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# BEFORE AND AFTER THE MOTORWAY

## A REVIEW OF METHODOLOGIES USED TO INVESTIGATE THE OCCURRENCE OF INDUCED TRAFFIC GROWTH IN INTERNATIONAL AND AUSTRALIAN CITIES

Institute for Sustainable Futures

UNIVERSITY OF TECHNOLOGY SYDNEY

# BEFORE AND AFTER THE MOTORWAY

# PART I

## A review of methodologies used to investigate the occurrence of induced traffic growth in international and Australian cities

Final Draft

For Department of Environment and Climate Change, RailCorp and the Department of Planning


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# Disclaimer



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This report reviews several early studies of induced traffic growth that were undertaken by staff working for the Greater London Council during the late 1970s and early 1980s. One of the authors of this early work — John Elliott — provided invaluable insights into that pioneer analysis and the debate that occurred in relation to its implications. His insights have enriched this report and his contribution is acknowledged and greatly appreciated.

# Executive Summary

This report is the first in a three-part series that investigates the occurrence of induced traffic growth in Sydney. The purpose of this first report is to review past empirical analyses — undertaken both internationally and here in Australia — of conditions before and after the opening of new urban motorway sections with a particular focus on the benefits and limitations of different testing methods. The results from this review have been used to inform analyses of changes to traffic volumes that occurred after the opening of sections of the M4 and M5 Motorways in Sydney, which are the subject of analyses presented in parts two and three of this series.

To begin, this report describes the variety of travel behaviour responses triggered by service level changes that can occur after the opening of a new urban motorway section. Some of these responses are classified as induced traffic growth while others are not. The responses classified as induced traffic growth include: *mode-shifting* — passengers changing from modes like rail and bus services, to car travel, because road speeds have become faster; *traffic redistribution* — drivers who choose to undertake longer trips than they had previously, because travel times to preferred but more distant destinations are less; *induced trips* — drivers who choose to undertake more trips than they had previously. These responses contribute to higher levels of Vehicle Kilometres Travelled (VKT) per capita by comparison with levels prior to the change in road travel speeds. Such responses are viewed as potentially negative as they can lead to higher levels of air pollution, fuel-use and travel delays which run counter to the reasons often used to justify construction of new urban motorways and additional road capacity.

Significantly, other travel behaviour responses like *traffic reassignment* — motorists shifting from an old route to a new route, because the new route is quicker — can also occur after the addition of new capacity. This response more often than not results in a decline in VKT per capita and can lead to reductions in air pollution, fuel-use and travel delays, which is in keeping with the reasons used to justify new roads and additional capacity.

Distinguishing the variety of different travel behaviour responses from one another is of central significance to the veracity of methodologies used to test for induced traffic growth. The testing methods canvassed in this review largely focus on how well this distinction can be achieved given conditions relating to the Sydney road and public transport network.

The first, and most common, method used to test for induced traffic growth uses comparative before and after *screenline* counts that cover an array of alternate routes that broadly connect the same origin and destination sets. The strength of this method is that the distinction between traffic reassignment and induced traffic growth can be inferred from volume increases and declines across the screenline. The method's weakness lies in that results from incomplete screenline counts can provide misleading results as not all sources of potential traffic reassignment are included. Further problems arise in that the potential sources of overall traffic increases — mode-shifting, traffic redistribution and induced trips — cannot be distinguished from one another. This method is used in analyses of Sydney's M4 and M5 motorways presented in Parts II and III as counts for complete screenlines are available.

The second method uses travel surveys of individual motorists and commuters. Problems with sample bias and size are identified in addition to the prohibitive cost of such studies. While this method is able to distinguish different travel behaviour responses, on its own, it

is a poor gauge of changes in total volumes. This method has not been used in relation to the M4 and M5 case studies presented in Parts II and III, however it could be used in standard post-implementation analyses of urban motorways undertaken by the NSW RTA.

The third method examined uses time series regression analysis of area-wide traffic volume data. The advantage of this method is that it can circumvent problems associated with data gaps encountered in comparative screenline counts. Its weakness is that it is difficult to run *controls* using this method — comparative parallel analyses of the road network where no capacity increases have taken place and a standard procedure in scientific analyses used to test the veracity of a testing method. A form of time-series regression is used in Part III of this series to examine potential mode-shifting from the rail to the road network after opening of the M4 and M5 motorways.

Finally, two Australian case studies are examined. These constitute the full extent of empirical analyses that specifically focus on the issue of induced traffic growth under Australian conditions. Of the two cases investigated, the first — which investigates the conditions before and after opening of the South-East Arterial in Melbourne — concludes that no evidence of induced traffic growth could be found. The case study is shown to have used a flawed method of screenline counts canvassed earlier in this review. The second — which investigates conditions before and after opening of the Sydney Harbour Tunnel — claims to show evidence consistent with the existence of induced traffic growth. This case study is shown to have used incomplete screenlines for the collation of road data so that its case for induced traffic growth is diminished. However, the analysis of rail and other public transport data on parallel rail, bus and ferry services, highlights the possibility of mode-shifting from the public transport network which is consistent with the presence of induced traffic growth.

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# Abbreviations

| | |
|---|---|
| AADT | Annual Average Daily Traffic |
| ARR | Amsterdam Ring Road |
| CBD | Central Business District |
| DECC | Department of Environment and Climate Change |
| DoP | Department of Planning |
| GDP | Gross Domestic Product |
| GHF | Gore Hill Freeway |
| GLA | Greater London Area |
| GLC | Greater London Council |
| GLDP | Greater London Development Plan |
| HMSO | Her Majesty's Service Office |
| ISTP | Institute for Sustainability and Technology Policy |
| LA | Los Angeles |
| LOS | Level of Service |
| RTA | Roads & Traffic Authority (of New South Wales) |
| RWRR | Rochester Way Relief Road |
| SACTRA | Standing Advisory Committee on Trunk Route Assessment |
| SEA | South Eastern Arterial |
| SHB | Sydney Harbour Bridge |
| SHLM | State Highway Lane Miles |
| SHT | Sydney Harbour Tunnel |
| TPDC | Transport and Population Data Centre |
| UK | United Kingdom |
| VKT | Vehicle Kilometres Travelled |
| VMT | Vehicle Miles Travelled |

# Before and after the motorway: a review of methodologies used to investigate induced traffic growth

This report is the first in a three part series that investigates the occurrence of induced traffic growth in Sydney. The purpose of this first report is to review past empirical analyses — undertaken both internationally and here in Australia — of conditions before and after the opening of new urban motorway sections with a particular focus on the benefits and limitations of different testing methods. Ultimately, the results from this review have been used to inform analyses of changes to traffic volumes that occurred after the opening of sections of the M4 and M5 Motorways in Sydney, which are the subject of analyses presented in parts two and three of this series.

Of the case studies reviewed, four broadly different transport data types were used, including:

- Traffic survey, or road traffic volume counts
- Travel survey, or data from individual questionaries and telephone interviews
- Area-wide VKT per capita estimates, or the total Vehicle Kilometers Travelled across a road network
- Public transport journey data estimated from ticket sales

Several different analysis methods have been used to interrogate these different data types, including:

- Comparisons of before and after road traffic volume counts across screenlines
- Comparisons of before and after travel surveys for sample populations and targeted user groups
- Time-series regression analysis, using area-wide VKT data and public transport passenger journeys, to identify statistically significant changes in travel behaviour

Understanding the benefits and limitations of each of these methods is dependent on the nature of induced traffic growth as a phenomenon and the particular aspects of it that need to be isolated so they can be investigated. Consequently, a working definition of what induced traffic growth is, its significance and the debates that have taken place over its existence, is an essential starting point for any methodology appraisal.

To this end, Section 1 discusses the array of different travel behaviour responses that can occur after the opening of additional urban motorway capacity. As will be shown, a significant aspect of analysis methods used to investigate induced traffic growth is the degree to which they are able to distinguish these responses from one another, and in particular, how well they are able to distinguish responses classified as induced traffic growth from those that are not.

All empirical analyses are guided by theory. Section 2 briefly reviews the explanation for induced traffic growth provided by microeconomic theory as presented by the Standing Advisory Committee on Trunk Route Assessment, or SACTRA[1]. This is followed by a brief review of several *commonsense arguments* considered by SACTRA. These arguments and explanations are important because they provide essential guidance when interpreting results and assessing methodology.

Section 3 reviews the standard norms of empirical science and how these apply to isolating different travel behaviour responses in light of the definitional issues raised in Section 1. Included in this section is an overview of the general data types that have been used in induced traffic growth case studies and the importance of *boundary conditions* when selecting case study parameters and collating data sets.

The remaining four sections examine specific case studies that use different methodologies to identify evidence of induced traffic growth.

In their investigation, SACTRA relied on several analyses of road traffic counts along *screenlines*. Section 4 examines a series of case studies that use this analysis method.

Section 5 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. Results from two examples are reviewed and compared.

Section 6 reviews several analyses — primarily undertaken in the United States — of changes to road capacity and VKT per capita levels on a region-wide basis. These analyses construct models that attempt to account for the degree to which changes in one variable — such as road capacity — might be responsible for changes in others — like VKT — using time series regression analysis.

