mays Hill to Prospect, however, increases in traffic volumes appear to reflect seasonal fluctuations soon afterwards.

The analysis undertaken here on ramp-up periods has not investigated specific Level of Service changes and how these relate to ceiling capacities on each of the motorway sections. A consistent pattern for the rate of traffic volume increase and period of growth maybe related to these features. This raises questions such as what the nature is of the relationship between the structure of the ramp-up period and prevailing speeds on the facility?

Further questions arise as to how the Level of Service on all alternate arterials across a screenline might change during the ramp-up period. The rate at which traffic volumes might grow if speeds become faster in the months after the initial round of traffic reassignment to the motorway is another issue that deserves further investigation, as there could be a cascade of feedback effects occurring across the network. But such an analysis would be highly dependent on data quality and availability.

A more detailed knowledge of what takes place during the ramp-up period for a new motorway facility could possibly provide a way to answer some of the questions about the source of the various types of induced traffic growth. This provides an opportunity for further research.

5.4 Conclusions

The case examined in this chapter has provided confirmation of the induced traffic growth hypothesis. It has done this by accounting for sources of traffic reassignment across a wide range of alternate route options, leaving a residual volume that is greater than historical growth rates where no increases in road capacity were made. It is concluded that these additional trips are likely to have been induced by the change in travel speeds brought about by the increase in capacity.

Rail patronage data for routes that offer a possible alternative to trips by car were also examined. While the regression shows a decline in rail journeys that coincide with the increases in road traffic volumes, results are inconclusive at this point and require further research as the declines could be in response to an array of other factors.

An examination of ramp-up periods following immediately after the addition of new road space has shown that much of the residual volume appears to occur in the first couple of months after opening. This suggests that adjustments to travel behaviour on the part of individuals comprise decisions that are motivated by goals that can be assimilated quickly. The reasons for additional travel, or explanation for why individuals might choose to travel further given changes to conditions, needs to take this potential into account.

> ... [L]ike beauty, a system lies in the eye of the beholder, for we can define a system in an infinite number of ways in accordance with our interests and our purpose, for the world is composed of very many sets of relationships.
>
> George Chadwick
> *A systems view of planning*
> (1978)

6 A systems theory of induced traffic growth

This chapter articulates a systems theory of cities that attempts to provide an explanation for the multiple travel behaviour responses that comprise induced traffic growth. It specifies the mechanism responsible for the phenomenon and shows how it interacts with several other processes fundamental to urban systems. Ultimately, this systems theory will assist an assessment of the sustainability implications of induced traffic growth for cities, within a wider systems framework.

Explanations couched in systems terms are valuable because the concepts and language of systems theory can be used consistently to describe both material systems that make up the biosphere as well as physically intangible processes like human decision-making systems. Many analyses, lacking consistency, come unstuck when jumping between the two. Further, because the rules of systems theory require recognition of the fundamental differences between the two system types, the analysis is able to avoid obfuscation when identifying how the two interact. As will be shown in Chapter Seven, this last point is particularly significant in sustainability science.

There are four key concepts in systems theory. These are *control* and *communication*, *hierarchy* and *emergence* (Checkland & Scholes 1990, pp. 18–19). In this chapter, each of these will be considered in the context of the relationship between transport and patterns of land-use development in urban systems.

The concept of system control is of central significance to any system. In natural systems the component that fulfils the control function brings order and stability to the processes that make up the system. In purposeful systems, like the decision-making system for urban motorway proposals explored in Chapter Two, a controller acts like a reference point to which a wide variety of system actors orient their activity. In that instance the control component, or system owner, was goal directed. The urban system that will be described here comprises a combination of artificial and natural subsystems. The natural subsystem — here called the transport system — will be shown in Section 6.1.2 to be non-teleological, or non-purposeful, because the system is not directed by a conscious goal. Instead the system is controlled by a confluence of material and human physiological factors that work to constrain the random array of individual decisions that form the collective travel behaviour of the urban transport system.

As with system control, the nature of communication differs between purposeful and natural system types. In a natural system, the medium that carries signals communicating changes between components is not consciously devised to carry out that function. In a purposeful system, communication systems are often consciously devised in accordance with the system controller, to send particular signals to system components, which change their behaviour accordingly.

As systems grow and become more complex, hierarchies develop within the many classes of components that make up the system. In urban systems, transport infrastructures generate differences between trunk, collector and distributor routes within their network structures. As new transport technologies with their attendant logistical properties are introduced to the system, new hierarchies develop that are distinguished by qualitative and quantitative differences (Vuchic 1999, pp. 40–49). Some of these features were briefly discussed in Section 1.2 and in the examination of Thomson's city typologies in Section 4.3.2.

Between the diverse array of components and hierarchies that develop within the subsystems, complex economic activity emerges. If assessed in isolation, the economic significance of each component is obscure, but when examined as part of a working system, the emergent string of activities and supporting infrastructures that form the economic structure of a city can take on a new significance. When viewed from a systems perspective, induced traffic growth may be seen as a shift towards a different order of economic relationships that has a particular structure, given the nature of the transport element that has induced the changes.

Section 6.1 begins the articulation of a systems theory of induced traffic growth by describing the rudimentary parts of an urban system using the nomenclature of General Systems Theory (GST). As will be shown, induced traffic growth is a form of positive system feedback that takes place when the speed of a transport infrastructure is increased as a result of a transport policy intervention — like the decision to increase urban motorway capacity. The transport system is controlled by a confluence of material and human physiological factors that work to keep average travel time budgets constant. The empirical analyses that provide an overview of travel time budget data are briefly reviewed to support the theoretical concepts presented in this section. At the outset, it needs to be stated that interpretation of this empirical aspect of travel behaviour has been controversial and so needs to be approached with caution. The reasons why will be explained in more detail in the latter parts of this section.

Section 6.2 explores the parts of an urban system from a dynamic perspective. It is shown that when an urban system is subjected to the feedback process that gives rise to induced traffic growth, it undergoes a change in its *phase state* that contributes to what will be called a *phase transition* in the system.

Section 6.3 describes system *leverage points* — points where small shifts can produce big changes in the system overall. This section presents a hierarchy of leverage points, starting with those that produce little change to those that can produce significant change. The purpose of this section is to gauge where the addition of urban motorway capacity, and the induced traffic growth it can give rise to, sits within this hierarchy. This section anticipates the wider discussion of the sustainability implications of motorway development for urban systems, which will be the focus of Chapter Seven.

6.1 The material structure of urban systems

The purpose of this section is to identify the generic system components that play a role in generating the process that gives rise to induced traffic growth. To do this, the process will be defined using the nomenclature and conceptualisations of process structure that form the basis of GST.

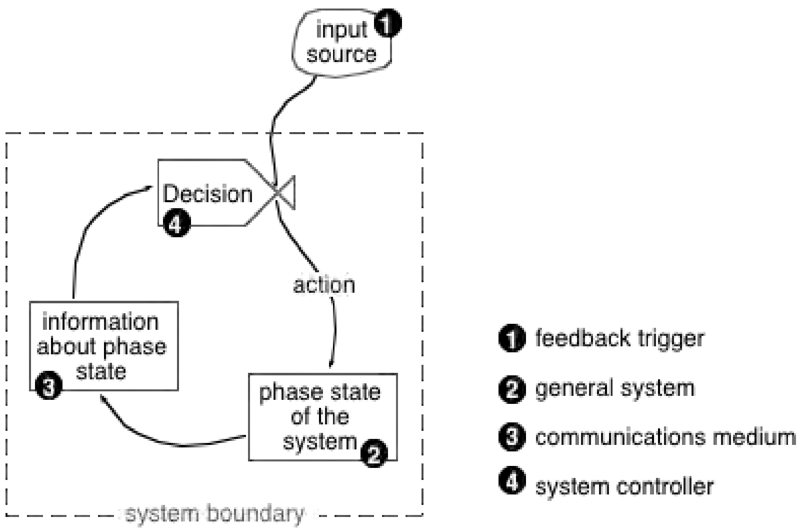
System feedback is a key concept in GST (Forrester 1968, p. 4.5). Complex systems like cities involve multiple forms of negative and occasionally positive system feedback loops that work simultaneously. Induced traffic growth is the product of but one of these loops. This section will begin by discussing the generic structural principles of system feedback processes and then apply them specifically to induced traffic growth. But first, it is useful to comment on why an explanation of induced traffic growth using GST might be useful over and above those already provided in Chapter Four.

There are two primary reasons for rendering the process in GST terms. The first picks up on a point made in Chapter Four — that microeconomic theory focuses on only one form of system feedback, where price is the system controller. As stated above, there are many different forms of system feedback that take place in urban systems, and as will be shown, many of these are triggered by changes brought about by induced traffic growth. If all these feedback processes are presented within a microeconomic framework, then assumptions have to be made about their structure in order to translate aspects of their operations into monetary values. Or in other words, some aspects of the changes triggered by an increase in urban motorway capacity become lost in the translation so that an understanding of how different aspects of the system are structurally related to each other is not provided. It is necessary to account for these *lost elements* if reasons are to be found for the discrepancies between macroeconomic outcomes and microeconomic estimations that were discussed in Section 1.3.2. The second reason is that the basic terms of GST will be used again in Chapter Seven, in which the sustainability implications of urban motorway development will be examined within the context of the global ecological system. An explanation couched in GST terms enables a consistency of language that an explanation using microeconomic theory alone does not.

6.1.1 The structure of positive and negative system feedback processes

Feedback loops have been described as the basic building blocks of systems (Forrester 1968, p. 4.3). Within a system boundary there are many *paths,* or sequences of actions, that form feedback loops — processes that produce outcomes that are then fed back into the same sequence to form a loop (Sandquist 1985, p. 24). In their most basic form, system feedback loops have four basic features — a feedback trigger, a phase state, a communications medium and a system controller (Forrester 1968, p. 2.4). The relationship between these features is illustrated in Figure 6.1.

Figure 6.1 Basic components of a system feedback process



Adapted from: Forrester, J. W. 1968, *Principles of systems.* 2nd preliminary edition. MIT Press, Cambridge, Massachusetts, p. 2.4.

To start a feedback process, an input of some kind is needed to trigger a change in the system. The illustration in Figure 6.1 shows the trigger coming from a source outside the system. Once set in motion, the input generates an action that changes the *phase state* or *level* at which a system parameter is operating at a particular time (Forrester 1968, p. 4.5). Information about the change in phase state is then communicated to a component within the system that makes a decision about what to do in response to the change. This last component is called the system controller.

In the case of natural systems, system controllers keep the system stable. In the case of designed, or artificial systems, controllers are critical to ensure that the system is able to achieve its design goal.

The significance of system control to feedback loops can best be appreciated through a simple example like a water heating system. In such a system, the thermostat operates as the system controller, regulating energy inputs to the system in accordance with a design goal. When the thermostat senses that the water temperature — or phase state — is dropping below the design goal, it sends a signal to the heating element to increase the amount of energy entering the system, thereby increasing its temperature. Once the thermostat senses that the water temperature is moving above the design goal, it sends a signal to the heating element to reduce the amount of energy entering the system. In systems nomenclature, both increasing and decreasing the amount of energy entering the system in this example constitute forms of *negative system feedback,* as each serve to stabilise the phase state.

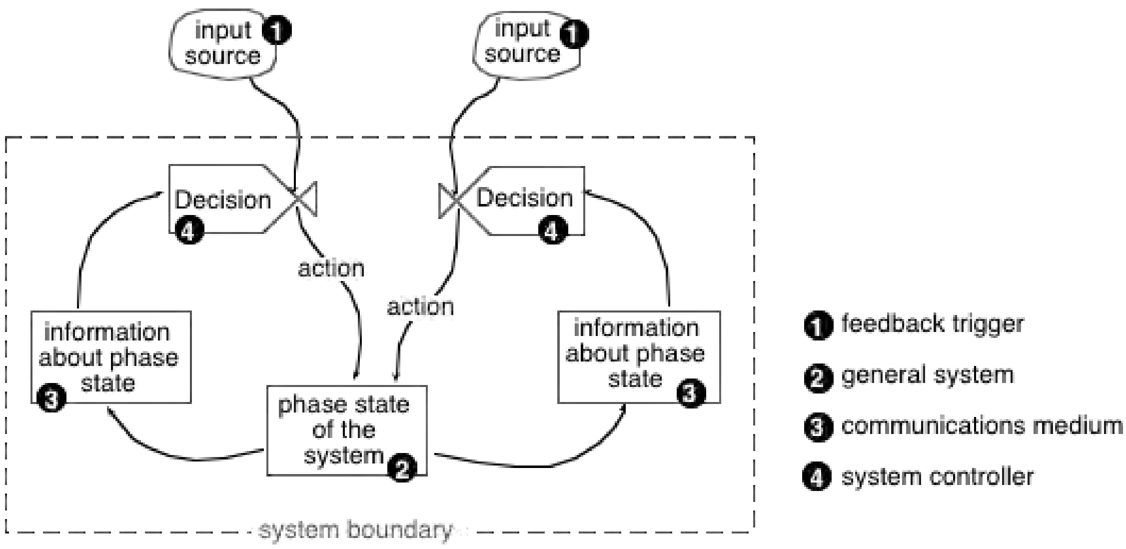
Negative system feedback generally works in the opposite direction from the stimulus or feedback trigger. In the case of the water heating system, the loss of energy through heat dissipation, or hot water usage, reduces the water temperature. The system controller senses this, triggering a switch that adds energy to the system to counter the losses. Similarly, as the water temperature rises and reaches the design goal, the thermostat triggers a reduction in water temperature by cutting the amount of energy entering the system.

By contrast, *positive system feedback* works in the same direction as the stimulus or feedback trigger and generally destabilises systems. This can be illustrated with the water heater by reversing the action of the thermostat to increase the amount of energy entering the system when it is above the design goal and decreasing the energy input when below. In each of these cases the water would either boil off, or permanently cool, depending on the initial condition, with no stable state in between.

While all components are necessary to the end function of a system, from an analysis perspective, the system controller plays a central role. This is because if the controller can be identified and understood, the underlying logic for the rest of the system structure can be identified more easily.

In nature, multiple arrays of system feedback loops often work together to form the general fabric of a system. In such cases, an outcome from one feedback loop may function as an input to another, generating a hierarchy. Multiple system controllers may be at work in such hierarchies, as shown in Figure 6.2, or a single system controller may lie at the centre of several feedback loops.

Figure 6.2 Multiple system feedback processes



In teleological systems that have been specifically designed — like a water heater — the system controller is easy to identify. In highly complex systems like cities that comprise both natural and artificial subsystems, identifying a system controller often requires some investigative work or chance discovery. Where multiple system feedback processes are at play, identifying control conditions becomes increasingly difficult and it is easy to confuse component parts from normative subsystems with those from positive subsystems.

The next section describes the controller that sits at the centre of the system feedback process that gives rise to induced traffic growth.

6.1.2 Travel time budget constancy and the control of urban systems

One of the more enduring points of interest in studies of urban travel behaviour is debate over the existence of what has been called the *travel time budget constant*[33]. Put simply, a travel time budget refers to the amount of time people spend in transit. What is most interesting about travel time budgets is that for a diverse cross-section of cities, the statistical distributions of these budgets have similar means and distribution shapes.

This relatively high degree of similarity, or *constancy*, as it has been called, appears to occur despite wide variations in levels of wealth (Schafer 1998, p. 459), degrees of industrialisation or differences in cultural norms (Robinson, Converse & Szalai 1972, p. 115), urban or rural locality (Tanner 1961, p. 12), and historically it has persisted over time (SACTRA 1994, p. 40). Where differences do occur upon disaggregation by gender, age and employment status, the variations appear to be systematic (for example, Roth & Zahavi 1981, p. 89).

Within the broader rubric of urban transport theory and analysis, the travel time budget constant has on occasions been used as an intellectual rallying point for the formulation of unorthodox transportation planning models (see, for example, Kitamura, Fujii & Pas 1997; Zahavi 1979) as well as general theories about cities and urban travel behaviour (Laube, Kenworthy & Zeibots 1998, p. 100). This is because universal constants have a habit of pointing to lynchpins within systems. By trying to account for constants, the organising principles generic to the operations of all systems within that class can often be identified.

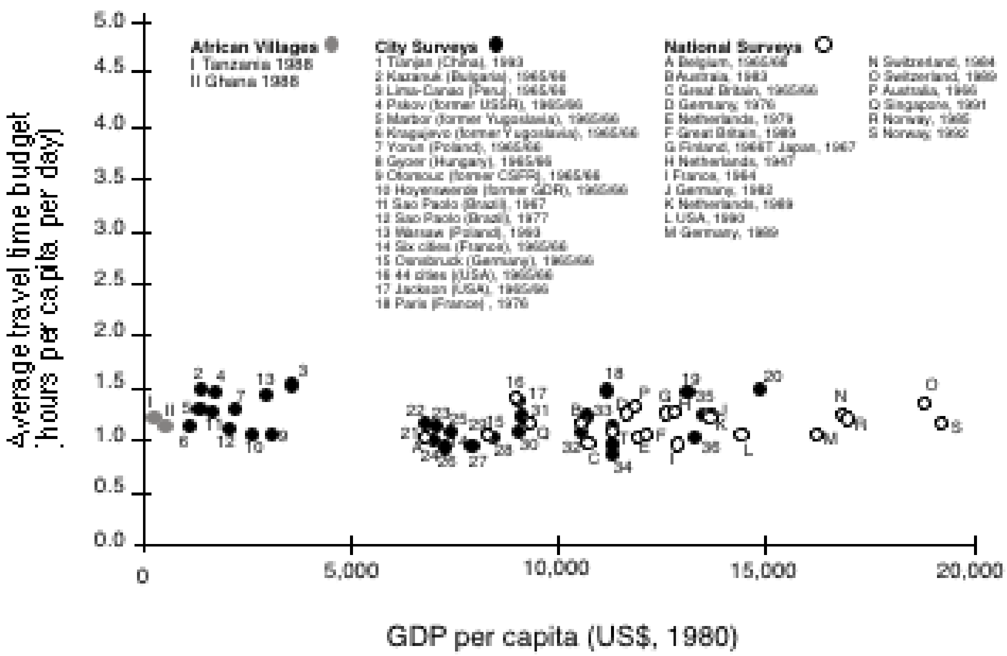
In this thesis, the confluence of material and human physiological factors that give rise to travel time budget constancy will be shown to play the role of a system controller. And travel time budget constancy will be shown to be the phase state that the system attempts to return to after changes have been made to the structure and consequent speed of the urban transport system.

[33] Use of the term travel time budget in this thesis refers to the amount of time spent on travel and not the general cost of travel that would include other costs such as fuel, capital cost of vehicles, etc. In other studies the term has been used to include these other costs.

The empirical evidence for travel time budget constancy

Schafer (1998) collated data from over 17 international studies of average daily travel time budgets, revealing that a wide selection of populations on average appear to budget around 70 to 75 minutes for their travel requirements. The data includes both national and city aggregations and encompasses a wide array of different cultures and degrees of industrialisation (Schafer 1998, p. 459). These data are shown in Figure 6.3.

Figure 6.3 Average daily travel time budgets for a selection of international populations

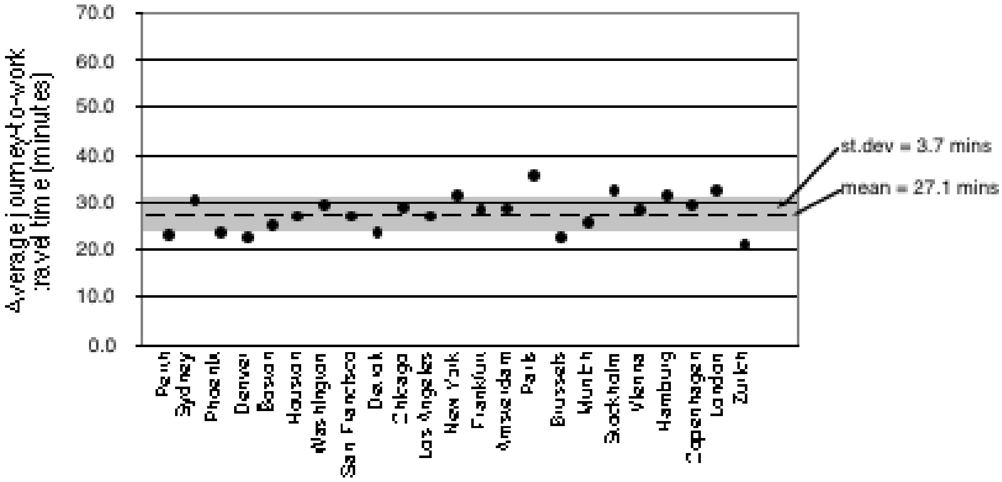


Source: Schafer, V. 1998, 'The global demand for motorised mobility' in *Transportation Research: Part A*, Vol. 32, No. 6, p. 459.

Researchers have also observed that average travel time budgets for the journey-to-work reveal a high degree of similarity between different cities which is usually cited as being around half an hour (Laube 1997, p. 18; Manning 1984, p. 42; Robinson, Converse & Szalai 1972, p. 123).

Figure 6.4 shows average travel times for the journey-to-work for a selection of EU, US and Australian cities. The average for these cities is just on 27 minutes and there is a difference of only a few minutes between the averages.

Figure 6.4 Average journey-to-work travel time budgets for 23 cities (1990)



Adapted from: Laube, F. B. 1997, *Optimising urban passenger transport*. Doctoral dissertation, ISTP, Murdoch University, Perth, p. 19.

