Adequacy of Transport Infrastructure: Intercity Roads

Working Paper

This Working Paper is the first in a series of Working Papers which disseminates the results of a large research project into the adequacy of Australia's transport infrastructure over the next 20 years. The assessment covers all four modes of transport - road, rail, air and sea - with the primary focus on freight.

Subject
Series
Date
A to Z
Search
Results
Print
Exit
GO BACK

Bureau of Transport and Communications Economics

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Adequacy of transport infrastructure
Intercity roads

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FOREWORD

The National Transport Planning Taskforce (NTPT) was established in October 1993 by the former Minister for Transport and Communications to report on national infrastructure needs and operational improvements required to meet future demands for freight transport.

The Bureau of Transport and Communications Economics was commissioned by the NTPT to carry out assessments of the adequacy of road, rail, seaport and airport infrastructure. In doing this it has attempted to adopt a strategic multimodal orientation. A summary of the Bureau's work is given in *Building for the Job: A Strategy for Australia's Transport Network, Commissioned Work vol. 1* produced by the NTPT.

The project was undertaken under the leadership of Mark Harvey and John Miller. Officers who contributed specific components included Johnson Amoako, Jane Brockington, Peter Collins, Glen D'Este, Bozena Dziatkowiec, Edwina Heyhoe and Chikkegowda Puttaswamy. Other officers of the BTCE, particularly Maurice Haddad, also made valuable contributions.

Details of the research undertaken for each component of the study are provided in a series of six working papers. Each paper describes the methodology used, future demand, and results of the adequacy analysis, and gives options for future research. This paper reports on the assessment of Australia's intercity road infrastructure.

Peter Collins was primarily responsible for the final production of this working paper and the economic assessment work presented in it. Valuable contributions were made by Glen D'Este (asset preservation), Mark Harvey (theoretical structure), Edwina Heyhoe (the HDM-C model and technical assessment), John Miller (demand projections, and data bases), Chikkegowda Puttaswamy (data bases and technical assessment). Travers Morgan, Ove Arup, and the Department of Transport are also to be thanked for their assistance in completing this project.

Russ Reynolds
Research Manager

Bureau of Transport and Communications Economics
Canberra
December 1994

CONTENTS

Page

FIGURES

Page

TABLES

BOX

ABSTRACT

This working paper is one in a series of working papers which disseminates the results of a large research project into the adequacy of Australia's transport infrastructure over the next 20 years. The subject of this paper is the assessment of road infrastructure in Australia. A network of strategic economic importance that links the mainland capital cities, Hobart and Burnie, and Brisbane and Cairns, is selected for analysis. The concepts and theory that underpin both a technical, and an economic method of infrastructure assessment are discussed in detail. The characteristics of the selected network are discussed in terms of the type of road infrastructure it consists of, and projections are made of future traffic volumes on the network in the year 2014-15. The adequacy of the current infrastructure is assessed with those traffic levels being imposed onto it. The results of the technical assessment give an indication of the relative service levels provided by each individual corridor at those traffic volumes, and hence, where inadequacies are most likely to arise in the future. The results of the economic assessment indicate how, and where the infrastructure may warrant improvement given the projected traffic volumes. Additionally, they give an indication of the likely cost of the improvements. Estimates are also made of the likely amount of expenditure that may need to be devoted to asset preservation to the year 2014-15.

KEY FINDINGS

TECHNICAL ASSESSMENT

The Pacific Highway stands out as by far the most inadequate.

The next most inadequate highways are the New England, Bruce, and Barton Highways. Some sections in Tasmania between Burnie and Devonport also exhibit very poor performance. The two lane sections of the Hume Highway will be technically inadequate before 2014-15.

Generally, performance deteriorates as the corridors approach capital cities due to high growth rates in traffic close to the main urban areas.

ECONOMIC ASSESSMENT

The estimated level of economically warranted expenditure for widening and adding lanes over the next 20 years is $10.0B, and a further $1.3B is required for town bypasses - excluding road works within town and city limits. If net economic benefits are to be maximised, many of the projects included in these estimates should be implemented as soon as possible. This strategic analysis does not include projects involving realignments, flood mitigation and associated bridgeworks, expanding from six to eight lanes, construction of overtaking lanes, projects in urban areas, and administration and pre-construction costs.

There are four corridors for which investment requirements exceed $1B each. Together they account for $9.1B (81 per cent) of the total. These corridors are the Pacific highway ($4.3B), the Bruce highway ($1.4B), the inland route between Sydney and Brisbane ($2.1B) and the Hume highway ($1.4B). The remaining seven corridors will collectively require around $2.2B of investment by 2014-15.

Per kilometre expenditure requirements will be proportionally higher close to the capital cities, this is where both traffic levels, and traffic growth rates are highest. Around 5.0 per cent of road outside town limits is within 50km of the designated corridor end points which are near capital cities, Cairns and Burnie. This part of the road network requires 16 per cent of the estimated expenditure, or $1.8B. The projected total expenditure on road maintenance over the period from 1995-96 to 2014-15 is estimated to be $6.5B. This is equivalent to some $325M. per annum.

The results of the economic assessment for each corridor suggest that the shares of New South Wales and Queensland will be greater while the shares of other states will be less.

CHAPTER 1 INTRODUCTION

The Bureau of Transport and Communications Economics was commissioned by the National Transport Planning Taskforce (NTPT) to assess Australia's transport infrastructure requirements for the next 20 years. This assessment covered all four modes of transport: road, rail, air and sea, with an emphasis on the movement of freight. Passenger transport is included in the analysis since it uses the same infrastructure as freight transport and contributes to congestion levels.

Each mode was assessed independently and this paper concentrates on the intercity road infrastructure assessment. The assessment of urban roads is the subject of another working paper.

A STRATEGIC APPROACH

A detailed analysis of Australia's road infrastructure would have taken more time and more resources than were available to this study. The aims of this research therefore had to be strategic in nature so that the Bureau's report to the NTPT could be completed within a set time frame, and that its conclusions could be supported by rigorous analysis. This therefore meant a strategic approach had to be taken to the selection of both the road network to be analysed, and the type of investment projects to be evaluated in the economic assessment of that network.

Aims of the road study

In this study, an important portion of Australia's road infrastructure was analysed to highlight areas where a full scale cost-benefit analysis would most probably indicate that capacity expanding infrastructure investment would be warranted before 2014-15. The results of the study should be valuable in alerting governments to parts of the selected network that are likely to require additional investment over the next 20 years. The dollar value of the investments likely to be warranted is also estimated to give an indication of the magnitude of the financial resources that may be required. Estimates have also been made of the amount that may be required for maintenance work. It needs to be emphasised, however, that these estimates should only be regarded as a broad indicator of the likely magnitude of future investment and maintenance requirements. It would be a grave misrepresentation to interpret the findings as a recommended investment and maintenance program.

It is also hoped that this study stimulates further research into this area, both to extend the scope of this study and to repair any data deficiencies this study encountered. The comprehensive data collection exercise undertaken for this study revealed serious deficiencies in the data available on road infrastructure characteristics and traffic volumes on Australia's intercity roads.

The selected intercity road network: a network of strategic economic importance

A limited amount of road infrastructure considered to be of national strategic economic significance was selected for examination. This selection consists of the National Highways system as well as the Pacific Highway. The corridors in this network link the mainland capital cities, Brisbane and Cairns, and Hobart and Burnie.

The Australian road transport network is much more extensive than the network on which this study has focussed. On the basis of previous studies by the Bureau and others, however, it is reasonable to assume that much of the network that serves local communities and sparsely populated regions is unlikely to require capacity expanding investment to meet future demand. These parts of the network generally service traffic flows substantially below their current capacities, and in some cases, traffic levels are falling. Indeed, much of the national network studied was found to have adequate capacity to meet the projected levels of demand over the next 20 years provided adequate maintenance work is carried out.

There will be some exceptions, however, particularly for road links in quickly growing regions which may require capacity expanding investment to meet demand. Furthermore, major reconstruction work may be required in some areas following the occurrence of natural disasters.

REPORT OUTLINE

The report is structured in the following manner.

Chapter 2 explains the notions of technical and economic adequacy and sets out the theoretical structure which supports an economic assessment of transport infrastructure. This structure is generic to the analysis of all transport modes. Extensions which are specific to the analysis of roads are set out in appendix II.

The current infrastructure status of the road network that is examined is discussed in chapter 3. This chapter also includes a discussion on how the demand for travel on the network was modelled. The output of this process is the projected future traffic volumes which are discussed at a corridor level. These projections are imposed onto the current infrastructure to estimate the road's performance and future infrastructure requirements. The technical and economic assessments are discussed in chapters 4 and 5 respectively. The approach taken to the technical and economic assessments is discussed first, and then, the results of both assessments are presented along with those of sensitivity tests. The issue of asset preservation is discussed in chapter 6 and estimates of maintenance expenditure to the year 2014-15 are presented.

Chapter 7 discusses the implications of this study including the limits that should be placed on the interpretation of this study. This leads onto the discussion of a future research program that logically follows from this study.

CHAPTER 2 ASSESSING INFRASTRUCTURE ADEQUACY

In the first part of this chapter adequate transport infrastructure is defined. A technical assessment and an economic assessment may be conducted to establish if infrastructure is adequate. These assessment methods are explained in the second part of the chapter with particular attention being paid to the theoretical structure that underpins an economic assessment. In the last part of the chapter, there is a discussion about which method is the preferred assessment method. It is acknowledged that it may not always be possible to implement the preferred method, and that data availability may often be the limiting factor. This leads to a discussion which summarises the data requirements of each method.

Even where the assessment of infrastructure has to be limited in some way, it is still important to bear in mind the ideal. This is because the gap between the type of analysis that is currently possible, and the ideal, provides a rich avenue for future research. This issue is further discussed in chapter 6.

THE ADEQUACY OF TRANSPORT INFRASTRUCTURE

Transport infrastructure is deemed to be adequate when it does not require additional investment to bring the level of service that it provides up to an acceptable standard. High operating costs, long service times and unreliability are all manifestations of a poor level of service being provided by infrastructure. Poor service levels may be caused by capacity shortages, the physical deterioration of infrastructure, and the current infrastructure becoming obsolete because of technological change, changes in demand, input prices, or safety requirements.

ASSESSING THE ADEQUACY OF TRANSPORT INFRASTRUCTURE

There are two types of assessment that may be used to assess the adequacy of transport infrastructure. First, adequacy may be assessed using a technical assessment, and second, adequacy may be assessed using an economic assessment. In some cases, both assessment types may be used to compliment each other, but in others data constraints may preclude the use of an economic assessment.

Technical assessment of adequacy

The notion that infrastructure adequacy may be assessed implies that there exists some criteria that clearly defines poor levels of service, and hence, inadequate infrastructure. Technical adequacy, however, is an extremely nebulous concept.

A technical assessment may be conducted by comparing the physical characteristics of different sections of infrastructure against some pre-determined standard deemed to be the minimum acceptable standard. The minimum acceptable standard is largely a matter of judgement. In some instances, extraneous information from previous economic assessments may be used to set minimum technical standards. In the absence of such information, natural breaks in the continuum of standards, or perceptions about acceptable standards may be called upon.

A more sophisticated form of technical assessment is based on performance characteristics such as delays, operation and travel times taken, reliability, and operating costs. This approach either requires data on the current level of these service indicators, or a model capable of estimating them. Future service levels that the infrastructure would provide, if projected future use levels were imposed onto the existing infrastructure, would also have to be estimated.

A model of this capability normally requires more detailed data on both the physical characteristics and current and future utilisation levels than is necessary for a technical assessment of physical characteristics. The performance characteristics approach is therefore more data intensive than the physical characteristics approach, and as a result, may not be suitable in all situations.

Even though the use of performance measures is more sophisticated and takes account of the level of demand, an arbitrary choice still has to be made about a minimum acceptable standard for adequate infrastructure. The only way to avoid this arbitrary choice is to conduct an economic assessment.

Economic assessment of adequacy

Transport infrastructure is deemed to be economically adequate at a point in time if investment to improve the level of service provided is not economically warranted. An investment is economically warranted at a point in time if:

1 the present value of benefits exceeds the present value of costs; *and*
2 there is no net welfare gain from delaying the investment.

The first condition ensures that the resources invested will earn at least what they could if used elsewhere in the economy and the second condition ensures that investment occurs at the optimal time. These criteria have sound theoretical foundations, meaning that the notion of economic adequacy is much more rigorous than that of technical adequacy. Furthermore, if these criteria are satisfied, scarce resources are used in the most efficient manner possible.

To explain the economic concept of adequacy in more detail, Figure 2.1 shows a demand curve and two 'short-run marginal social cost' (SRMC) curves for the use of a piece of infrastructure. Quantity provided or demanded per period of time is graphed on the horizontal axis and 'generalised social cost' of infrastructure use on the vertical axis. This 'generalised social cost' consists of all the costs associated with use of the infrastructure regardless of to whom they accrue.

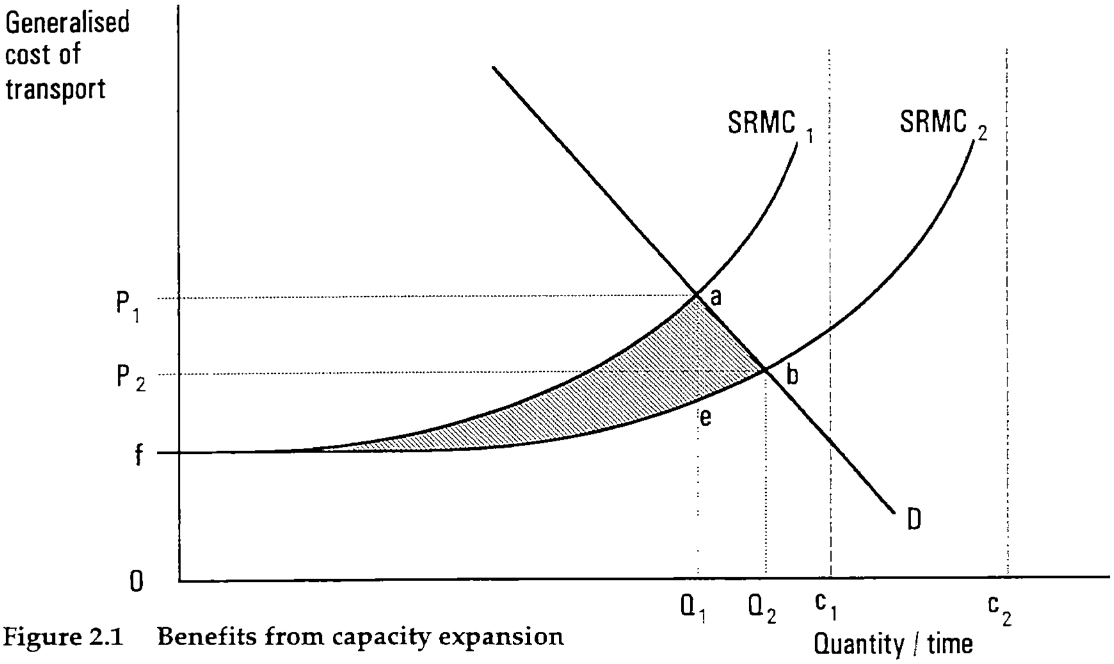

Figure 2.1 Benefits from capacity expansion

In the case of roads, generalised social costs include: the variable operating costs of vehicles, ongoing maintenance related to use, travel time costs, and externalities such as congestion and vehicle emissions. Estimating the value of time and the value of externalities entails significant measurement problems that are not addressed in this discussion.