Section 7 examines before and after case studies undertaken in Australia that specifically target induced traffic growth. While many studies of urban motorway development have been undertaken in Australia, surprisingly few focus on the specific issue of induced traffic growth. As will be shown in Part II of this series, there have been studies commissioned by road building and planning agencies in Australia that present road traffic counts as a way of monitoring network conditions before and after the opening of a new urban motorway, however most of these do not analyse the data so as to identify unusually large traffic volume increases even though the data show these on close inspection. Of the two case studies that are the exception to this rule, one claimed to confirm the induced traffic growth hypothesis (Mewton 1997, 2005) while the other is ambivalent at best, claiming no empirical evidence of it (Luk & Chung 1997). Both of these case studies encounter methodological problems discussed in previous sections. Each case is reviewed in some detail given that they form the bulk of such work undertaken in Australia.

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[1] SACTRA is a group of independent academic and practitioner transport experts regularly commissioned by the UK Government to investigate transport problems. In the early 1990s, SACTRA was commissioned to investigate the issue of induced traffic growth. The committee's findings were published in 1994 (SACTRA 1994).

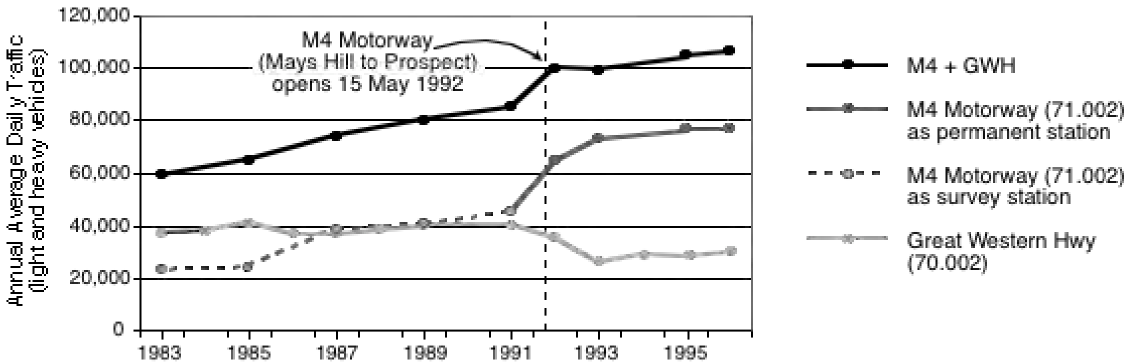
# 1 Definition of induced traffic growth

Up until the late 1990s, many transport professionals working within industry and government disputed the existence of induced traffic growth (for a more detailed explanation, see SACTRA 1994, p. 55). Opposition to the concept has receded however since publication of the *SACTRA Report,* which examined the extent of its occurrence and impacts on road network performance (SACTRA 1994). To begin, some discussion of these disputes is necessary because they affect the definition of the phenomenon in such a way 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 experienced after increases in road capacity in urban areas. In such cases, traffic volumes and apparent congestion levels become greater on some sections of the road network. Individuals using those sections may experience an increase in travel times rather than reductions, which contradict the primary reason given for increasing capacity.

For professionals with access to road traffic volume data for multiple-routes across a whole network, the perception is often different. Increases on some parts may occur in conjunction with declines on others leading to reductions in travel times for some motorists but increases for others. When examined as a whole — and provided that a new link is strategically appropriate — points in the network where conditions decline should be outweighed by points where conditions improve. Or at least this has been the general expectation on the part of most professionals and certainly government agencies.

Figure 1.1 AADT volumes for Sydney's M4 Motorway and Great Western Highway



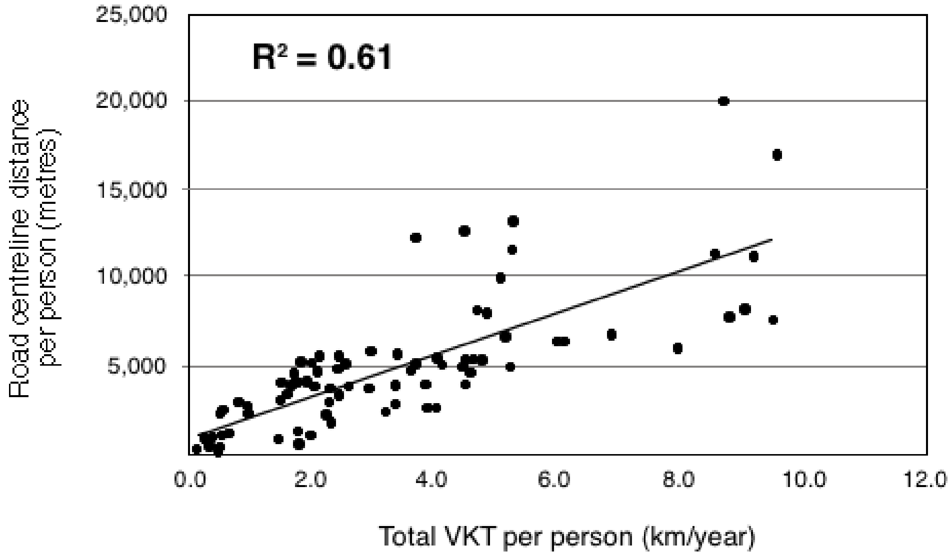

Source: RTA. 1995, *Traffic volume data for Sydney Region 1993.* Roads & Traffic Authority of New South Wales, Sydney. Armstrong, B. 2004, *Personal communication.* Roads & Traffic Authority of New South Wales, Sydney.

The time series data shown in Figure 1.1, illustrate just such an example. 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 individuals using the network can usually perceive the changes. When the increase is large in scale, the changes can become a cause for travel delays and queuing for some travellers at key points in the network that in-turn can lead to public complaint and frustration at the apparent increase in traffic (see, for example, Hutchings 1992, p. 1).

The example cited in Figure 1.1 is examined in more detail in Parts II and III of this series 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 advocate the construction of urban motorway development often cite this evidence against the existence of induced traffic growth. They claim that the observed increase in traffic volumes is not an increase at all, but merely traffic shifting to the new route from multiple routes across the network (SACTRA 1994, p. 54). But as will be shown, even when all possible routes from which traffic reassignment may have taken place are taken into consideration, the increase in traffic volumes is greater after a capacity increase than in those years when there is no capacity increase. From a research perspective, this *residual volume* is considered to be induced traffic growth as it is thought to represent traffic that would not exist unless the increase in capacity had taken place. The response from professionals and commentators who dispute the existence of induced traffic growth is to then question empirical testing methods used to identify such residual volumes (for example, Crow and Younes, 1990).

In more recent years, data have become available that compare the relative amounts of per capita travel for whole cities. These sets appear to show a systemic relationship between the amount of urban road space and the amount of travel per capita that is undertaken within a city system. In cities where road space is high, VKT per capita is high. Where per capita road space allocation is low, VKT is also low. Researchers and transport professionals who acknowledge the existence of the induced traffic growth often cite such relationships in the empirical record as further evidence of its existence. An example of this relationship is shown in Figure 1.2.

**Figure 1.2 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 and could increase the $R^2$ value.

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

The comparison of data for whole systems is to some extent able to skirt around the problem of not being able to access complete sets of data for all alternate routes to a new motorway or improved route. The problem however, is that whole system data sets are unable to identify precisely the source of the increases. For example, it is unknown whether these increases occur as a result of trip redistribution, trip generation, network reassignment or mode-shifting (Noland & Cowart 2000, p. 5).

But despite debate over interpretation of the empirical record, there has been a persistent belief that 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 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'(Hall 1980, p. 66).

In light of the debate that has taken place over the issue, 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 that have gained currency in popular debates. Alternate explanations for traffic volume increases — like traffic reassignment — are also the reason why the very existence of the phenomenon has been contested within some professional and industry circles.

The more detailed example in Figure 1.1 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 takes 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 Figure 1.1. 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* or *generated trips* (SACTRA 1994, p. 51 and 53).

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).