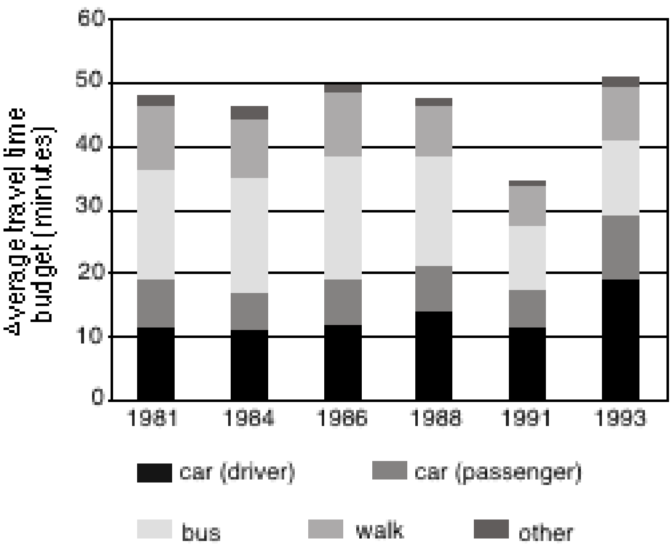
While the observations are interesting, the problem that researchers have encountered is knowing what to do with the concept of travel time budget constancy. Researchers have not been able to successfully use this feature of aggregate travel behaviour in a model to predict behaviour or evaluate transport proposals (Goodwin 2004, pers. comm.). Some researchers, such as Moriarty (2002), have been highly critical of the way the concept of travel time budget constancy has been used. Moriarty provides compelling arguments against its use by researchers like Ausubel, Marchetti and Meyer (1998) and Schafer and Victor (2000), who have applied it in a way that attempts to predict mode share for urban populations. They conclude that private car travel will decline, while high speed modes used for long-distance travel will increase, which in turn justifies the development of high-speed magnetic levitation transit systems (Moriarty 2002, p. 3). Such arguments do not locate the confluence of factors responsible for travel time budget constancy within the general structure of an urban system. Consequently, they misunderstand what can reasonably be deduced with the concept about changes to travel behaviour. Like Goodwin, Moriarty argues that the degree of variation between populations is such that behaviour cannot be robustly predicted.

In addition to the problems that arise when attempting to use travel time budget constancy to predict changes to travel behaviour, the phenomenon is difficult to measure. Variations in how data are collected and collated appear to be a primary cause for differences between sets for different cities. As noted by Scheuch:

> … [R]epresenting the expenditure of time is one of those subject matters where reliability and validity of data are extremely sensitive to details in the manner of data collection. There is little in tables of time budget data that enables a social scientist to make even an inspired guess about the accuracy of the information (Scheuch in Hedges 1974, p. 39).

The problems that confronted Scheuch in the 1970s were still causing problems for researchers 20 years later. A particularly telling example can be found in a series of travel time budget data for South Yorkshire, as cited by Stokes.

Figure 6.5 Average travel time budgets by mode for South Yorkshire



Source: Stokes, G. 1994, 'Travel time budgets and their relevance for forecasting the future amount of travel', in proceedings from *PTRC European Transport Forum 1994*, pp. 25–36.

As can be seen in Figure 6.5, travel time budget data have been collected for South Yorkshire every two or three years since 1981. By 1993, six tranches had been collected. The average for 1991 is conspicuously lower than preceding years. As Stokes explains:

> Between 1981 and 1988 the same survey firm conducted the survey using the same survey manager. In 1991 a different firm conducted the survey and trip rates were down to 1.95 (from around 2.5) due to interviewers having similar written instructions, but different verbal instructions and levels of supervision and management. For the 1993 survey another firm was used and, as a reaction to the 1991 survey the instructions on trip recording were changed, which lead [sic] to a higher recording of trips (2.75 per person per day) (Stokes 1994, p. 28).

In this example, simply changing the personnel conducting the survey is more than likely responsible for the 20 per cent difference that can be seen between the 1991 figures and those of the four preceding survey years. The task of timing the different activities that make up a person's daily routine seems fairly simple — set the stopwatch going when an activity begins, push the button when it stops and a new one begins and record the respective time periods. Difficulties occur, however, on deciding when the stopwatch should be turned on and off. This is because the distinction between different activities is more blurred in some city typologies than others, as two activities often take place simultaneously (Bullock et al. 1974, p. 56). For example, in walking cities the difference between walking purely for the purpose of travelling and walking for the purpose of window-shopping or socialising is often unclear. If people meet in transit and stop to talk to one another for a few minutes during their journey, then technically time spent socialising is included in their travel time budgets. Similarly, if people stop to look in shop windows during a walking trip, then travel times appear to be longer because shopping time is included in the total for travel. In auto-based cities the distinction between time spent in transit and time spent on other activities is more easily distinguished because of the segregation and restrictions that vehicle use imposes on activities. Problems with activity differentiation do affect measurement and can in part explain why many large walking cities have slightly higher average travel time budgets than auto-based cities, thereby creating greater variation between empirical data sets for different cities than may actually be the case (for example, Laube 1997, p. 19).

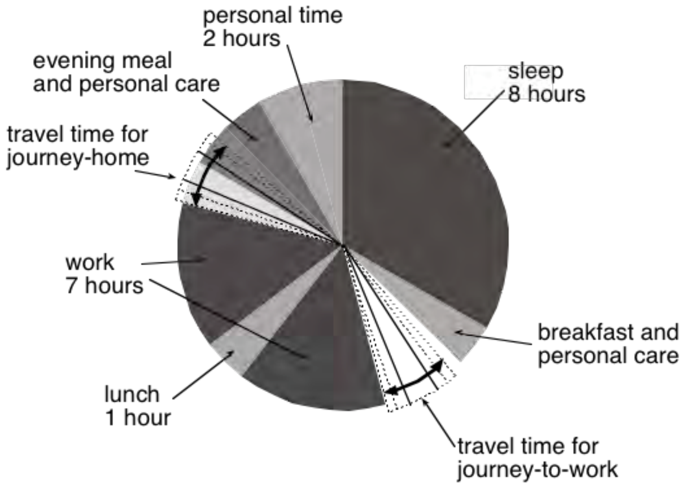
Debate over the existence, implications and technical use of travel time budget constancy has also been exacerbated by wide variations in the way that travel time data are aggregated (for a detailed critique, see Supernak 1983, pp. 402–405). Some researchers only include travel time for motorised trips in their analyses (for example, Zahavi 1979). Some average time spent travelling over entire populations while others calculate average per capita values over the number of travellers only. Values for average travel time budgets reveal greater stability when samples measure travel times for individuals over a weekly period rather than a few days (for example, Goodwin 1981, pp. 102–103). Further adding to difficulties is people's perception of time and how this can affect recording travel times for journeys. For example, some surveys ask participants to record the journey time of trips while others ask people to record the start and finish times, leaving actual travel times to be calculated by the survey team. This is important because it has been found that individuals regularly underestimate travel times when using private transport and overestimate when using public transport.

Despite the difficulties confronting empirical analyses of travel time budgets, the degree of similarity between averages for different cities is remarkable, providing a starting point for the development of an urban systems theory that articulates key processes and relationships that animate the working structures of the system.

The nature of the system controller of the transport system

The similarity between average travel time budgets for different urban populations can in part be explained by the presence of common material factors that work to shape the structure of people's daily routines. For example, every person, irrespective of income, ethnicity or culture, is allotted 24 hours each day. Within this 24-hour period, human physiology demands that everyone has to sleep sometime, eat and attend to ablutions. Similarly, everyone has to earn a living and attend to the management of her or his household. This constellation of factors is generic and forms a pattern when individuals synchronise their activities with one another (Hedges 1974, p. 35; Robinson, Converse & Szalai 1972, p. 29). As can be seen in Figure 6.6, once time spent at work and other essential activities is taken out of the equation, the window left for travel is relatively constrained. From this perspective, travel time budget constancy might be explained as time remaining once time spent on other essential activities is subtracted from the 24-hour period (for example, Kirby 1981b, pp. 3–4; Stokes 1994, p. 26).

Figure 6.6 Typical tasks that form a daily routine



Source: Zeibots, M. E. 2003, 'How do cities work and why is transport so significant? Regional sustainability and the search for new evaluation tools', in proceedings of *Network of Regional Governance for Sustainable Development: second meeting of the academic forum of sustainable development*, Perth, p. 6.

But this explanation alone cannot account for travel time budget constancy. This is because travel takes place within the context of working transport systems that regularly undergo changes to travel speeds for standard trips, and therefore travel times. Consequently, an explanation for travel time budget constancy needs to incorporate reference to the dynamic relationship between the factors outlined above, changes to the speed and capacity of the transport system and travel behaviour changes that occur in response to these changes. It is also important to keep in mind that while the window of time spent on each of the activities that make up a daily routine is similar, including travel, there can be great variation between individuals. As a result, it is not possible to anticipate how much time individuals will spend on travel but it is possible to anticipate average travel time budgets for whole populations. Travel time budget constancy must therefore be acknowledged as a group or societal phenomenon only (Stokes 1994, p. 26).

If travel time budget constancy is to be viewed as an empirical indication of some form of system control — as is argued here — then the conception of the controller must incorporate the material factors that constrain behaviour, as well as the motivation for the multitude of different decisions made by individuals.

Forrester notes that in complex systems like cities, the broadest purpose of interest determines the scope of the whole system *and the controllers* (Forrester 1968, p. 1.7). As stated in Chapter One, the primary reason why people build and live in cities is economic. By living in relatively close proximity to one another, distances and the amount of time needed to cross these are reduced when accessing a wide range of activities needed to create the division of labour and complex forms of production. If city systems really are creatures of space, time and economics, then the control mechanism that governs behaviour will comprise features that steer the system towards the goal of economic production within the context of space-time constraints.

When viewed in relation to the general system goal of economic production, travel time budget constancy is best accounted for as the product of a confluence of three different sets of factors that work to control and stabilise urban systems. The first comprises the material and human physiological constraints outlined previously. The second is the general desire to minimise time spent travelling in order to free up time for other activities that enhance economic and social exchanges. The third is the impetus to spend additional time accessing more distant destinations because they offer some feature or service that is preferable to destinations within closer proximity. The last two factors — the desire to reduce travel time and the impetus to spend more time travelling to preferable destinations — are both responses on the part of individuals motivated by the desire to increase social and economic exchanges, many of which work towards increasing economic production. However, there is no conscious intention on the part of individuals to undertake their travel in a way that creates a cogent collective pattern. The empirical face of travel time budget constancy occurs by chance. The confluence of factors responsible for the phenomenon, and which control the system, are non-teleological — random acts constrained by a set of generic material factors.

Later sections will discuss the structure of these behavioural responses and how they are able to influence a variety of other urban system parameters. But before doing this, the tension that exists between the desire to reduce travel time and the impetus to spend more time travelling will be discussed. These competing demands provide the rationale for induced traffic growth, as well as the logic for why growth does not continue indefinitely. When combined, these factors sit at the centre of the system feedback process for urban transport systems.

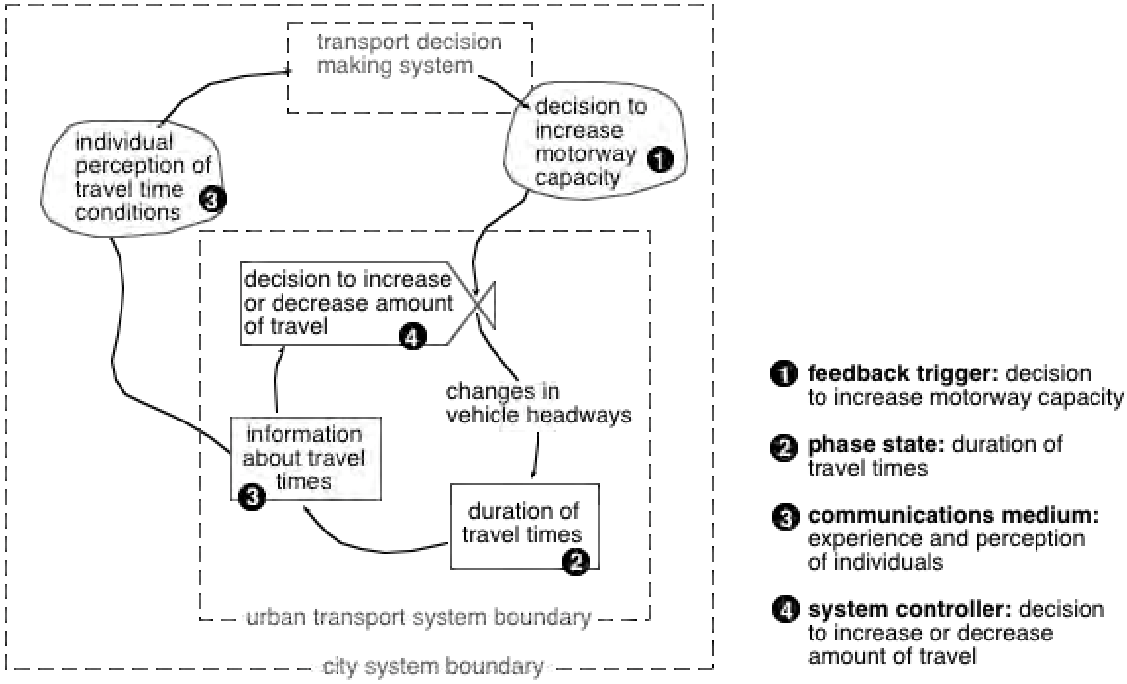
6.1.3 Induced traffic growth as a form of positive system feedback

Induced traffic growth is a form of positive system feedback. While this observation is often made by transport researchers when discussing the phenomenon (see, for example, Blunden 1971, p. 263; Luk & Chung 1997, p. 3), few have articulated the structure and consequences of the process using the standard nomenclature of GST. And few, if any, have articulated specifically how this process sits within a wider systems framework of feedback processes that combine to form complex urban systems. This shortcoming is likely due to problems with articulating a system controller and the difficulties incurred when seeking its empirical verification.

The sequence of events that make up the feedback loop that gives rise to induced traffic growth begins when capacity is added to a congested urban motorway network. As a consequence, traffic density is reduced so that the headways between vehicles increase, and with this the speeds at which vehicles can travel. The increase in speed reduces travel times for standard journeys. In this way, the addition of motorway capacity changes the phase state, or amount of time that people need to spend in order to complete the trips that make up their daily routines. As people perceive the changes in travel time, they make decisions as to how they will use the time saved as a result of the quicker travel speeds. In line with the confluence of factors that control behaviour in the transport system, some people may choose to spend it on additional travel, either to new destinations or on additional trips, so that traffic volumes grow.

As the volume of traffic on the system increases, headways between vehicles are reduced, slowing travel speeds and increasing journey times. This change in the system phase state is experienced by individuals in such a way that the number of people choosing to travel further slows, reducing the rate of growth in vehicle numbers within the terms of the urban transport system. This response constitutes a form of negative system feedback. The sequence is shown in Figure 6.7.

Figure 6.7 Induced traffic growth feedback process nested within complex city system



There are two consequences that arise from the change in phase state that is communicated to individuals through their direct experience of conditions in the transport system. The first concerns changes to travel behaviour within the transport system. The second concerns the way individuals perceive these changes and communicate them back to the transport decision-making system.

Once the sequence shown in Figure 6.7 has been set in motion, the *chokepoints* in the road network shift to new positions. In many cases, the effects of congestion confront a different set of individuals from those who may have benefited from the original decision. This second set may be unhappy about the change in traffic conditions because their travel times are now longer. Some subsequent changes in travel behaviour will feed back into the urban transport system, but perceptions in the form of opinions will be fed into the political processes of the transport decision-making system. Feedback to the transport decision-making system may include ideas about what needs to be done in order to ameliorate the apparent decline in Level of Service on the road network. Individuals in the community may advocate increasing road capacity or changes to intersection treatments to those areas that directly affect them, for example. But whatever the calibre of the response, it is important to acknowledge that for many people such a problem is not experienced or perceived, and so they do not register complaints with governments, but nor do they register their satisfaction. Consequently, feedback to governments concerning Levels of Service on the road network is predominantly about perceived problems, so that responses may be slanted.

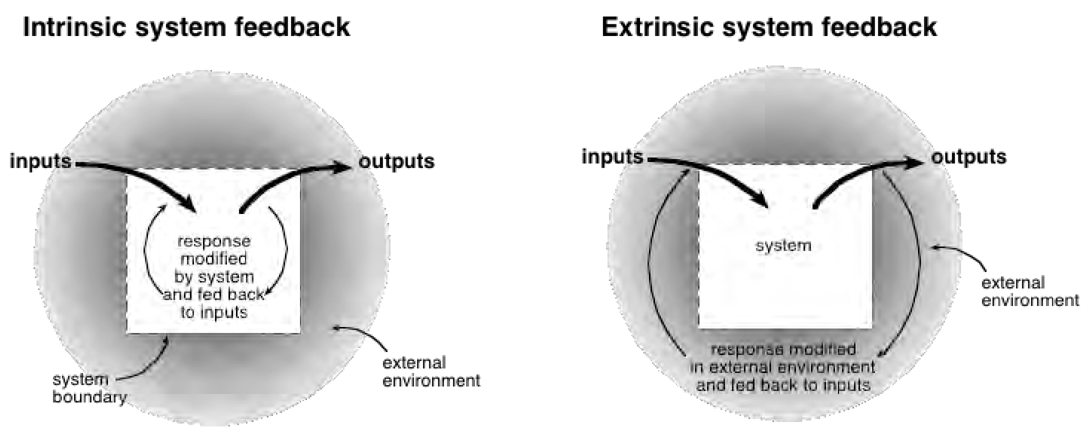
In earlier discussion about the workings of the transport decision-making system in Chapter Two, responses from the community were shown to be more complex than what has been presented here. The views of professional transport planners and traffic engineers, as well as commercial industry sector interests interplay with the perceptions and opinions of individuals who contribute to form *public opinion*. So that while a diversity of views is recognised in this general analysis, for the purposes of understanding induced traffic growth as a positive system feedback loop, the views of people will be kept simple.

A positive system feedback loop is completed within the urban system if a further increase in road and motorway capacity is implemented because of outcomes from the transport decision-making system. The feedback is positive because the response moves in the same direction as the stimulus. An example of such a response could be seen in the sequence of developments that followed in the wake of the capacity that was added to the Sydney network after opening of the Sydney Harbour Tunnel. Significant bottlenecks were generated to the south of the tunnel, which led to further motorway development in the form of the Eastern Distributor, which in turn gave rise to further increases in traffic volumes in the corridor.

In its entirety, the feedback loop crosses the boundaries between two different subsystems nested within the urban system — the transport decision-making system and the urban transport system. The sequence engages with two ontologically disparate forms of system control — a soft political system with a teleological controller and the behaviour of a hard infrastructure system with a non-teleological controller. As outlined in Section 2.1.1, this means that elements — in this case perceptions — from two logically different categories are interacting with each other, consequently, confusion may arise and actions may be pursued that bring about outcomes that are different from those that were intended.

In addition to positive and negative system feedback, Sandquist notes that system feedback loops have one of two different configurations. They can be *intrinsic* and have an internal feedback structure, or *extrinsic*, and have an external feedback structure (Sandquist 1985, pp. 34–36). The distinction is dependent on the location of the elements that modify the original response that is fed back into the system that initiated the sequence of events. As can be seen in Figure 6.8, intrinsic feedback locates the system controller inside the system boundaries, whereas extrinsic feedback locates the system controller outside the system boundary in the system environment. The distinction is significant because intrinsic feedback loops enable self-regulation, while extrinsic loops do not. Consequently, extrinsic feedback loops are more prone to instability.

Figure 6.8 Intrinsic and extrinsic system feedback processes



Source: Sandquist, G. M. 1985, *Introduction to system science.* Prentice Hall Inc., New Jersey, pp. 34–35.

Induced traffic growth is a form of extrinsic feedback. This is because the path, or sequence of decisions that form the feedback loop, crosses the boundaries of two different subsystems. While the feedback loop in its entirety is located within the boundaries of the urban system, the control mechanism — or confluence of factors that modifies travel behaviour in response to changes in travel times — is located outside the transport decision-making system that initiates the process and determines what response will be made, given the modification that takes place within the transport system.

The difference between intrinsic and extrinsic feedback is significant from the perspective of sustainability, because self-regulated systems are more able to respond to changes in a way that enables their survival. In complex systems like cities, there are various subsystems that undergo both intrinsic and extrinsic feedback processes. The sustainability of the urban system as a whole can become precarious when outcomes from subsystems whose feedback processes are extrinsic destabilise other subsystems. Such disjunctions can be more readily appreciated when induced traffic growth — an outcome from an extrinsic feedback process — is conceived as taking place between subsystems that are nested within a wider urban system, as shown in Figure 6.7.

The decision to increase urban motorway capacity is not generated by the urban transport system, but by the transport decision-making system. The latter is a normative subsystem of the urban system. Significantly, the feedback process that influences responses from the transport decision-making system is extrinsic and so potentially less stable. The degree to which subsystems that contain extrinsic and intrinsic feedback processes interact with one another affects the sustainability of complex systems. This aspect of system stability and its implications for sustainability will be discussed in more detail in Chapter Seven.

The next section discusses other system parameters that measure the phase state of the urban system and its transport subsystem. For while the amount of time that an urban population on average spends on travel will return to its previous level after the addition of motorway capacity, significant and lasting changes occur in other parameters that affect the material structure of urban systems.