The marginal cost of infrastructure use is the cost imposed by an *additional* user. The short run refers to the time frame in which it is not possible to invest to change the infrastructure. Capital costs and fixed operating costs of infrastructure are excluded because these will not be affected in the short term by infrastructure usage. The short-run marginal social cost curve, $SRMC_1$ rises as usage rises towards maximum capacity at c_1 and operating costs, delays and unreliability increase. If the maximum capacity was increased, say to c_2 the short run marginal cost curve would shift to the right - to $SRMC_2$.

The demand curve D shows the quantity of infrastructure use demanded at each level of generalised cost. Users are assumed to pay the generalised social cost for the use of infrastructure. That is, taxes and charges are levied so that the user pays the short run marginal social cost of using the infrastructure. This is the economically optimal price for users to pay. When capacity expands, users gain from a reduction in generalised cost from P_1 to P_2 and so increase their use from Q_1 to Q_2. The net gain to society from expanding infrastructure capacity is equal to the shaded area *abf* in figure 2.1.[1] Clearly, the shaded area and hence the benefits from expanding capacity will be greater in size, the higher demand is in relation to capacity.

When a social cost-benefit analysis is conducted, the present value of capital costs is compared with the present value of future benefits expected to be derived from the increased capacity. The first condition of the above definition of economic adequacy requires that the net present value of the expansion project must be greater than, or equal to zero, before it is economically warranted.

The optimal time to invest

Even when the present value of benefits exceeds the present value of costs, it may still be preferable to delay an investment to maximise its net present value. Assuming that the upgrade will be permanent, if an investment project was delayed by one year, society would forgo the benefits from the project for that year. As an offset, society could gain by investing the funds required for one year elsewhere and earn interest. Assuming perfect capital markets so that the interest rate equals the discount rate which in turn equals the opportunity cost of capital, society would gain rK where r is the discount rate and K the capital cost of investment. Hence an investment would be better delayed so long as

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[1] The area between the two SRMC curves from *0* to Q_1 (*aef*) represents the saving in costs on existing throughput. The area from Q_1 to Q_2 (*abe*) is the gain to society associated with the generated demand. It is the difference between the gain to users represented by the height of the demand curve and the social cost of meeting the additional demand represented by the height of the $SRMC_2$ curve.

$B(t) < rK$ where $B(t)$ is the benefits in year t.[2] If demand is growing over time, annual benefits will grow as well, so the time will eventually be reached when investment is warranted. This illustrated in figure 2.2. Time is graphed on the horizontal axis and annual benefits and costs on the vertical axis. Two annual benefit curves are shown along with the value of rK. The annual benefit curves have been drawn as rising at an increasing rate because, as the demand curve in figure 2.1 moves to the right over time, the distance between the $SRMC_1$ and $SRMC_2$ curves increases. If the annual benefit curve labelled A is applied, the investment would be warranted immediately. In this case, the optimal time to invest occurred in the past. In the case of the B curve, it would be better to delay the investment until time T_B.[3]

If it is assumed that annual benefits are growing at a constant rate over time then the benefit in year t = $b(1+g)^t$, where b is the benefit in year zero from undertaking the investment, and g is the annual growth rate in benefits.[4] Substituting the formula for annual benefit into the optimal timing condition,

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[2] This condition is sometimes expressed as: a project should be delayed if the 'first year rate of return' is below the discount rate, that is, $\frac{B(1)}{K} < r$.

[3] It is assumed that the be benefit function is continuous and monotonically increasing. With investment occurring at time T and continuous compounding, the net present value of benefits and costs is: $NPV = \int_T^{\infty} B(t)e^{-rt}dt - Ke^{-rT}$. This equation must be differentiated with respect to T and set equal to zero to obtain the optimum time to invest: $\frac{dNPV}{dT} = -B(T)e^{-rT} + rKe^{-rT} = 0$; which reduces to: $B(T) = rK$. The second order condition for a maximum is that, in the region of the optimum: $-e^{-rt}\frac{dB}{dt} < 0$ which holds if $\frac{dB}{dt} > 0$. Thus the annual gain from implementing the project must be growing over time. The optimal timing condition derived here assumes that the project has an infinite life. There may be periodic maintenance costs and replacement costs which occur at definite times following initial construction. Deferral of the initial investment also defers these. NPV could then be expressed as:

$NPV = \int_T^{\infty} B(t)e^{-rt}dt - Ke^{-rT} - k_1e^{-r(T+x_1)} - k_2e^{-r(T+x_2)} - \ldots - k_ne^{-r(T+x_n)}$ where the k's are periodic maintenance of replacement expenditures each one occurring x years after time T. The optimum timing condition then becomes: $B(T) = r\left(K + k_1e^{-rx_1} + k_2e^{-rx_2} + \ldots + k_ne^{-rx_n}\right)$. Thus one could use the simple optimal timing condition derived previously but augment K by an amount equal to the present value of these periodic maintenance and replacement costs. For maintenance costs which occur every year and are the same for each, it is simpler to reduce annual benefits by the amount.

[4] If the demand curve shifts rightward at a constant growth rate, benefits from infrastructure expansion will in fact rise faster because the gap between marginal costs with and without the investment rises as figure 2.1 shows.

the optimal time to invest is $\frac{ln(rK/b)}{ln(1+g)}$. From this it can be seen that a higher discount rate and capital cost will delay the optimum time while higher benefits and growth in benefits will bring it forward.

The discontinuous nature of transport infrastructure investment

If infrastructure could be expanded in finely divisible amounts, one would keep on increasing capacity by small amounts as long as the two adequacy conditions were satisfied. In practice, however, it is often the case that capacity may only be expanded by large amounts and not several small amounts. This may be because of economies of scale in construction, and thus it may be cheaper to expand to a given capacity with one large investment project than to do so with a series of smaller investment projects. In other cases, the nature of transport infrastructure is such that it is impossible to expand capacity by small units.

Benefit cost ratios

The benefit-cost ratio (BCR) (the present value of benefits divided by the present value of capital costs) from the investment under the assumption that benefits grow at a constant rate is $\frac{b(1+g)^T}{K[r-ln(1+g)]}$ where T is the time of implementation. Thus the BCR grows over time at the growth rate. If the investment is undertaken at the optimal time, the formula for the BCR reduces to $\frac{1}{1-ln(1+g)/r}$. The b and K terms drop out of the expression and it can be seen that with a positive growth rate and optimal timing, the BCR may not be less than one. A project having a BCR below one, would, with optimal timing, be delayed into the future by which time its BCR would have risen above one. At the optimal time, how far the BCR lies above one will depend on the size of the growth rate relative to the discount rate. If the project has its optimal time in the past as illustrated by the annual benefit curve *A* in figure 2.2, the BCR will be higher still, depending on how late the project is. Application of the optimal timing criterion to identify investment projects and timings therefore means that BCRs will be above one and significantly so where growth rates in benefits are high relative to the discount rate and where there is already substantial underinvestment.

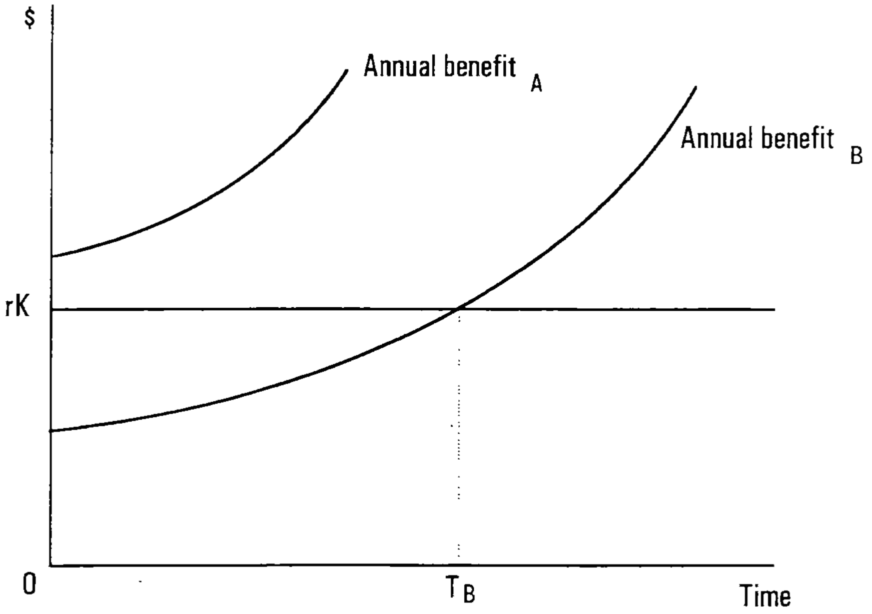

Figure 2.2 Optimal timing of investments

Non-capacity expanding investments

The SRMC curves in figure 2.1 were drawn such that the investment shifts the SRMC curve to the right. Short-run marginal costs at low outputs remain unchanged. The improvements in service levels eventuate because there is more capacity to handle any given volume of demand. Some investments will shift the SRMC curve downwards as well as, or instead of, to the right. An example would be an investment to save on variable maintenance costs. Even if there is no congestion whatsoever, the principles for assessing whether the investment is warranted and estimating the optimal time are the same. In terms of figure 2.1, the demand curve would pass through the flat parts of the SRMC curves. The annual benefit would still be measured by the area bounded by the two SRMC curves and the demand curve.

Non-optimal pricing

To simplify the exposition, it was assumed in the discussion of figure 2.1 that the value of taxes and charges were such that users always paid the short-run marginal social cost. This is the optimum pricing rule to achieve economic efficiency because the marginal user (that is, the user on the borderline of deciding whether or not to use the infrastructure), pays the full cost that individual imposes on society. In practice, prices will never perfectly reflect marginal social costs and may be quite different. Where prices differ from marginal costs, measurement of benefits from infrastructure upgrading will be more complicated than just the shaded area in figure 2.1.[5] If prices are above marginal costs, infrastructure will be underutilised compared with the most efficient level, and less investment will be required. Conversely, if infrastructure is underpriced, there will be more congestion than at the most efficient level of use and additional investment will be required.

CHOOSING AN ASSESSMENT METHOD

An economic assessment of infrastructure adequacy is the most rigorous method of assessment. Furthermore, it is the only method that leads to an economically efficient level of infrastructure investment, and should, therefore, be the preferred assessment method. Social cost-benefit analysis is, however, a data intensive and time consuming process, and this may preclude its use in many situations.

In these cases a technical assessment may be employed to identify investment projects, and if the projects can be costed, estimates of the costs of likely future investment needs may be derived. The investments identified would be those that would bring the infrastructure's level of service up to a minimum acceptable level. When doing this it needs to be remembered that infrastructure that is deemed to be technically inadequate may not necessarily be economically inadequate. This is particularly the case if use levels are low, or construction costs are high, and therefore, the results of such an assessment should be interpreted carefully.

In many cases it will be desirable to use a technical assessment and an economic assessment in a complimentary manner. The technical assessment could be used to rank the relative performance of infrastructure, and thus, identify infrastructure improvements that are most likely to pass a cost-benefit test. A cost-benefit analysis could then be conducted to see if these infrastructure improvements are warranted on economic grounds.

Alternatively, both a technical assessment and an economic assessment could be conducted on the same infrastructure. The results of each assessment could then be checked for consistency.

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[5] Benefits in the form of increased willingness-to-pay would be measured with reference to the demand curve and actual generalised costs incurred including taxes and charges. Benefits in the form of net cost savings would be measured as the areas under the marginal social cost curves.

Data requirements

The choice of assessment method will to a large extent be driven by data availability. For this reason the data requirements of each method will now be summarised.

Technical assessments

To conduct the most basic technical assessment data is required on the physical characteristics of each individual piece of infrastructure. Details are also required on levels of utilisation if the physical characteristics are expressed in terms of per unit of throughput.

The more sophisticated form of technical assessment requires data on current service levels, or data for a model which will estimate these. This data needs to contain details on physical characteristics and utilisation levels, but it needs to be more comprehensive than the data required for the more basic technical assessment. Demand forecasts are also required to estimate future levels of service that would be provided at the forecast use levels.

Economic assessments

A rudimentary economic assessment requires little more data than that required for a more sophisticated technical assessment. The additional requirements include capital costs of investment projects and data on operating costs. These include both the value of time, and reliability where time savings and improved reliability are major benefits to be derived from an investment project. The data requirements quickly become much more burdensome as cost benefit analysis becomes more detailed.

Another requirement of an economic assessment is that the type of infrastructure improvements need to be specified. If alternative ways of achieving the same level of service improvement exist, all the alternatives need to be analysed and compared. It has already been noted that a technical assessment may assist in the identification of these projects.

SUMMARY OF METHODOLOGY

The approach to assessing infrastructure adequacy outlined above offers great flexibility in terms of the depth of analysis, and this is essential given the variation of data availability and the variable ease of modelling the different transport modes. At the lowest level is the technical review of the physical characteristics of infrastructure. The next level is a technical assessment of adequacy based on current and projected infrastructure performance in terms of service levels. This has the advantage that it can formally incorporate demand projections. Finally, if it is possible to specify investment projects and estimate costs and benefits, there is the economic assessment. This too may be undertaken in varying degrees of depth ranging from a rudimentary calculation to a major cost-benefit study. With its strategic focus this study does not go beyond cost-benefit analysis at a rudimentary level.

CHAPTER 3 THE CURRENT ROAD INFRASTRUCTURE AND THE FUTURE DEMAND FOR TRAVEL

INTRODUCTION

This chapter consists of two main sections, each of which discusses one of two key determinants of future infrastructure investment designed to increase road capacity. The first is the current status of the infrastructure on the selected intercity network, and the second is the demand for travel on the network over the 20 year study period.

The infrastructure discussion includes details on corridor length and the proportion of different road types that currently exist on the network. First, however, there will be a section in which the different road categories that the network has been divided into for this study are defined.

In the second part of the chapter the methodology used to model the demand for travel on the network will be discussed first. After this, the forecast quantity of travel to be demanded both in the year 1995-96, and in the year 2014-15 will be discussed.

In this chapter, the quantity demanded will be expressed in terms of the weighted sum of vehicles using a corridor in a year. The annual vehicle count (that is., the estimated AADT multiplied by the number of days in a year) for each road section was weighted by that section's share of the total corridor length (that is., the section's length divided by the corridor's length). The weighted sum therefore gives the average number of vehicles passing through any one section of the road in a year.

The split between the weighted sum of cars and the weighted sum of trucks will also be discussed, and this will give an insight into which corridors are important in terms of national freight movement.

ROAD CATEGORIES

In each corridor, the road was divided into two broad categories because of the different project types analysed in each category. These are road that is outside of town limits and road that is inside town limits. Town limits were defined as those parts of the road network with a recommended speed limit of 60 kilometres per hour. This limit was used in preference to 80 kilometres per hour or less because many sections of open road have recommended speed limits of between 60 and 80 kilometres per hour. These observations may have distorted the results of this assessment if the higher speed limit was used to define town limits.

Roads outside town limits were divided into four further categories. These are:

- 2 lane roads with a pavement width less than seven metres (narrow 2 lane roads);
- 2 lane roads with a pavement width greater than seven metres (wide 2 lane roads);
- 4 lane roads;
- 6 lane roads.