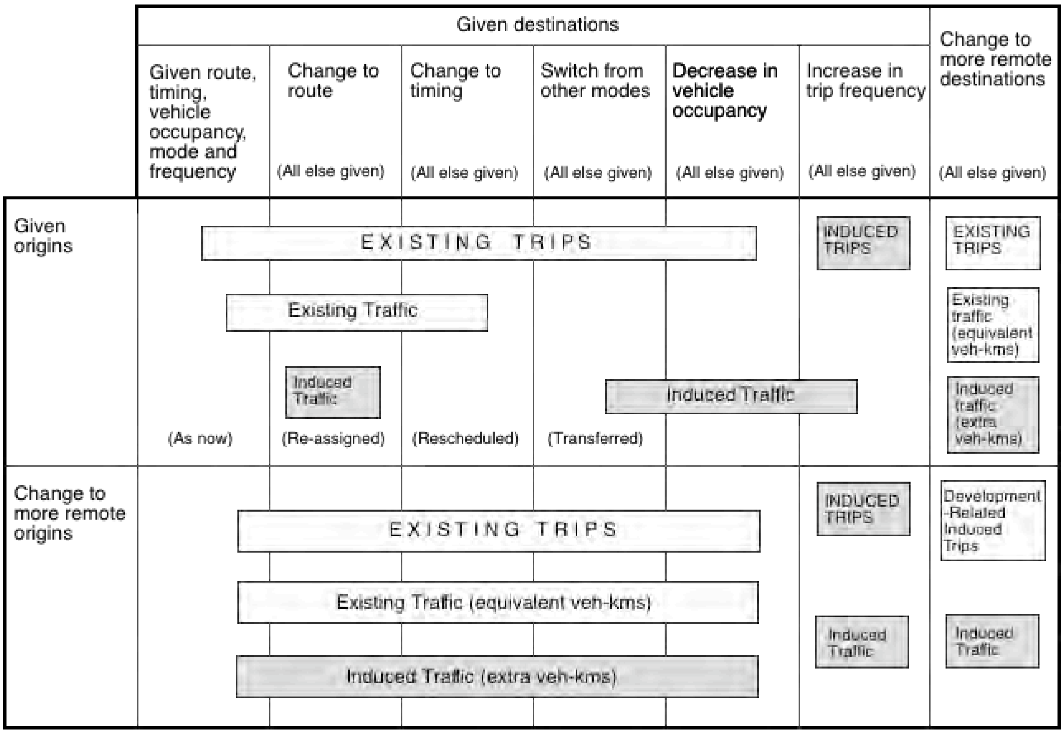
Much of the professional and scholarly argument about the definition of induced traffic growth is revealed in disputes over the merits of fixed-trip vs. variable-trip matrixes[2] in traffic models (SACTRA 1994, pp. 22–25). The key question in these disputes is whether or not changes to the transport 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

[2] 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.

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 VKT by road traffic.

**Figure 1.3 Definitions of existing and induced traffic and trips**




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

Figure 1.3 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 SACTRA identified these definitions after discussion with relevant government agencies, transport professionals and community organisations who made submissions to their inquiry (SACTRA 1994, pp. 20–21).

## *1.1 Conclusions about the definition of induced traffic growth and its implications for empirical testing*

The definition of induced traffic growth that will be used in this analysis is generally the same as that used by SACTRA. There are several reasons for using this definition in addition to the obvious one of deferring to SACTRA's authority and impartiality on the subject. First, induced traffic growth is generally considered to be a negative outcome and so its definition needs to conform to travel behaviour responses that would potentially contribute to a deterioration of road network conditions. Increases in VKT from existing levels would potentially do this. Second, the NSW Government has cited reductions in VKT as a key goal of its transport development policy (EPA 1998, p. 21), consequently responses to capacity increases that generate higher rates of VKT per capita are particularly relevant to transport policy in Sydney.

The next section examines some general arguments that attempt to explain why individuals might choose to travel more by road after the addition of road capacity which gives rise to induced traffic growth. These explanations — or theories about why induced traffic growth occurs — provide useful reference points when examining the results from empirical analyses.

# 2 SACTRA and the generation of traffic: explanation of what causes induced traffic growth

SACTRA approached the issue of empirical evidence with the view 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 — far reaching effects in the form of multiple responses over entire urban networks — and the consequent limitations encountered when collecting data to test for it (SACTRA 1994, p. 29).

In response, the committee appealed to the *logic* of what is likely to take place given an array of simple observations as well as general theories about demand behaviour. Consequently, they sought theoretical explanations to supplement their survey of empirical analyses when trying to decide whether or not the body of evidence supported the likely existence of induced traffic growth. The inquiry approached the issue of theoretical explanation from two angles. First, existing theoretical frameworks and conventions were used as a basis from which to speculate on travel behaviour changes. Micro-economic theory was used to support the committee's conclusions in this respect. Second, the committee appealed to what they called *common sense arguments* that drew on the day-to-day experience of transport practitioners.

This section briefly reviews these two forms of explanation that support the existence of induced traffic growth.

## 2.1 Explanations for induced traffic growth using micro-economic theory

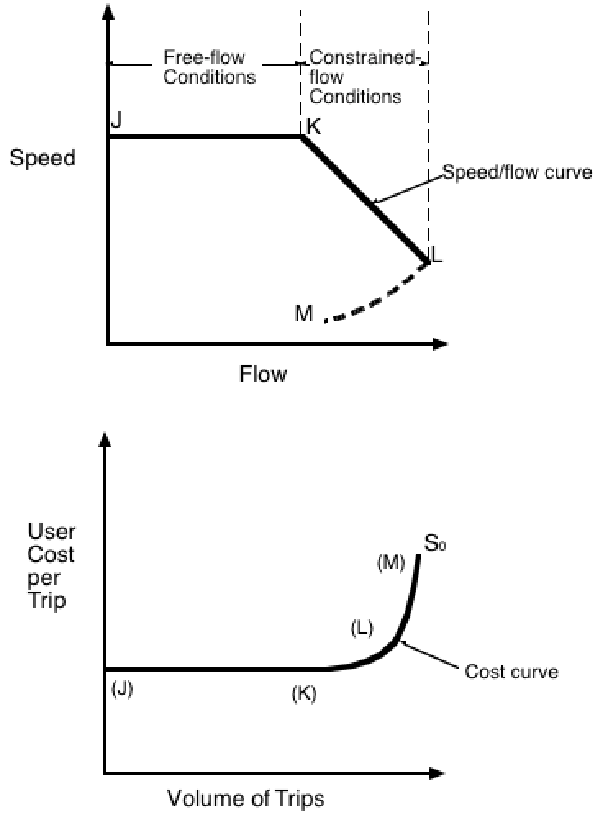
When viewed through the lens of microeconomic theory, the key question concerning induced traffic growth is whether the demand curve is flat and therefore inelastic, or whether it is sloped and therefore elastic (Goodwin & Noland 2003, p. 1452). If flat, induced traffic growth does not occur. If sloped, 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. Rejection of such a concept implies acceptance of the idea that the demand for transport is independent of supply.

The following section reviews this logic and the circumstances that give rise to this concept.

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 theoretical framework (SACTRA 1994, pp. 123–128).

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 2.1 shows the form of this relationship.

**Figure 2.1 The Speed–Flow–Cost relationship**



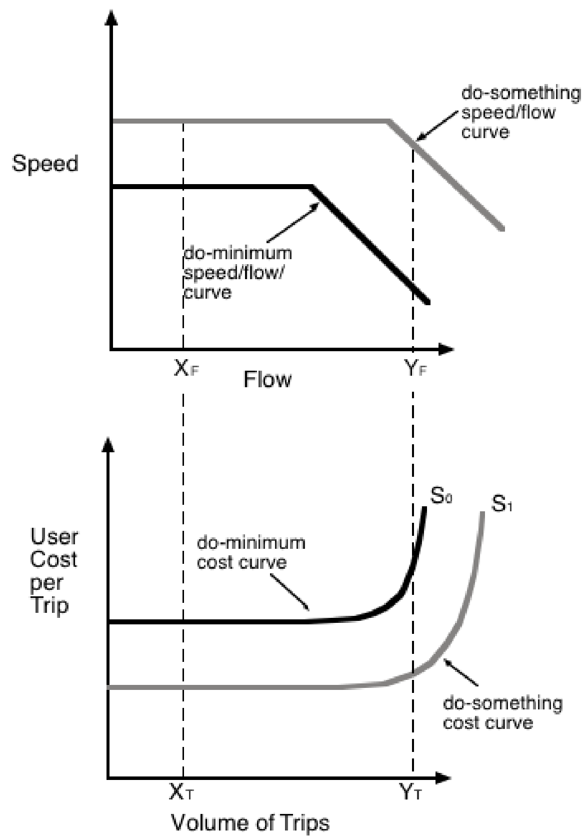

Source: SACTRA. 1994, *Trunk roads and the generation of traffic*. HMSO, London, p. 116.

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 2.1 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 2.2, 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).

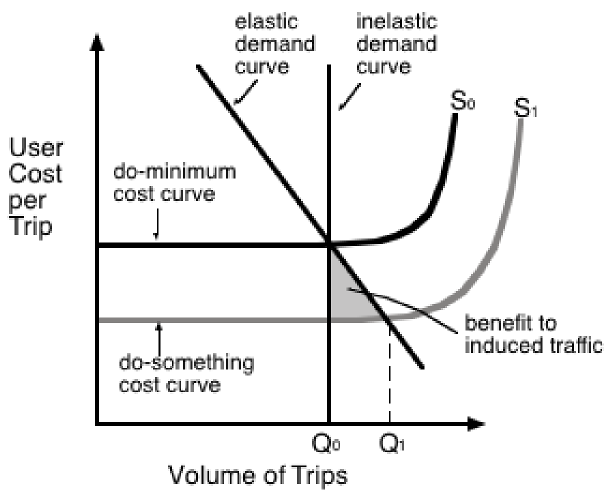
Figure 2.2 The effect of User Costs on road improvements




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 2.3. 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 2.3 Addition of road space in uncongested conditions

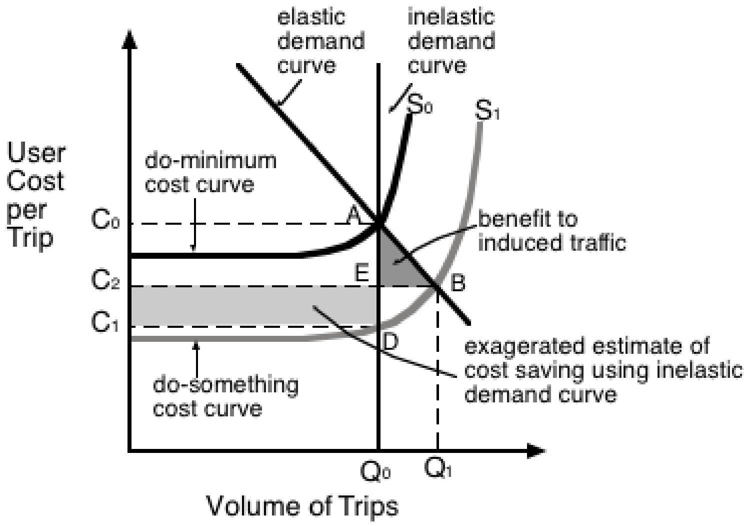



(Case X: increasing free-flow speed)

Source: Source: SACTRA. 1994, *Trunk roads and the generation of traffic*. HMSO, London, p. 118.