6.1.4 The relationship of travel time budget constancy and induced traffic growth to other urban transport parameters

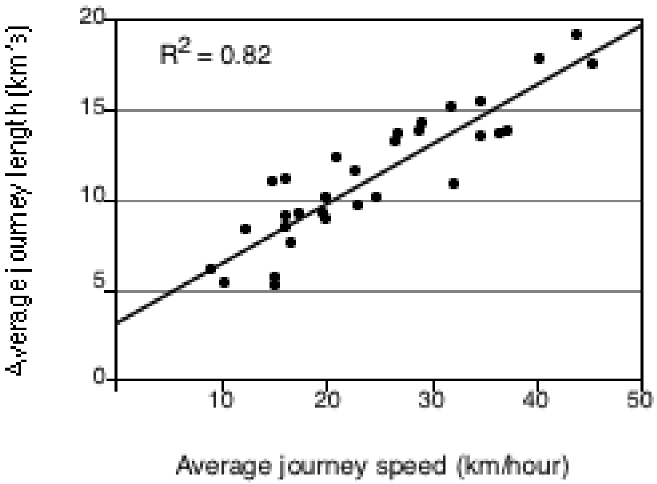
Complex systems like cities comprise a multiplicity of both positive and negative system feedback loops (Forrester 1969, p. 108). Change to one system component can trigger changes in a score of others, setting off a series of system feedback effects that cascade through the system.

This section examines changes to other system parameters triggered by changes in road capacity. Some of these changes relate to travel behavioural characteristics of the resident population, while others relate to changes to the material structure of the urban system. This examination provides further reason to view travel time budget constancy as an indication of the confluence of factors described in Section 6.1.2 that control travel behaviour, as well as a general overview of how it is able to affect other parameters. The precise workings of the control conditions will be discussed in more detail in Section 6.2.

Speed and journey distances

As discussed in the previous section, when capacity is added to the motorway network of a city so that travel speeds increase, some individuals will choose to spend the subsequent time saved on additional travel. In line with this response is a general increase in average journey distances. This relationship can be seen in Figure 6.9.

Figure 6.9 Average journey length and speed for the journey-to-work in 31 international cities (1990)



Data source: Kenworthy, J. R., Laube, F. B., Newman, P. W. G., Barter, P. A., Raab, T., Poboon, C. and Benedicto, G. 1999, *An international source book of automobile dependence in cities 1960–1990.* University Press of Colorado, Boulder, p. 610.

As can be seen in Figure 6.9, there is a high positive correlation between average speeds and average distances for the journey-to-work (Kenworthy et al. 1999). Empirical analyses undertaken by Pfleiderer and Dietrich have found that empirical data show a speed elasticity of 1. Or in other words, if travel speeds double then average journey distances also double (Pfleiderer & Dietrich 2003, pp. 22–23).

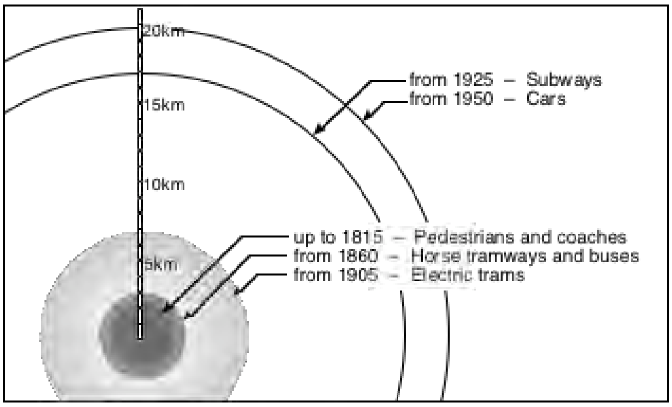
The empirical findings of Kenworthy *et al.* and Pfleiderer and Dietrich are consistent with the contention that travel time budgets remain similar across cities. Their data also support the induced traffic growth hypothesis. As average speeds increase through the addition of road capacity for example, the amount of travel measured by average trip distances also increases. Changes to average speed and trip distances have implications for other parameters used to describe the various phase states that apply to other feedback loops that form part of the urban system.

Urbanised area and relative distance to the urban centre

If travel times remain relatively constant, but the prevailing speed of a city's transport system and average journey distances change, logically the urbanised area of the city should be a product of the travel time budget and the transport network speed.

Marchetti argues that, historically, increases in the dimensions of the urbanised area of human settlements occurred in response to changes in the speed of the transport system. He provides a schematic diagram to illustrate the point that as successive transport technologies were introduced to Berlin, the urbanised area increased (Marchetti 1994, p. 77). Figure 6.10 is a reproduction of Marchetti's diagram.

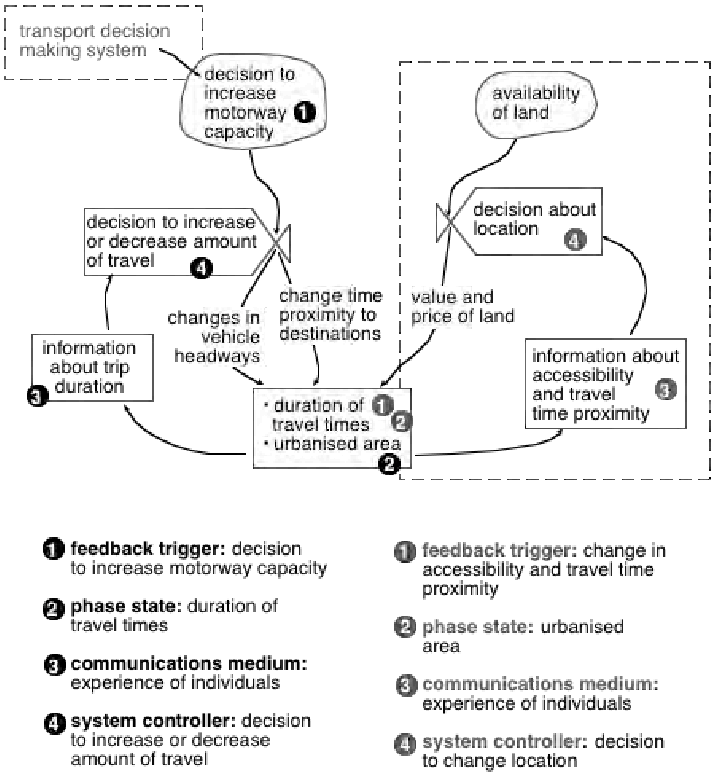
Figure 6.10 Changes in transport speed and urbanised area in Berlin



Source: Marchetti, C. 1994, 'Anthropological invariates in travel behaviour' in *Technological Forecasting and Social Change*, Vol. 47, No. 1, p. 76.

Changes in urbanised area indicate another feedback process triggered by the increase in motorway capacity. Figure 6.11 shows how, in addition to changes in travel speeds, changes in time proximity alter the phase state of the system that is critical to other feedback loops. Information about changes in time proximity triggers a second feedback process that makes decisions about the location of land-use activities within the urban system. This second feedback loop can also be affected by other system inputs, such as the availability of land.

Figure 6.11 Induced traffic growth feedback process and location decision feedback process

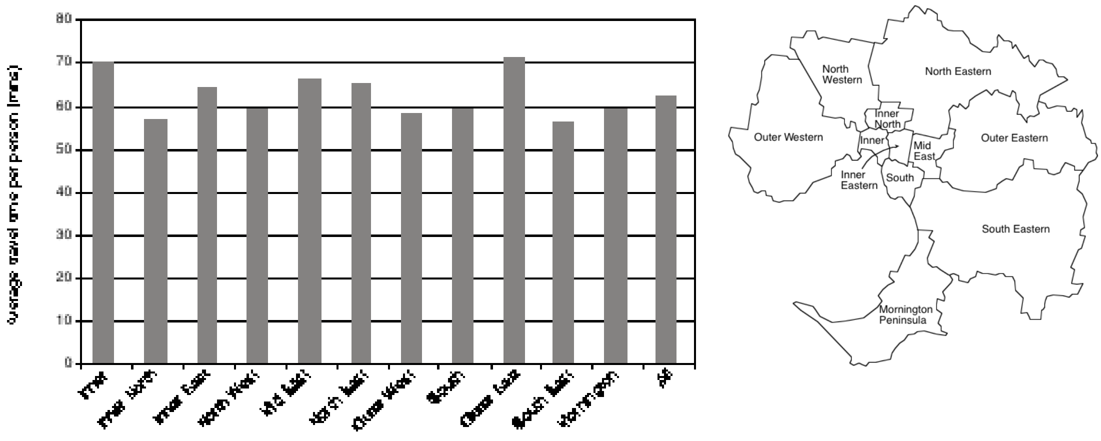


Supernak has argued that as cities sprawl and the relative distance of individuals to the city centre increases, travel times should increase (Supernak 1983, p. 406). His empirical analysis of travel times for individuals living in Baltimore, however, shows no systematic differences based on relative distance from the city centre. Supernak's analysis does show systematic differences in travel time based on age and employment status (Supernak 1983, p. 416).

Generally there appear to have been few empirical analyses that focus specifically on relative distance to the city centre and travel time budgets, but one Australian study suggests that travel time budget constancy appears to prevail.

In a study of average travel time budgets for a suite of districts in Melbourne, Hodges found no apparent systematic differences between average travel time budgets for populations living in the inner suburbs of Melbourne from those living on the outer fringes (Hodges 1994, p. 51). As can be seen in Figure 6.12, average travel time budgets for total travel in Melbourne range from between 58 and 70 minutes. Districts with the lowest travel time budgets are located in both central and outer areas — *Inner North* and *South Eastern*. Similarly, districts with the highest average travel time budgets are located in both inner and outer areas — *Inner* and *Outer Eastern*.

Figure 6.12 Average per capita travel time for all trips in Melbourne



Source: Hodges, F. 1994, *Travel time budgets in an urban area*. Master's Thesis. University of Melbourne, Melbourne, pp. 48 and 51.

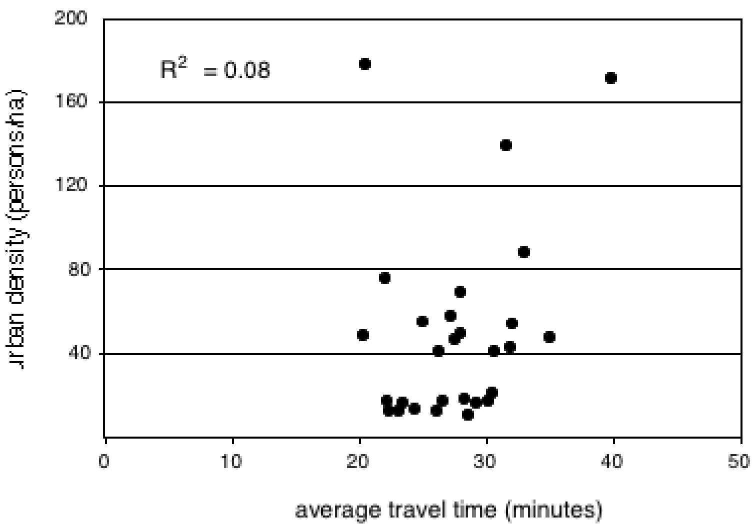
Differences between the values for average travel time budgets in Hodges' study are of some concern. Given the general contention in this thesis of average travel time budget constancy, less variation might be expected. It is important to note that travel time data used by Hodges were collected via a 24-hour mail back travel diary (Hodges 1994, p. i). Other researchers have reported that greater variation exists when travel time data are collected for only a single day. Average travel time budgets become more stable when results are recorded over a period of three or more days for each individual (Goodwin 1981, pp. 101–102). But despite this possible problem with the sample method, if there is no sampling bias affecting relative distance to the urban centre, the empirical analysis undertaken by Hodges, and her general conclusion that proximity to the urban centre does not significantly affect the average expenditure of time on travel, appears robust (Hodges 1994, p. 118).

Urban density

Urban density is another critical parameter that describes the complex nature of the phase state of the urban system and which might be expected to impact on the amount of time individuals spend on travel. Cox argues that as urban densities increase, congestion and time spent in traffic should rise. He does not use a time parameter to test his contention about travel times; instead he uses a spatial parameter — traffic density (Cox 2000, p. 7). But despite this confusion in his analysis, the argument is often made that travel times must increase in concert with urban densities.

Studies undertaken by Goodwin (1975) and Tanner (1979) have shown that travel time expenditure seems to be unaffected by urban density (Goodwin 1975 and Tanner 1979, as cited in Gunn 1981, p. 12). SACTRA noted this finding in conjunction with the observation that rural and urban populations spend about the same amount of time in transit (SACTRA 1994, p. 40).

Figure 6.13 Urban density and average travel times for the journey-to-work in 28 cities (1990)



Data source: Kenworthy, J. R., Laube, F. B., Newman, P. W. G., Barter, P. A., Raab, T., Poboon, C. and Benedicto, G. 1999, *An international source book of automobile dependence in cities 1960–1990.* University Press of Colorado, Boulder, p. 610.

Figure 6.13 shows data for a suite of international cities collated by Kenworthy *et al.* (1999). After outliers are removed[34], there appears to be no distinct relationship between urban density and average travel times for the journey-to-work.

[34] In some cases, the inclusion of an outlier in a regression analysis can generate a higher R square value than is indicative of those scores that are within a similar range of one another. For example, if a city with a population in excess of 15 million is included in a regression when most of the other cities in the sample have populations of only two or three million, a relatively high R square value can result. The high R square value is achieved because of the quantitative disparity between the scores, however, and not because of any particular relationship in the subject matter. Removing such outliers is viewed as a necessary precaution in such analysis, as it provides a way of overcoming high

Asian cities have also been removed from the set shown in Figure 6.13, as well as from later regressions using journey-to-work data in this chapter. This has been done because the structure of travel in Asian cities is different from that of US and European cities. Average trip rates are lower and the mode share to public transport and walking is higher, suggesting that greater trip chaining takes place (Kenworthy et al. 1999, p. 612). Consequently, journey-to-work trips undertaken in Asian cities probably include a greater number of other purposes than is the case for journey-to-work trips in US and Australian cities. Comparable travel time data for total travel were not available and so this could not be verified. Consequently, when Asian cities with urban densities in the range of 300 persons per hectare are added to the regression, the R square increases slightly, as average travel times for the journey-to-work are higher.

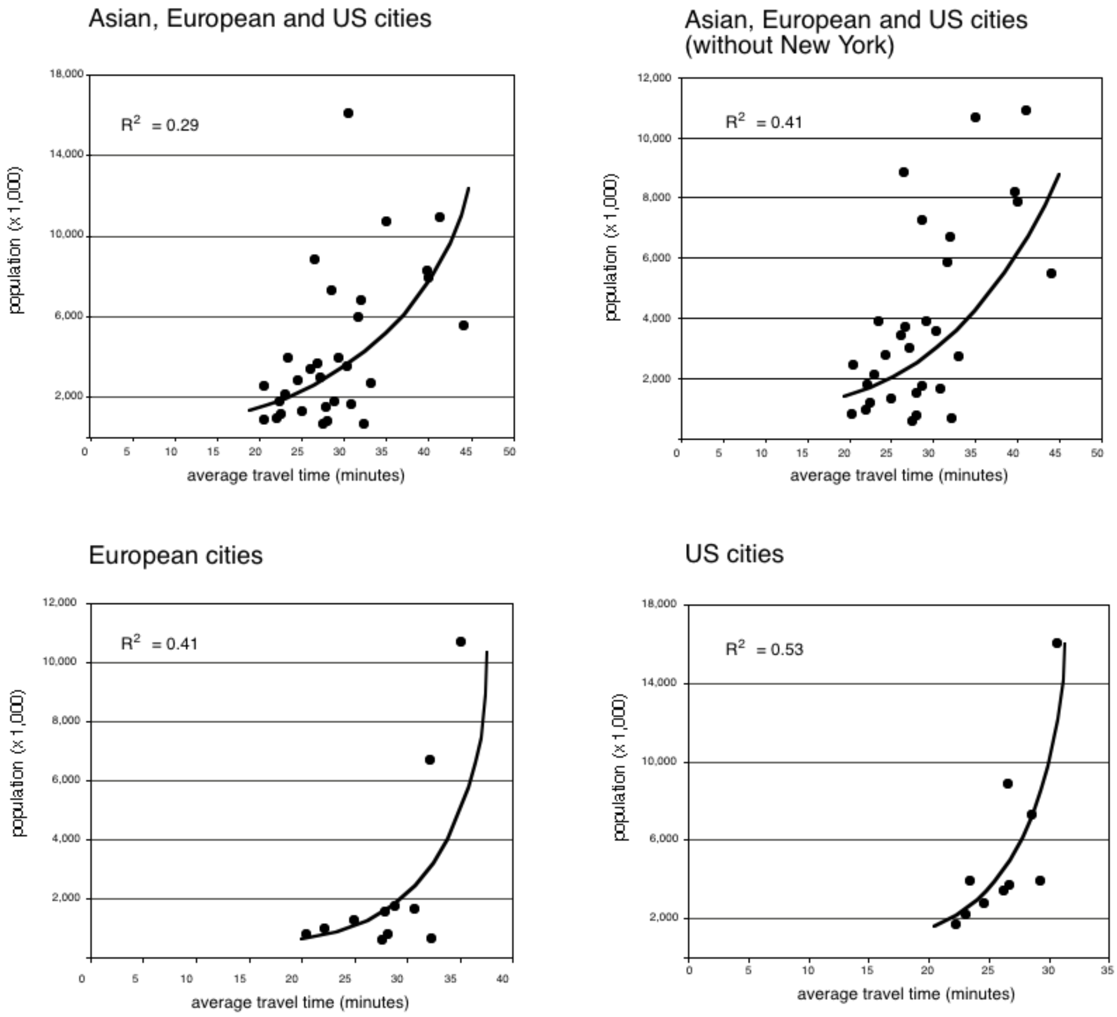
Population size

The one material parameter other than the confluence of factors that make up the system controller that does appear to have some systematic affect on average travel time budgets is the net population of cities. As cities increase in population there appears to be an increase in average travel time budgets for total travel and journey-to-work trips (Stokes 1994, p. 26). Mega cities[35] in particular appear to have travel time budgets for the journey-to-work that are generally higher than smaller cities and towns.

regression correlations that occur because of the methodology, rather than an actual relationship (Barnett & Lewis 1984, pp. 316–318).

[35] Cities with populations in excess of ten million are often referred to as *mega cities*.

Figure 6.14 Travel time budgets and population size for Asian, European and US cities (1990)



Data source: Kenworthy, J. R., Laube, F. B., Newman, P. W. G., Barter, P. A., Raab, T., Poboon, C. and Benedicto, G. 1999, *An international source book of automobile dependence in cities 1960–1990.* University Press of Colorado, Boulder, p. 610.

Figure 6.14 shows average travel times for the journey-to-work for an array of international cities. When assessed as an international set, the R square values are low, indicating no significant trend, although there does appear to be a positive correlation in the data. If New York is removed — a clear outlier — the R square value improves slightly, but not enough to provide a significant correlation. When assessed as continental groupings where system typologies and data collection conventions are similar, a more systematic relationship between average travel times for the journey-to-work and population size appears to emerge in the data. This suggests that the data may be influenced by problems concerning data collection and the empirical analysis of travel time budgets that were discussed in Section 6.1.2.

A possible explanation for why average travel times for the journey-to-work might increase as population numbers grow is that the opportunity to make exchanges also increases both in terms of absolute number and diversity. Greater exchange opportunities present individuals with an added impetus to spend more time travelling. A small minority of the population may choose to take advantage of these opportunities despite the long travel times, thereby pushing up average travel time budgets. The number of exchange opportunities — and therefore opportunity to undertake trips of long duration — is less in cities and towns with smaller populations.

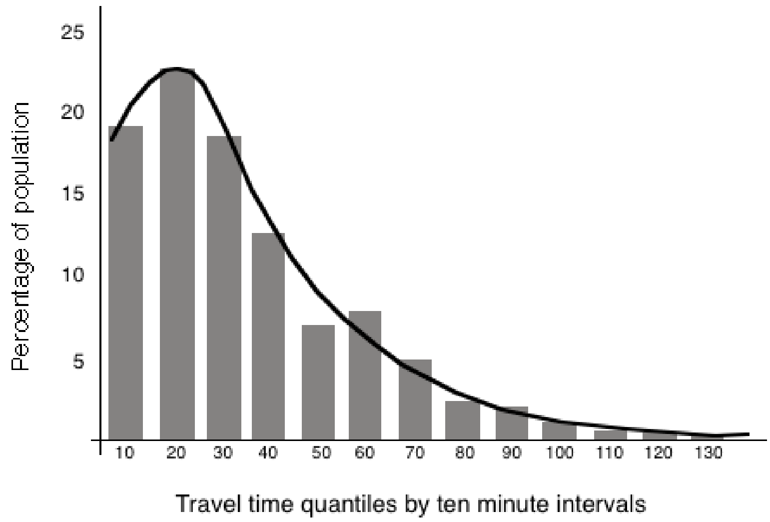
6.1.5 The travel time budget fuzzy controller hypothesis

If it can be accepted that average travel time budgets remain constant regardless of changes to other urban system parameters, such as travel speed and urban density, then it is reasonable to assume that the confluence of factors that give rise to the phenomenon function as a system controller. That population size may systematically influence travel times does not undermine the control function revealed by travel time budget constancy. This is because allowance can be made for systematic differences to statistical distributions.