No further division of roads inside town limits was undertaken because the need for capacity expanding investment was not examined for these roads.

CHARACTERISTICS OF THE SELECTED NETWORK

A pictorial representation of the selected network is shown in figure 3.1 and table 3.1 contains statistics which give details on the different road types that make up the network. The network has a total length of 19 329 kilometres of which around 3 per cent is inside town limits and around 97 per cent is outside town limits.

Around 89 per cent of the network is still 2 lane road with around 60 per cent of that having a pavement width of less than 7 metres (or 33.5 % of the network). As to be expected, the majority of the 2 lane road is on those parts of the network which traverse the more sparsely populated areas of Australia and that have the lowest traffic volumes.

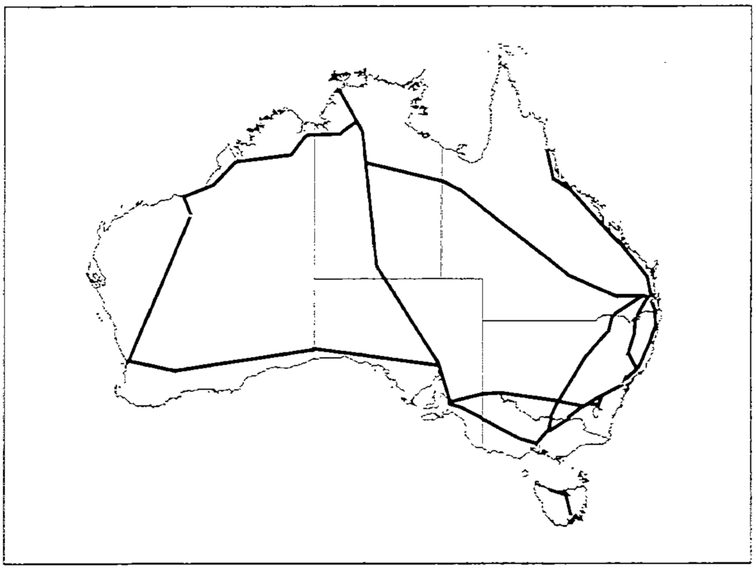


Figure 3.1 Intercity road network

Conversely, the corridors that form the part of the network which passes through the more densely populated areas in the south east corner, and those along the eastern seaboard, carry much higher traffic volumes. Not surprisingly, the majority of the 1427 kilometres of 4 lane road is on these corridors. Just over 40 per cent of this 4 lane road is on the corridor that joins Australia's two most populous cities, Melbourne and Sydney (the Hume highway).

There is also a limited amount of 6 lane road (less than 1 per cent) on the network.

TABLE 3.1: INTERCITY ROAD NETWORK

Kilometres of road

Corridor	*Road outside town limits*					*Road inside town limits*	*Corridor Totals*
	Road type						
	Narrow 2 lane	*Wide 2 lane*	*4 lanes*	*6 lanes*	*Sub-total*		
Adelaide to Darwin	1096	1553	18	0	2667	27	2695
Adelaide to Perth	1610	951	74	1	2636	35	2671
Brisbane to Cairns	291	1228	113	0	1631	68	1699
Brisbane to Darwin	1065	1218	70	0	2353	80	2433
Canberra connections	6	65	50	0	121	0	121
Hobart to Burnie	0	263	56	0	319	15	333
Melbourne to Adelaide	0	493	191	1	685	31	716
Melbourne to Brisbane	727	582	1	0	1310	130	1440
Perth to Darwin	1359	2332	3	0	3694	14	3708
Sydney to Adelaide	239	673	46	6	965	36	1001
Sydney to Brisbane (inland route)	50	634	118	42	844	70	914
Sydney to Brisbane (Pacific highway)	40	575	85	10	710	84	794
Sydney to Melbourne	0	181	603	1	785	18	804
Total Km by road type	6482	10750	1427	61	18720	609	19329
% of network length by road type	33.5	55.6	7.4	0.3	96.9	3.1	100.0

Source BTCE estimates

Notes 1 Sydney to Brisbane via Newcastle.

2 Newcastle (Hexham) to Brisbane.

3 Tarcutta (Hume Highway) to Adelaide (Cavan).

4 Seymour to Toowoomba.

5 Port Augusta to Darwin.

6 Midland (Perth) to Katherine.

7 Brisbane to Threeways Roadhouse (Tennant Creek).

8 The route length between Hobart and Burnie is 320km. There is also 13km of parallel roadway declared as a National Highway.

DEMAND FOR TRAVEL ON THE ROAD NETWORK AND PROJECTED TRAFFIC VOLUMES

Estimating the quantity of travel demanded at a constant level of service

When demand rises towards capacity, the level of service will fall, and this will choke off some demand. Investment in new capacity may have the opposite effect, and stimulate demand. To assess the future adequacy of roads, however, it is desirable to estimate the quantity of travel that would be demanded in the absence of these effects.

In order to keep the effects of demand growth, that is, a rightward movement of the demand curve, separate from the effects of congestion on demand, that is, movements along the demand curve, it has been assumed that the level of service provided by infrastructure will remain unchanged as demand increases. This is illustrated by figure 3.2.

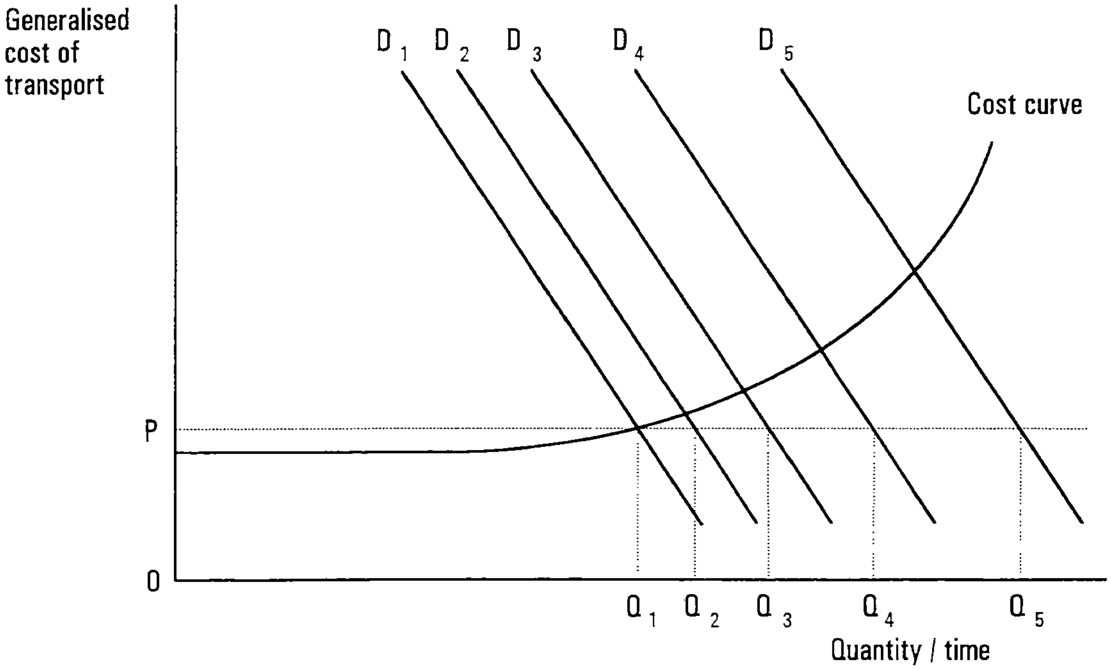


Figure 3.2 Quantity of transport demanded at a constant level of service

The position of a demand curve is shown for five time periods where demand is growing over time. The price level *P* represents the generalised cost at time 1 when the demand curve is at D_1. If the generalised cost remained constant at *P* as demand increased, the quantity demanded would equal the series of *Q's* along the horizontal axis. These are the quantities of travel that are estimated for the demand projections. If the effects of congestion were taken into account, the quantities demanded in each time period would be found at the intersection point of the demand curve for each time period and the cost curve.

Modelling the demand for travel on the selected network

A schematic representation of the processes used to model the demand for travel, and thus to estimate future traffic volumes on the network is shown in figure 3.3. The first task was to gather location specific traffic data from the available data sources. This enabled us to compile location specific AADT estimates for 1994 and to decompose them into light vehicle traffic volumes, and truck volumes.

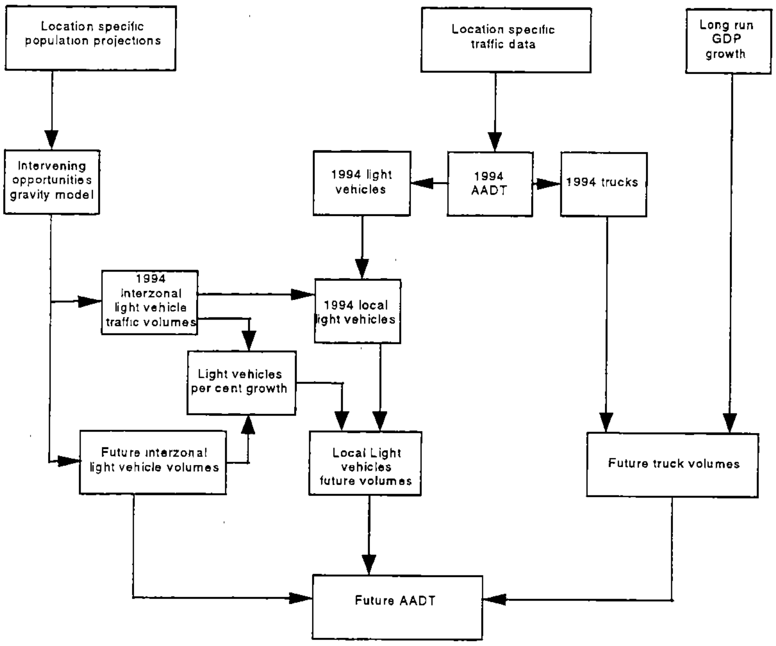


Figure 3.3 The demand for travel model

The next task was to gather location specific population data for 1994. These data are required for the intervening opportunities gravity model used to estimate inter zonal light vehicle traffic volumes for 1994. This model relates travel between zones to the population of those zones, the distances these are apart, and a parameter which reflects individual's propensity to travel (for a full documentation of the model see Roads and Traffic Authority of NSW 1991). Intra-zonal light vehicle traffic volumes for 1994 were estimated by subtracting the inter-zonal light vehicle volume from the aggregate light vehicle volume for each recorded location.

To estimate inter-zonal traffic volumes for a future time period, population projections had to be made from the base year to a future time period (that is, 1995-96 and 2014-15). These were drawn from ABS and state sources and where necessary, the published series were extrapolated out to the year of interest. Once the population projections were complete, the gravity model was used to estimate the inter-zonal light vehicle traffic volumes for 1995-96, and 2014-15. This process was completed for a base case, a high population growth scenario, and a low population growth scenario.

Once the inter-zonal traffic volumes for light vehicles had been estimated for the three time periods, the average annual growth rate between the three periods could be estimated. It was assumed that intra-zonal light vehicle traffic volumes would grow at the same rate as inter-zonal traffic volumes for light vehicles. This allowed the inter-zonal growth rates to be applied to the 1994 base estimate for the intra-zonal light vehicle traffic volumes, and thus, estimate the both the 1995-96, and 2014-15 intra-zonal traffic volumes for these vehicles.

To estimate truck volumes for 1995-96 and 2014-15, an assumption had to be made to overcome the paucity of data for much of the network. It was assumed that the growth rate in truck volumes would be the same as the average annual GDP growth rate over the same period. This was estimated to 3 per cent, and this rate was applied to the 1994 truck volumes to estimate the 1995-96 and 2014-15 truck volumes.

In this study, both time and data constraints have meant that the approach taken to modelling the demand for travel has been somewhat simplistic. This is particularly the case with regard to the estimation of future truck volumes on the road network. The GDP growth rate, and therefore, the growth in truck volumes is applied network wide. This does not allow for different economic conditions across regions, and has almost certainly resulted in truck volumes being under-estimated for regions with high growth regional economies, and an over-estimation of truck volumes in regions with contracting, or low growth regional economies.

Quantity of travel demanded: projected traffic volumes on the selected network

The average traffic levels on each corridor of the network are shown in table 3.2.

TABLE 3.2 PROJECTED AVERAGE TRAFFIC VOLUMES ON THE INTERCITY ROAD NETWORK BY CORRIDOR IN 1995-96

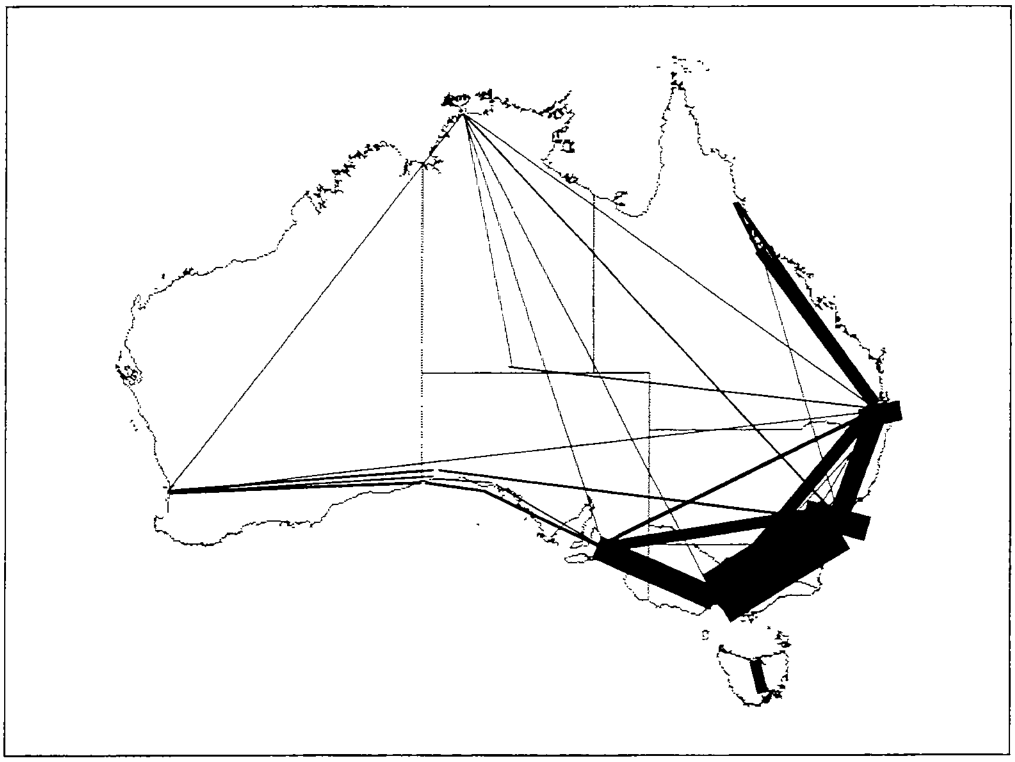
Thousands of vehicles a year

Corridor	*Trucks*	*Cars*	*All vehicles*
Adelaide to Darwin	64	153	217
Adelaide to Perth	101	394	495
Brisbane to Cairns	235	1817	2052
Brisbane to Darwin	68	475	543
Canberra connections	331	2893	3224
Hobart to Burnie	427	1721	2148
Melbourne to Adelaide	504	2253	2756
Melbourne to Brisbane	365	854	1219
Perth to Darwin	35	121	156
Sydney to Adelaide	212	1133	1345
Sydney to Brisbane (inland route)	601	3582	4183
Sydney to Brisbane (Pacific highway)	619	4740	5359
Sydney to Melbourne	1239	3509	4748

Source BTCE estimates

There are three corridors where the average traffic level exceeds 4 million vehicles a year. These are three of the four selected corridors that link Australia's three most populous cities; Sydney, Melbourne and Brisbane. The Pacific highway with an average traffic level of around 5.4 million vehicles a year is clearly the corridor that carries the most traffic. It is followed by the Sydney Melbourne corridor with 4.8 million vehicles a year and the inland corridor between Sydney and Brisbane with 4.2 million vehicles a year.