Figure 2.4 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 2.4 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 2.4, costs are reduced from C0 to C1. But when an elastic demand curve is used, User Costs are only reduced to C2. 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 C1 and C2 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 evaluating changes to road networks, it does not provide an entirely satisfying explanation as to why in *causal terms* individuals might choose to change their travel behaviour in such a way that they travel further or more often when travel speeds increase. The demand for transport has often been categorised as a *derived demand*, meaning that other conditions in the urban system — like the need to access particular goods, services and employment opportunities — are responsible for the amount of travel that people undertake rather than the state of the transport system. For an explanation along causal lines, SACTRA appealed to what they called *commonsense arguments*.

## 2.2 Commonsense arguments about the nature of road traffic growth

In their deliberations, SACTRA noted that it is widely accepted that demand curves for constituent parts of the generalised cost of transport — like petrol and other running costs for vehicles — are considered to be sloped. As stated previously, if induced traffic growth does occur in practice, then within the framework of micro-economic assessment, the demand curve for *travel time* should also be sloped. Consequently, questions arise as to what types of conditions and scenarios could be responsible for creating a sloped demand curve in relation to travel time and what types of behaviour should we be able to observe that would be indicative of this?

In answer to these questions SACTRA compiled several commonsense arguments, inspired by simple observations about the nature of travel behaviour changes in response to changes in travel times brought about by road capacity increases.

The first observation related to the role of congestion, which is reduced in the aftermath of road capacity additions. If no allowance is made for the suppression of trips by congestion, the committee reasoned, 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). These occurrences show that the demand for travel changes according to prevailing travel times so that the demand curve is sloped.

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 logical inference being that the amount of road space must to some degree influence the amount of driving that takes place on the network. In this way, traffic volumes are the result of an interplay between supply and demand factors and not driven by a level of demand that exists independently of supply conditions.

The third, admittedly exaggerated, argument is that if it were possible to construct a transport link capable of providing five-minute trips between London and Melbourne, for example, the amount of traffic between the two cities would increase in response (SACTRA 1994, p. 34). Such a condition suggests that demand can be created, or triggered, by a new supply where travel time is changes dramatically.

Such considerations are useful because they enable the construction of rudimentary theories about the causes and likely existence, or otherwise, of induced traffic growth. This assists in the interpretation of results from empirical testing.

## *2.3 Interpreting observations in the light of theory*

After considering the implications of these ideas, SACTRA then examined some simple cases of what were incidents wherein induced traffic growth probably 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 Figure 2.5.

**Figure 2.5 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.

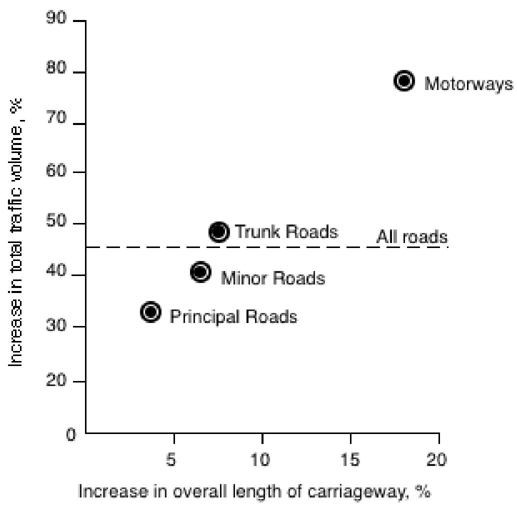
As can be seen, in the years immediately after opening, traffic volumes across the two routes increased by more than 600 per cent. When reviewing these data, SACTRA (1994) also noted comments by Leslie Burgin, then Minister for Transport in 1938:

> [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). This early example is similar to that shown in Figure 1.1.

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 2.6.

**Figure 2.6 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 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).

Section 4.1 will provide 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). But before doing so, it is useful to consider some of the methodological concerns that have enabled literature reviews like that provided by Howard Humphreys and Partners (1993) to conclude that no empirical evidence of induced traffic growth can be found.

# 3 Applying the standard norms of empirical science to testing for induced traffic growth

This section discusses the standard norms of empirical science, their significance to analysis of material phenomena and how they should be applied to traffic and transport analyses 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 logic is based on the argument that in the absence of purposeful thought that would introduce random signals to a system, similar sets of conditions should function in the same way.[3] 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 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.

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).

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.

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[3] *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 that give rise to the standard norms of empirical science, as their outcomes fall within a set of probabilistic outcomes determined by the material conditions that constrain system behaviour (Sandquist 1985, p. 2).

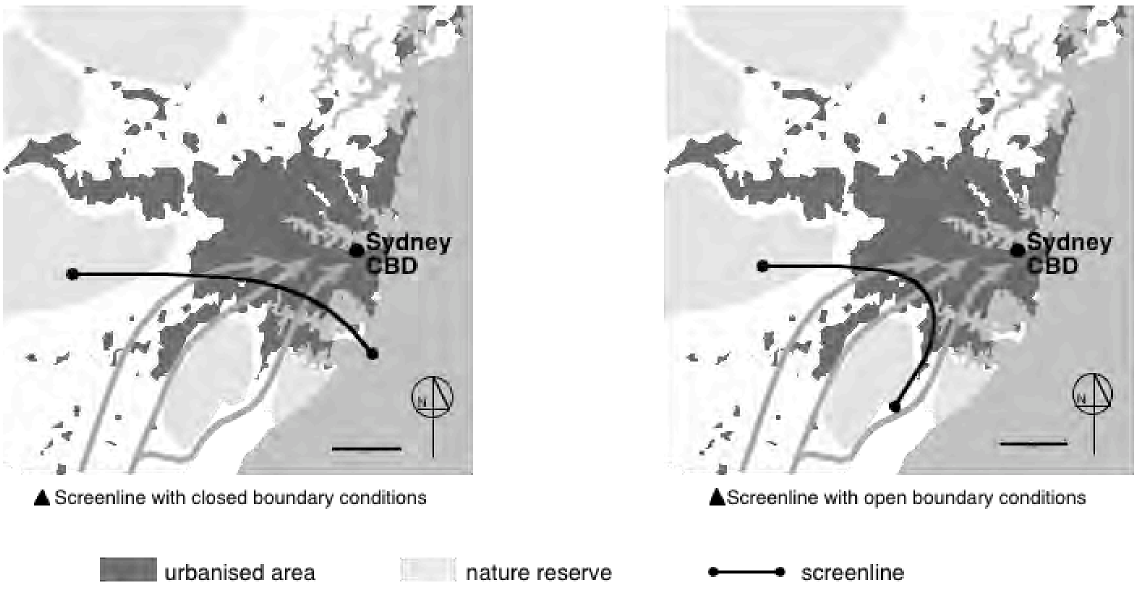
## 3.1 Boundary conditions

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).

When testing for the presence of induced traffic growth, the central aim of empirical analysis 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). In particular, *traffic reassignment* has to be distinguished from *traffic redistribution* and *induced trips*. The selection of appropriate screenlines that are able to account for all possibilities and so capable of producing what will here be called *closed boundary conditions*, is critical.

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.

**Figure 3.1 Screenlines showing open and closed boundary conditions**




Source: Zeibots, M. E. 2007, *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.* Doctoral dissertation, Institute for Sustainable Futures, University of Technology, Sydney, p. 126.

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.

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.

## 3.2 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.

The next three sections review in some detail different methods and data types that have been used to test for induced traffic growth.