The figures for travel time budgets discussed so far have been averages. As stated in Section 6.1.2, in practice individuals from the same population spend very different amounts of time travelling to work and other destinations. This can be seen on examination of the statistical distribution for any given population.

Figure 6.15 shows the statistical distribution of travel times for the journey-to-work for the Sydney workforce. The significant characteristic of the distribution is its shape, for this is the real face of travel time budget constancy. Not an average, but different proportions of the community spending given amounts of time on their journey-to-work. In this example, around 19 per cent of the population spent less than 10 minutes travelling to work, 23 per cent between 10 and 20 minutes, 18 per cent between 20 and 30 minutes, 12 per cent between 30 and 40 minutes and so on.

Figure 6.15 Travel time budgets for the journey-to-work in Sydney (2000)

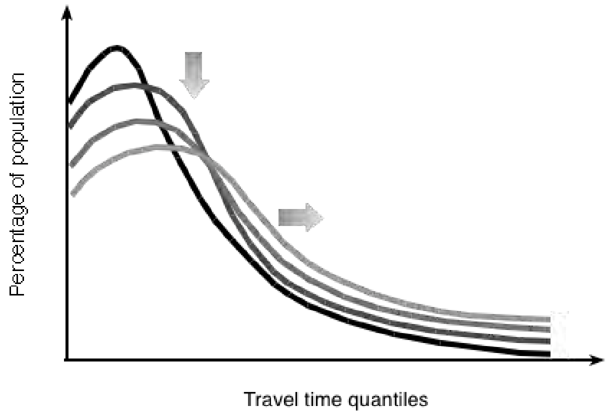


Source: TDC. 2000, *Household interview survey.* TransportNSW, Sydney.

In the journey-to-work distributions for other cities, the percentages of the population represented in each travel time quantile may not be exactly the same as those for Sydney, but they are very similar. As population size increases, the number of individuals undertaking journeys whose travel times fall into the higher travel time quantiles increases. This is because the number and diversity of exchange opportunities is greater due to the larger population. As the percentage of individuals in the higher travel time quantiles increases, the skew[36] and kurtosis[37] of the statistical distribution for the population changes in a systematic way. This is illustrated in Figure 6.16.

[36] The *skew* of a statistical distribution refers to its symmetry. A perfectly normal distribution has a skew of zero. A distribution that bulges to the left such as the distribution for travel times for the journey-to-work, has a positive skew. If a distribution bulges to the right it has a negative skew (Stevens 1986, pp. 44–45).
[37] The *kurtosis* of a statistical distribution refers to how flat or humped the distribution is. A flat distribution where the differences between the median, or middle score, and those at the edges are less is referred to as *leptokurtic*, while a distribution that concentrates scores around the median is refereed to as *platykurtic* (Stevens 1986, pp. 45–46).

Figure 6.16 Statistical distribution shift due to population increases



For journey-to-work travel times, the distribution has a left, or positive, skew. Individuals try to reduce their travel times as much as possible in order to free up time for other more productive activities. The peakiness, or *kurtosis,* of the distribution for small cities is leptokurtic with the distribution of individual scores clustering more around the lower travel times. As the city increases in population size, and the number and diversity of potential exchange opportunities increases, a growing number of individuals spend more time travelling so as to take advantage of these, which has the effect of making the distribution flatter or *platykurtic*. Figure 6.16 shows the systematic change, or shifting, in the statistical distribution as population size increases. This condition gives rise to what might be considered a form of fuzzy control (Yager & Filev 1994, pp. 111–112). In this instance, the phase state value to which the controller sets conditions shifts as population increases, but in such a way that is in keeping with the essential purpose of the system — to maximise economic and social exchanges — while at the same time controlling other parameters crucial to stabilisation of the system.

Summary

This section has described the central control mechanism for travel in urban systems and how, in light of travel time budget constancy, changes to travel speeds can affect other travel behaviour and urban system parameters. This section has also shown that significant problems exist with regard to standardisation of the measurement of travel time for the purposes of empirical verification and cross-city comparisons of travel time budget constancy. But despite these problems, there is merit in the theoretical contention that average travel time budgets remain relatively constant for any given population and thereby provide an indication of the factors responsible for the control and stabilisation of the behaviour of urban systems.

The next section describes in more detail the dynamics of the various system feedback processes responsible for the transition of urban systems from one system typology to another. In this section it will be shown that the phenomenon defined as induced traffic growth is the primary driver for this process.

6.2 Phase transitions between city typologies

The confluence of factors responsible for travel time budget constancy works in conjunction with the logistical properties of different transport systems to control travel behaviour as well as patterns of land-use development. This section focuses on how different types of transport development can bring about what will here be called phase transitions or incremental changes to the phase state of an urban system that in aggregate change the general character of the system. This is achieved through different forms of system feedback. Induced traffic growth, brought about by the addition of urban motorway capacity, is just one example of such system feedback processes.

Use of the term phase transition is usually confined to physical sciences like physics and chemistry. Its most widely familiar application can be found in chemistry, where it is used to describe changes between the *three states of matter* — solids, liquids and gases.

The concept of phase transition can also be used to describe the way in which urban systems change from one typology to another — for example, walking, transit and auto-based city typologies. The use of the term is particularly apposite when analysing transport systems within a systems theory framework. This is because many of the concepts used to explain phase transitions in chemical problems are analogous to the structural changes that occur in urban systems as they move from one phase state to another. For example, when water changes its phase state from ice to liquid form, the spatial relationship between the water molecules changes because different levels of energy in the system enable different types of molecular bonding to determine the characteristic structure of the system. Just as different forms of molecular bonding have different strengths and geometric properties, so too do different modes of transport, although these are usually referred to as logistical features.

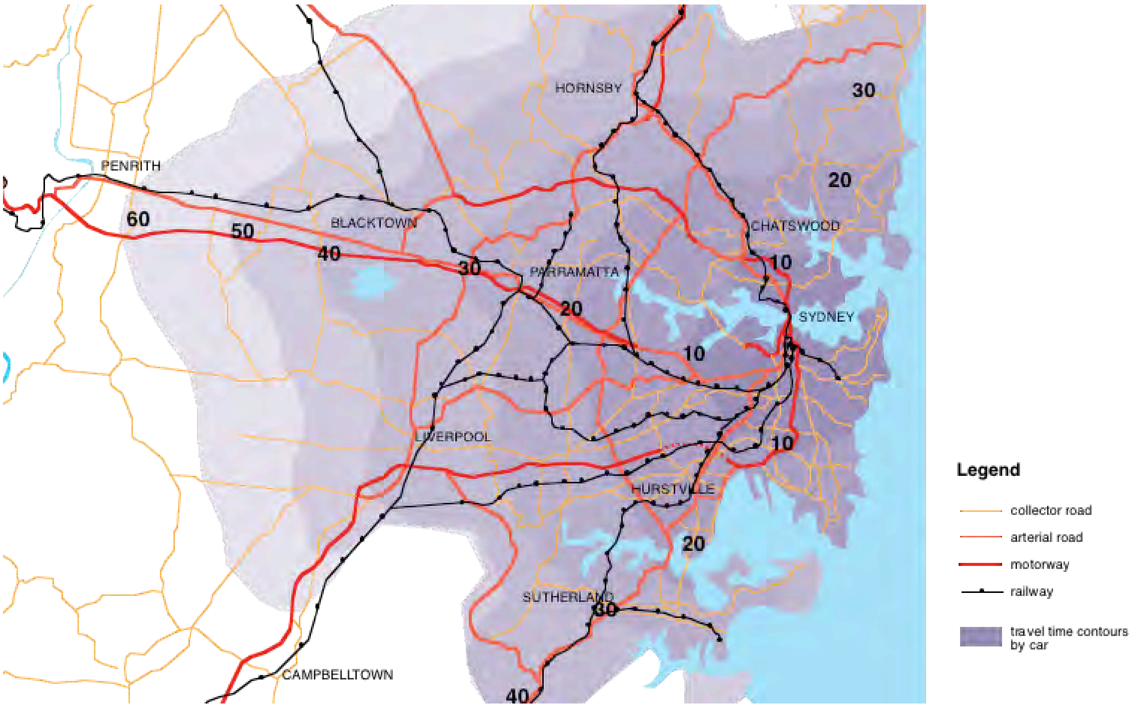
This overview of phase transitions in urban systems is presented in two parts. Section 6.2.1 takes the concept of travel time budget constancy as outlined in Section 6.1 and translates it into a form of spatial data through the use of *travel time contours*. Changes to travel time contours that occurred as a result of building the section of the M4 Motorway examined in Chapter Five are used to illustrate how and why the spatial relationships between system elements change when new infrastructures are introduced to the system. This section also describes several other factors that affect travel time contours, providing a general description of what might be considered the *mechanics* of urban transport and land-use interaction.

Section 6.2 builds on the descriptions of logistical features discussed in previous sections by focusing on how the outcomes from one mode of transport can override those of an existing and alternate hierarchy, thereby leading to more widespread change that generates phase transitions. Different logistical features are shown to produce travel time contours that cause the system to shift to phase states that have different urbanised areas, densities, speeds and average journey distances. Induced traffic growth is an integral part of the particular form of phase transition that sees urban systems move from walking and transit-based to auto-based urban system typologies.

6.2.1 The mechanics of urban systems

While travel time budget constancy sits at the centre of the control of urban systems, it always works in combination with other system parameters, creating different urban typologies that in turn exhibit a multitude of different formations. How this occurs can best be appreciated when the quantiles that make up the statistical distribution of travel times for the journey-to-work are mapped and represented as spatial data. An example of such mapping is shown in Figure 6.17.

Figure 6.17 Travel time contours for trips to Sydney CBD by car under ideal conditions (2000)



▲ Travel time contours have been calculated on the basis of legal speed limits. Unrestricted access road speeds were reduced by five per cent to allow for time spent waiting at intersections.

Source: Zeibots, M. E. 2003, 'How do cities work and why is transport so significant? Regional sustainability and the search for new evaluation tools', in proceedings of *Network of Regional Governance for Sustainable Development: second meeting of the academic forum of sustainable development*, Perth, p. 10.

In this example, the centre of the Sydney CBD has been used as a point from which to map distances that can be travelled by private car in 10, 20, 30 and so on minutes. Each of these *travel time contours* corresponds to the travel time budget quantiles in the statistical distribution for journey-to-work travel times shown in Figure 6.15.

In accordance with the logic of travel time budget constancy, if journeys by car were the only means of accessing jobs in the Sydney CBD, probability-wise 19 per cent of the CBD workforce would have started their journeys within the area accessible within ten or less minutes, 23 per cent within the 20 or less minute range, 18 per cent within the 30 or less minute range and so on. Such a phase state would emerge as a result of the logistical characteristics of the transport system under the influence of the control conditions of travel time budget constancy.

Understanding the conditions responsible for changes to travel time contours enables a wider understanding of the *mechanics* of urban systems and ultimately of phase transitions.

Travel time contours change when the speed of the transport system is altered. Such changes induce travel behaviour change, or different forms of system feedback, because the areas that fall within easier access are expanded. Within such a framework it can be seen that feedback processes do not occur at random and nor do they continue unabated. They are controlled, operating within the conditions set by travel time budget constancy described in Section 6.1.

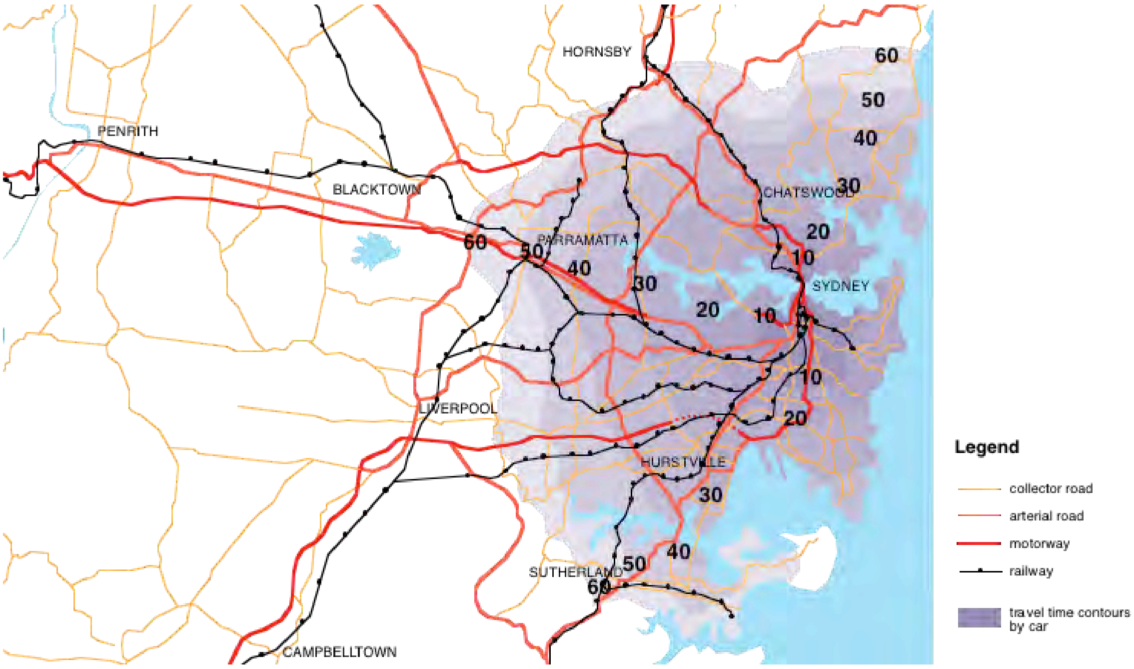
The shape of the travel time contours in Figure 6.17 reflects the logistical properties of auto-based transport systems. Accessible areas are diffuse, due to the ability of cars to use mixed rights-of-way and the vehicle operating conditions that allow individuals to determine route structures and trip scheduling themselves. The accessible area is also relatively large, due to the high speeds at which cars can travel.

The following sections will examine various mechanical aspects of urban systems, focusing on how changes to the transport system are able to change travel time contours that trigger changes to travel behaviour.

Congestion

The travel time contours shown in Figure 6.17 are for travel by private vehicle under ideal conditions. When contours are drawn for travel during the morning peak period, as shown in Figure 6.18, the areas from which access to the Sydney CBD can be afforded within the allotted travel time contours shrink substantially. This occurs because of congestion.

Figure 6.18 Travel time contours for trips to Sydney CBD by car in AM peak period (2000)



▲ Travel time contours have been calculated on the basis of aggregate average AM peak speeds published by the RTA for 2000–01. Contours would differ if more detail were used for districts where average speeds are less than 30 km/h.

Source: Zeibots, M. E. 2003, 'How do cities work and why is transport so significant? Regional sustainability and the search for new evaluation tools', in proceedings of *Network of Regional Governance for Sustainable Development: second meeting of the academic forum of sustainable development*, Perth, p. 11.

The logistical features of car travel make the mode particularly susceptible to congestion. Table 6.1 lists the basic logistical features of the most common modes of transport used to serve urban populations. As can be seen, while car travel has a range of features that make it very attractive from the perspective of reducing travel times — high speeds and a high degree of flexibility in relation to features like route geometry and scheduling — it also has a low capacity that limits traffic flows more readily than high-capacity modes. The flexible features of the mode are also the reason why individuals using the system are more exposed to potential delays due to congestion. While mass transit services that operate to a fixed schedule may also have insufficient capacity to meet demand, not everyone wishing to use the service is delayed. Only those unable to board the service are delayed. If there is a capacity shortfall for car transport, then everyone using the system is affected.

Table 6.1 Logistical features of different transport modes

mode	capacity	speed	right-of-way	route geometry	scheduling
walking	low	slow	mixed	unspecified	unscheduled
cycling	low	slow	mixed	unspecified	unscheduled
bus	medium	medium	mixed/seg	fixed	scheduled
tram & light rail	med/high	medium	mixed/seg	fixed	scheduled
metro & heavy rail	high	high	segregated	fixed	scheduled
car	low	high	mixed	unspecified	unscheduled

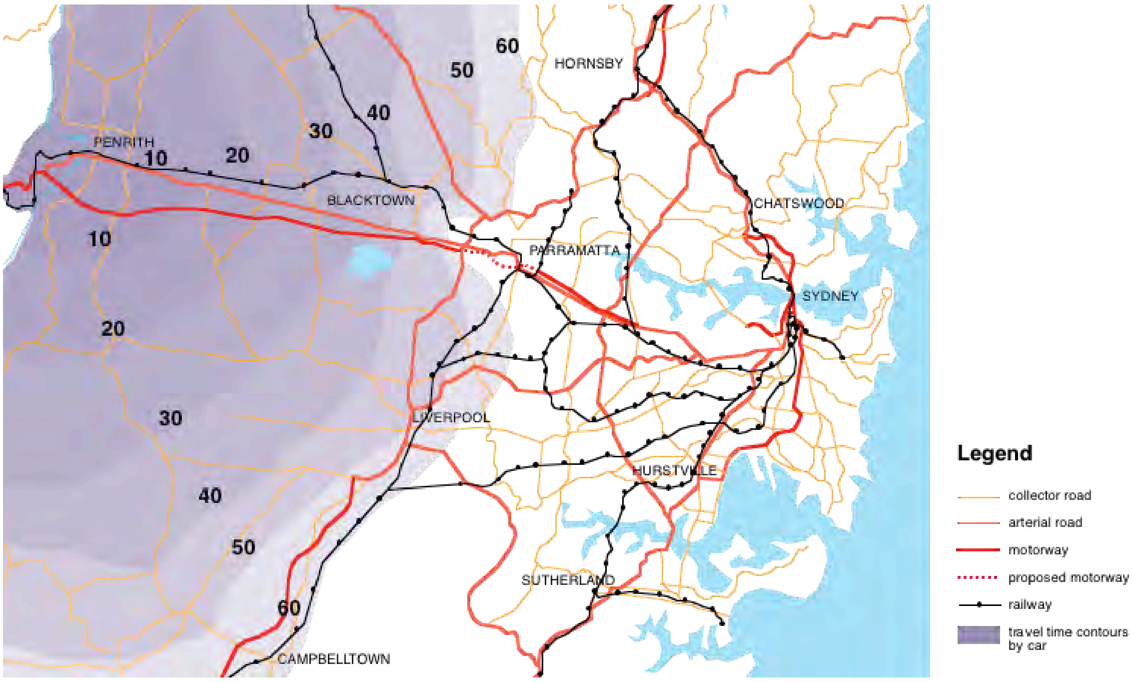
As congestion increases on the road network with the rise in vehicle numbers, travel speeds are reduced and the travel time contours for trips by car morph in such a way that accessible areas shrink. This is how the control conditions of the urban system trigger negative system feedback responses.

The example used here is relatively simple and illustrates only one aspect of the mechanics of how and why travel behaviour changes in response to changes to the speed of the transport system. The morphology of travel time contours also changes in accordance with changes to the geometry and capacity of the infrastructures, or carriageways, that support them.

Network geometry and new capacity

Figure 6.19 shows travel time contours for trips by car from Penrith in Sydney's far west before, opening of the M4 Motorway section from Mays Hill to Prospect. As can be seen, queuing and congestion reduced travel speeds and therefore accessible areas at the network section where traffic from the motorway had to join traffic using the Great Western Highway.

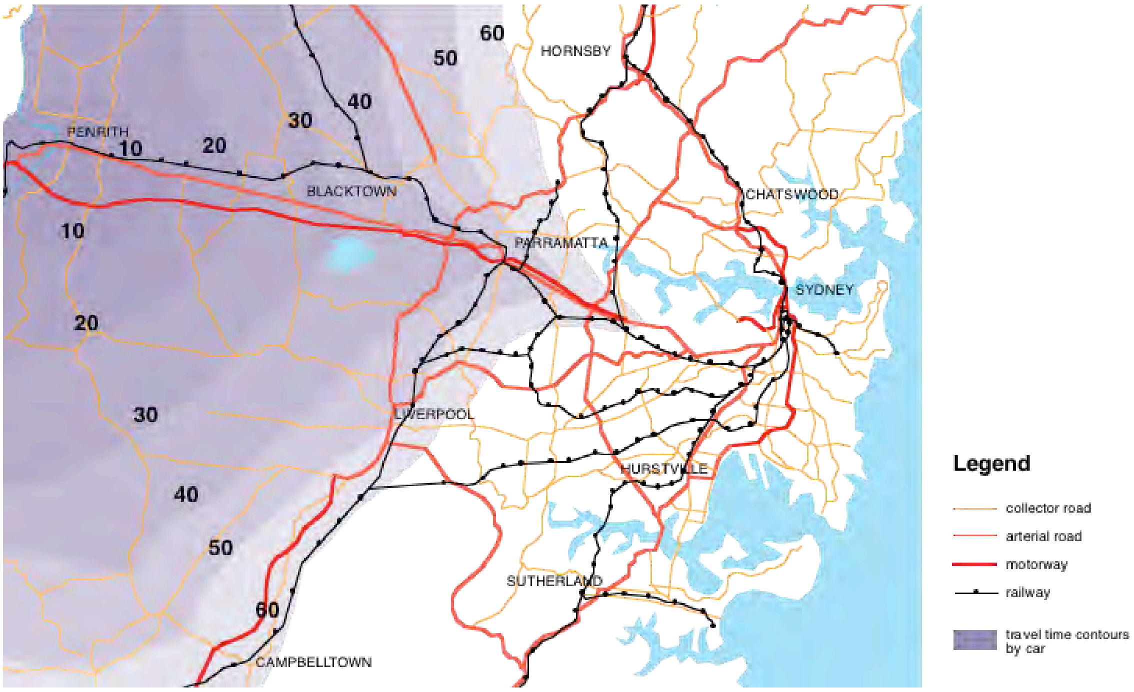
Figure 6.19 Travel time contours for journeys by car from Penrith before the opening of the M4 Motorway from Mays Hills to Prospect (1992)



Source: Zeibots, M. E. 2003, 'How do cities work and why is transport so significant? Regional sustainability and the search for new evaluation tools', in proceedings of *Network of Regional Governance for Sustainable Development: second meeting of the academic forum of sustainable development*, Perth, p. 13.