These three corridors also have the highest truck travel volumes and this suggests that these are the most important of the selected corridors in terms of the movement of freight. The Sydney Melbourne corridor (the Hume highway) has the highest volume of trucks, and as a result, appears to be the corridor that carries the largest amount of road freight.



Source Derived from data supplied by the Centre for Transport Policy Analysis Wollongong.

Figure 3.4 Road freight movements in 1994-95

This is confirmed by figure 3.4, which is a representation of current Australian road freight movements. These are the flows in both directions between 20 major centres in 1994-95. Only movements in excess of 100,000 tonnes per annum are included. Additionally, all freight that does not enter or leave the network at one of the 20 selected centres, and all intra-regional freight, is not included. These components are substantial proportions of total road freight, but the relative importance of corridors in terms of freight movement will still be evident.

The widths of the lines are proportional to the tonnages moved, and the areas of 'lines' are proportional to the tonne-kilometres moved. The dominance of the east coast and in particular, the Sydney-Melbourne corridor and the Sydney-Newcastle and Gold Coast-Brisbane segments of the Sydney-Brisbane corridor are clearly evident.

TABLE 3.3 PROJECTED AVERAGE TRAFFIC VOLUMES ON THE INTERCITY ROAD NETWORK BY CORRIDOR IN 2014-15

Thousands of vehicles a year

Corridor	*Trucks*	*Cars*	*All vehicles*
Adelaide to Darwin	112	228	340
Adelaide to Perth	176	468	644
Brisbane to Cairns	411	2917	3328
Brisbane to Darwin	120	696	816
Canberra connections	581	4204	4785
Hobart to Burnie	749	2091	2840
Melbourne to Adelaide	883	3428	4311
Melbourne to Brisbane	640	1160	1800
Perth to Darwin	61	189	250
Sydney to Adelaide	372	1542	1914
Sydney to Brisbane (inland route)	1068	4814	5882
Sydney to Brisbane (Pacific highway)	1094	7639	8733
Sydney to Melbourne	2173	4847	7019

Source BTCE estimates

By 2014-15 traffic volumes on all corridors are projected to have increased. The ordering of corridors, however, from those with the highest traffic volumes to those with the lowest traffic volumes is likely to remained unchanged. The corridors along the eastern sea board will remain those with both the highest overall traffic volumes, and those with the highest truck volumes.

The Sydney Melbourne corridor and the two Sydney Brisbane corridors are projected to have the largest absolute increases in traffic volumes. They are followed by the Federal and Barton highways leading into Canberra; the Melbourne to Adelaide corridor, and the Brisbane to Cairns corridor. All these corridors are either in the south eastern corner of Australia, or along the eastern seaboard where population growth is projected to be highest. Although the Adelaide to Darwin and Perth to Darwin corridors are projected to have high growth rates, they start from low base volumes, and as a result, are projected to have the smallest absolute increases in traffic volumes (see table 3.4).

TABLE 3.4 PROJECTED GROWTH IN ANNUAL TRAFFIC VOLUMES FROM 1995-96 TO 2014-15

Corridor	*Traffic volumes ('000 vehicles)*		*Absolute change ('000 vehicles)*	*Average annual growth (%)*
	1995-96	*2014-15*		
Adelaide to Darwin	217	340	123	2.4
Adelaide to Perth	495	644	150	1.4
Brisbane to Cairns	2052	3328	1276	2.6
Brisbane to Darwin	543	816	273	2.2
Canberra connections	3224	4785	1561	2.1
Hobart to Burnie	2148	2840	691	1.5
Melbourne to Adelaide	2756	4311	1555	2.4
Melbourne to Brisbane	1219	1800	581	2.1
Perth to Darwin	156	250	95	2.5
Sydney to Adelaide	1345	1914	569	1.9
Sydney to Brisbane (inland route)	4183	5882	1699	1.8
Sydney to Brisbane (Pacific highway)	5359	8733	3374	2.6
Sydney to Melbourne	4748	7019	2271	2.1

Source BTCE estimates

CHAPTER 4 TECHNICAL ADEQUACY OF THE ROAD INFRASTRUCTURE

INTRODUCTION

In this chapter, a technical assessment is made of the selected road network's infrastructure. First, a technical assessment is conducted whereby the levels of service (LOS) given by different road sections are estimated. First, however, the LOS measure (freedom from congestion) used in this study and how it is estimated is explained. The LOS estimates are compared to rank the relative performance of various parts of the selected highway system.

LEVEL OF SERVICE

Level of service is a traffic engineering concept that is used as an indicator of road congestion levels. It is a performance based measure and there are six defined service levels which correspond to particular traffic flow characteristics. These range from 'A' to 'F'. 'A' indicates that a road is uncontested and that users do not interfere with one another. 'F' indicates that the traffic volume exceeds a road's maximum traffic flow rate, and as a result, it is highly congested.

The particular level of service at which a road may be defined as technically inadequate is quite arbitrary, and for this reason, no attempt has been made in this study to classify roads as either technically adequate, or technically inadequate. Rather, this concept is used to give an indication of those parts of the road network that are most likely to provide poor levels of service in the future. That is, those parts of the current infrastructure that will most likely require capacity expanding infrastructure investment to cater for projected future traffic volumes.

LEVEL OF SERVICE ESTIMATION

The level of service that a road provides is dependent upon a road's capacity utilisation (the volume capacity ratio) level, and as capacity utilisation increases, the level of service declines. In this study, the HDM-C model (see Appendix I for a detailed description of the model) is used to calculate volume capacity ratios and translate them into level of service values. In the model, road capacity is dependent upon pavement width, shoulder width, terrain type, the number of lanes, and the proportion of heavy vehicles. Traffic volumes are an exogenous input into the model and are determined by the projected level of demand from road users. Traffic volumes and hence congestion levels vary considerably over time. The annual hourly traffic volume distribution is therefore an important consideration in the level of service estimation process. This distribution is represented in the model by a histogram which shows the traffic volume (on the y-axis) in each hour of the year from the hour with the highest volume of traffic to the hour with the lowest volume of traffic (along the x-axis).

The levels of service that each section of the current road network may provide at the projected traffic volumes for both 1995-96, and 2014-15, were estimated at the hundredth highest hour of the year.

LEVEL OF SERVICE PERFORMANCE SCORES

To enable an inter-corridor comparison to be made of road service levels, it is necessary to calculate a performance score for each corridor. Similarly, to enable and an intra-corridor comparison to be made of road links that contain more than one section, a performance score needs to be calculated for each of these links.

This score is calculated by multiplying the proportion of a link's length that provides a given level of service by a weight assigned to that particular level of service. This is done for each defined level of service and the sum of these amounts is the performance score for that section of road. The weights assigned to each level of service are shown in table 4.1.

TABLE 4.1 LEVEL OF SERVICE WEIGHTS

Level of service	*Weight*
A	0
B	20
C	40
D	60
E	80
F	100

A link or corridor that provides level of service 'A' over its total length will have a performance score of 0. If it provides level of service 'F' for its entire length, it will have a performance score of 100. These scores may not be used to make any inferences other than to rank the relative performance of different road corridors/links.

FINDINGS

Performance of individual sections on the network

If no further investment took place, the majority of the current road network would still be providing LOS 'A' in 2014-15. There would be, however, several thousand kilometres providing LOS 'E' or 'F', and the majority of this would be on the road corridors along the eastern seaboard. The length of road that will provide each level of service on the selected network is shown in figure 4.1.

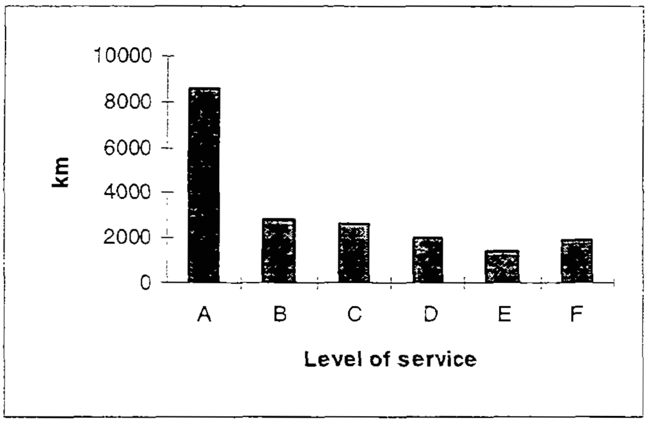


Figure 4.1 Level of service to be provided by the selected road network in 2014–15

Detailed analysis of individual corridor sections indicates that in general, performance deteriorates as the corridors approach capital cities. In the absence of upgrading, several sections outside of Sydney, Melbourne, Brisbane, Adelaide and Hobart are expected to provide relatively low levels of service by 2014-15. This is due to high traffic growth rates close to the main urban areas.

This analysis also indicates that several sections of the Barton Highway and some sections of the road between Burnie and Devonport in Tasmania provide poor levels of service. The two lane sections of the Hume Highway will provide poor levels of service before 2014-15.

Corridor level of service performance

The level of service performance scores for each corridor are presented in table 4.2.

TABLE 4.2 LEVEL OF SERVICE SCORES BY CORRIDOR

Corridor	*1995-96*	*2014-15*
Sydney - Brisbane (Pacific Highway)	89	98
Sydney - Brisbane (New England Highway)	55	77
Brisbane - Cairns	44	62
Canberra connections	51	57
Melbourne - Brisbane	32	56
Sydney - Melbourne	34	55
Hobart - Burnie	38	52
Melbourne - Adelaide	26	42
Sydney - Adelaide	19	33
Adelaide - Perth	13	20
Brisbane - Darwin	6	11
Perth - Darwin	6	7
Adelaide - Darwin	3	5

Source BTCE Estimates

The Pacific Highway, the only inter capital road corridor not part of the National Highway system, clearly stands out as the worst performer. As early as 1995-96, it is expected to be highly congested for more than 100 hours annually along most of its length. It is followed by the New England Highway, and the Bruce Highway. The road corridors in the western half of mainland would provide the highest levels of service.

More details of the findings for individual corridors are in box 3.1, and findings for individual corridor links are in appendix III.

BOX 4.1 FINDINGS OF THE TECHNICAL ASSESSMENT

Sydney-Melbourne: Overall the Hume Highway provides a good level of service and this is expected to continue for the next 20 years. The two lane sections in NSW are currently providing a low level of service. Substantial traffic growth over the next twenty years is expected to cause the service levels on much of the four lane road close to Sydney and Melbourne to deteriorate rapidly if no improvements are made.

Sydney-Brisbane: The Pacific Highway provides low levels of service for almost its entire length. The large volumes of traffic expected on the Queensland section of the highway make this part of the road slightly worse than the rest. There are low levels of service expected for some parts of the Pacific Highway that are already six lanes. The Hornsby to Minmi link, close to Sydney, which is common to both routes is one of the least adequate links in the system.

Canberra connections: The Federal Highway has a score of 38 and the Barton Highway a score of 91 for 2014-15. Despite the vast difference in the scores for the two highways, they both provide good levels of service in the three and four lane sections and low levels of service in the two lane sections.

Melbourne-Adelaide: The Victorian sections perform badly due to the high proportion of heavy vehicles expected and a rapid increase in demand between 1995-96 and 2014-15.

Sydney-Adelaide: This corridor starts at the intersection between the Hume and Sturt Highways and therefore it does not enter Sydney. In general this road provides a good level of service apart from some sections approaching Adelaide.

Melbourne-Brisbane: Apart from the Queensland sections of this highway which perform well, this highway will only have a reasonable performance by 2014-15. The corridor excludes the Cunningham Highway from Toowoomba to Ipswich included in the Brisbane-Darwin corridor.

Brisbane-Cairns: The least adequate sections of this road are close to Brisbane. The large traffic volume and substantial growth rate contribute to the rapid deterioration in performance of the road. Some parts of the Bruce highway have regular passing lanes and four lane sections which reduce congestion.

Adelaide-Perth: This corridor carries only a small amount of traffic and has a correspondingly good level of service. Short sections of road entering Adelaide and Perth, however, do not perform well.

Adelaide-Darwin: All sections of this road provide good levels of service and will continue to do so until 2014-15. The corridor excludes the road from Adelaide to Port Augusta, included in the Adelaide-Perth corridor, and which provides a lower level of service.

Perth-Darwin: Apart from a short section approaching Perth and another section of one lane road, this corridor provides a good level of service.

Brisbane-Darwin: The link from Ipswich to Toowoomba is relatively poor but the remainder of the highway provides some of the best levels of service in the system.

Hobart-Burnie: Burnie to Devonport contains some poorly performing sections as well as some sections which provide a high level of service.

CHAPTER 5 ECONOMIC ADEQUACY OF ROAD INFRASTRUCTURE

INTRODUCTION

In this chapter, an economic assessment is conducted to estimate the amount of capacity expanding infrastructure investment that may be economically justified by the year 2014-15. This analysis draws on the theoretical model set out in chapter 2 and the extensions to it that are discussed in appendix II. A series of sensitivity tests are also conducted to establish how sensitive the results are to the values of some key parameters.

ECONOMICALLY JUSTIFIED INVESTMENT: OPTIMAL TIMING AND THRESHOLD AADTS

Each corridor of the selected network was assessed to gain an insight into the level of infrastructure investment that may be warranted according to the economic criteria explained in chapter 2. The optimal timing condition was used to estimate threshold AADT values for a range of investment projects in a range of traffic and terrain conditions. A threshold AADT value is the AADT value above which a capacity expanding investment project may be economically justified in a given set of traffic and terrain conditions.

With demand growing, the optimal time for capacity expanding investment to occur is the first year when the annual benefit from having the expanded capacity exceeds the gain from delaying the project by a year. The latter is found by multiplying the discount rate (8 per cent) by the capital cost. The methodology is explained further in chapter 2.

When this condition is satisfied in a cost benefit model (see appendix II for a full description of the model used in this study), the AADT level on the unimproved road is an estimate of the threshold AADT value.

ASSESSMENT PROCEDURE

Investment assessment of roads outside town limits

The road categories defined in chapter three enabled the following investment projects to be defined for roads outside town limits:

- the widening of narrow two lane roads;
- the duplication of wide two lane roads, that is, two lanes to four lanes; and
- the expansion of four lanes roads to six lane roads.

To estimate threshold AADT values for possible widening projects, narrow two lane roads were assumed to be widened either from six to 7.0 metres, or from 6.5 to 7.0 metres. In both cases it was assumed that a 1.5 metre sealed shoulder was also put in place. Threshold AADT values were estimated for these projects in three different terrain conditions: flat, undulating and mountainous, and with four different levels of heavy vehicles measured as a percentage of the AADT level (50%, 40%, 30% and 20%). The proportion of heavy vehicles assumed to be articulated vehicles was 70 per cent while the remaining 30 per cent were assumed to be rigid trucks. This meant 24 threshold AADT values were estimated for widening projects.