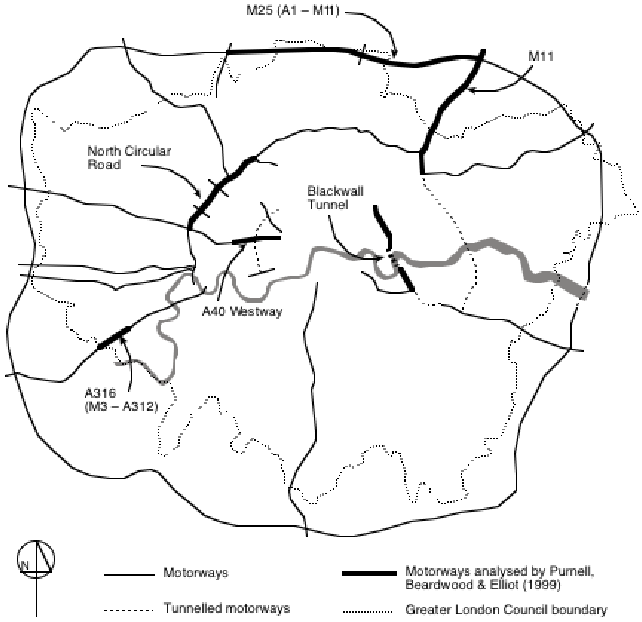
# 4 Method One: observing changes to traffic volumes across screenlines

During the early 1980s, staff working for the Greater London Council (GLC ) 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. The case studies reviewed in this section use data drawn from the 1999 paper.

## *4.1 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 (GLA). The location of these is shown in Figure 4.1.

## Figure 4.1 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 4.1, 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 4.1 24 Hour two-way traffic flows before and after opening of Westway

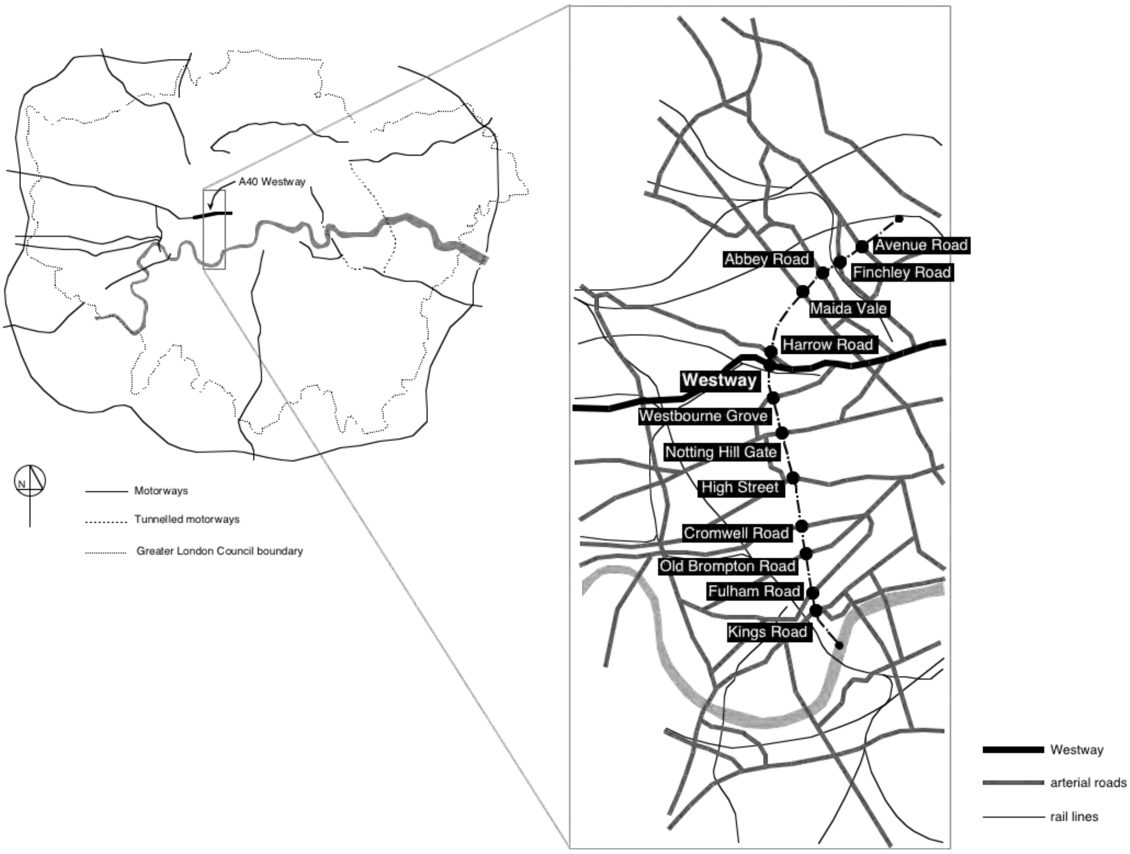
| Westway corridor* | Before | After | % Change |
|---|---|---|---|
| Notting Hill Gate | 52,300 | 44,700 | -15 |
| Moscow Road | 7,800 | 5,000 | -36 |
| Dawson Place | 7,900 | 3,500 | -56 |
| Westbourne Grove | 19,900 | 15,100 | -24 |
| Talbot Road | 11,400 | 4,300 | -62 |
| St Stephen's Gardens | 1,500 | 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 4.2.

### Figure 4.2 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 4.1.

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 4.1, 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 15,000 vehicle movements, or 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 4.2 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 4.2, 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 4.2 24-hour two-way flows in Westway, Finchley Road and Old Brompton Road corridors**

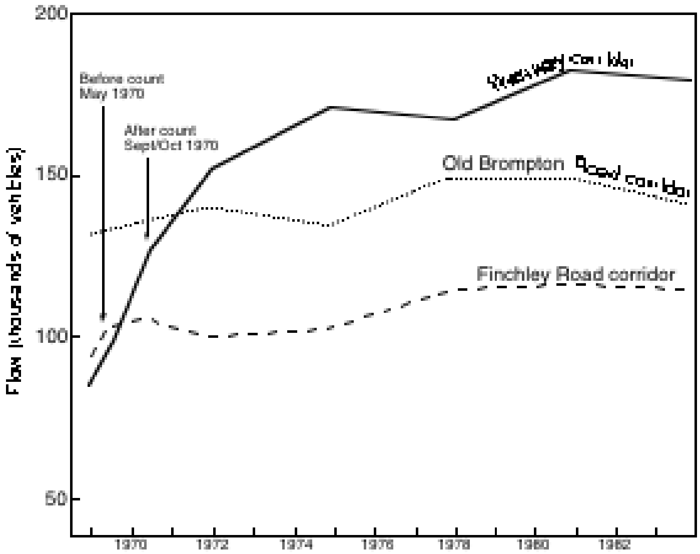
| '000s of vehicles | 1969 | 1970 Before | 1970 After | 1972 | 1975 | 1978 | 1981 | 1984 |
|---|---|---|---|---|---|---|---|---|
| **Westway corridor** | | | | | | | | |
| Notting Hill Gate | 53.7 | 52.3 | 44.7 | 44.4 | 50.0 | 46.3 | 51.8 | 50.0 |
| Westbourne Grove | 16.7 | 19.9 | 15.1 | 14.8 | 14.8 | 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 4.2. 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 4.3.

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 4.3 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 author's 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 4.3. 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 4.3 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 |

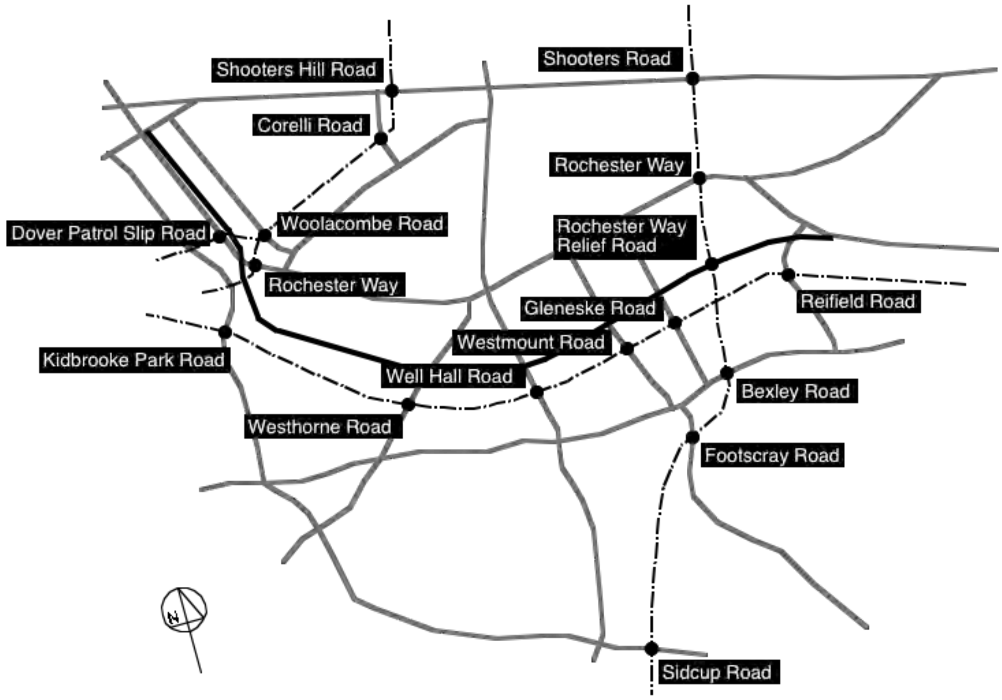
Source: Purnell, S., Bearwood, J. & Elliot, J. 1999, 'The effects of strategic network changes on traffic' in *World Transportation Policy and Practice*, Vol. 5, No. 2, pp. 37, 39, 42, 45 and 48.