Once the M4 Motorway section was opened to traffic, as shown in Figure 6.20, the morphology of the travel time contours from Penrith changed dramatically. Key centres to the east, such as Parramatta, fell within the range of quicker travel times, enabling more trips to be made within relatively shorter travel times. The motorway addition triggered changes to the control conditions of the system that in turn gave rise to an increase in the number of individuals who responded to the impetus to make additional trips or exchanges at more distant locations. The change in travel time contours shown in Figure 6.20 illustrates the mechanism that causes forms of positive system feedback to occur, like induced traffic growth. As greater numbers of individuals used the road network, vehicle headways and average speeds were reduced. Accordingly, the morphology of travel time contours changed until the impetus to make additional trips or drive further was counteracted by the desire to save time, and system behaviour was controlled by the effects of negative system feedback manifesting as rising levels of congestion.

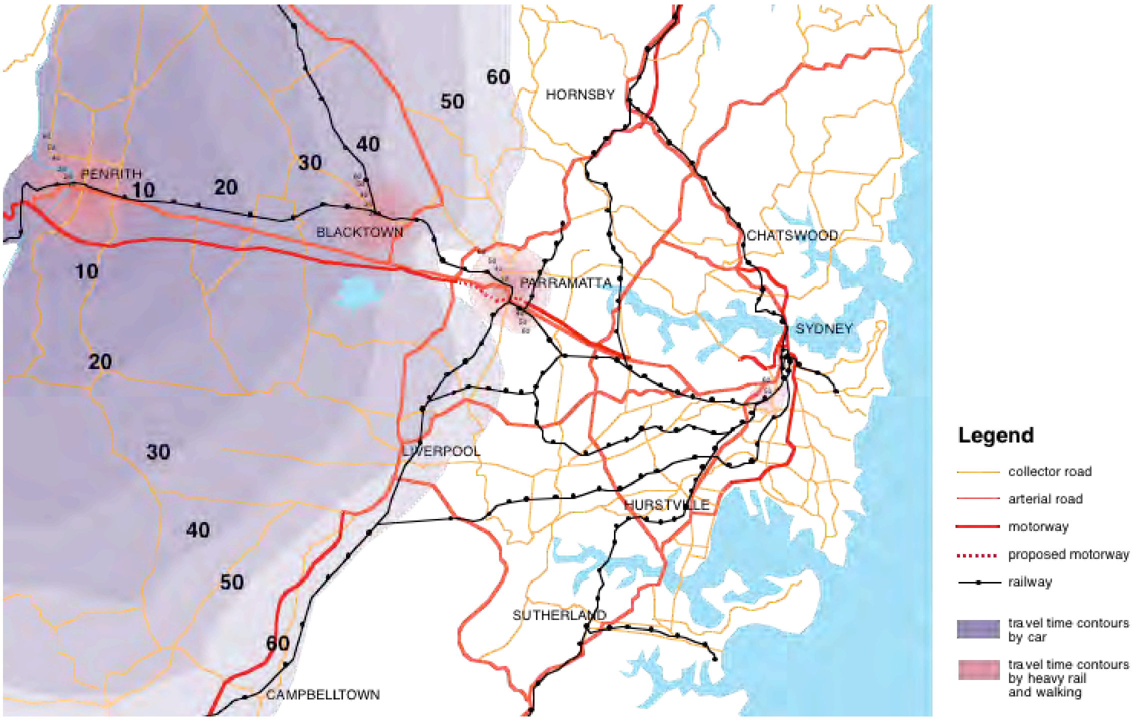
Figure 6.20 Travel time budget contours for journeys by car from Penrith after the opening of the M4 Motorway from Mays Hills to Prospect (1992)



Source: Zeibots, M. E. 2003, 'How do cities work and why is transport so significant? Regional sustainability and the search for new evaluation tools', in proceedings of *Network of Regional Governance for Sustainable Development: second meeting of the academic forum of sustainable development*, Perth, p. 13.

The analysis in Chapter Five examined the possibility as to whether or not some commuters changed modes after opening of the M4 Motorway section. Figure 6.21 shows travel time contours for trips by rail from Penrith in addition to trips by car before the opening of the motorway section. As can be seen, travel times for some people using a combination of rail travel and walking were quicker than travel by car if accessing key destinations to the east. The phase state of the system at that time meant that there was a higher proportion of trips undertaken using rail and walking. After the opening of the motorway section, the relative accessibility of areas falling within the travel time contours for car and rail travel changed, inducing travel behaviour change which in turn changed the phase state of the system.

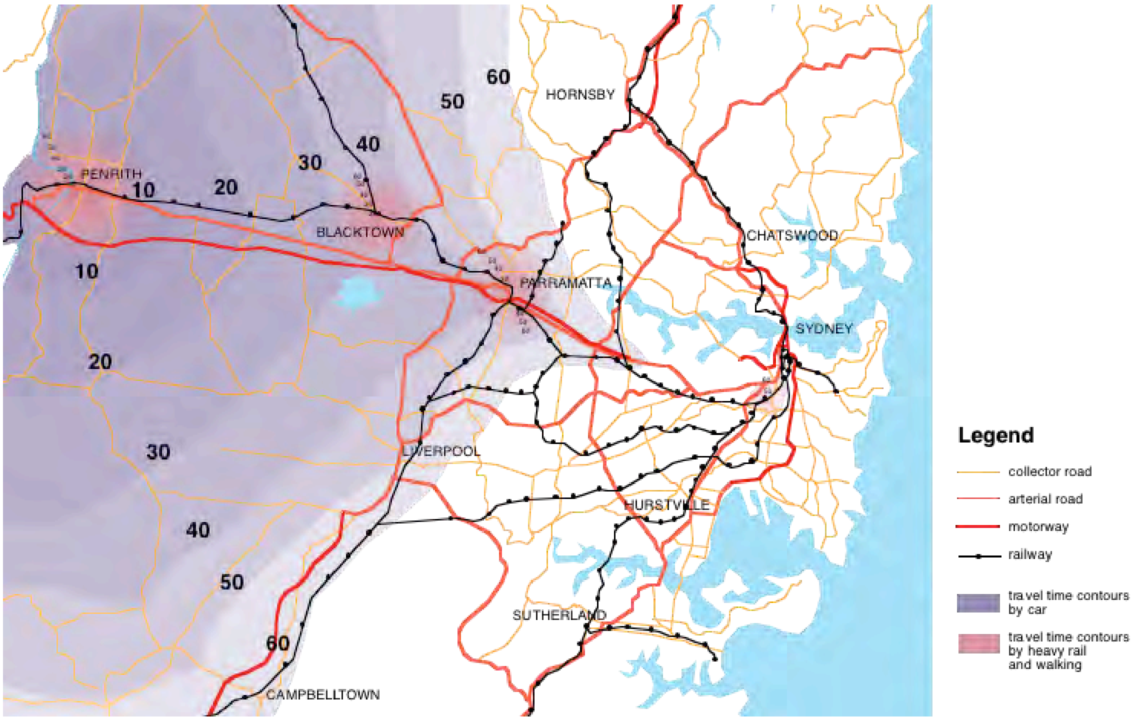
Figure 6.21 Travel time budget contours for journeys by car and rail from Penrith before opening of the M4 Motorway from Mays Hill to Prospect (1992)



Source: Zeibots, M. E. 2003, 'How do cities work and why is transport so significant? Regional sustainability and the search for new evaluation tools', in proceedings of *Network of Regional Governance for Sustainable Development: second meeting of the academic forum of sustainable development*, Perth, p. 14.

Figure 6.22 shows travel time contours for trips by car and rail in combination with walking from Penrith after the opening of the M4 Motorway section. As can be seen, in some cases the additional motorway capacity meant that travel time contours for car travel morphed in such a way as to overtake those for travel by rail and walking. When changes to travel time contours like this occur, mode shifting takes place from rail to road until road traffic congestion increases and brings travel times into equilibrium, as proposed by the Mogridge conjecture that was outlined in Section 4.3.

Figure 6.22 Travel time budget contours for journeys by car and rail from Penrith after the opening of the M4 Motorway from Mays Hill to Prospect (1992)



Source: Zeibots, M. E. 2003, 'How do cities work and why is transport so significant? Regional sustainability and the search for new evaluation tools', in proceedings of *Network of Regional Governance for Sustainable Development: second meeting of the academic forum of sustainable development*, Perth, p. 14.

The changes to travel time contours shown in Figures 4.19 to 4.22 illustrate the effects of changes to network geometry and capacity. When new infrastructure sections like motorways are built and opened to traffic, they extend the reach of transport systems into new territories. When capacity is increased, the accessibility to those new territories can be sustained for a larger number of people. The significance of network geometry and capacity can be more readily appreciated, however, when the features of the transport systems operating on segregated carriageways are compared with those operating on mixed-rights-of-way.

Segregated carriageways

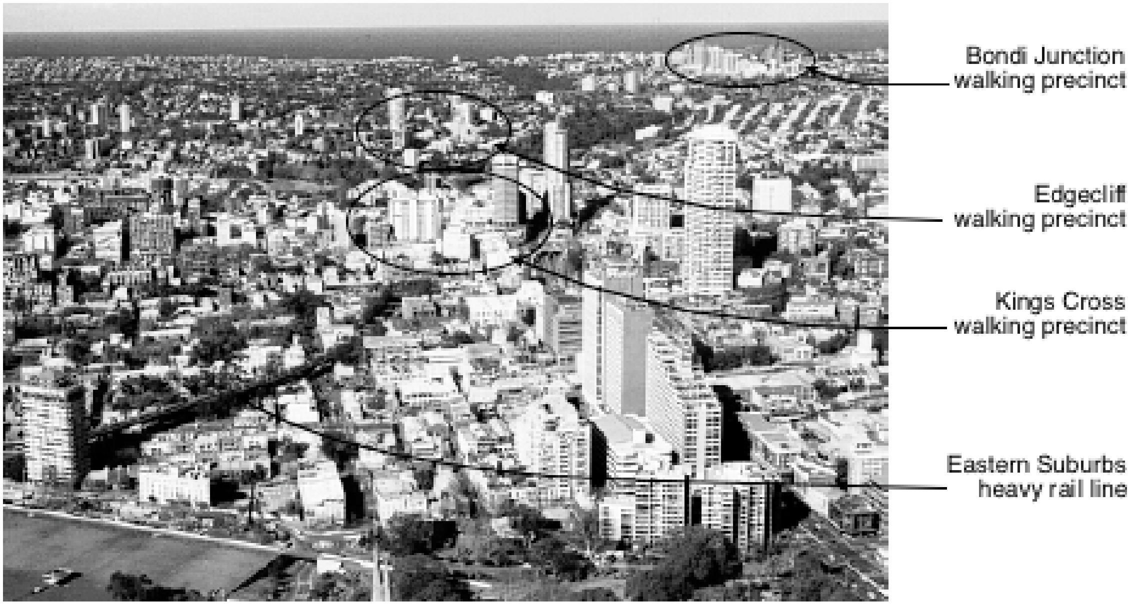
Another key factor affecting the likely probability of OD pairs is the availability of different transport modes. As set out in the Mogridge conjecture — which was reviewed in Section 4.3 — average road speeds are affected by the speed of alternate mass transit services. If access to areas by mass transit proves quicker than travel by car, or if travel time contours for similar trip times extend beyond the reach of those by car, individuals are likely to use mass transit instead. Figure 6.23 shows travel time contours for trips by heavy rail and walking to the centre of the Sydney CBD.

Figure 6.23 Travel time contours for journeys by train and walking to the Sydney CBD in the AM peak (2000)

Source: Zeibots, M. E. 2003, 'How do cities work and why is transport so significant? Regional sustainability and the search for new evaluation tools', in proceedings of *Network of Regional Governance for Sustainable Development: second meeting of the academic forum of sustainable development*, Perth, p. 12.

As can be seen, the shape of the travel time contours created by the rail system is distinctly different from those created by the road network. Instead of a diffuse shape, access is concentrated at distinct nodes along the route of the rail system. The distinct nodes of land-use areas that can be accessed by rail and walking correspond to concentrations in building form. Figure 6.24 provides an aerial view of Sydney's eastern suburbs. The high-density concentrations of building form located around the heavy rail stations can be seen amongst the lower density development. Nodal points around heavy rail stations afford concentrated areas of high access that are less susceptible to congestion than land-use areas serviced predominantly by road transport.

Figure 6.24 Aerial view of Eastern Sydney showing high-density development at rail stations

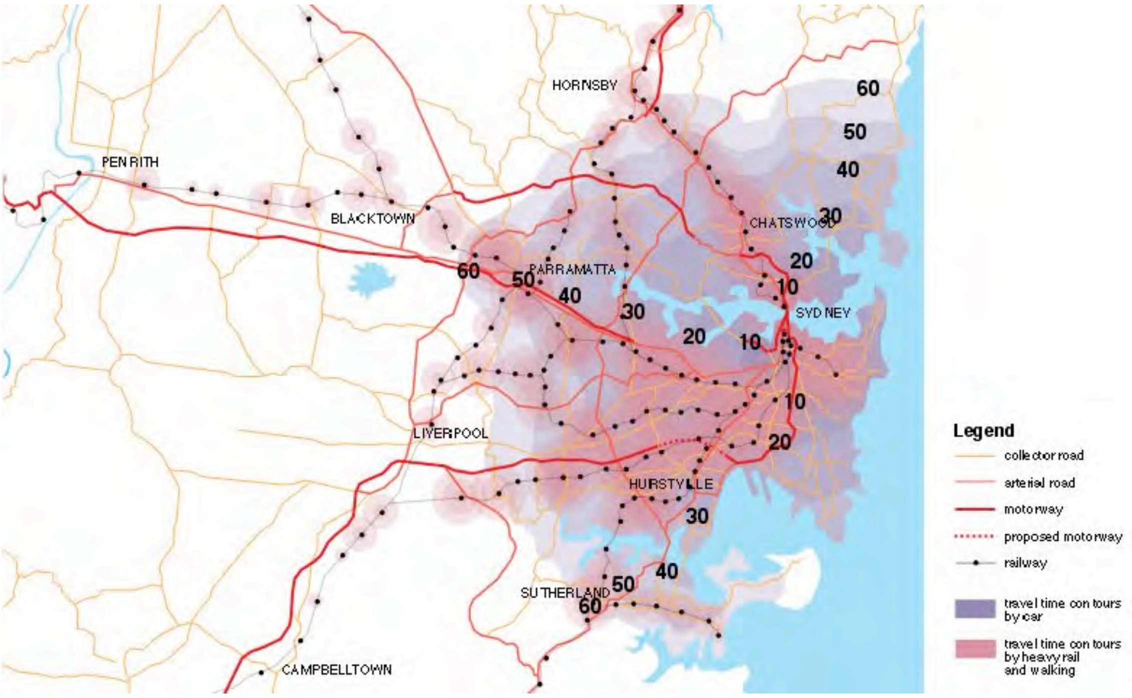


Source: Zeibots, M. E. 2003, 'How do cities work and why is transport so significant? Regional sustainability and the search for new evaluation tools', in proceedings of *Network of Regional Governance for Sustainable Development: second meeting of the academic forum of sustainable development*, Perth, p. 16.

If travel time contours were drawn for the tram network that served Sydney before it was systematically removed in the late 1950s and early 60s and replaced by bus services, then the shape would extend along distinct arms in much the same way that occurs for heavy rail, except that nodal points at stops would be closer together. Such contours conform to the form of concentrated ribbon strip development shown in Figure 1.1.

In Sydney, around 75 per cent of all journey-to-work trips to the Sydney CBD are undertaken by public transport or a mode other than private car travel. Approximately three quarters of these trips are by heavy rail (ABS 2001). This is because in the majority of cases, travel to the CBD by mass transit is quicker than travel by private car. As can be seen in Figure 6.25, travel time contours for rail services extend well beyond those for the road network during the morning peak period. While travel time contours for the bus network are not shown, the same conditions apply. Due to congestion and parking restrictions, in the majority of cases travel by bus is quicker than travel by private car, and while the addition of motorway capacity in the last 15 years has changed the relative morphology of travel time contours for car-based travel, the changes and capacity limitations have been unable to counteract those of the heavy rail and mass transit system.

Figure 6.25 Travel time budget contours for journeys by car and rail from Sydney CBD (2000)



Source: Zeibots, M. E. 2003, 'How do cities work and why is transport so significant? Regional sustainability and the search for new evaluation tools', in proceedings of *Network of Regional Governance for Sustainable Development: second meeting of the academic forum of sustainable development*, Perth, p. 13.

Before discussing the interaction between travel time contours for different modes, it is useful to consolidate and reflect on the details concerning the mechanism of urban transport and travel behaviour in this way.

Travel time contours can be calculated as shown in Figures 4.17 to 4.23 from any number of points within an urban system. If contours had been drawn from Blacktown before the opening of the M4 Motorway section, then a very different shape would have been achieved. Travel times using parallel arterial roads would in many cases have enabled access to areas well beyond the motorway alignment. This raises the point of how such a mechanism works within an urban system whose travel behaviour comprises a multitude of different trips with numerous origin and destination pairs, all of which can be represented by a unique set of travel time contours. From the perspective of the millions of individuals who live and travel in cities like Sydney, each is confronted by such a set of unique travel time opportunities whenever they prepare to travel. In practice, the travel time contours for each individual morphs in accordance with the network geometry and logistical characteristics of the transport system, as well as the travel behaviour of other individuals. Each isomorph in the contour set represents, to varying degrees of probability, the destination point of individual trips.

Even at a cursory level, the complexities of such a mechanism are clear, raising obvious difficulties if it were to be used as the basis for a travel model. But while the calculations involved in such a model are daunting, there is a consistent logic or understanding of mechanism achieved by viewing the system and the cause and consequences of induced traffic growth in this way. It also has the advantage over gravity models of being able to account for how and where other system parameters, like patterns of land-use development, are cogently related to one another.

The journey-to-work, although an important trip type because it is associated with earning an income, is but one of many and must be viewed as a subset of total travel time budgets that incorporate both single-purpose trips and trip chaining. Other factors, such as the availability of car parking, affect travel times and trip numbers. While Sydney is a strong-centre city with a large concentration of jobs in the CBD, viewing the mechanics of urban systems in this way becomes more complex when trips for the entire city involving multiple destinations are at play. But despite these complexities, the significant point is the proposition that travel time budget constancy is a statistical distribution that, in combination with the structure and speed of an urban transport network, can be mapped to produce travel time contours that indicate the probable location of origins to destinations.

The illustrations of travel time contours discussed so far have focused on car and heavy rail use. By mapping travel time contours for different transit systems, it is possible to see how differences in logistical characteristics produce different shapes and areas accessible within given time periods. How these different travel time contour profiles interact and overtake one another, as was shown in the sequence of Figures 4.19 to 4.22, provides an insight into how it is that urban systems change from one distinct typology to another — the process of phase transition.

6.2.2 Phase transitions

When a new transport element embodying different logistical properties is added to an urban system and the shape of travel time contours changes, creating a new accessibility regime, the pattern of land-use and density of development also changes. If the morphology of the resulting travel time contours created by one mode become stronger than another by affording greater accessibility, then the system undergoes a form of transformation or phase transition. The transformation, or phase transition, is similar to that which occurs between states of matter — solids, liquids and gases. When energy levels within water are reduced, for example, different forms of molecular bonding are able to predominate between individual molecules.

Changes to the transport system and consequent pattern of land-use development along the western Sydney sector provide a good example of an urban system having undergone a phase transition. For example, prior to the development of the M4 Motorway, many suburbs along the western Sydney axis had a strong concentration of local facilities that were located around rail stations. As road space increased and travel speeds by car became faster, a greater number of trips in the area were undertaken by car. Patronage levels on rail services dropped and, as a consequence, so did the commercial viability of shops and small businesses that had located in clusters around rail stations in order to take advantage of the high concentrations of pedestrians, or potential customers.

In this example, the ability of the travel time contours generated by the heavy rail systems was not able to provide greater accessibility than those generated by car travel supported by road and motorway development. In the case of the Sydney CBD, the network configuration is such that car travel will never be able to afford the level of accessibility to such large numbers of people that is generated by mass transit services. This is why, in terms of the Thomson city typologies, Sydney is likely to remain a strong-centre city. This is not the case for districts in the outer sectors of the urbanised area.

Summary

This section has described the various aspects of the mechanism responsible for changes in the material phase state of urban systems. In particular it has focused on the role that induced traffic growth plays within the terms of this general mechanism and how the urban motorway development that gives rise to it is able to activate phase transitions within these systems. Before discussing the sustainability implications of such changes in Chapter Seven, it is useful to briefly discuss where such changes might sit within the wider scheme of possible changes that can alter the underlying structure of cities and the travel behaviour of its population.