These four heavy vehicle levels and three terrain types were also used to estimate threshold AADT levels for both the duplication of wide two lane roads to four lane highways, and, for expanding four lane highways to six lane highways. This meant that 12 threshold AADT values were estimated for each one of these latter project types.

Once the threshold AADT values had been estimated, each individual observation in the roads data base was screened. If the recorded AADT level was above the threshold AADT level for the particular project type being assessed, and given the conditions defined by the recorded proportion of heavy vehicles and the recorded terrain type for that observation, it was marked as a successful candidate for that particular project type.

Observations which conformed to the definition of a narrow two lane road were assessed first to ascertain if they may warrant widening to a wide two lane road. The successful candidates were then upgraded to wide two lane road and assessed along with all the existing wide two lane road for duplication to four lane highway. The successful candidates were then upgraded to four lane highway and assessed with all the existing four lane highway for expansion to six lane highway. At each stage, successful candidates were marked to indicated that may warrant that particular level of improvement (that is, widening and /or duplication to four lanes and/or expansion to six lanes).

This procedure was carried out for both the 1995-96 and 2014-15 traffic levels. The highest level improvement defines the level of capital works required to service these projected traffic levels. These road improvements were then costed using unit costs that are specific to the type of improvement required, and the terrain in which the improvement is expected to be made. These are listed in table 5.1.

TABLE 5.1 UNIT COSTS FOR ROAD CONSTRUCTION PROJECTS

Project type	*Terrain Type*		
	Flat	*Undulating*	*Mountainous*
Widen from 6 to 7 meters ($m per 1000 sq. meters)	0.8	0.8	0.8
Widen from 6.5 to 7.0 meters ($m per 1000 sq. meters)	0.7	0.7	0.7
2 to 4 lanes ($m per Km.)	2.5	3.7	5.0
4 to 6 lanes ($m per Km.)	3.7	5.5	7.4
2 to 6 lanes ($m per Km.)	5.4	8.1	10.8

Source BTCE estimates

The aggregate costing figure indicates the amount of road investment that may be required on roads outside town limits by the year 2014-15.

In this study we concentrated on capacity expanding investment projects for intercity roads. It was not possible to consider realignment projects because state road authority databases do not contain details of gradients and curvatures. Another important component of road investment, flood mitigation and associated bridgeworks, similarly could not be included because of lack of data on flooding frequency. Possible projects to move from six lanes to eight were not considered.

For the projects that were analysed, it is likely that the investment estimates are too low. Overheads, administration and project pre-construction costs were not included and, based on past expenditure levels, these could be expected to add 5 to 7 per cent to our expenditure estimates. Reduced accident costs have not been considered because the BTE (1985) found that they may only account for some 3 per cent of benefits.

Construction of overtaking lanes has not been considered because of the difficulties in modelling their effects on traffic dynamics and because their frequency and lengths will vary with the type of terrain. This strategy is further justified on a number of grounds:

- Overtaking lanes relieve congestion caused by slow vehicles, and do not add greatly to the capacity of a road. These may therefore be regarded as an inferior and intermediate step to duplication, particularly when funds are in short supply.

- It does not follow that omission of overtaking lanes from the analysis will necessarily lead to an overestimate of future spending requirements. If used as an intermediate stage between two and four lanes, construction of overtaking lanes could result in higher infrastructure costs. This is because the third lane may not be reused if a divided highway, with a median strip, is constructed some time after the overtaking lane. Indeed, overtaking lanes may not be a cost-effective way to increase capacity if duplication is required in the foreseeable future.
- The analysis indicates that for 70 per cent of warranted expenditure on duplication, the AADTs exceed the thresholds at the beginning of the period, and therefore, overtaking lanes would not be satisfactory as an intermediate stage for a large part of the road network which is in need of duplication in the short term.

Town bypass assessment procedure

Where the road network passes through towns, an analysis was conducted to establish if the construction of a bypass may be warranted. This analysis demands that both the amount traffic expected to use a bypass, and the amount of traffic expected to use the road inside the town after construction of a bypass to be estimated. For each town, the expected bypass traffic was assumed to be 75 per cent of the existing traffic level on the road outside the town. The expected town traffic level after the bypass is the current town traffic level less the estimated bypass traffic.

The cost benefit model used to estimate threshold AADT values for road investment outside of towns was enhanced to allow demand for the use of both a bypass, and a town road, to be incorporated into the analysis. Threshold AADT levels for a bypass were estimated by fixing the town road AADT level and increasing the AADT level on the bypass until the benefits of construction exceeded the benefits of delaying construction. The bypass AADT level at this point was recorded as the threshold AADT level for a given set of conditions, and the set quantity of post bypass town road traffic. This process was carried out for 21 different town road AADT levels.

Threshold AADT levels for a bypass were examined for two and four lane town roads, and a two lane bypass road. The same four levels of heavy vehicle traffic used for open road investment projects were used for bypasses. The terrain type for all towns, however, was assumed to be flat. This meant that 168 threshold AADT levels were estimated for bypass projects.

The data was then screened to locate road inside town limits. This allowed the expected bypass traffic level, and expected town road traffic level after the bypass to be estimated for each town. These AADT values were then compared with the threshold AADT value for the particular set of road and traffic conditions recorded for a particular town. This established whether a two lane bypass may be warranted.

Where a 2 lane bypass may be economically justified, the expected bypass AADT level was then compared with the threshold AADT for duplication from 2 to 4 lanes. If it exceeded the threshold, it was deemed that a 4 lane bypass may be warranted.

The capital cost of successful candidates was then estimated using unit costs for the particular type of bypass that may be warranted (see table 5.2).

TABLE 5.2 UNIT COSTS FOR BYPASS CONSTRUCTION

Project type	*$m per Km.*
2 lane bypass	3.3
4 lane bypass	6.6

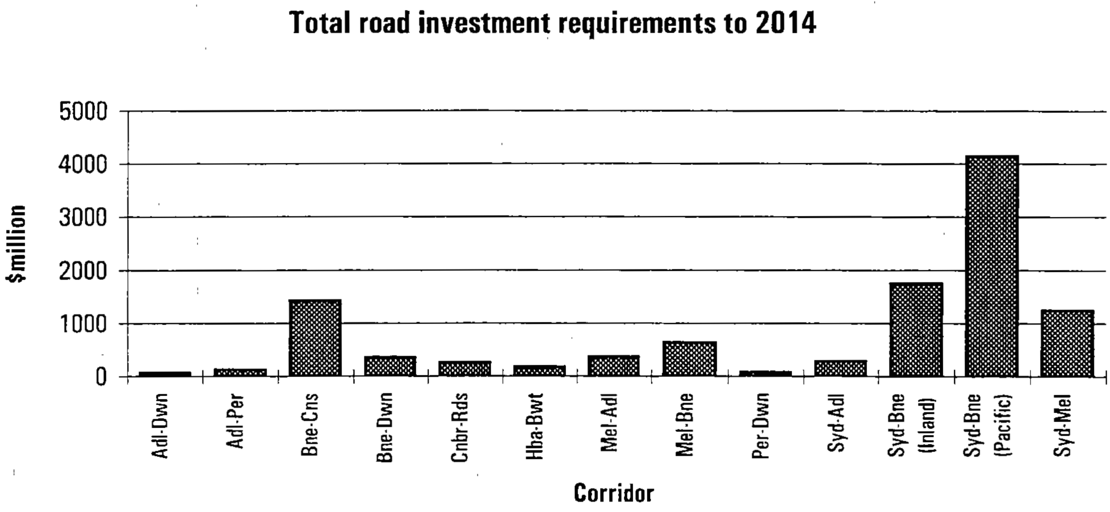
Source BTCE estimates

It was assumed the bypass would be the same length as the road inside the town limits for this purpose.

This procedure may under estimate the cost of a bypass for large towns that have a long length of approach road with a speed limit of between 60 and 110 kilometres per hour.

FINDINGS

The estimated level of warranted expenditure on the intercity road network under consideration over the next 20 years is \$11.3B. This includes \$10.0B for widening and lane adding projects, and \$1.3B for the construction of town bypasses. It is acknowledged that construction costs for individual road projects will be highly variable, but by using typical costs to arrive at an aggregated estimate, the overestimates and underestimates should tend to average out. The distribution of these expenditures between corridors is illustrated in figure 5.1 and table 5.3 provides details by corridor and project type. The tables in appendix III give expenditure at the link level.



Source BTCE estimates

Figure 5.1 Estimated road investment by corridor

There are four corridors for which investment requirements exceed \$1B each. Together they account for \$9.1B (81 per cent) of the total. These corridors are the Pacific Highway (\$4.3B), the Bruce Highway (\$1.4B), the inland route between Sydney and Brisbane (\$2.1B) and the Hume Highway (\$1.4B). The Pacific Highway between Sydney and Brisbane is clearly the corridor that requires the highest level of investment. The remaining nine corridors will collectively require around \$2.2B of investment by 2014-15.

TABLE 5.3 ESTIMATED INVESTMENT REQUIREMENTS TO 2014-15

($ million)

Corridor	*Roads outside town limits*					*Town bypasses*	*Total corridor expenditure*[1]
	Widening	*2 to 4 lanes*	*2 to 6 lanes*	*4 to 6 lanes*	*Sub-Total*		
Sydney to Brisbane (Pacific highway)	4	2 376	421	990	3 791	463	4 254
Sydney to Brisbane (inland route)	16	1 511	51	435	2 013	101	2 114
Brisbane to Cairns	61	733	16	394	1 203	168	1 372
Sydney to Melbourne	0	510	0	767	1 277	69	1 346
Melbourne to Brisbane	220	9	0	0	313	309	621
Brisbane to Darwin	9	106	0	140	255	89	344
Melbourne to Adelaide	0	43	11	241	295	45	340
Sydney to Adelaide	50	140	0	39	228	31	260
Canberra connections	0	256	0	0	256	0	256
Hobart to Burnie	0	141	0	0	141	12	153
Adelaide to Perth	1	37	0	41	80	19	99
Perth to Darwin	13	61	0	0	74	0	74
Adelaide to Darwin	1	15	0	24	40	0	40
Total by project type	374	6 021	499	3 071	9 965	1 306	11 271

Source BTCE Estimates

1. Estimates exclude projects involving realignments, flood mitigation and associated bridgeworks, expanding from six to eight lanes, construction of overtaking lanes, projects in urban areas, and administration and pre-construction costs. Many of these expenditures are proportional to those considered and so the distribution provides a good indication of the proportions of intercity road expenditure.

A detailed analysis of individual road sections revealed that per kilometre expenditure requirements will be considerably higher close to the capital cities because this is where both traffic levels, and traffic growth rates are highest. About 5 per cent of the length of road assessed is within 50km of the designated corridor end points in the outskirts of the capital cities, Cairns, and Burnie. This section of the road network requires 16 per cent of the estimated expenditure, or $1.8B. Table 5.4 contains the details.

TABLE 5.4 ESTIMATED COST OF ROAD IMPROVEMENTS WITHIN 50KM OF SELECTED CORRIDOR END POINTS

($ millions)

Corridor	*Beginning*	*End*	*Total*
Sydney-Melbourne	134	115	249
Canberra con[1] (Federal Highway)	101	na	101
Canberra con (Barton Highway)	149	na	149
Sydney-Brisbane:			0
Inland route[2]	112	97	209
Pacific Hwy[3]	na	225	225
Sydney-Adelaide (Sturt Highway)[4]	na	44	44
Melbourne-Adelaide	135	110	245
Melbourne-Brisbane (Newell Hwy)[5]	na	na	0
Brisbane-Cairns	186	48	234
Adelaide-Perth	14	66	80
Adelaide-Darwin[6]	na	39	39
Perth-Darwin[7]	67	na	67
Brisbane-Darwin[8]	61	na	61
Hobart-Burnie	34	59	93
Australia	993	803	1 796

Source BTCE Estimates

Notes 1 Two highways that connect Canberra with the network.

2 Sydney to Brisbane via Newcastle.

3 Newcastle (Hexham) to Brisbane.

4 Tarcutta (Hume Highway) to Adelaide (Cavan).

5 Seymour to Toowoomba.

6 Port Augusta to Darwin.

7 Midland (Perth) to Katherine.

8 Brisbane to Threeways Roadhouse (Tennant Creek).

na not one of the selected corridor end points.

It is also worth noting that the technical and economic assessments have provided similar findings in terms of the location of potential infrastructure inadequacies. This is observable by comparing tables 4.2 and 5.3.

SENSITIVITY ANALYSIS

Further analysis was carried out to test the sensitivity of the foregoing results (that is. the base case) to alternative assumptions about:

- the weighting of benefits that accrue to cars;
- traffic growth rates; and
- the discount rate.

The results of these sensitivity tests are displayed in table 5.5.

By assigning a zero weighting to benefits that accrue to cars, a greater emphasis is placed on the movement of freight by heavy vehicles. This increases all threshold AADTs but thresholds for roads with low proportions of heavy vehicles increase much more than thresholds for roads with high proportions of heavy vehicles.

In most cases, this will reduce the expenditure requirement of roads with a low proportion of heavy vehicles by a greater percentage amount than roads with a high proportion of heavy vehicles. It should be noted, however, that a corridor's expenditure requirement may not change much even if it has a low proportion of heavy vehicles. If a corridor has large sections of road for which projected AADTs exceed the threshold AADTs by a considerable margin, the results for such a corridor may be insensitive to this test.

By only counting benefits that accrue to heavy vehicles, the total expenditure requirement was reduced by 32 per cent with the largest reduction being on the passenger orientated Brisbane to Cairns corridor. The smallest reductions were on the Adelaide to Darwin corridor and the Hume Highway. Both these corridors have a relatively high proportion of heavy vehicles.

To test the sensitivity of the results to alternative demand projections, the 2014-15 traffic volumes where adjusted by amounts consistent with the high and low traffic volume growth rates derived from high and low population growth projections. The adjustment factors for each corridor are listed in table 5.6.

TABLE 5.6 HIGH AND LOW GROWTH DEMAND SCENARIOS

% change to AADTs relative to base

Corridor	*Low growth*	*High growth*
Sydney-Melbourne	-10	11
Sydney-Brisbane (Inland)	-9	8
Sydney-Brisbane (Pacific)	-10	9
Federal highway	-7	5
Barton highway	-9	6
Melbourne-Brisbane	-13	14
Sydney-Adelaide	-12	14
Melbourne-Adelaide	-13	15
Adelaide-Perth	-14	23
Brisbane-Darwin	-9	4
Adelaide-Darwin	-16	15
Perth-Darwin	-8	11
Brisbane-Cairns	-8	8
Hobart-Burnie	-1	1
Weighted average	-11	12

Source BTCE estimates

Under the high growth rate assumption which involved an average increase in AADTs of 12 per cent, the expenditure requirement increased by around 18 per cent . Both the Adelaide to Perth and Perth to Darwin corridors have very large increases in expenditure from the base case, suggesting that there is some road that is close to needing investment in 2014-15. Under the low growth rate assumption, which involved an average decrease in AADTs of 11 per cent, the expenditure requirement fell by around 8 per cent. The 30 per cent reduction in expenditure for the Melbourne - Brisbane corridor suggests that much of the recommended investment is marginal. As in the heavy vehicles sensitivity test, the results, particularly for the low growth case, are dependent to some extent upon how marginal the required investments are in the base case.