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). Given these widely different conclusions, it is useful to review this case study in an attempt to understand what methodological differences may have given rise to such different conclusions.

## 4.2 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 4.4 shows the configuration of the RWRR in relation to the surrounding network.

Figure 4.4 Rochester Way Relief Road and surrounding network




Adapted from: Crow, G. & Younes, B. 1990, *The Rochester Way Relief Road: an appraisal of the operations, 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 screenlines is indicated in Figure 4.4.

Table 4.4 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 4.4 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 4.5.

**Table 4.5 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 operations, 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 undertaken by Purnell, Beardwood and Elliott that was examined in Section 4.1, where, steep growth rates were shown to occur after the addition of motorway capacity.

**Table 4.6 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 operations, 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.

## 4.3 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 a set of generic principles responsible for the organisation of urban systems.

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).

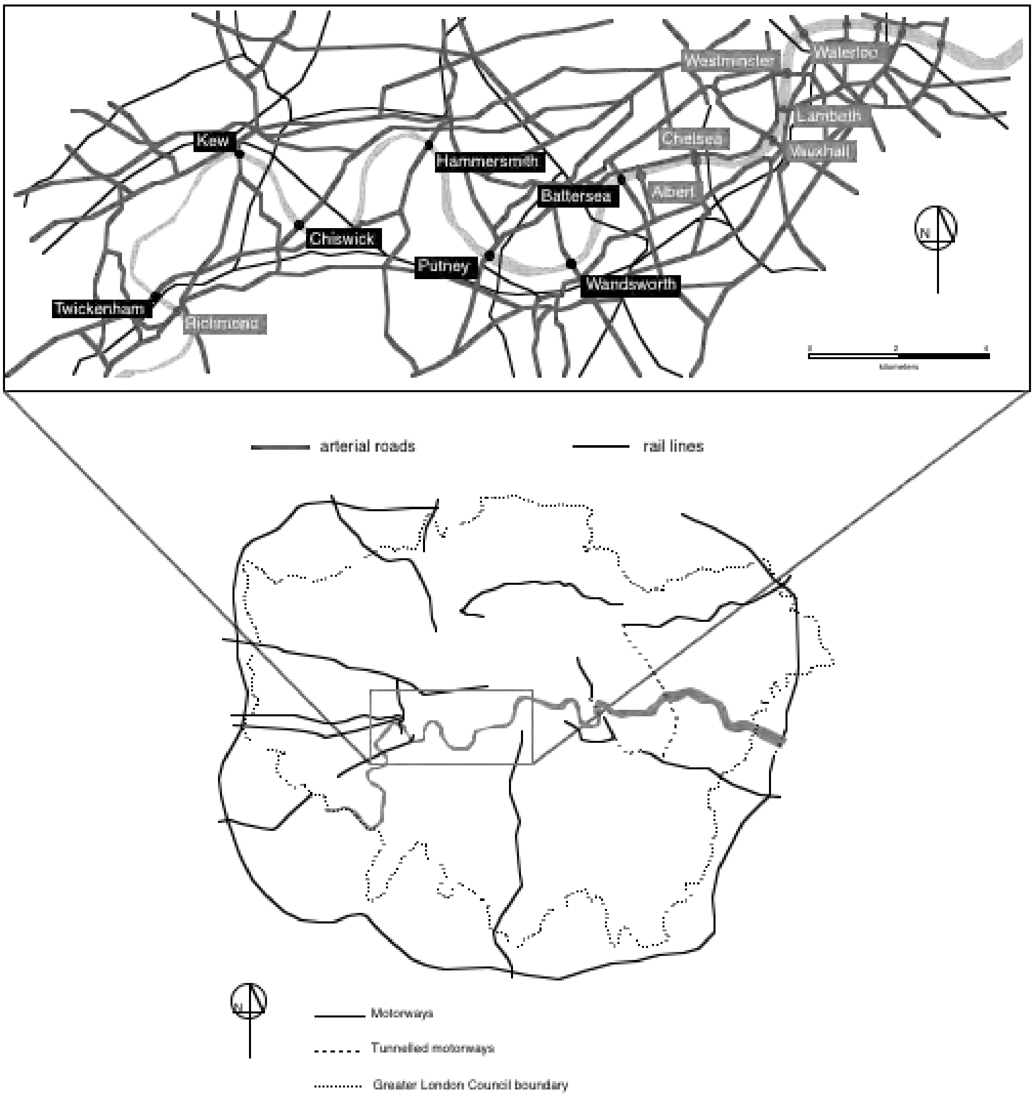
Cairns, Hass-Klau and Goodwin (1998) examined empirical data for more than 60 case studies wherein road capacity had been reduced as a result of road closures, through accident or safety concerns, or dedication of former road space to public transport services, cycleways or pedestrian-only access (Cairns, 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 methodological considerations hen analysing the effects of trunk route capacity reductions.

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 4.5. The position of these districts within the Greater London Area is also shown. The River Thames provides a good natural boundary along which to place a screenline for the purpose of 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 4.5 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.

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 4.7.

**Table 4.7 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 4.5 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 4.8 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 4.8 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.

### 4.4 Conclusions about assessments using comparative screenline counts

The 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.

## 5 Method Two: comparative travel surveys using questionnaires and telephone interviews

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.

## 5.1 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 RWRR near London that was the subject of the analysis by Crow and Younes (1990) discussed in Section 4.2. 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 5.1.

**Table 5.1 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.[4] Questionnaires

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

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).

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

## 5.2 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 5.1 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 5.1 Amsterdam Ring Road

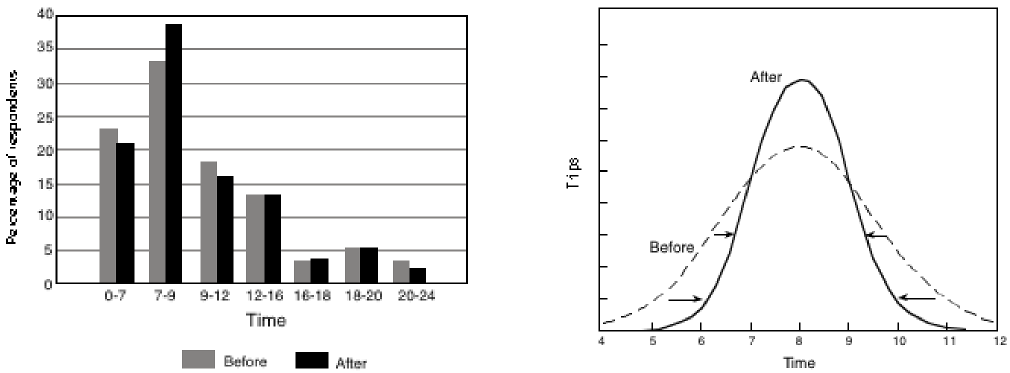

Adapted from: Kenworthy, J. R., Laube, F. B., Newman, P. W. G., Barter, P., Raad, T., Poboon, C. and Guia, B. 1999, *International sourcebook of automobile dependence in cities 1960-1990*, University Press of Colorado, Boulder, pp. 71 and 73 and Kroes, E., Daly, A., Gunn, H. and van der Hoorn, T. 1996, '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 5.2.

**Figure 5.2 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 5.2, 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 5.2. 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 5.2 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.

## 5.3 Conclusions about assessments using travel surveys

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).

# 6 Method Three: time series regression analysis using aggregate VKT data

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 phenomena or the mechanism that relates different functions of a given set of components to one another.

## *6.1 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 3.1 and demonstrated in the case studies examined in Sections 4.1 to 4.3. By analysing the relationship between total road space and VMT, possible problems with open boundary conditions, as discussed in Section 3.1, 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 what has been called the *predict and provide* approach to transport planning 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, proponents argue, 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.

## 6.2 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).

## *6.3 Cervero's path analysis*

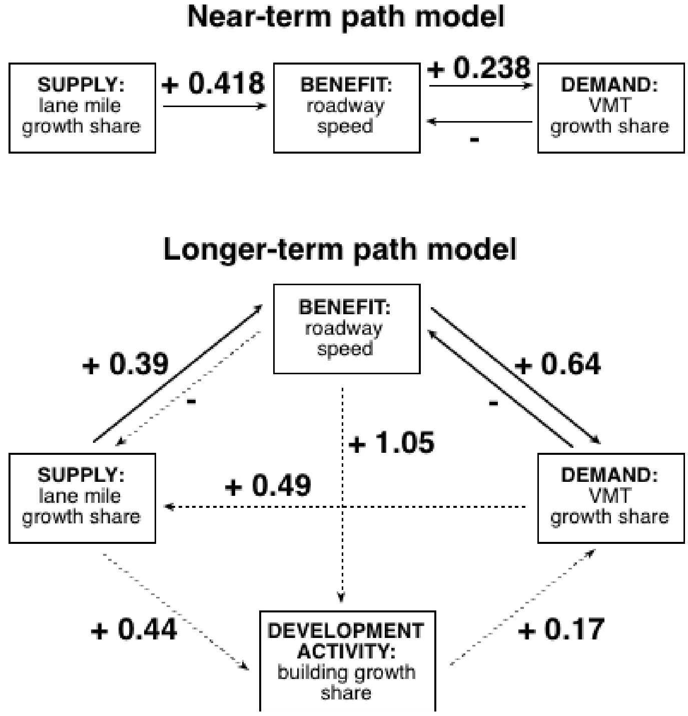
The model developed by Cervero (2003) is the most recent in what has been a series of time series regression analyses. As was shown in the brief overview of studies by Hansen & Huang (1997) and Prakash, Oliver and Balcombe (2001), the need to clarify issues concerning causality has undermined the confidence 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 6.1 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 6.1.