6.3 Leverage points in the urban system: where small shifts produce big changes

Some components of a system are more central, or fundamental, to its operations than others. When faced with the practical problem of identifying actions that will change the course of a system, so that a desired outcome may be achieved, systems theorists often try to identify what have been called *leverage points*.

Meadows describes leverage points as '… places within complex systems where a small shift in one aspect can produce big changes in the system as a whole'. She adds to this that 'Leverage points are points of power' (Meadows 1999, p. 1).

The purpose of this section is to establish the degree to which adding urban motorway capacity might be a leverage point over and above other transport interventions. Ultimately, the aim is to establish the degree to which such a leverage point might affect the sustainability of cities.

Meadows lists 12 leverage points in complex systems, starting with the least effective — or least likely to cause change — to the most pervasive and fundamental which would be likely to cause a high degree of change. These are shown in Table 6.2, which has been adapted so that transport examples are used to illustrate the leverage point.

Table 6.2 Places to intervene in a system

	Leverage point	Hard system example	Soft system example
12	Parameters and numbers	public transport fares and vehicle registration fees	EIS exhibition period
11	Buffer sizes and stabilising stocks relative to their flows	capacity of a transport system relative to demand	size of electorate relative to scale of decision
10	Structure of material stocks	network geometry and logistical properties of transport networks	–
9	Lengths of delays relative to the rate of system change	time period between transport intervention and behaviour change	time period between a decision and public reaction to it
8	Strength of negative feedback loops relative to impacts they are trying to correct	demand management programs or traffic congestion	ability of a community to stop a decision with bad consequences
7	Gain around driving positive feedback loops	induced traffic growth	ability of a community to start a decision with good consequences
6	Structure of information flows	ability of users to experience the full cost of trips	relative transparency of decision-making
5	Rules of the system	maximum service flows on motorways, travel time budget constancy	direct democracy or representational democracy
4	Power to add, change, evolve or self organise system structure	changes to land use morphology in response to congestion	election of different system owner or transport policy
3	Goals of the system	maximise the number of exchanges that can be made	provide high quality service for customers or create projects for construction industry
2	Mindset or paradigm from which system goals, rules, structure, delays and parameters arise	–	weltanschauung — motorways reduce congestion or public transport sets default speed of system
1	Power to transcend paradigms	–	ability to acknowledge when a paradigm is inappropriate or wrong and change to another

Adapted from: Meadows, D. H. 1999, *Leverage points: places to intervene in a system*. Working paper. The Sustainability Institute, Hartland, p. 3.

The leverage points listed under hard system examples describe various aspects of a functioning transport system like those discussed in Sections 6.1 and 6.2. The leverage points listed under soft system examples describe various aspects of the transport and wider political decision-making system, like those described in Chapter Two.

Significantly, there are no hard system examples listed as leverage points ranked at positions one and two — the most powerful. This is because hard systems — or natural systems — do not have a mindset or paradigm. As was explained in Section 2.1.1, in and of themselves hard systems do not have conscious goals. They are non-teleological. Only soft systems have leverage points of the type ranked at positions one and two.

Induced traffic growth is a form of positive system feedback that occurs between the hard system functions of an urban transport system and the soft system decisions made by the transport decision-making system. Sections 6.1 and 6.2 have demonstrated how this form of system feedback changes the spatial structure of cities, thereby changing a wide range of aspects concerning the other hard infrastructures of an urban system. As discussed at the start of Chapter One, transport plays a ubiquitous role in the day-to-day life of urban systems and so this particular leverage point has the power to bring about considerable change. Meadows describes such positive feedback loops in the following way:

> A system with an unchecked positive loop will ultimately destroy itself. That's why there are so few of them. Usually a negative loop will kick in sooner or later. … Reducing the gain around a positive loop — slowing the growth — is usually a more powerful leverage point in systems than strengthening negative loops, and much preferable to letting the positive loop run (Meadows 1999, p. 11).

In other words, if the consequences of unleashing such a positive feedback loop prove problematic — like increased traffic volumes — then not adding motorway capacity to an urban system is likely to be a more powerful way of addressing that problem than trying to strengthen the negative feedback loops that work to counteract it. In his path analysis, which was reviewed in Section 3.5.3, Cervero concluded that road pricing and improved management of land-use changes spawned by highway development, would be a better means of combating the negative outcomes of induced traffic growth (Cervero 2003, p. 161). Meadows' views on leverage points conflict with Cervero's conclusions. In keeping with her estimation, it would be better to initiate a form of transport development that complements and supports the preferred form of land-use development than to attempt to legislate for it. However, it could also be argued that if the mindset, or paradigm, that dominates transport decision-making cannot be overcome

— points one and two — then perhaps Cervero's conclusions, while not ideal, are more practical.

But despite the power of adding road space to change the nature of an urban system, Meadows lists it as less important than several other leverage points. The remainder of this section will explain why.

The leverage points in the list of hard system examples ranked above number seven all comprise aspects of an urban transport system that human beings as city builders cannot consciously change as easily as those listed below point seven. The structure of information flows that communicate to individuals the full cost of each trip they undertake using either public transport or private transport can never be immediate, due to physical attributes and differences between the two modes. The rules of the system, like maximum service flows and travel time budget constancy, arise as a result of specific material factors endemic to the system. These leverage points cannot be changed, they can only be observed and worked with. The power to self-organise is similar in this respect. Patterns of land-use development will change and adapt in accordance with the logistical properties of the transport system set at lower order levels in the list of leverage points. If such land use patterns do not achieve a desired outcome, it is pointless to try and change them to reflect the workings of a different transport system that had not been built. The goal of an urban transport system is to access exchange opportunities. To change this would be absurd and miss the fundamental reason for building cities and urban transport systems in the first place.

Cities are complex systems, comprising both hard and soft subsystems, natural and artificial, unconscious and teleological. The soft system side of the urban transport system equation does list examples above point seven and many of these can be changed. These leverage points are more powerful, because it is through these that the necessary decisions are made to set lower order leverage points in motion.

Many of the leverage points ranked below one and two are set by conscious decisions arising from a society's mindset, or paradigm, of how cities work. This is why the material considered in Chapter Two is ultimately so important to understanding the implications that urban motorway development has for the sustainability of cities.

It is possible to have a sound descriptive understanding of the causal mechanism responsible for induced traffic growth, but if the political and social context is such that those in positions of decision-making power are not inclined to acknowledge or act on that knowledge, then good science alone will not be enough to enhance the sustainability of the system in practice.

It now remains to consider the manipulation of these leverage points — both material and social — with a view to understanding how the addition of urban motorway capacity might affect the sustainability of urban systems.

There are questions that one chooses to ask and other questions that ask themselves. And the question that had long asked itself without response tends to be abandoned to children.

Henri Poincaré
Science and hypothesis
(1952)

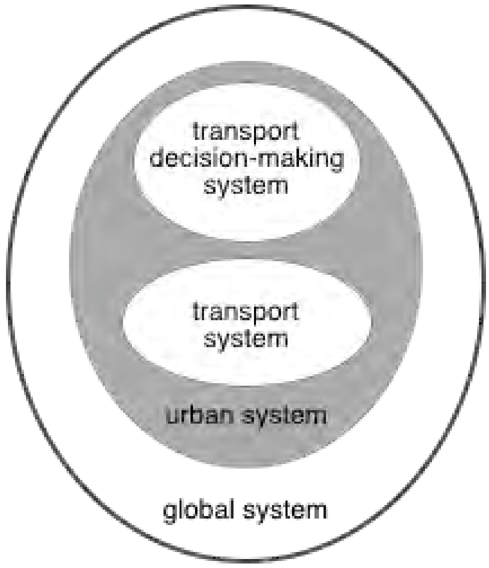
7 Motorways and the sustainability of cities

This chapter asks the question: *what implications dos urban motorway development and the induced traffic growth to which it gives rise have for the sustainability of cities*? It asks this question in light of the problems of oil depletion and global climate change, while focusing on the primary purpose of a city, which is to provide a form of spatial organisation that facilitates the division of labour and complex economic production.

The central question, and the many related questions and qualifiers that it necessarily raises, will be asked within a systems theory framework. As will be seen, a key benefit of such a framework is its ability to provide a way of understanding the relationship between purposeful systems that are goal directed and natural systems that operate without a teleological controller. This is accomplished by recognising a structural relationship between these disparate system types, known as *nesting.*

Figure 7.1 shows how the transport decision-making system described in Chapter Two, and the material transport system described in Chapter Six, function as nested sub-systems within the confines of a complex urban system. Urban systems are in turn nested within the wider global system that includes the natural resource base and earth's biosphere, which supplies many critical inputs as well as absorbing wastes, or outputs, from urban systems.

Figure 7.1 Urban and global system nesting configuration



Nesting provides a way around the problem of Hume's Guillotine that was discussed in Section 2.1.1. By treating the operations within the boundaries of each system as discrete sub-systems, logical consistency is maintained, but not at the expense of understanding how these systems interact with one another in practice.

Through this complex array of nested systems, paths, or system phase states that are sustainable, must be found. Sustainable in this case means that the urban system must be able to continue carrying out its primary economic function in the face of changes to the conditions under which the system has to operate. To do this the urban transport system must be able to sustain a level of accessibility to both people and goods so that economic and social exchanges may continue. If access is disrupted, the system becomes dysfunctional.

The potential for disruption raises the question of how *resilient* a city's transport infrastructures are and how well individuals might be able to adapt their travel behaviour in response to disruptions. It also raises the question of what form of disruption poses the greatest risks to sustained operations. From an input perspective, disruption to essential inputs like fuel supply can undermine transport operations considerably. From an output perspective, disruption to transport operations is minimal unless outputs are directly fed back into the transport system in such a way that systematically retards operations. Where an output creates disruption to a wider system, as is the case with GHG emissions and their contribution to global climate change, direct impacts to a transport system are random. However, if a policy decision is made to reduce outputs in order to mitigate general impacts, then the operations of some transport system types may be more affected than others.

If the issue of sustainability is approached from a systems perspective, such as the one briefly sketched above, then the central question concerning urban motorway development and induced traffic growth can be clarified and restated in the following way: *dos urban motorway development, and the phase state that induced traffic growth pushes a system towards, provide sufficient scope for adaptation when input and output conditions change?*

In answer to this question, the material presented in this final chapter has been divided into four sections. The first (Section 7.1), examines the critical issue of energy inputs to urban transport systems. It focuses on the long-term future of petroleum resources essential to sustaining auto-based transport systems and assesses the viability of alternative fuels. The concept of Energy Profit Ratios (EPR) is discussed, as well as differences in the quality of fuel types and the forms of transport they are able to support.

The second section (Section 7.2) discusses the relationship between the outputs produced by urban transport systems like GHG emissions and the global climate system. In particular, it focuses on the communication links between the transport sub-systems of cities and natural systems like the global climate system. Communication is identified as important because it provides the potential means by which transport emissions might be controlled in order to mitigate their contribution to climate change. Where no natural communication link exists to control emissions, artificial links have had to be developed, such as carbon taxes and emissions quotas. The impact of such measures on transport operations is assessed in addition to their likelihood of success in actually reducing emissions.

The third section (Section 7.3), combines the issues concerning inputs to transport systems, like oil and energy, and outputs, such as GHG emissions. It examines how the use and production of inputs and outputs enmesh with the day-to-day work and economic organisation that transport systems, and motorway development in particular, provide for urban populations and their economies. This section examines the potential for changes in the supply of inputs and restrictions on outputs to trigger system feedback processes that adversely affect macroeconomic stability. This discussion highlights the critical role that transport systems play in determining the spatio-economic structure of cities. It is argued that if the operations of a transport system are not resilient to change, then the economic fabric of the city becomes potentially unsustainable. It is argued that cities whose spatial structures have been developed around motorway development are shown to be particularly vulnerable on this front, as their subsequent phase states cannot easily adapt to changing conditions.

The last section (Section 7.4), discusses the link between the material state of urban and natural ecosystems and the political decision-making systems used to structure and determine responses to perceived problems by society. It is argued that all systems, whether they be artificial or natural, can only survive if the information they receive about the future is clear and their structures able to respond appropriately. This section argues that in practice, knowledge of the degree to which urban motorway development jeopardises the ability of city systems to sustain their essential functions is only of value if decision-making systems are structured in such a way that sustainability for the entire population is the goal of that system. Other goals that unduely diverge from this central purpose can undermine sustainability programs. This section concludes that sustainability is not achieved merely through changes to technologies and infrastructure-building programs, but also through democracy and transparency in the political decision-making processes within the communities affected by such developments.

7.1 Oil dependency and energy economics

The energy sources that fuel motorised transport systems are critical to sustaining the economic activity of large urban settlements. As has been discussed in previous sections

(Sections 1.2.1 and 4.3.2), the spatial relationships between land-use units in auto-based city typologies are orientated around the logistical features of car-based transport that were listed in Table 6.1. If access to a transport system offering these logistical features is denied, much of the movement within the travel time contours afforded by car travel cannot be sustained, thereby denying people access to the various destinations that make up their daily routines. As will be shown in this section, energy-wise, purely auto-based cities and urban districts, unlike walking and transit-based development, have less scope for adaptation through the use of alternative fuels and transport modes.

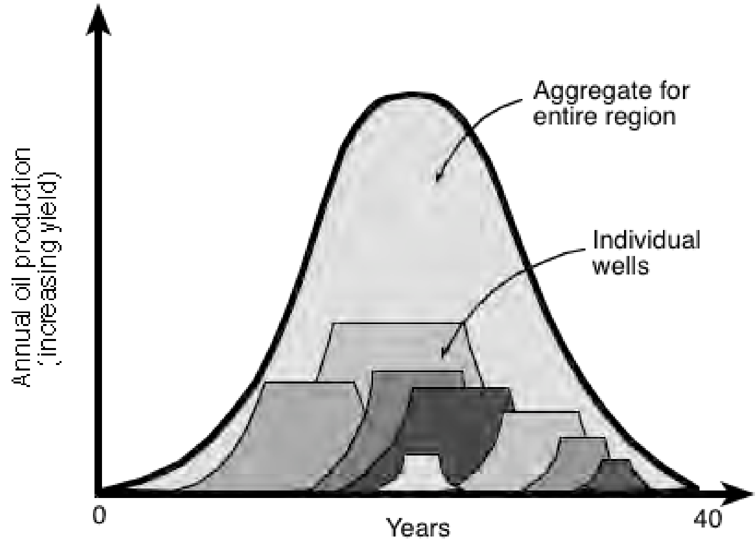
Section 7.1.1 begins with a brief overview of the current debate surrounding global oil supply and the point at which global production will peak and then go into decline. The second section (Section 7.1.2), discusses changes to the underlying economics of energy use once oil production begins to decline. Section 7.1.3 examines other transport fuels that have been suggested as alternatives to petroleum-based fuels. The final section (Section 7.1.4), concludes with a discussion of those transport systems most able to adapt to the emerging energy climate, taking into account the economic viability of renewable and non-renewable fuel options.

7.1.1 Peak oil and current global production

As discussed in Section 1.1.2, there has been considerable debate about the point in time at which global oil production will peak. The peak is significant because after such a point, supply will not be able to keep pace with the growth in demand, forcing changes to consumption patterns.

The anticipated structure of *peak oil* is drawn from the observation that just as oil production from a single well passes through a lifecycle — to begin output increases exponentially before reaching a plateau, followed by a gradual decline as the well ages and deposits become more difficult to extract — so too does aggregate production as shown in Figure 7.2. Hubbert (1956) successfully used this concept to estimate the point at which US oil production would peak before going into permanent decline (Ivanhoe 1996, p. 91).

Figure 7.2 Conceptual structure of peak oil



Bell-shaped production profile
The actual curve of each oil region differs from this depiction, but follows this basic pattern. There are also differences between on-shore and off-shore profiles.

Adapted from: Campbell, C. J. & Laherrere, J. H. 1998, 'The end of cheap oil' in *Scientific American* Vol. 278, Issue 3, p. 79.

The issue of peak oil is significant because of the questions it raises about what will happen to the global economy in the post-peak period. In the past, oil shortages have caused considerable disruption to services and triggered economic recessions (Campbell & Laherrere 1998).

Current debate about the advent and implications of peak oil can be broadly classified as coming from either one of two perspectives. On one side of the debate are those who have calculated that the peak in global oil production is imminent and likely to occur some time towards the end of this decade. This group subscribes to the view that the flow of oil needed to meet global demand is constrained by a range of material factors including the volume and geological condition of remaining reserves, potential recovery rates and the capacity of refinery and transport infrastructures needed to process crude oil into its end-use products like petrol and diesel for transport. In this thesis, this group will be refereed to as the *Geological Rationalists*, so called because their view of oil and petrol supply is based on an analysis of the material and geological constraints that limit the production of oil-based products.

The second perspective puts peak oil production at some time in the relatively distant future, say 2030 or beyond. Individuals and institutions who approach the issue from this perspective hold the view that conventional reserves[38] are potentially much larger than the Geological Rationalists claim and that oil sourced from non-conventional reserves like tar-sands is very large and can be used to make up shortfalls in supply from conventional reserves when market conditions are appropriate (Hughes 2006). This group, which will be referred to as the *Economic Idealists* in this thesis, essentially believe that as oil supply and production conditions change, human ingenuity and technological advancement prompted by market economics, will facilitate the development of alternatives to replace petroleum-based fuels and so there is no cause for alarm (for example, Deming 2001).

By contrast, Geological Rationalists generally believe that the advent of peak oil is cause for concern and that governments throughout the world need to begin overhauling and adapting systems like transport networks (for example, Hirsch, Bezdek & Wending 2005, pp. 20–25). If such measures are not initiated now and the need to adapt industrial and agricultural practices is ignored, the global economy could be pushed into economic recession, in which many systems will crash rather than adapt (for example, Fleay 2006).

Generally, analysis from the Geological Rationalist camp contains greater reference to empirical evidence than arguments put forward by Economic Idealists — a point noted in a recent Senate Inquiry into Australia's fossil fuel reserves (Commission on Oil Independence 2006, p. 7). When those arguing the Economic Idealist position do present empirical evidence, its details are often picked over by Geological Rationalists and robustly refuted (for example, Laherrere 2001; Zagar 2006).

From a systems perspective, the essential difference between the two sides of the debate is that Geological Rationalists view material constraints as largely responsible for what is likely to happen within this sphere of activity, while Economic Idealists believe

[38] *Conventional reserves* refer to oil deposits that have a relatively high viscosity. Unconventional reserves refer to heavy oils with low viscosities, tar sands, shale oil deposits and liquids extracted from natural gas. These sources all require much higher amounts of energy to extract and refine them into end-use products than is the case for conventional reserves.

in the mechanism of the market. Through the eyes of Economic Idealists the way forward may not be known, but there is a faith that the system will find a way of replacing or adjusting to new conditions, because of pressures from market demand as expressed through pricing changes (for example, Holmes 2006).

Current analysis from the Geological Rationalists appears to be converging on the expectation that production of conventional oil reserves is likely to peak towards the end of this decade (Skrebowski 2006; Vidal 2005b). The expectation is based on the observation that production from several major oil producing nations has clearly peaked and is now in decline, including the UK, Norway, Malaysia and Mexico; 90 per cent of all known reserves are now in production; new discoveries are not large enough to replace the volumes currently being consumed; output is increasingly being confined to a small number of producers with little scope for large increases in production in those countries, such as Saudi Arabia and the Former Soviet Union (Skrebowski 2006).

At present, most governments and planning authorities throughout the world do not explicitly acknowledge oil depletion and the advent of peak oil as a problem, although there are some notable exceptions like Sweden and Iceland (Commission on Oil Independence 2006; Hirsch 2001). In the popular media in Australia, little has been said about the problem of peak oil, so that coverage of the issue has defaulted to the view of Economic Idealists, which does not address the prospect of any problems in the foreseeable future (Mushalik & Gatenby 2005).

During 2006, however, the price of oil hit record highs. Fears of oil shortages brought about by increased military conflict and political instability in the Middle-East have led to stockpiling (Shenk 2006). Severe weather events that have damaged oil platforms in the Gulf of Mexico have also brought about sporadic shortages (*The Star Ledger* 2006). In the past, such events would not have put such pressure on prices. But given that output from such a high proportion of producers is now in decline, with little scope to increase supply, small cuts to supply matter and can impact significantly on prices, suggesting that global production is approaching its peak (Skrebowski 2006). These events have led to increases in petrol prices which have impacted on car sales and declines in traffic volumes on tolled motorways in Sydney (Garnaut & Baker 2006, p. 1). Higher inflation levels, acknowledged as partly due to higher petrol prices, have prompted the Reserve Bank of Australia to increase interest rates in a bid to curb inflation, which has impacted on household incomes and business activity (RBA 2006). The political pressure generated by these events has created a climate in which the position advocated by Geological Rationalists has been given more attention as they appear to provide some explanation for why these economic events might be occurring (for example, Skrebowski 2006). By contrast, the Economic Idealist position has been largely unhelpful and attributes the recent increases in inflation to a wide range of factors, downplaying the impact of rising oil prices (for example, Wade 2006).

From a transport perspective there are three significant points that arise from the discussion on peak oil. The first concerns *when* global oil production is likely to peak. This point is significant because it determines how much time communities and governments will have to adapt their urban transport systems in order to maintain accessibility to job markets and essential services. The time frame also determines *what* forms of adaptation are possible. For example, it takes many years to plan and build an electrified rail line to service a new region. Similarly, overhauling the rolling stock that comprises a city's car fleet can take decades. Changes to social organisation can occur quickly, but only if the changes are known and, where required, enabling legislation enacted. The forms of adaptation needed also raise the issue of *how* such measures might be financed and whether or not they might be economically feasible.