The 12 per cent discount rate test not only tests the sensitivity of the base case results to this particular parameter change, it also provides an indication of which corridors will be in most need of the required infrastructure investment. The higher discount rate increases the threshold AADTs for all investment projects. It follows that the corridor with the least marginal investment requirements will be the least sensitive this parameter change. The most marginal corridors are therefore Melbourne to Brisbane, Brisbane to Darwin and Brisbane to Cairns with around a 20 per cent reduction in expenditure from the base case. Overall, this test reduces the total expenditure requirement by around 8 per cent.

TABLE 5.5 RESULTS OF SENSITIVITY ANALYSIS

($ millions)

Corridor	*Base*	*Heavy vehicle benefits*		*High traffic growth*		*Low traffic growth*		*12% discount rate*	
		New	*% Change*	*New*	*% Change*	*New*	*% Change*	*New*	*% Change*
Adelaide to Darwin	40	34	-14	40	0	34	-14	35	-12
Adelaide to Perth	99	68	-32	316	219	94	-5	85	-14
Brisbane to Cairns	1 372	511	-63	1 519	11	1 160	-15	1 111	-19
Brisbane to Darwin	344	130	-62	395	15	282	-18	276	-20
Canberra connections	256	123	-52	256	0	256	0	256	0
Hobart to Burnie	153	87	-43	153	0	153	0	149	-3
Melbourne to Adelaide	340	217	-36	573	68	308	-10	302	-11
Melbourne to Brisbane	621	307	-51	799	29	432	-30	487	-22
Perth to Darwin	74	31	-57	162	120	67	-9	67	-9
Sydney to Adelaide	260	106	-59	395	52	209	-20	244	-6
Sydney to Brisbane (inland route)	2 114	1 638	-23	2 234	6	1 944	-8	1 963	-7
Sydney to Brisbane (Pacific highway)	4 254	3 311	-22	4 951	16	4 220	-1	4 193	-1
Sydney to Melbourne	1 346	1 087	-19	1 476	10	1 228	-9	1 234	-8
Totals	11 271	7 649	-32	13 269	18	10 387	-8	10 401	-8

Source BTCE estimates

CHAPTER 6 MAINTENANCE

INTRODUCTION

After road infrastructure has been constructed, there is usually an obligation to maintain its condition to preserve the asset's value. Maintenance of road infrastructure is a major component of expenditure on roads. In 1994-95 the budgeted expenditure on maintenance of the National Highway System is some $330M or about 40% of total expenditure. It follows that over the period from 1995-96 to 2014-15, spending on road maintenance may be expected to total several billion dollars.

Estimates of this expenditure for the selected network are presented both on a state basis, and on a corridor basis in this chapter. First, however, there is a non-technical explanation of the methodology used to make the estimates. Further technical detail is contained in appendix IV. Lastly, the results of an alternative approach are presented and these are used to help define a likely range for the estimated maintenance expenditure figure.

METHODOLOGY

The cost and variability of economically justified road maintenance expenditure over the period from 1995-96 to 2014-15 was estimated with a generalised maintenance regime and pavement deterioration model. The annual maintenance expenditure estimation procedure was based on the following premises :

- the state of the pavement should not deteriorate beyond a minimum standard, which may be expressed as a critical pavement roughness level;
- pavement roughness may be used as a measure of deterioration and as a trigger for major maintenance works;
- the timing of major pavement rehabilitation work may be related to its deterioration to a specified roughness threshold;
- a representative routine maintenance regime may be developed around rehabilitation works.

It follows that the evolution of pavement roughness is the key process to be modelled. A simplified pavement deterioration model was develop by drawing upon work undertaken by the World Bank and the BTCE. The key equation used to predict the timing of maintenance intervention was:

$$\text{Pavement Life Expectancy} = (1/m) . \ln[R_C/R']$$

where Pavement Life Expectancy is the time elapsed from the present until the pavement reaches critical roughness R_C , given its current roughness R' and an environmental parameter m that is related to the rate of pavement deterioration.

The model has modest data requirements and was applied uniformly across the selected road network. Further details on the model's underlying theory, its derivation, and specification are set out in Appendix IV.

Critical roughness was assumed to vary with traffic volume according to the relationship derived in a previous BTCE (1992) study. The relationship is based on optimising the economic return of a road by minimising the sum of vehicle operating costs and pavement lifecycle costs. The outcome is that roads with low traffic volumes are allowed to deteriorate to a greater roughness level than roads with high traffic volumes. The roughness levels and associated average traffic volumes used in this study are as follows:

- 150 NRM for AADT<800;
- 120 NRM for 800<AADT<2000;
- 110 NRM for AADT>2000.

The maintenance requirements of each pavement section were considered separately and costs were calculated for the following maintenance regime:

- routine maintenance (patching, grass cutting, replacing signposts) which occurs every year;
- resealing (about every 10 years it is necessary to spray bitumen and spread a thin layer of gravel or aggregate over roads to seal cracks and to waterproof the surface and therefore slow the rate of deterioration) and possibly also shape correction; and,
- reconstruction or overlay (the pavement is either totally replaced or overlaid with a thick layer of bitumen) when the pavement reaches an unacceptable level of roughness.

Details about unit costs and other parameters are contained in Appendix IV.

The maintenance estimates were based on the current infrastructure of the selected road network and were made in constant 1994 prices.

PROJECTED MAINTENANCE EXPENDITURE

The projected total expenditure on road asset preservation over the period from 1995-96 to 2014-15 is estimated to be $6.5B. This is equivalent to some $325M per annum or an average annual amount of around $16 800 for each kilometre of road. On the Hume and Pacific highways, this figure increases to around $35 000 per kilometre per annum.

In figure 6.1, a 5 year moving average of annual maintenance requirements has been plotted to smooth out annual fluctuations and to reflect standard engineering practice of developing a rolling maintenance program.

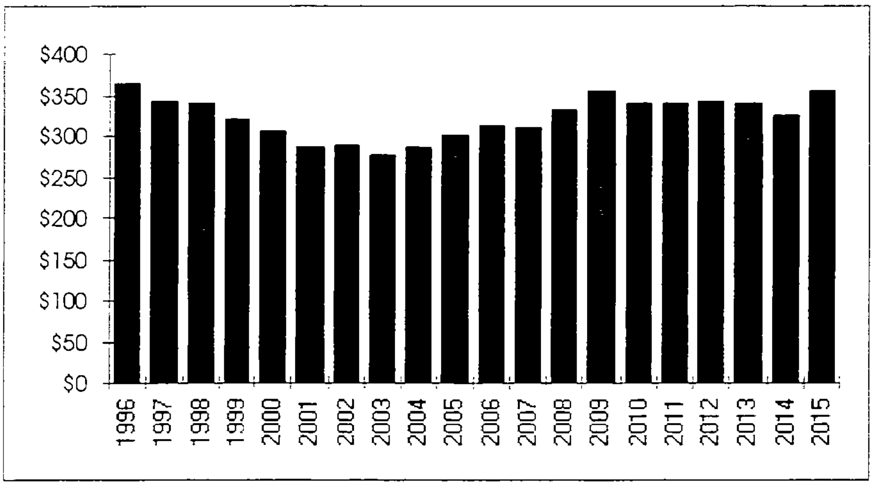


Figure 6.1 **Variation in projected road maintenance expenditure from 1995-96 to 2014-15**

The demand for expenditure on road maintenance is predicted to be some $365M per annum at the start of the study timeframe and then to fall to around $280M by the year 2000. Maintenance expenditure will increase over the next few years and then fluctuate between $330M and 360M from 2008 until 2014-15.

The ageing of current road infrastructure will be a significant determining factor of future maintenance requirements, and this is likely to result in higher levels of maintenance expenditure than those shown in figure 6.1.

The breakdown of forecast maintenance expenditure by corridor is shown in table 6.1, and by state in table 6.2.

TABLE 6.1 FORECAST ROAD MAINTENANCE EXPENDITURE BY CORRIDOR

Link	*Kms*	*20 year Cost ($M)*	*Avg. yearly Cost ($M)*	*Av. Cost ($/km/year)*
Hume	804	$574	$29	$35,700
ACT Links	121	$77	$4	$31,800
Pacific	794	$616	$31	$38,800
New England	914	$450	$23	$24,600
Sydney-Adelaide	1,001	$500	$25	$25,500
Melbourne-Adelaide	716	$379	$19	$26,500
Bruce	1,699	$810	$41	$23,800
Newell	1,440	$756	$38	$26,300
Tasmania	333	$101	$5	$15,200
Brisbane-Darwin	2,433	$829	$41	$17,000
Adelaide-Darwin	2,695	$503	$25	$9,300
Adelaide-Perth	2,671	$570	$29	$10,700
Perth-Darwin	3,708	$342	$17	$4,600
ALL	19,329	$6,510	$325	$16,800

TABLE 6.2 FORECAST ROAD MAINTENANCE EXPENDITURE BY STATE

$M

State	*20 year Cost*	*Avg. yearly Cost*
NSW	2330	115
Victoria	630	32
Queensland	1860	93
South Australia	550	28
Western Australia	660	33
Tasmania	100	5
Northern Territory	360	18
ACT	20	1.0
TOTAL	6,510	325

An alternative approach: critical roughness

An alternative approach to the timing of maintenance intervention is to adopt a uniform critical roughness standard (for example 100, 110 or 120 NRM) across the entire network. The corresponding demand for road maintenance expenditure is shown in Table 6.3. The results from using a critical roughness that varies with traffic volume has also been included for comparison.

Depending on the road roughness standard that is adopted, the projected demand for road maintenance expenditure varies between $6.5B and $7.8B over the 20 year period. On the basis of figures in Table 6.3, it may be concluded that the cost of asset preservation over the 20 year study period is likely to be between $6.5B and 7.8B. This amounts to an average expenditure amount of between $325M and 375M per annum.

TABLE 6.3 SENSITIVITY OF ROAD MAINTENANCE EXPENDITURE TO CRITICAL ROUGHNESS

Critical Roughness (NRM)	*20 year cost ($B)*
100	$7.8
110	$7.1
120	$6.4
110,120,150	$6.5

Impact on maintenance expenditure of new road infrastructure

The limited time available for this study has meant that the maintenance analysis was based on the current infrastructure. Future investments would be expected to have a limited impact on the results shown. It is difficult to predict which way this impact would go as there are factors working both to decrease and to increase maintenance costs. New sections of road, such as by-passes, will have lower maintenance costs in the study period because reconstruction will not be necessary until well after 2014 15. On the other hand, projects such as duplication will increase the total area of road to be maintained. If the original carriageway is retained, it will still require the same program of routine maintenance and reconstruction. The net effect is that the annual cost of asset preservation is unlikely to be significantly reduced by the construction of new infrastructure, and in fact, it could be significantly higher.

CHAPTER 7 CONCLUSIONS, IMPLICATIONS AND FUTURE RESEARCH

INTRODUCTION

In this chapter the major implications of the findings will be discussed. The major findings are set out at the beginning of this paper. Following an assessment of the task there will be a brief discussion into the limits that should be placed on the inferences that may be drawn from the findings of this study. This will lead into a discussion about a future research program that logically follows from this study. This will consist of two parts. First, research that is urgently required to fill the gaps in our knowledge in areas that provided inputs into this study, and second, research that may build on the findings of this study and extend its insights into new areas.

AN ASSESSMENT OF THE TASK

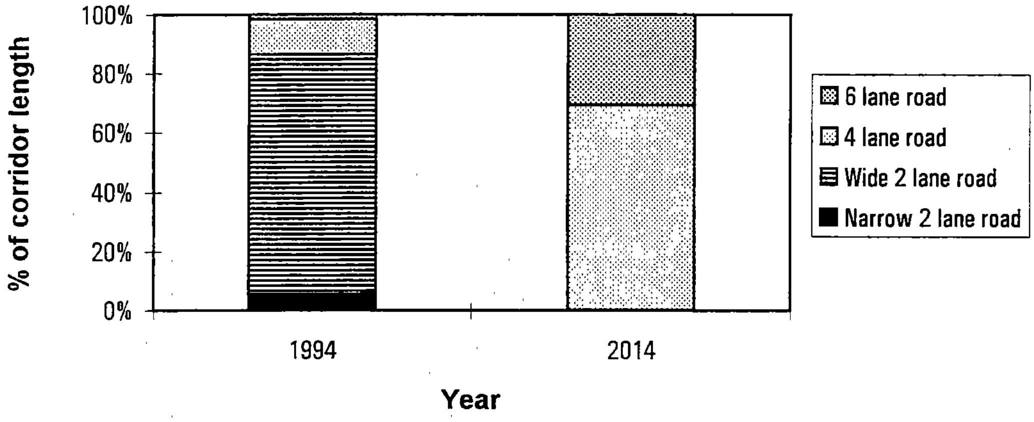
The major task in this study was to highlight areas on the selected network where a full scale cost-benefit analysis would most probably indicate that capacity expanding infrastructure investment would be warranted before 2014-15. This has been achieved and an estimate has also been made of the likely magnitude of a resulting investment program. The costs of asset preservation has also been estimated. The estimates indicate that if future infrastructure investment is to be made in a manner that will maximise economic efficiency, it will have to be directed more towards areas of high population growth than it has been in the past.

The scope of this study was necessarily limited because of time and data constraints. It was noted in chapter 2, however, that the gap between the analysis that was possible in this study, and the ideal, provides exciting opportunities for further research. This research has been discussed and it has the potential to significantly extend the insights of this study. It also has the potential to make a valuable contribution to policy formulation, and to the debate about the merits of infrastructure investment. If this occurs, the second major aim of this research will have been fulfilled.

IMPLICATIONS OF THE FINDINGS

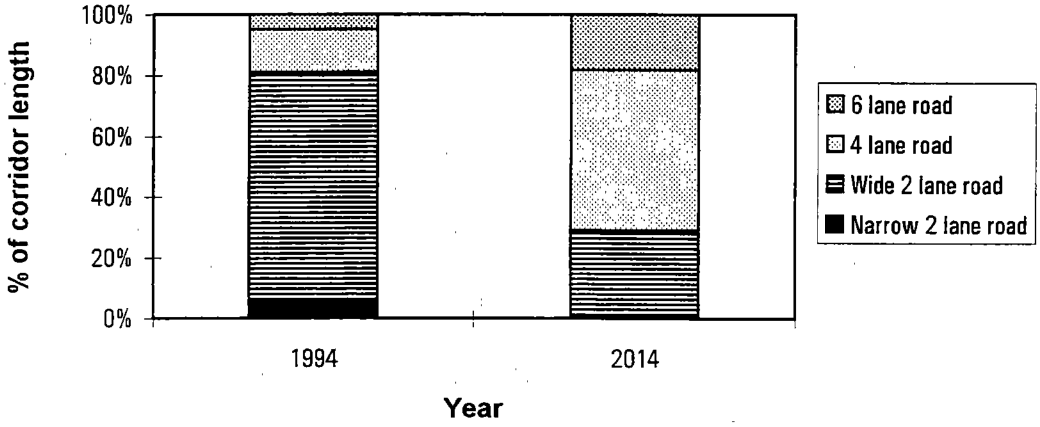
Changes to the infrastructure on the selected network

If implemented, the capacity expanding investments foreshadowed by the economic assessment would significantly change the nature of road infrastructure on the four corridors with expenditure requirements in excess of $1B. Figures 7.1 to 7.4 illustrate the changes for roads outside towns on these corridors.