Figure 6.1 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.

## 6.4 Conclusions about assessments using regression modelling

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 section concludes the review of methodologies used to test for the presence of induced traffic growth. It now remains to examine the two empirical case studies of network conditions relating to before and after motorway constructions in Australian cities.

# 7 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).

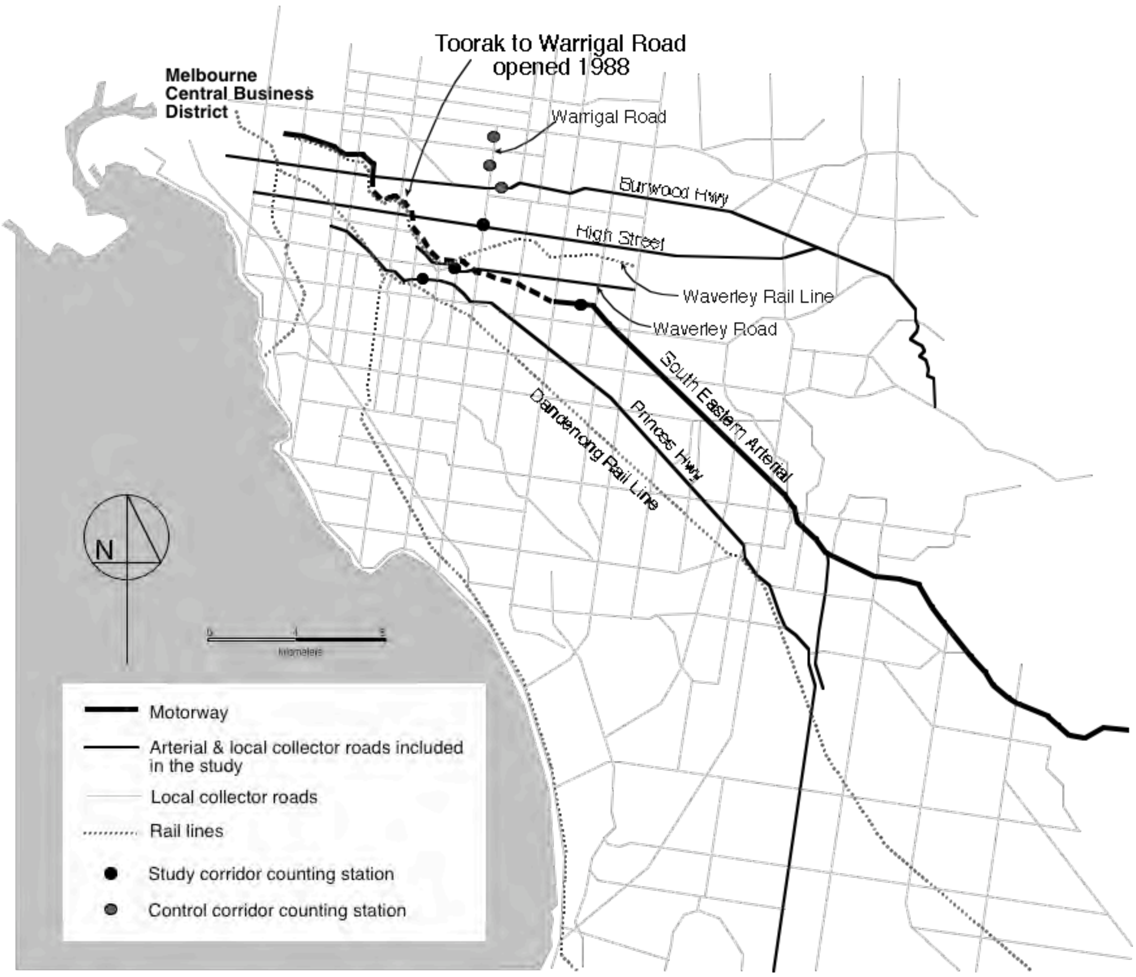
A significant feature of these studies is the stark differences in the quality and availability of data, particularly rail and public transport data. Luk and Chung (1997) were only able to access limited road and rail data. The methodology and extent of their analysis is similar to many of the early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

## *7.1 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 7.1shows the alignment of the motorway as well as the alignments of alternate road and rail routes throughout the corridor.

Figure 7.1 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 7.1, 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 7.1, 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 Table 7.1 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 7.1 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 |
| Princess 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 Group** | | | |
| 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.

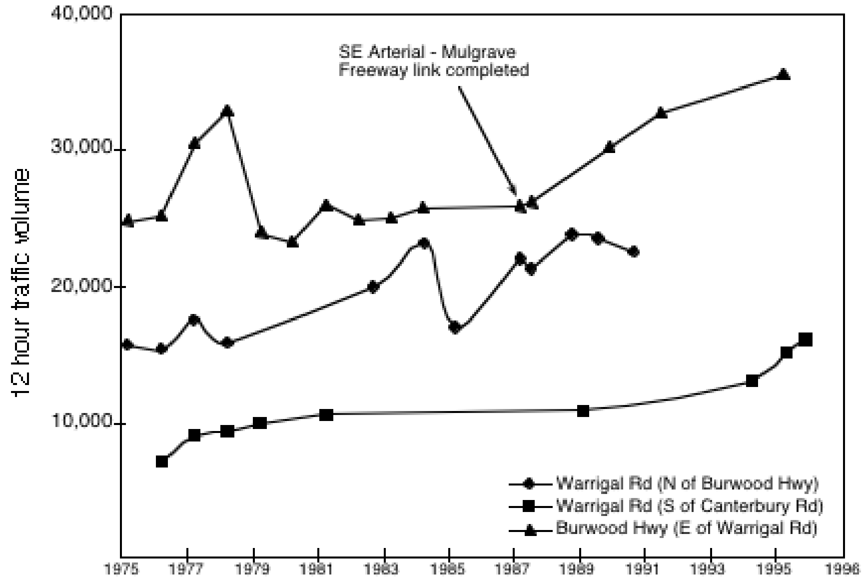
Unfortunately, Luk and Chung only provided a table of percentage differences for the various roads used in their analysis and they provided no clear indication of the configuration of screenlines used. This stands in stark contrast to the reporting standards observed by researchers like Purnell, Beardwood 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. This same problem was encountered in the case study undertaken by Crow and Younes that was reviewed in Section 4.2.

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 7.2. 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 7.2 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 7.2, 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 7.2, 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 7.2 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 7.2 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 appear 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).

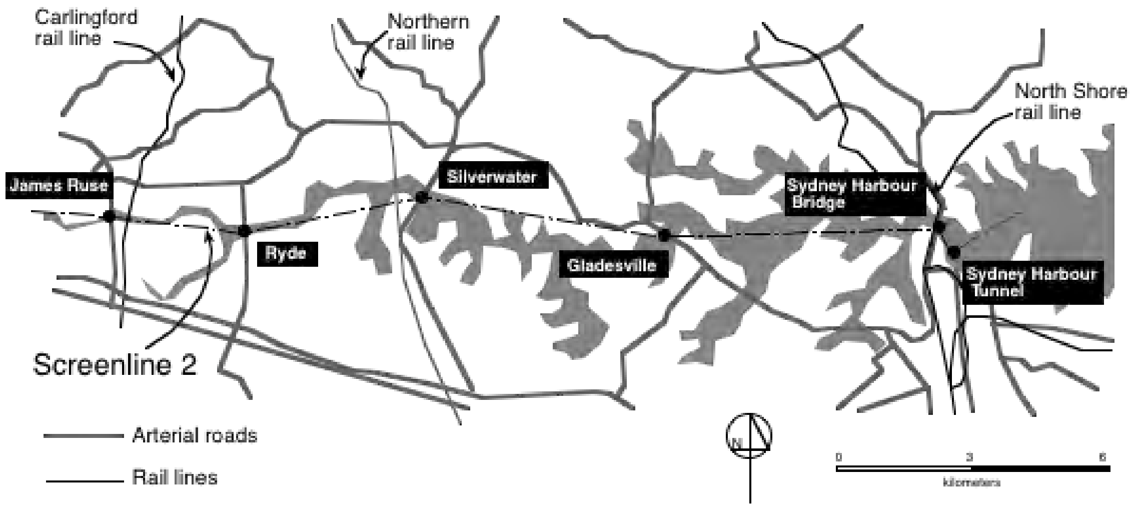
In light of the problems and inconsistencies in the data presented, however, it is unreasonable to conclude that evidence of induced traffic growth has been provided either way. From a methodology perspective, this case study is a poor example of how to go about testing for the presence of induced traffic using screenline counts.

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.