These questions seem straightforward enough, but when attempting to sort through the many considerations with an eye to synthesising them into a coherent program of reform, it can be difficult to know where to start.

A point often made by those in the Geological Rationalist camp is that as the world moves into the period of post-peak oil production, the fundamental economics of systems reliant on petroleum resources will change (for example, Fleay 2006; Skrebowski 2006). They argue this on the basis that the amount of energy required to find and extract oil reserves will increase relative to the amount of energy that can be feasibly recovered, so that in net terms there will be less energy available for end-use applications. These features of energy supply affect the viability of end-uses like motorised transport systems. The next section examines this critical aspect of energy economics.

7.1.2 Energy Profit Ratios

A key factor in the peak oil scenarios discussed by the Geological Rationalists is the observation that energy must be spent in order to gain access to a useful energy source. For example, in order to gain access to the energy content of petrol, energy must be spent on exploration, building and installing drilling rigs and deep-sea platforms. Energy then needs to be spent pumping the resource out of the ground. If wells are old and have lost pressure, then pressurisation has to occur, which requires more energy to be spent. Energy must also be spent on shipping the oil in its raw form to a refinery before it is transported once again to its point of end-use. All these links in the energy supply and production chain consume energy themselves (Hall, Murphy & Gagon 2006).

When the amount of energy required to bring an energy source to its point of end-use is greater than the energy contained in the fuel itself, its economic usefulness is diminished (Fleay 1995, p. 7). Many deposits throughout the world fall into this category. In some cases the size of a deposit may be small and contain less energy than it would take to drill to it. In other cases, deposits might be difficult to access because they are located in extremely deep water, or a combination of such factors might apply (Skrebowski 2006).

Energy Profit Ratios (EPR) measure such physical aspects of energy sources and are calculated in the following way:

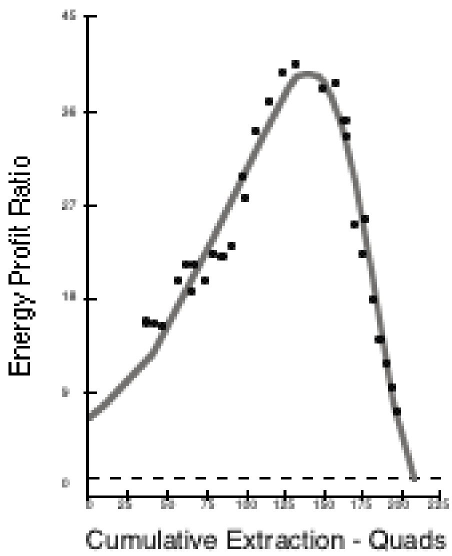
$$\text{EPR} = \frac{\text{Energy content of fuel}}{\text{Energy used in fuel production}}$$

The EPR of a fuel essentially measures the amount of energy left after the amount required to produce it has been deducted from the final output, or as Fleay defines it, the amount of *free energy* (Fleay 1995, pp. 6–7).

The higher the EPR for any given fuel, the more economically useful and commercially viable the fuel is. For example, oil acquired from Saudi Arabia has higher EPRs than oil from most other producers these can be well above 20. This is because most crude oil is acquired from large wells that are relatively easy to access (Zagar 2006). By contrast, crude oil produced in Australia is acquired at an average EPR of around 12. This lower EPR occurs because most Australian reserves are small, dispersed and located in deep waters offshore, requiring more elaborate and expensive mining techniques (Fleay 2006, pers. comm.).

The EPRs for oil wells change over the lifecycle of extraction from a reserve or group of reserves. For example, Figure 7.3 shows the EPRs for oil and gas extraction from Louisiana. As can be seen in the early phases of production, oil was extracted at EPRs starting at around 16, so that for every unit of energy expended on extraction, 16 were acquired. After the initial expenditure on wellheads, the EPRs rose significantly, reaching a peak of around 40. But as the volume of oil in the wells began to fall and pressures dropped, the amount of energy required for extraction increased, and as a consequence, the EPRs began to fall until they reached levels of about seven. At that point, further extraction required greater amounts of energy than remaining deposits could yield, so that production ceased despite there being oil left in the wells.

Figure 7.3 EPR profile for oil and gas production (Louisiana, USA)



Source: Hall, CAS., Cleveland, CJ. & Kaufmann, R. 1986, *Energy and resource quality: the ecology of the economic process.* Wiley-Interscience, New York. <www.bu.edu/cees/index.html>

EPRs are useful for assessing the economic viability of extraction and production. They also explain why some oil deposits will never be mined, despite the high demand for oil.

The EPR of the energy supply that a city, or community, is able to access, also plays a part in determining the general scope and calibre of economic activity that community will be able to sustain. While EPRs are central to energy economics, there are three other factors that, when combined with EPRs, determine the net amount of energy a community can access. The first is the rate at which energy can be supplied, the second is the degree of competition for that energy and the third is the ultimate scarcity of the source — whether it is finite or renewable. Once the supply of a finite energy source begins to dwindle and competition for the resource increases, the EPR of an energy supply becomes critical. This is because of the opportunity cost that extraction and production present to other sectors of economic activity.

If a fuel source has a low EPR, it does not necessarily mean that it cannot be used. From an economic perspective, however, it does mean that what can be performed with that fuel must be of a high economic value. This is because the additional energy and resources needed to access the low EPR fuel is effectively taken from some other end-use. For example, being able to transport sick or injured people to a hospital quickly by ambulance is seen by most people as a high-value activity because of the value placed on human life. If the energy source used to fuel such a vehicle has a very low EPR — as is the case with ethanol grown from sugar cane — rather than the high EPRs that petroleum-based fuels have at the moment, then society would still run those vehicles in order to provide that emergency service. However, society would probably not make that same fuel available in the quantities now used for trips that have a relatively low value, such as driving to the corner store to purchase a carton of milk. Using small amounts of ethanol for emergency services poses a small opportunity cost to other areas of activity, such as food production. The opportunity cost of using the same fuel for large numbers of low-value trips would be considerably greater — the trade off being the country’s food supply (Pimentel 2003; Rutovitz & Passey 2004).

If the fuels used by the transport sector to move a workforce around in a city have low EPRs, then clearly a city that has found a way of accomplishing the same task by using less fuel will be at a distinct economic advantage. The transport task will pose a far lower opportunity cost to other sectors of activity. When a fuel becomes scarce and there is intense global competition for that fuel, then clearly those cities able to produce the same amount of work, without consuming high volumes of energy at low EPRs will outperform those that cannot. These aspects of energy consumption in the transport sector will be discussed in more detail in Section 7.3.

When the underlying EPRs of an economy change dramatically, the economy is forced to reorganise itself. This can take any number of different paths, including the substitution of different fuels on the supply side of the energy equation. EPRs can be calculated for other fuel types, thereby providing a way of assessing their viability as alternatives to petrol and other finite fossil fuels.

All of this points to a set of emerging conditions where available energies will have generally lower EPRs and involve possibly the use of resources — like agricultural land — that is in direct competition with other activities. In light of these emerging constraints, a key question is can existing transport systems adapt to these changing conditions?

7.1.3 Alternative transport fuels: their quality and quantity

A key advantage of petroleum-based transport fuel is its mobility. Because the fuel is light-weight and liquid, it can be carried with the vehicle it is powering. This aspect of the fuel has implications for the configuration of the transport infrastructure and vehicles that will use it. For example, petrol as a transport fuel enables cars to deviate from arterial carriageways, enabling them to create the dispersed travel time contours that were shown in Figures 6.19 to 6.22 in the previous chapter. It also means that the infrastructures do not need to facilitate the energy-supply, as is the case with electric rail systems.

In many debates, these features of private vehicles are cited as beneficial because they afford high levels of *flexibility* for commuters. But these features can become significant constraints when fuel availability changes.

There are several alternate fuels to petrol and diesel that are also portable and relatively light-weight. These fuel types include liquid petroleum gas (LPG), bio-fuels, hydrogen-fuel cells and battery powered electric cars. Like petrol, LPG has a relatively high EPR. But also, like petrol, LPG comes from a non-renewable source and so ultimately suffers from the same supply problem — a peak in production followed by a period of inexorable decline. Bio-fuels and hydrogen-fuel cells encounter different problems — high amounts of energy and resources are required to produce them. A bio-fuel like ethanol must be grown from a suitable crop and this requires the use of agricultural land. Fertilisers and labour must be used to cultivate that crop — all of which amounts to relatively high energy and resource consumption (Pimentel 2003, pp. 128–130). Similarly, the production of hydrogen-fuel cells requires large amounts of electricity that must be generated from some source before being transformed into a hydrogen fuel cell that can be transported in a motor vehicle (Wald 2004, p. 66). The same problems are encountered with electric cars where the electricity is stored in on-board batteries.

Table 7.1 shows a range of different EPR values for different energy sources in Australia. While there is some doubt about the EPR for ethanol production in Australia, these values are similar to those achieved in the US (Hall, Murphy & Gagon 2006; Pimentel 2003, p. 130).

Table 7.1 EPR values for a range of energy sources

Australian oil	**12 EPR**
Coal fired power	**9 EPR**
Nuclear	**4 EPR**
Natural gas	**10 – 25 EPR**
Photovoltaics	**10 EPR**
Ethanol	**<1 to 2**

Source: Fleay, B. J. 1995, *The decline of the age of oil.* Pluto Press Austrailia, Sydney, p. 65. and (Fleay 2007, pers. comm.).

Two significant points arise from this brief overview. The first is that high value alternate fuel sources that are portable — like petrol and diesel — are not readily available. While LPG is another high value portable source of energy, its use — like petrol and diesel — cannot be sustained because it is a finite resource. Bio-fuels like ethanol have low EPRs and would directly compete with other critical activities like food production. This leads to the next point, which is, that if relatively high EPRs can only be achieved from energy sources with different physical qualities — like electricity generated from renewable and non-renewable sources — then what effect does this have on transport, given that fuel qualities can constrain their transport applications?

7.1.4 Adaptation of urban transport systems in response to oil depletion

Three critical issues determine the degree to which urban transport systems that are currently dependent on petroleum fuel sources will be able to adapt to an environment in which these fuels become increasingly scarce.

The first is the prevailing mode-split for total trips, as this would determine the degree to which adaptation would be necessary. Clearly, non-motorised transport would be largely unaffected. Trips undertaken by mass transit and private motor-vehicles would be affected, but to varying degrees.

The second critical issue is the cost and price of alternative energy sources. Energy costs are determined by their EPRs, while price, is determined by several factors, including the demand for an energy source relative to its supply.

The third is the relative efficiency of the transport mode to which the power source is applied. For example, the efficiency of an electric rail system, in comparison to a fleet of electric cars, when measured on a passenger kilometre basis, is significantly greater. This factor ultimately has implications for the relative price and demand for trips undertaken on different modes.

As the price of petroleum-based fuels begins to increase, the immediate short-term responses would comprise shifting from those transport modes affected by the price increase — which would primarily be private car travel — to modes that were less affected, including mass transit, walking and cycling. There may also be a general reduction in the amount of travel, as individuals with few alternatives elect to reduce non-essential trips or combine multiple trip purposes into one trip. The degree to which this can occur would be dependent on the prevailing travel time contours afforded by the system and the variety of destinations that fall within their reach, as described in Chapter Six. Adaptation of this kind would have little impact on the economic functions of the system, although over-crowding on mass transit services may become a problem.

For essential trips, like the journey-to-work, where alternatives are not available, adaptation becomes more difficult. Where individuals cannot afford higher fuel prices, especially for long-distance trips, alternative fuel and vehicle types may be sought. In practice, real time factors would constrain what might be feasible. For example, it may not be possible to introduce an alternate technology in the time-period between increases in prices that signal the need for adaptation and the time needed for the practical implementation of an alternate solution. Most importantly, the EPR of the prevailing fuel would determine how feasible such an alternative would be. Where EPRs are low and costs consequently high — like ethanol — governments may choose to subsidise fuel in order to make it more affordable. However, this would present opportunity costs to other areas of government spending. If increases in fuel prices occurred relatively slowly, rather than as a price spike, the uptake and development of alternatives may become more feasible, as there would be more time to plan and change systems. But if fuels with considerably lower EPRs have to be used, the productive output of the city would need to be high, relative to the degree of fuel substitution required to maintain access.

Cities whose patterns of land-use development have been formed by the logistical properties of private car travel could find adaptation more difficult, especially where the trunk route transport task is dominated by urban motorway development. In such areas, substantial public transport alternatives do not usually exist.

In conclusion, cities with transport systems that are currently serving a higher proportion of its access needs using non-motorised modes like walking and cycling, as well as mass transit systems that are powered by electricity, would generally require less adaptation in order to sustain access and current economic functions. Where cities are highly dependent on private motor-vehicle transport, adaptation becomes more problematic, given the degree to which access provision has been locked in to transport technologies that require a shift in fuel types that have traditionally had very high EPRs to alternatives with low EPRs.

Inputs to the urban transport sector are not the only factors that affect the sustainability of urban systems. Outputs also have the capacity to affect transport operations.

7.2 Climate change and the city

This section discusses the relationship between GHG emissions from the urban transport sector and the natural global systems that are the subject of climate change. It discusses how GHG emissions affect the sustainability of cities in terms of the direct impacts of climate change, as well as how programs and policies aimed at stabilising and reducing emissions might affect urban economic processes.

While debate about what to do to minimise the impact of climate change persists, it seems reasonable to conclude that a consensus has been reached on the existence of anthropogenic climate change (IPCC 2007). Debate as to whether or not the phenomenon might be real has largely ceased, with attention now focused on analysis of the calibre and extent of its material impacts and the feasibility of various responses (Throsby 2007). This being the case, it is not necessary for this thesis to review that debate but rather to accept, that as a matter of practice, urban transport systems need to be developed and reformed in such a way that their GHG emissions are minimised and reduced.

As stated in Section 1.1.3, everyone is materially affected by climate change in some way, irrespective of whether they recognise the phenomenon, live in countries that have signed emissions treaties, or agree to the instigation of carbon taxes. This is because the material problem of climate change has global dimensions that are random and undiscriminating.

The undiscriminating nature of climate change impacts is an impediment to mitigating the problem, for if a community recognises that particular activities emit high volumes of GHG emissions, and then reforms those activities to reduce emissions, it should be rewarded for its efforts and protected from the consequences. Or at least this is what would happen if there were a systematic relationship between the two. But the factors that control human activity systems and the global climate system have no direct communications medium that connects the workings of one system with those of the other.

Section 7.2.1 discusses the nature of the system feedback relationship between activity taking place within the urban transport sector and the atmospheric processes of the earth’s biosphere. The absence of any systematic relationship that produces direct communications between these two activities is discussed and identified as the primary obstacle to successfully addressing the problem of global climate change.

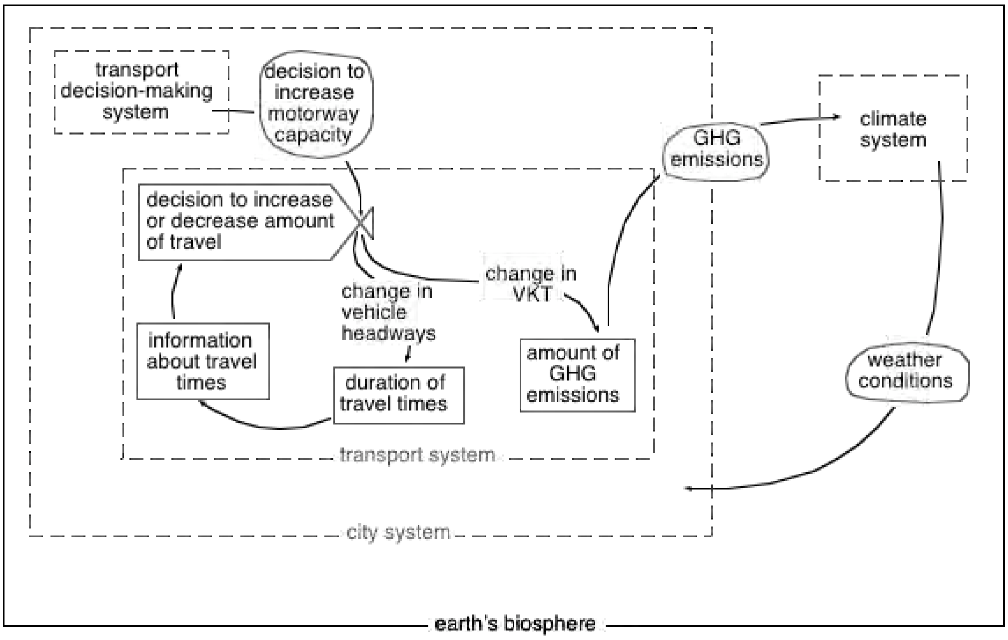
Section 7.2.2 identifies various options that have been suggested as ways of overcoming the communications shortfall between travel behaviour and transport systems and the natural processes and impacts that constitute climate change. The effectiveness of such options is discussed in light of the hierarchy of leverage points presented in Section 6.3.

Section 7.2.3 discusses how effective the options discussed in the previous section might be and what impacts they might have on accessibility — the central function of transport systems.

7.2.1 The relationship between urban systems and the natural processes of climate change

From a purely descriptive perspective, the disjunction between human-made systems like cities and their transport networks, and natural systems like the earth's biosphere, occurs because of the type of system feedback relationships that exist between the two. Figure 7.4 shows the relationship between an urban system, its GHG emissions output and the biosphere that absorbs those emissions. As can be seen, the urban processes directly connected with travel behaviour, and transport decision-making, which combine to produce the level at which GHG emissions are generated, have no direct connection with how the effects from such emissions are then fed back into the urban system in the form of adverse impacts from the global climate system.

Figure 7.4 Feedback relationship between natural biosphere and human-made systems



The form of system feedback shown in Figure 7.4 is extrinsic, meaning that as an urban system emits GHGs into the biosphere, the processes that control the effects on climate occur outside the urban system. The consequences of climate change are then fed back into the urban system in a variety of forms that could range from food shortages for its population because of drought, to storm damage to infrastructures from severe weather events, or heat-waves that affect the health and wellbeing of individuals.

Empirically, urban motorway development, and the induced traffic growth to which it gives rise, increase per capita GHG emissions from the urban populations using those motorways (Kenworthy 2003). Because there is no direct relationship between the many causes of climate change — like emissions from transport — and the consequences — like extreme weather events — systems are unable to self-regulate their behaviour. Consequently, many urban systems may continue to pursue forms of development, like urban motorway expansion, that facilitate behaviour that produces emissions at levels that will ultimately contribute to the destruction of some part of their structure or operations.

When trying to identify ways in which to address the problem, from a systems perspective, a way of overcoming the communications disjunction needs to be found. This is usually achieved by generating an artificial feedback loop that acts as a communications link between the source of the emissions and the adverse impacts from climate change created by those emissions for such responses.

7.2.2 Communication links and material solutions

Various mechanisms have been proposed to overcome the absence of a communications medium between the cause and effects of climate change. How successful such mechanisms might be can be assessed using the hierarchy of leverage points discussed in Section 6.3.

Table 7.2 lists a set of typical responses that have been suggested as ways of reducing GHG emissions from the urban transport sector. The list outlines both the material response aimed at reducing the level of GHGs emitted into the atmosphere, as well as the power of the signal used to communicate the need for travel behaviour change.

Table 7.2 Responses to greenhouse gas emissions from the transport sector

	Change to the urban transport system	Communication mechanism
1.	Improve fuel efficiency of vehicle fleet so that fewer GHGs are emitted per travel unit	Introduce legislation specifying vehicle standards (leverage=12)
2.	Develop carbon sinks to absorb and reduce GHGs emissions in the atmosphere	Include price of carbon sink equivalent in price of petrol or LPG (leverage=12)
3.	Power vehicles using renewable energy and low or carbon-neutral sources	Introduce legislation specifying fuel standards or change price structure to encourage use of renewables (leverage=10)
4.	Develop infrastructures to facilitate use of alternate transport modes that produce fewer GHG emissions, such as walking, cycling and mass transit	Introduce appropriate transport policy interventions and pricing signals (leverage=10 and 8)
5.	Stop expansion of road capacity to limit the growth of road transport use and GHG emissions	Introduce appropriate land-use policy interventions and pricing signals (leverage=7)
6.	Reduce road capacity to trigger reduction in road travel and GHG emissions	Change travel time contours of system for private car and road transport (leverage=4)

Note: leverage points in the right column refer to the Meadows list discussed in Section 6.3, where 12 is the least effective and 1 the most effective.

When considering the effectiveness of such responses, it is important to remember that the operations of at least three systems are at issue — the transport decision-making system, the urban transport system and the global climate system. In some cases other systems are involved, like the energy supply system, so that all need to be considered when gauging the effectiveness of the response.

The first two responses — the introduction of more fuel-efficient vehicles and the development of carbon sinks — largely constitute changes to the *parameters* of the transport system, and sit at position 12 — the least effective — in Meadows' list of leverage points. These responses do not encompass substantial changes to the core operations of the transport system. The development of carbon sinks uses a third system to absorb the carbon emitted from the urban transport system, such as a forestry program that would plant trees to absorb carbon from the atmosphere. To work, such a response would be reliant on an elaborate regulation and measurement system to ensure carbon is absorbed at rates that are equivalent to transport emissions. In terms of the transport system, both responses would mean increases to the generalised cost of transport by increasing the price of fuel, however, neither would affect the time structure of travel, and ultimate accessibility levels, as described in Chapter Six.