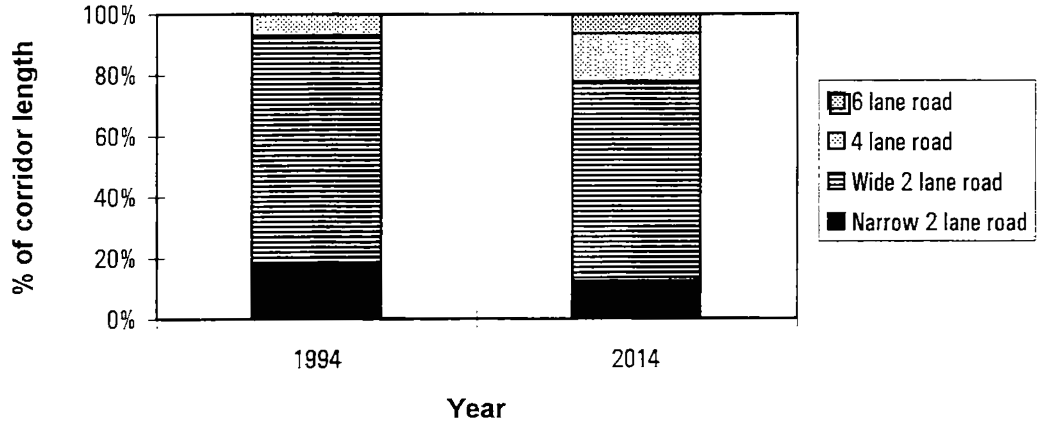
Source BTCE estimates

Figure 7.1 Sydney-Brisbane: Pacific Highway



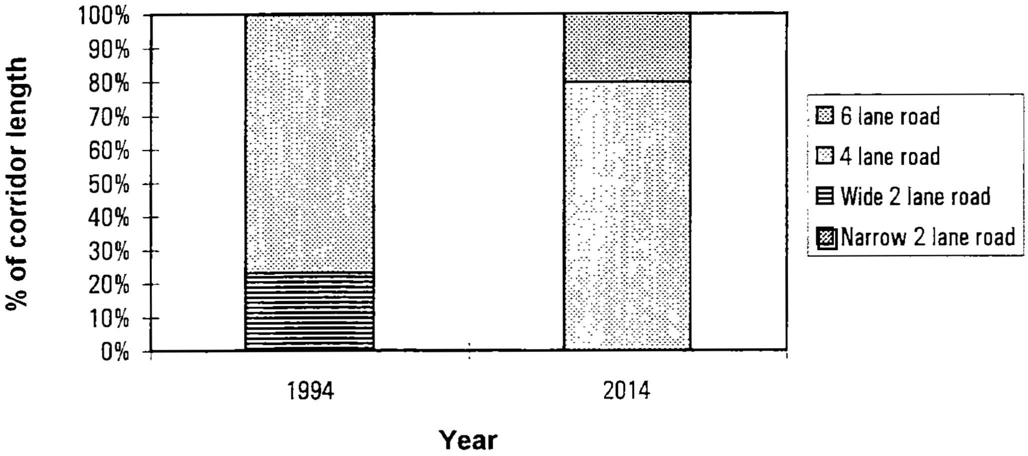
Source BTCE estimates

Figure 7.2 Sydney-Brisbane: New England Highway including Sydney Newcastle



Source BTCE estimates

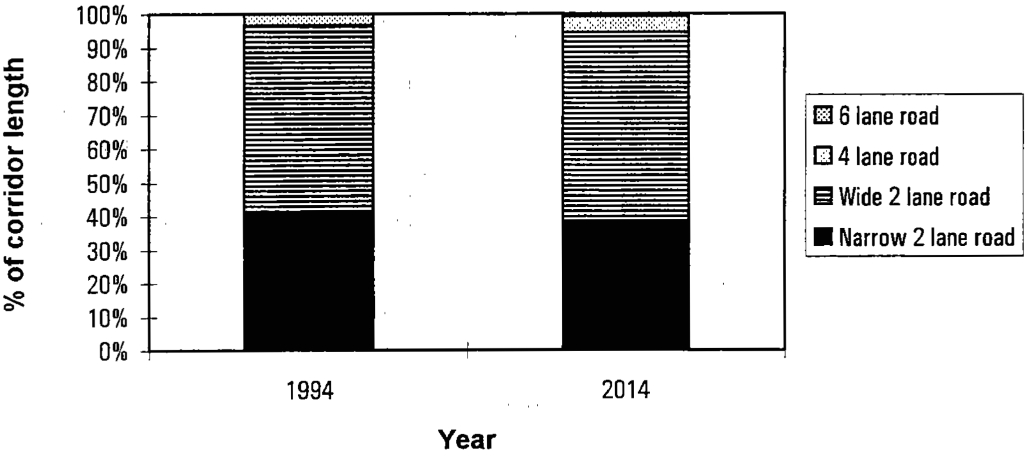
Figure 7.3 Brisbane-Cairns: Bruce Highway



Source BTCE estimates

Figure 7.4 Sydney-Melbourne: Hume highway

The Pacific and Hume Highways will need to be upgraded to primarily four lane roads with substantial amounts of six lane road at the end points. It is clear from the graphs that these two corridors will undergo the biggest proportional changes to the type of road that makes up their infrastructure. Both the Brisbane to Cairns corridor, and the inland Sydney to Brisbane corridor will need considerably more four and six lane road than they have at present. Although the Brisbane to Cairns corridor will require a large investment program to expand capacity, a large proportion of its length will remain adequate as wide 2 lane road.



Source BTCE estimates

Figure 7.5 **Other corridors**

Figure 7.5 presents the projected changes on all the remaining corridors and shows that major parts of the selected network are unlikely to require capacity expanding investment.

Redirection of infrastructure investment and maintenance expenditure

Information on historical National Highways expenditure is only available on a state basis. Furthermore, the expenditure estimates made in this study include those for the Pacific Highway which is not a part of the National Highway system. To compare this study's estimates with past National Highways expenditures, therefore, the Pacific highway has to be removed and they have to be collated by state. Table 7.1 presents the new construction estimates in this form.

In table 7.2, each state's share of National Highways expenditure over the last five years is compared with each state's share of estimated expenditure for the period 1995-96 to 2014-15. The estimates are those that exclude the Pacific Highway and the comparison includes both new construction expenditure, and maintenance expenditure.

The lower part of the table compares the average annual amounts for maintenance expenditure during the same periods. It would not be valid to do this for new construction because, as has been noted in chapter 4, it has not been possible to make estimates for projects that normally comprise a significant portion of new construction expenditures. Even the comparison of state shares rests on the assumption that the construction expenditures that have been omitted are distributed similarly to those that have been estimated.

TABLE 7.1 ESTIMATED ROAD EXPENDITURE REQUIREMENTS BY STATE: 1995-96 TO 2014-15[1]

($ millions)

State	*Excluding Pacific Highway* *Town bypass*	*Other works*	*Total*[2]	*Share of total %*	*Including Pacific Highway* *Town bypass*	*Other works*	*Total*[2]	*Share of total %*
NSW[3]	426	3 059	3 485	50	889	6 370	7 259	64
VIC	110	647	757	11	110	647	757	7
QLD	266	1 819	2 085	30	266	2 298	2 565	23
WA	13	139	152	2	13	139	152	1
SA	16	330	346	5	16	330	346	3
TAS	12	141	153	2	12	141	153	1
NT	0	39	39	1	0	39	39	1
TOTAL	843	6 174	7 018	100	1 306	9 965	11 271	100

Source BTCE Estimates

Notes 1 Estimates exclude projects involving realignments, flood mitigation and associated bridgeworks, expanding from six to eight lanes, construction of overtaking lanes, projects in urban areas, and administration and pre-construction costs.

2 Owing to rounding, figures may not add to totals.

3 Includes expenditure for ACT.

TABLE 7.2 COMPARISON OF ACTUAL EXPENDITURES AND BTCE ESTIMATES FOR THE NATIONAL HIGHWAY SYSTEM

(per cent)

	Share of NHS expenditure: 1989-92/93			*Share of NHS/ BTCE analysis: 1995-2015**		
State	*Construction*	*Maintenance*	*Total*	*Construction*	*Maintenance*	*Total*
NSW	39.6	40.2	39.8	49.7	29.1	40.3
Vic	18.3	4.3	13.6	10.8	10.7	10.7
Qld	16.8	34.6	22.7	29.7	31.6	30.6
WA	11.1	5.7	9.3	2.2	11.2	6.3
SA	7.5	4.7	6.6	4.9	9.3	6.9
Tas	3.6	3.7	3.6	2.2	1.7	2.0
NT	3.2	6.9	4.4	0.6	6.1	3.1
ACT	0.0		0.0	0.0	0.3	0.2
Total	100.0	100.0	100.0	100.0	100.0	100.0
Total	n/a	(1989-92/93)	n/a	n/a	(1995-2015)	n/a
$ m		935			5 894	
$m per year	n/a	207.8	n/a	n/a	294.7	n/a

* BTCE results are those excluding the Pacific Highway to ensure greater comparability.

It appears that significant shifts may be needed in the splits between the states. If new construction funding is redirected towards the corridors with the highest traffic volumes and the highest traffic growth rates, then the spending shares of New South Wales and Queensland will be greater, while the shares of other states will be less. The reallocation would be even greater if the Pacific Highway projects were taken into account. Victoria, Western Australia, South Australia and the Northern Territory, however, could all experience an increase in their share of maintenance expenditure.

It is also apparent that the average annual amount devoted to maintenance may need to be increased by around 42 per cent.

This demand for infrastructure investment of the type considered in this study is primarily driven by demand for travel that translates into congested roads. This is ultimately determined by population growth and the current capacity utilisation of the infrastructure. The level of service performance scores for 1995-96 show that the corridors in the south east corner and along the eastern seaboard currently provide the lowest levels of service on the network (see chapter 4). The areas that these corridors pass through are also projected to have the highest population growth rates over the study period, and therefore, the largest absolute increases in traffic volumes (see chapter 3). One should therefore expect that the need for capacity expanding investment will, as the findings indicate, be heavily concentrated on corridors linking Australia's three most populous cities.

LIMITS ON THE INFERENCES THAT MAY BE DRAWN FROM THIS STUDY

The approach taken in this study means that there are strict limitations on the inferences that may be drawn from this study. The strategic nature of this study means that the key findings may not be regarded as a recommended investment program, but, that they give an indication of the likely magnitude of economically warranted expenditure that may be required to expand capacity, and the corridors where such investment is most likely to be required.

Since the projected traffic volumes for 2014-15 were imposed onto the current infrastructure to see where the infrastructure may face capacity constraints with such traffic volumes, nothing may be said about the optimal timing of the forecast expenditure. The only interpretation is that some time between now and 2014-15, capacity expanding investment to the tune of $11.3B may be required.

FUTURE RESEARCH PROGRAM

Inputs into this study: data

One of the primary reasons that the economic assessment concentrated on capacity expanding projects is that the data that would facilitate the analysis of other project types (such as realignment and flood mitigation projects) were not available. Other areas of this study could also have undergone more in depth analysis had the requisite data been available. The modelling process used to make the demand projections would have benefited from more data, particularly with regards to the future truck volume projections. The asset preservation model had to be simplified from its initial theoretical form because all the required data was not available.

The scope of research is often defined by data availability, and this research project was no exception. While it is acknowledged the analysis could be improved in some areas, the supporting data bases will need to be improved before this is possible in many instances. If this study is to be improved upon in terms of its scope, it is imperative that a concerted effort is devoted to improving the supporting data bases before a study of this type is attempted again. Appendix VI gives details of the information that the ideal data bases should contain. It needs to be noted that much of this data should be available from the state road authorities.

Extensions to this research

Inter-temporal resource allocation

The logical extension to this project is to identify the time period when corridors are likely to become congested. This would allow the optimal time for the identified investments to be specified. To do this, a time path for the growth in traffic volumes on the network would have to be specified.

The policy relevance of this type of research is that to maximise the net economic benefits gained from the use of scarce resources, the inter-temporal allocation of these resources is as important as their allocation between competing uses. If an economically warranted investment is unduly delayed, then the net present value of benefits derived from the use of our resources will be reduced. By definition resources will be applied to a lower valued use during the period of the delay.

Similarly, if a project goes ahead before the time period in which it becomes economically warranted, then it will draw resources away from a higher valued use during that time.

This information is essential if governments are to plan ahead. That is, they need to know when large expenditures are likely to become economically warranted. This gives governments the opportunity to allocate funds to public sector projects in such a way that the economic benefits gained from these are maximised.

Economy wide impact of road infrastructure investment: CGE modelling

Even with a full analysis into the optimal inter-temporal allocation of infrastructure investment funds, there are many policy issues that are not able to be addressed by an analysis of the type conducted in this study. These are all issues related to who will be affected by the investments in road infrastructure over the next 20 years and how they will be affected. They are issues such as:

- how will employment be affected, and in what industries?;
- how will the output of different industries be affected?;
- what will the regional impact be for different industries, occupations and aggregate employment?;
- and how will this investment affect key macro economic variables such as the CPI, the trade balance, aggregate consumption, aggregate investment, and real GDP?

The ideal tool to address these issues is a computable general equilibrium (CGE) model. These models give us insights into the economy wide affects of different policy actions, both at a microeconomic level, and a macroeconomic level. Traditional CGE models (such as ORANI) are comparative static models and only show the impact on the economy after it has adjusted to the investment into road infrastructure. New generation CGE models (such as MONASH94 which is being developed from ORANI) are able to model the dynamic effects of policies. The use a dynamic CGE model such as MONASH94 will allow researchers to investigate both the impact of investment in infrastructure over an optimal time path, and to investigate how the economy adjusts to such an investment program. Such an analysis should look at both the first round effects of the higher investment demand, and the ongoing effects from lower transport costs and higher productivity in the transport sector that may result from improved infrastructure.

This type of research is currently the topic of another research project being conducted within the BTCE. It would therefore provide vital information to governments when they compare the relative merits of different policy options in the context of the general economic environment. Furthermore, these issues are often raised the public debate about the merits of infrastructure investment, and this research would make a valuable contribution to that debate.

APPENDIX I THE HDM-C MODEL

The HDM-C (Highway design and maintenance) model has been developed to provide information on the capacity, levels of service (LOS), and vehicle operating costs incurred on the selected network. The current model has five separate components which calculate the following:

- the capacity of the road;
- volume-capacity ratios;
- levels of service; and
- the speed and vehicle operating costs associated with travelling on a given road.

The first three parts have been developed primarily by the BTCE, and the last two parts, although slightly modified, are based on the HDM-III model (see. ARRB, 1993 for details on HDM-III).

The flow chart, figure I.1, outlines the HDM-C model and the following pages describe it in more detail.