## 7.2 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 7.3 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 Roads and Traffic Authority (RTA) as Screenline 2, which runs along an east–west axis from Sydney Harbour to Penrith in Sydney's outer west.

**Figure 7.3 Sydney Harbour Tunnel and other bridge crossings of Sydney Harbour**




Source: Zeibots, M. E. 2007, *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.* Doctoral dissertation. Institute for Sustainable Futures, University of Technology, Sydney, p. 156.

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 7.3.

### Table 7.3 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).

## *7.3 Conclusions*

The review of Australian case study literature of induced traffic growth has revealed that:

- 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.
- Data can be aggregated in such a way that obscures historically high traffic volume increases as shown in the case study by Luk and Chung.
- 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.

Generally, the paucity of Australian induced traffic growth studies reveals the need for more detailed analyses.

# 8 General conclusions about appropriate testing methods for induced traffic growth in Sydney

The selection of an appropriate methodology is dependent on several factors. Among these are:

- The particular aspect of the phenomenon under investigation that is of interest
- Data availability and site conditions that apply to the facility to be tested
- Research budget

Given the small number of induced traffic growth studies that have been undertaken in Australia and the comparative inexperience of transport institutions and practitioners with the phenomenon, it may be the case that incontrovertible empirical evidence is expected before acceptance of its implications is incorporated into policy. If however, the existence of induced traffic growth is generally accepted and there is an awareness of the difficulties associated with testing for it, then methodology requirements are potentially much simpler. This is because different aspects of the phenomenon can be focussed upon while acknowledging that some others have not been tested for.

The advantages and limitations of the testing methodologies surveyed in this review of the literature are summarised in Table 8.1.

### Table 8.1 Summary of advantages and limitations of induced traffic growth testing methodologies

| | Data Required | Advantages | Limitations |
|---|---|---|---|
| **Method One:** **Comparative Screenline Counts** | Vehicle counts | • Provides an indication of scale of residual volumes once traffic reassignment is accounted for | • Results are ambiguous if data for screenlines are incomplete<br>• The precise source — eg. mode-shift, traffic redistribution, induced trips etc. — of the increase is unknown |
| **Method Two:** **Travel Surveys** | Interview or questionnaire responses | • Can distinguish between source of traffic increases, eg. mode-shifting, traffic redistribution etc. | • Sample results do not provide an indication of network-wide changes to volumes |
| **Method Three:** **Time-series Regression** | Vehicle counts and corresponding network segment distances | • Monitors fluctuations in network-wide VKT levels | • Attributing cause can be difficult given the complexity of the system and difficulty involved in controlling for other variables |

The intention of this research program is to undertake before and after analyses of the effect that opening of sections of the M4 and M5 Motorways had on traffic conditions in Sydney. The purpose is to gauge the extent to which these developments may have contributed to increases in VKT through the rise of induced traffic growth.

Because the analysis to be undertaken is project specific, an analysis that undertakes comparative screenline counts would seem most appropriate. These results could then be supplemented with average journey distance data calculated as part of the Sydney Household Interview Survey conducted by the TPDC in order to estimate increases in VKT levels.

# 9 References

Bonsall, P.W. 1996, 'Can induced traffic be measured by surveys?' in *Transportation*, Vol. 23, pp. 17–34.

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

Cairns, S., Atkins, S. & Goodwin, P. 2001, 'Disappearing traffic? The story so far', in *Municipal Engineer: proceedings of the Institution of Civil Engineers*, No. 1, pp. 13–22.

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

CART 1989, *Traffic calming: the solution to route 20 and a new vision for Brisbane*, Citizens Against Route Twenty, Brisbane.

Cervero, R. 2003, 'Road expansion, urban growth and induced travel: a path analysis', in *Journal of the American Planning Association*, Vol. 69, No. 2, pp. 145–163.

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

DeCorla-Souza, P. & Cohen, H. 1999, 'Estimating induced travel for evaluation of metropolitan highway expansion', in *Transportation*, Vol. 26, pp. 249–262.

Engwicht, D. 1992, *Towards an Eco-City: calming the traffic*, Envirobook, Sydney.

EPA 1998, *Action for air: the NSW Government's 25-year air quality management plan*, NSW Government, Sydney.

Evans, D.E., Lee, P.M. & Sriskandon, K. 1986, 'M25 London orbital motorway', in *Transportation*, November, pp. 6–27.

Fröhlich, P. 2003, 'Induced traffic: review of the explanatory models', 3rd Swiss *Transport Research Conference*, Institute für Vekehrsplanung und Transportsysteme, Eidgenössische Technische Hochschule Zürich, Ascona.

Goodwin, P. & Noland, R.B. 2003, 'Building new roads really does create extra traffic: a response to Prakash et al.' in Applied Economics, Vol. 35, No. 13, pp. 1451–1457.

Goodwin, P.B. 1981, 'The usefulness of travel budgets', in *Transportation Research A*, Vol. 15A, pp. 97–106.

Hall, P. 1980, *Great planning disasters*, Weibenfeld and Nicholson, London.

Hansen, M., Gillen, D., Dobbins, A., Huang, Y. & M. Puvathingal 1993, *The air quality impacts of urban highway capacity expansion: traffic generation and land use change*, Institute of Transportation Studies, University of California, Berkeley, Los Angeles.

Hansen, M. & Huang, Y. 1997, 'Road supply and traffic in California urban areas', in *Transportation Research A*, Vol. 31, No. 3, pp. 205–218.

Howard Humphreys & Partners 1993, *A publication review of traffic generation studies: evidence for Inquiry on A406 North Circular Road Popes Lane to Western Avenue Improvement*, Howard Humphreys & Partners, London.

Hutchings, C. 1992, 'The F4's a dud', *Holroyd and Parramatta Advertiser*, p. 1.

Jacobs, J. 1964, *The death and life of great American cities: the failure of town planning*, Penguin Books, Harmondsworth.

Kroes, E., Daly, A., Gunn, H. & Van Der Hoorn, T. 1996, 'The opening of the Amsterdam ring road: a case study on the short term effects of removing a bottleneck', in *Transportation Policy*, Vol. 23, pp. 71–82.

Luk, J. & Chung, E. 1997, *Induced demand and road investment – an initial appraisal*, Report Number 299, Australian Road Research Board, Vermont South.

Mewton, R. 1997, *The costs and benefits of induced traffic on the Sydney Harbour Tunnel and Gore Hill Freeway*, University of New England, Armidale.

Mewton, R. 2005, 'Induced traffic from the Sydney Harbour Tunnel and Gore Hill Freeway', in *Road and Transport Research*, Vol. 14, No. 3, pp. 24–33.

Noland, R.B. 2001, 'Relationships between highway capacity and induced vehicle travel', in *Transportation Research A*, Vol. 35, pp. 47–72.

Noland, R.B. & Cowart, W.A. 2000, 'Analysis of metropolitan highway capacity and the growth in vehicle miles in travel', *Transportation Research Board 79th Annual Meeting*, Transportation Research Board, Washington DC.

NSW Treasury 1997, *NSW Government guidelines for economic appraisal*, NSW Treasury Publications Office, Sydney.

Pells, S.R. 1989, *User response to new road capacity: a review of published evidence*, Report Number 283, Institute for Transport Studies, University of Leeds, Leeds.

Pickrell, D. 2002, 'Induced demand: its definition, measurement and significance', *Working together to address induced demand*, Eno Foundation, Washington DC.

Prakash, A.B., Oliver, E.H.D.a. & Balcombe, K. 2001, 'Does building new roads really create extra traffic? Some new evidence', in *Applied Economics*, Vol. 33, pp. 1579–1585.

Purnell, S., Beardwood, J. & Elliott, J. 1999, 'The effects of strategic network changes on traffic', in *World Transportation Policy & Practice*, Vol. 5, No. 2, pp. 28–48.

Rayner, T. 2003, 'The access to Hastings multi-modal transport study', *REGIONET Workshop III: evaluation methods and tools for regional sustainable development*, CURE, Manchester University, Manchester.

Roess, R.P., Prassas, E.S. & McShane, W.R. 2004, *Traffic engineering*, 3rd Edn, Pearson Prentice Hall, Upper Sadle River, New Jersey.

SACTRA 1994, *Trunk roads and the generation of traffic*, HMSO, London.

Sandquist, G.M. 1985, *Introduction to systems science*, Prentice-Hall Inc., New Jersey.

SAS Institute 2006, *Bivariate Granger causality test*, SAS Institute, 2006 <www.support.sas.com/rnd/app/examples/ets/granger>.

Stevens, G. 1986, *Statistics*, Faculty of Architecture, University of Sydney, Sydney.

Wilcock, J.L. 1988, 'Roads generate traffic: data collection', Leeds.

Wilson, E.B. 1952, *An introduction to scientific research*, McGraw-Hill Book Co., New York.

Wurz, F. 1992, *Umfahrungsstrassen - entlastung für wen? 20 Fallbeispiele aus der ganzen Schweiz*, Verkehrs - Club der Schweiz: Politik und Information, Herzogenbuchsee.

Wynn, C.M. & Wiggins, A.W. 1997, *The five biggest ideas in science*, Wiley, New York.

Zeibots, M.E. 2007, *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*, Doctoral Thesis, University of Technology, Sydney, Sydney.