The effectiveness of such measures is doubtful, however. Greater vehicle efficiency can take decades to make appreciable differences, due to the time it takes to turn over the vehicle fleet of a city. If average journey distances and per capita trips rates increase because of urban motorway expansion and induced traffic growth, then such measures would be counteracted. The effectiveness of carbon sinks has been questioned on several grounds, the primary concern being the accuracy of the monitoring process (Throsby 2007).

The third and fourth responses — powering vehicles from renewable energy sources and development of infrastructures that facilitate low GHG emission modes like walking, cycling and mass transit — correspond to points ten and eight in Meadows' list of leverage points. Point ten refers to the *material structure of the system*, while point eight refers to the *strength of negative feedback loops* relative to the strength of the impacts they are trying to correct. As with the previous points, changes to other systems are required — in this case the energy supply systems that power the transport system. Unlike the development of carbon sinks, greater control and certainty can be exerted over these systems. Importantly, however, the structure of the infrastructures of the transport system itself are also crucial, as these determine the degree to which alternate energy sources can be used. For example, fixed-track rail systems and trolley bus networks can be powered by electricity from renewable sources. While private cars can also be powered by electricity generated from renewable sources, the viability of doing so is limited because of dramatic reductions in the spatial reach of electric-powered vehicles and the sharp increase in energy costs per VKT.

The development of alternate transport modes is critical, however, their effectiveness is highly dependent on the availability of private car travel.

The fifth and sixth responses — stopping further increases and reducing road capacity of the urban transport system — uses the power of leverage points seven and four in Meadows' list. Point seven refers to reducing the gain around positive feedback loops and point four refers to the power to self-organise. As stated in Section 1.1.3, the transport sector has the fastest growing GHG emission rates. Halting the increase in urban road capacity would help to arrest this growth. Reducing the capacity of urban roads can also be used as a means of leveraging the systems inherent ability to change, add, evolve and self-organise. This makes responses five and six potentially the most effective leverage points for reducing GHG emissions in Table 7.2.

By removing a transport element, so that the prevailing travel-time contours of the urban transport system are changed, short-term changes to travel behaviour, and long-term changes to patterns of land-use development, would be possible, owing to the way the system self-organises its behaviour and structure around its control features.

To implement changes like the removal of road space requires change to the paradigm, or mindset, used to steer the decisions arising out of the transport decision-making system. As Meadows points out, 'people who have managed to intervene in systems at the level of paradigm have hit a leverage point that totally transforms systems' (Meadows 1999, p. 18). However, it is also the point of change that is met with the greatest resistance (Meadows 1999, p. 19).

7.2.3 Induced traffic growth and its implications for climate change and the sustainability of cities

In simple terms, induced traffic growth, brought about by urban motorway development, generates an increase in VKT levels that in turn increases the GHG emissions responsible for global climate change. Global climate change impacts on the various systems that cities rely on to feed and supply city systems with the resources they need to function. However, urban motorway development and induced traffic growth also present a legacy of problems that need to be overcome by those urban governance systems that decide to take active measures to reduce GHG emissions from their transport sectors.

As discussed in Section 1.3, and again in Chapter Six, urban motorway development produces a particular pattern of travel time contours that control urban travel behaviour and patterns of land-use development to suit the logistical properties of private car travel. If an urban community decides to reorganise its transport infrastructures in an attempt to reduce its GHG emissions, it effectively has to operate within the accessibility boundaries that apply to a set of travel-time contours generated by low GHG emission transport technologies. Such a transition will be easier for multi-modal cities. But for mono-modal cities, especially those with transport systems orientated around road and motorway networks and private car use, the transition is likely to be slow and costly, so much so that the degree to which such systems can be sustained during such a transition process may be questionable.

Combined, the advent of peak oil and climate change present near-term problems for cities and the degree to which they will be able to sustain access for resident populations, businesses and industry. The final question that needs to be asked is: which of the options has the least impact on the essential economic functions of urban systems and how might these functions be sustained in the long-term future?

7.3 The city as an economic engine

This section discusses how different urban system types are likely to respond to the problems of oil depletion and climate change. It discusses the degree to which their material structures — shaped largely by the geometry and logistical features of their transport networks — will be able to sustain access to the goods and services essential to the economic well-being of a city's resident population and business community.

This is done by drawing together many of the concepts about urban systems that have been discussed in previous chapters. Section 7.3.1 discusses how changing the unit of macroeconomic organisation from nations to cities potentially shifts the notion of economic structure away from social and political relationships to spatial and material structural relationships. It is argued that this approach to macroeconomic appraisal enables a greater appreciation of the role that transport infrastructures play in determining economic conditions from a whole system perspective.

Section 7.3.2 examines how such a conception of the macroeconomic unit is able to refocus the role of transport infrastructures and competitiveness when considered from the perspective of cities competing and trading with cities rather than nations competing and trading with nations. In particular, this section focuses on the issue of differences in requisite resource consumption to serve basic needs, such as access.

Section 7.3.3 briefly revisits the effects that urban motorway development and induced traffic growth, have on the structure of cities and how they might affect economic performance in light of the concepts introduced in Sections 7.3.1 and 7.3.2.

7.3.1 Cities as units of economic organisation

Most scientific theories organise their subject matter around a unit of organisation. In chemistry, the basic unit of organisation used to make sense of the world is the atom. In biology, the critical unit is the cell. In evolutionary biology, it is the organism and in macroeconomics, it is the nation state.

Units of organisation are fundamentally significant in systems theory because the boundary characteristics that distinguish the unit or system from its environment must be consistent with those used to derive the system components. In other words, if the chosen unit of organisation is a soft system — as described in Section 2.1.1 — then the various system components that work to form its structure must also have a soft-system ontology. If they do not, logical consistency is not maintained and Hume's guillotine is transgressed.

Questioning a theory at the level of its organising unit is rarely undertaken. This is because such a change tends to generate fundamentally new theories. Undaunted by such prospects, however, arguments have been put forward by theorists like Jane Jacobs (1984), that the city is a more appropriate unit of organisation for the analysis of economic activity at the macro level. As she explains:

> Nations are political and military entities, and so are blocs of nations. But it does not necessarily follow from this that they are also the basic, salient entities of economic life or that they are particularly useful for probing the mysteries of economic structure, the reasons for the rise and decline of wealth … It affronts common sense, if nothing else, to think of units as disparate as, say, Singapore and the United States, or Ecuador and the Soviet Union, or the Netherlands and Canada, as economic common denominators. All they really have in common is the political fact of sovereignty (Jacobs 1984, pp. 31–32).

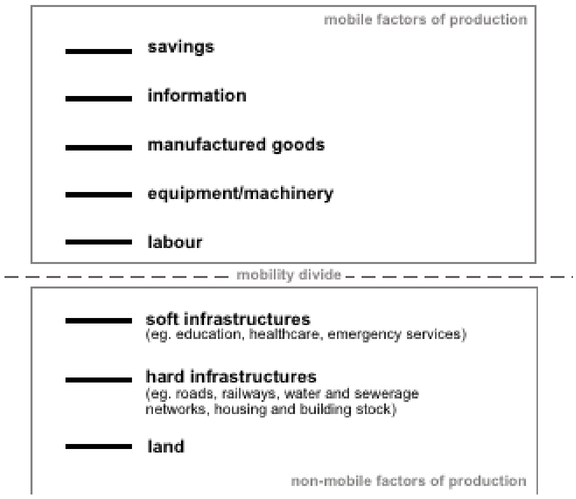
When considered as a system, the generic property that relates the various components that form a city is *relative proximity*, or spatial association. Its significance to economic activity was discussed at the start of Chapter One. Relative proximity is a material characteristic, which places cities and their sub-systems in a different category from that of nation states. Nations are largely defined by different forms of ownership, and ownership is a social construct rather than a material property.

Jacobs' questioning of the nation state as the preferred unit of organisation in macroeconomic analysis was motivated by her attempts to find a more robust explanation for economic development (Jacobs 1984, p. 44). Explanations using orthodox theory, in her view, are too abstract and often lead to arbitrary decisions about the location of industries that can lead to their eventual demise. This thesis is not the place to enter into a detailed description of Jacobs' work in that area, except to say that her ideas — made possible by her city-based view of macroeconomic activity — spawned a new generation of analysis of industrial development and ideas about the nature of economic growth (for example, Lucas 1988). This thesis maintains that a similar shift in analysis and system definition also has the potential to provide a new way of looking at the role of infrastructures and how they might affect the economic sustainability of cities.

Within the terms of the orthodox approach to macroeconomic analysis, the conception of economic structure is articulated by the *circular flow of income and expenditure* (McDonald 1992, p. 42). In schematic terms, a macroeconomy is seen to comprise two primary sub-components — firms and households. Firms supply households with goods and services, while households supply firms with the labour required to operate their industrial production processes. Money flows in the opposite direction from the material flow of goods, services and labour. Importantly, the distinction between firms and households gives rise to notions of aggregate supply and demand. The circular flow of income and expenditure includes other system components, like government, which regulates these exchanges through the imposition of taxes. Inputs and outputs in the form of trade in goods and services with other macroeconomic systems, is also included.

If a different unit of organisation is used to develop a conception of a macroeconomic system — like a city — then the identification of sub-components needs to be derived using the same system boundary characteristics that distinguish the whole system from its environment. In the case of cities, the key characteristic is relative proximity, which alters in accordance with varying degrees of mobility. Figure 7.5 lists the typical factors of production according to their levels of mobility.

Figure 7.5 Prud'homme's ladder of mobility



Adapated from: Prud'homme, R. 1994, 'On the economic role of cities' in *Cities and the new global economy. An international conference presented by the OECD and the Australian Government*. 20-23 November, Melbourne, p. 731.

As can be seen, the factors listed below the line marked *mobility divide* are all immobile. These factors are physical fixtures — infrastructures. Because of their mobility characteristics, they cannot be traded in the same way that goods and services can be exported and sold to consumers for consumption in another city. Because they cannot cross the boundary of the city system to become a potential export — or income-generating commodity — from a whole system perspective, these factors act as inputs to general production. The factors listed above the mobility divide, generally tend to form part of industrial processes that produce goods and services that can be consumed within their city of origin or traded for consumption in another city for income. These last factors largely comprise the work of industrial output sector activities that produce mobile goods and services.

The significance of the distinction between *industrial output sector activities* and *infrastructure input activities* becomes apparent when the concept is applied to the dynamic processes of domestic and international trade.

7.3.2 Cities engaged in trade and competition

The Jacobs view of the world invites us to think about the global economy as a vast network of cities, their hinterlands and supply regions, all trading goods and services and competing with each other. Such a view is different from orthodox views in that it highlights physical structures and spatial differences between economic units rather than jurisdictional or legislative differences. In the past, these physical aspects of an economy have been given little attention in macroeconomic analyses. How the pattern of land-use development in one city might affect its performance when engaged in trade and competition with another city, which has a significantly different structure, is not usually considered when governments determine transport policy. Consequently, the implications these features of cities may have for sustainability, which includes the ability to maintain city specific functions as well as maintain environmental integrity, are rarely considered.

In the same way that plant equipment comprises the machinery of production in a factory, the infrastructure networks of cities act as the machinery that supports the productive output of the industries and businesses located within them. Where the viability of a factory with highly inefficient machinery might be expected to decline in the face of competition from a factory that uses less materials and energy inputs to perform the same work, a city can become less viable as a location for businesses and industries due to the overexpansion, or high cost nature, of its infrastructures. For example, in recent decades, many manufacturing industries have shifted their operations from the sprawling cities of developed economies which have relatively high infrastructure costs per capita, to the high-density cities of developing economies where infrastructure costs per capita are lower. In these cases, differences in infrastructure costs are not viewed as responsible for the apparent shifts, but labour costs. However, labour costs are necessarily higher in economies where soft and hard infrastructure costs are also high. Little scope exists to reduce labour costs significantly in these cities, as individuals would not be able to sustain the basic functions that make up their daily routine. These issues were discussed in the introduction to Section 1.1.

This thesis has focussed on the relationship between urban motorway development and access for commuter traffic, not the contribution that motorway networks might make to industrial production through the facilitation of freight movement. It is possible that the cost of urban motorway development and the associated pattern of land-use development that it gives rise to, is sufficiently offset by increases in industrial output. However, if such increases do not occur, then to sustain increases in infrastructure consumption, where the ratio of output levels has dropped, a city must either subsidise its operations with income generated by its hinterlands, or with income generated by other cities that fall within the jurisdictional, or national, boundaries to which it belongs. In such cases, the city is not sustaining itself on the basis of its own productive capacity.

Identifying which policy decisions lead to per capita increases in the cost of infrastructure provision without off-setting such costs with increases in productive output, is critical to understanding how city-building might be managed in a sustainable way.

7.3.3 Changes to urban structure and access caused by motorway development

As discussed in Chapter Six, adding urban motorway capacity changes the shape of the travel time contours of the prevailing transport system. By changing travel time contours, changes to patterns of land-use development also occurs, creating changes in the material fabric of the urban system.

In the case of existing urbanised areas, change is slow, occurring over many years. Land-uses may change in the short-term, with changes to building form occurring over the longer-term. The degree and calibre of changes that occur to building form is dependent on the mix of transport modes servicing the system, as these determine the shape of travel time contours and the consequent feasibility of different building typologies.

In the case of new release areas — especially those on the fringes of urban areas where transport provision is usually dominated by private motor-vehicle access — patterns of land-use development are likely to conform to the typologies discussed in Section 1.2.1 and illustrated in Figure 1.12 and Figure 1.13.

Adaptation in these fringe districts is difficult and costly. This is because the prevailing spatial pattern of land-use development is difficult to serve efficiently by mass transit. This makes retrofitting districts with public transport services difficult, should changes occur to inputs like the price of fuel. If conditions were to change dramatically because of a petrol price spike brought about by a sudden and extended conflict in the Middle-East for example, maintaining accessibility could be jeopardised. Similarly, if increases in the price of transport occur because of measures introduced to reduce GHG emissions, access may be compromised because few low cost alternatives exist.

7.4 Political decision-making systems and sustainability

The most critical aspect of a decision-making system is the ability of its structure and conventions to match its stated goal. For if this cannot be achieved the system is open to instability and, ultimately, failure.

Many of the debates surrounding sustainability conclude that changes need to be made to material systems — or hard systems — as defined in this thesis. The focus on hard system issues often overlooks the significance of soft systems, or decision-making systems, and why it is that changes are often also required in this sphere of activity.

Researchers working in other areas of sustainable infrastructure provision, like water and sewerage services, have drawn much the same conclusion (for example, Guy, Marvin & Moss 2001). In their experience, realising sustainability outcomes requires an understanding of the political and social circumstances in which services are to be provided, so that new technologies and ideas about material changes are compatible with the associated soft system conditions. If these conditions are overlooked, outcomes are likely to fall short of expectations.

The material presented in Chapter Two has sought to demonstrate that structural differences in decision-making systems can bring about significant differences in the way that transport issues, like induced traffic growth, are approached and evaluated. It has also sought to demonstrate the degree to which power distribution within communities can affect outcomes.

While it is not within the scope of this thesis to make specific recommendations as to what should be done in relation to transport decision-making systems, it is appropriate to state that unless the system is able to sincerely embrace sustainability as a goal, then decisions are unlikely to realise sustainable outcomes. In general, there are several features that must be present in a decision-making system if it is to adapt to changing conditions in a way that supports sustainability. These include:

- The ability to anticipate and respond to potentially adverse conditions
- The capacity to learn from past mistakes and reform inappropriate practices
- Accessibility to information necessary to monitor the performance of the system
- The capacity to relay this information to the community that relies on the system in question.

Where outcomes like induced traffic growth are not discussed, or remain unexamined, because their implications may not be in the best interests of special interest groups within society, the long-term sustainability of urban transport systems is jeopardised. How such issues might addressed in practice is beyond the scope of this thesis, however, it is clear that it is a critical aspect of the subject.

All of us, if we are reasonably comfortable, healthy and safe, owe immense debts to the past. There is no way, of course, to repay the past. We can only pay those debts by making gifts to the future.

Jane Jacobs
Quebec and the question of separatism
1981

8 Conclusions

This thesis has sought to investigate the implications that urban motorway development has for the sustainability of cities by focusing on the phenomenon of induced traffic growth. The research has been carried out within a systems framework, which has enabled a wide raft of questions and issues — usually analysed within the confines of different disciplines — to be addressed in a unified way, thereby generating a form of transdisciplinary research.

The thesis has demonstrated that a transdisciplinary approach is important when analysing sustainability problems because it is able to identify issues that arise in practice when natural and human-made systems interact with each other, but which are often overlooked in analyses when the two are studied as separate entities. The analysis of the transport decision-making system — carried out in Chapter Two — was able to identify that the decision to proceed or not to proceed with an urban motorway development is determined largely by the way that power is distributed between different groups within society and their ascendancy over the process. This can affect the analysis of outcomes arising from urban motorway development, including the induced traffic growth, as well as whether or not the potential problems that arise from the development are taken into consideration when making decisions about future development. Where alternative transport proposals are advocated in an attempt to overcome the negative impacts that may arise from urban motorway development, an appropriate decision-making process is critical to achieving sustainable outcomes. This aspect of induced traffic growth research, and the influence that it can have on research findings, is not ordinarily assessed as part of a sustainable development issue.

Within this context, the thesis reviewed the international literature of induced traffic growth case studies with a particular focus on methodological difficulties — the unresolved nature of which has worked to maintain the contested nature of the phenomenon. This was presented in Chapter Three. Problems with boundary conditions were identified as an obvious way of refuting the induced traffic growth hypothesis. These were discussed in Section 3.1. A case study of Sydney's M4 Motorway, which was presented in Chapter Five, was able to overcome the problem with boundary conditions by assessing changes to traffic volumes across an extensive screenline and therefore, ruling out increases that could be attributed to traffic reassignment rather than the various responses that are classified as induced traffic growth. This case study not only extends the small number of induced traffic growth studies undertaken for motorways built in Australia, but has also contributed to the robustness of such analyses because of its attention to boundary conditions while confirming the induced traffic growth hypothesis.

The case study also examined changes to passenger journeys on parallel rail services, in an attempt to identify traffic volume increases that could be attributed to mode-shifting. The result from this analysis was inconclusive, due to a positive result which was achieved when using the same method to analyse changes in passenger volumes on another Sydney rail line that was unaffected by motorway development. This result also cast doubt on a similar analysis undertaken by Mewton (1997, 2005) of the Sydney Harbour Tunnel. However, it points to further analysis which could be undertaken, where other factors need to be included in the method of regression modelling that was used to isolate any signal in the data that may be present due to mode shifting. These results have been discussed with Mewton and Petocz, with the prospect of further research in the near future.

A review of the theoretical explanations for induced traffic growth highlighted possible shortcomings with current theories, given that these are primarily a product of transport evaluation methods. A systems explanation for the phenomenon was presented in Chapter Six, in order to articulate the causal mechanism responsible for the phenomenon. This explanation defined induced traffic growth as a form of positive system feedback that takes place between the urban transport system and the transport decision-making system. Within the transport system itself, multiple forms of negative system feedback are triggered in order to return the system to a phase state that is controlled by a series of conditions that give rise to an empirical phenomenon known as travel time budget constancy. By representing this feature of the system using spatial data, the effects on patterns of land-use development can be shown. The positive feedback loop was shown to be completed when information about the state of the transport system is fed back into the transport decision-making system and interpreted in a way that misinterprets the negative feedback responses.

The original contribution made by this systems-based explanation of induced traffic growth is that it is able to define the phenomenon in spatial terms, which enables a form of access assessment that is difficult to do if using purely arithmetic based assessment methods. There is potential for further research to be undertaken that incorporates the affects of changes to other factors — like fuel prices — in a spatial data format.

The thesis concluded with a discussion of the sustainability implications of urban motorway development — presented in Chapter Seven. Critical changes to the supply of transport fuel and energy inputs, and impacts from emissions outputs, were examined in light of the problems of oil depletion and global climate change. It was concluded that urban motorway development can have negative implications for the sustainability of cities on two grounds. The first occurs when the development of urban areas is orientated around road and motorway based transport infrastructures and the consequent pattern of land-use development is difficult to service with other forms of transport such as walking, cycling and mass transit. Adaptation in the face of changes to fuel supplies can be difficult and therefore jeopardises the ability of the system to provide access to job markets and other essential services. Adaptation of the system in response to increased transport costs caused by policies aimed at reducing GHG emissions could also retard access. The second form of negative impact can occur when the input costs of infrastructure generally increase beyond a city's ability to pay for those costs. This can occur for a variety of reasons, including competition from other cities with lower infrastructure costs because they have developed their structures around other modes of transport, which provide greater opportunities for adaptation and so have lower infrastructure costs than those cities with road and motorway based structures.

Appendix A

Notes on the use of personal communications.

Personal communications are used as references in many parts of this thesis. These have been used to gain additional information and insights on some topics where there was little available through other sources.

A variety of individuals were also contacted in relation to events that took place aver motorway decisions made during the 1970s and 1980s in London, Sydney and Zürich.

In all cases, the individual was contacted and asked if they would be willing to discuss the relevant topic. It was made clear that this was for the purposes of informing a research project. Notes from the discussion were made and a copy sent to the individual for them to check. Where necessary corrections were incorporated into the final copy of the notes. In critical cases — where more than a reference to data or a single event was at issue — the relevant text was sent to the individual so that they could gain a full understanding of the context in which they were being cited.

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