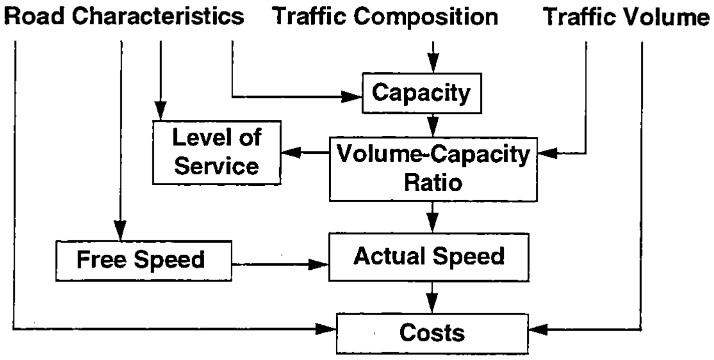


Figure I.1 The HDM-C model

DATA REQUIREMENTS

The model needs an extensive amount of information on road and traffic characteristics. A highway is divided into sections of varying lengths, and for each section, the the following details are required to run the model:

- section name;
- roughness 80 NRM;
- 3 general terrain types: 1 for flat, 2 for undulating, and 3 for mountainous;
- AADT, that is the annual average daily traffic volume;
- divided/undivided to specify whether a road is undivided or divided;
- width, that is width of the pavement (m);[1]
- number of lanes;
- link length, that is the length of the link (km);
- design Speed (km/h);
- proportion of rigid trucks;
- proportion of articulated trucks;
- width of lanes (m); and
- average width of each shoulder (m);

It is assumed that there are three types of vehicles on the road: cars, rigid trucks and articulated trucks. The HDM-III model calculates VOCs for ten different vehicle types this level of detail was not required for this study.

---

[1] Pavement width is defined as that part of the road used for regular travel, and it does not include the shoulders.

One of the primary aims of the ARRB version of HDM-III is to show the effects of roughness on both free speeds and costs. In this study, however, we are more interested in the technical adequacy of the roads in terms of capacity, of which roughness is not a significant contributor. To make the results consistent throughout the selected network, we have ignored the actual roughness of roads and run this model using an average roughness level of 80 NRM.

VOLUME AND CAPACITY

There are two measures used for traffic volume. First, there is the number of vehicles (AADT), and second, there is passenger car units (PCU). To convert traffic volumes from the number of vehicles to passenger car units, the following conversion factor is used:

$$Convfactor = PercCar + PercRig * adPce_{factor} + PercArt * adPce_{factor}$$

where;		
	PercCar	percentage of cars in AADT;
	PercRig	percentage of rigid trucks in AADT;
	PercArt	percentage of articulated trucks in AADT;
	adPce	factors are listed in table I.1, below;

TABLE I.1 CONVERSIONS TO PCUS

	Vehicle Type	
Terrain	*Rigid*	*Articulated*
1	1.7	3
2	4	9
3	7	15

Source BTCE

The capacity module in the model that converts the AADT measure into PCU units, uses the following equation:

$$AADTPCU = AADT * Convfactor$$

where *AADTPCU* AADT in PCUs

The calculation of a road's capacity is relatively simple. First, the mean service flow is multiplied by the number of lanes. This number is the capacity of a perfect road.

TABLE I.2 MAXIMUM ROAD CAPACITY

No of Lanes	*Mean Service Flow*	*Capacity*
1	1800	1800
2	1400	2800
4	2000	8000
6	2000	12000

Source NAASRA (1988)

This initial road capacity is reduced by a series of factors relating to road and traffic characteristics to get the actual capacity. These factors are as follows:

- The divided or undivided factor (*adFe*),

TABLE I.3 CARRIAGEWAY FACTOR

divided	1
undivided	0.95

Source Mannering and Kilareski (1990)

- The lane and shoulder width factor (*adFw*),

TABLE I.4 ROAD AND SHOULDER WIDTH FACTORS

	Lane Width (m)			
Shoulder Width(m)	*>3.5*	*3.15-3.5*	*2.85-3.15*	*<2.85*
<0.6	0.70	0.65	0.58	0.49
0.6-1.2	0.81	0.75	0.68	0.57
1.2-1.8	0.92	0.85	0.77	0.60
>1.8	1.00	0.93	0.84	0.70

Source NAASRA (1988)

- Finally all capacities are reduced by a factor of 0.95 to account for non-regular traffic (*fFp*)

The equation for capacity is:

$$Capacity = iMsf * NoL * adFw * fFp * adFe$$

The units of capacity are PCUs per hour.

The above formula is applied to the one, two, four and six lane roads, three lane roads are assumed to have a capacity of 2800 PCUs/hr regardless of the other road characteristics.

The original capacity calculation is also converted into vehicles per day with the equation. The units are equivalent to the AADT:

$$CapacityAADT = \frac{Capacity * 24}{Convfactor}$$

HOURLY VOLUME PROFILE

There are peaks and troughs in traffic volume over a day, therefore AADT/24 is not an accurate representation of the hourly traffic volume for many hours during the year.

The available data indicates that the integral of the Gamma probability distribution is a reasonably accurate representation of the traffic volume distribution sorted from highest traffic volume hour to lowest for rural roads. It has not been possible, however, to use the Gamma probability distribution directly, so it has been approximated using the histograms shown in tables I.5 I.6, and I.7.

The percentage of daily traffic in the peak hour will be higher on rural roads than on urban roads. Rural roads will have a short high peak of between twenty and thirty per cent, like that in table I.5. Roads approaching urban areas may have lower and longer peaks such as those in the profiles shown in tables I.6 and I.7.

In the technical assessment, the profile in table I.5 is used for all the highways apart from those on the Sydney to Brisbane corridor. The New England and Pacific highways use the profile in table I.7 because the large traffic volumes on these corridors make it unlikely that they have a typical rural profile.

In the economic assessment, widening projects, duplications from two to four lanes and bypasses are all assessed using the rural histogram. It was found that the majority of road likely to need upgrading from four to six lanes was close to urban centres, and therefore, the low peak profile in table I.6 was used for these roads.

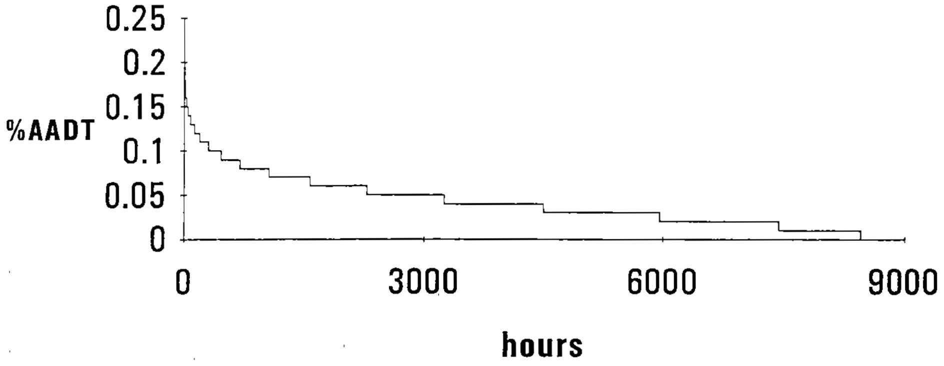


Figure I.2 Hourly volume profile

The vertical axis of figure I.2 represents the proportion of the daily traffic occurring in any one hour of the year and the horizontal axis is the hours in a year. The total number of hours in a year were used in preference to a smaller time period so that the effect of weekends, public holidays and seasonal variations in traffic volumes could be taken into account.

TABLE I.5 RURAL ANNUAL TRAFFIC DISTRIBUTION

Hours in year	*Percentage of AADT (%)*
3	22
3	20
10	18
17	16
18	15
30	14
45	13
71	12
107	11
161	10
241	9
354	8
509	7
714	6
967	5
1242	4
1467	3
1482	2
1017	1
308	0

Source BTCE

TABLE I.6 SEMI-URBAN CONGESTION PROFILE

Hours in year	*Percentage of AADT (%)*
22	12
40	11
78	10
223	9
304	8
719	7
1170	6
1287	5
1067	4
1303	3
1378	2
1175	1

Source BTCE

TABLE I.7 SYDNEY - BRISBANE CORRIDOR CONGESTION PROFILE

Hours in year	*Percentage of AADT (%)*
3	16
3	15
7	14
13	13
26	12
48	11
90	10
185	9
309	8
546	7
848	6
1252	5
1640	4
1736	3
1375	2
600	1
85	0

Source BTCE

LEVEL OF SERVICE (LOS)

Level of service is a measure of a road's capacity utilisation expressed as LOS A (the best LOS) through to LOS F. The model's output is expressed as the percentage of time in a year that a road provides less than a given level of service for LOS A through to LOS E.

The calculation is based on a volume-capacity ratio (*VCR*) expressed in PCUs per hour,

$$VCR = \frac{\% AADT * AADTPCU}{Capacity}$$

where *%AADT* is taken from the congestion histogram

The precise value of the *VCR* applicable to each LOS is also dependent on the general terrain number for two lane roads and the design speed for roads with more than two lanes. The concept of level of service is not applied to one lane roads, but, since there is only a small length of the road system with one lane, this will not significantly affect the results.

TABLE I.8 LEVELS OF SERVICE DEFINITION FOR TWO LANE ROADS

Level of Service	*VCR by terrain type*		
	1	*2*	*3*
A	0.12	0.05	0.02
B	0.24	0.17	0.12
C	0.39	0.32	0.20
D	0.62	0.48	0.37
E	1.00	0.91	0.87

Source BTCE

TABLE I.9 LEVEL OF SERVICE DEFINITION FOR ROADS WITH MORE THAN TWO LANES

Level of service	*VCR by design speed*		
	110 km/h	*100 km/h*	*80 km/h*
A	0.36	0.33	na
B	0.54	0.50	0.45
C	0.71	0.65	0.60
D	0.87	0.80	0.76
E	1.00	1.00	1.00

Source BTCE

If the *VCR* for the first time period equals 0.5 on a 2 lane road in general terrain type 1, then the road provides service below levels A to C for 3 hours of the year.

The total number of hours that the road provides service in each of the categories below LOS A through to LOS E is calculated and then converted to the proportion of the year. It is found using the following formula:

$$LOSX = \frac{\sum_{i=1}^{noblocks} hours_{Xi}}{8766}$$

where $LOSX$ proportion of time spent below LOS X

$noblocks$ number of time periods

$hours_{Xi}$ hours in time period i if below LOS X, zero otherwise

The level of service achieved in both the 30th, and 100th highest hour of traffic have been calculated using the hourly volume profiles.

SPEED

The speed calculations in HDM-C closely follow those in the HDM-III model. There have, however, been some changes which will now be explained.

To make speed calculations, the HDM-III model (that is, the ARRB model) needs values for gradient and curvature. This detailed information is not currently available nationally, so as an approximate measure, general terrain numbers have been used. The following table lists the gradient and curvature values associated with the three general terrain types.

TABLE I.10 ROAD ALIGNMENT

General Terrain	*Gradient*	*Curvature*
1	6.5	11.72
2	20.5	15
3	36.3	20

Source BTCE

The *freespeed* is the speed of a vehicle when unimpeded by other vehicles.The HDM-III model uses desired speed as a control variable to ensure that the maximum value of free speed is equal to the design speed of the road. We have produced several different values for the desired speed depending on the design speed of the road. These numbers are the values of the desired speeds that produces a *freespeed* approximately equal to the design speed for roads in general terrain number 1 with a low roughness level.

TABLE I.11 DESIRED SPEED

Design speed	*Car*	*Rigid*	*Articulated*
<80	60	63	60
≥80	83	97	88
≥100	113	250	160
≥110	134	na	na

Source BTCE

The desired speeds used for all the design speeds are listed in table I.11. Values are not recorded for heavy vehicles travelling on roads with a design speed greater than 100 km/h. This is because heavy vehicles have a legal speed limit of 100 km/h.

There may be periods of time where congestion may occur and during these times, vehicles are unable to achieve *freespeed*. While the HDM-III model assumes that *freespeed* was obtained at all times, the HDM-C model uses a congestion profile histogram to find out when congestion occurs, and then it adjusts vehicle speeds accordingly.

A road is said to be congested when the *VCR* is greater than 0.25. For those time periods of the histogram in which congestion occurs, the actual speed that a vehicle travels at is reduced using the following formula;

$$speed_i = \frac{4 * freespeed * (1 - vcr_i)}{3}$$

where $speed_i$ speed in time period i

If the calculated $speed_i$ is less than 2.2m/s then $speed_i$ is made equal to 2.2m/s. Time periods of the histogram without congestion have $speed_i$ equal to *freespeed.*

From the $speed_i$ of each time period we are then able to calculate an average speed (*averspeed*) for each vehicle type over the year. The average speed is not used in any further parts of the HDM-C model, but it is a useful measure a road section's overall performance. It is calculated as follows;

$$averspeed = \frac{\sum_{i=0}^{noblocks} speed_i * hours_i}{8766}$$

where *noblocks* number of time periods in the histogram

$hours_i$ hours in histogram time period i

VEHICLE OPERATING COSTS

The *speed* that is calculated for each time period in the histogram is then used to calculate travel costs for the same time periods. The avoidable financial and economic costs are calculated for each vehicle type. The costs that make up total VOCs are listed in table I.12 below.

TABLE I.12 AVOIDABLE VEHICLE OPERATING COSTS

Cars	Heavy Vehicles
Fuel	Fuel
Oil	Oil
Maintenance Parts	Maintenance Parts
Maintenance Labour	Maintenance Labour
Tyre	Tyre
Time	Crew
	Depreciation
	Overhead
	Registration (financial only)

Source BTCE

The fuel, oil, tyre, maintenance parts, and labour consumption calculations are based on the HDM-III model. The calculations for crew, time and overhead costs, and annual kilometres travelled are also based on the HDM-III model.

The HDM-C model, however, calculates depreciation as an annuity as described below.

$$anndepr = vehcst * \left(\frac{discrate}{1-(1+discrate)^{vehyrs}}\right)$$

where *anndepr* annual depreciation,

vehcst the cost of the vehicle and

vehyrs length of the vehicle's life.

The *anndepr* is divided by the annual kilometres travelled to get the depreciation per kilometre.

In the HDM-C model, the cost of registration and third party insurance is added to the avoidable costs for heavy vehicles. This is calculated by dividing the annual registration charge by the annual kilometres travelled.

While many of the formulas used in the HDM-III model where not changed, the unit cost of goods have been updated to current costs. The unit value of each of these costs is listed in table I.13 below.

TABLE I.13 UNIT COSTS 1992-93

Cost	Car		Rigid Trucks		Articulated vehicles	
	Financial	*Economic*	*Financial*	*Economic*	*Financial*	*Economic*
Fuel	0.633	0.343	0.604	0.294	0.604	0.294
Oil	3.6	3	3.36	2.8	3.12	2.6
Vehicle	21540	18881	110426	96229	190755	167212
Maintenance Labour	50	50	50	50	50	50
Tyre	117.4	99.2	490.3	421.6	521	475.1
Time	7.6	7.6	na	na	na	na
Crew	na	na	17.1	17.1	17.4	17.4
Overhead	na	na	10%	na	10%	na
Registration	na	na	2453.4	na	3031.2	na

Source BTCE

Note not applicable

1. economic costs = financial costs less taxes

The occupancy rate used for cars is 2, and for heavy vehicles, a value of 1 is used. The discount rate (*discrate*) that has been used in the calculation of depreciation is 7 per cent.

The average cost for each vehicle is calculated from the cost in each time period using the following formula. The unit of this variable is cents.

$$VOC = \frac{\sum_{i=1}^{noblocks} hours_i * VOC_i}{8766}$$

where VOC_i cost of time period i

The VOC for each vehicle type are used to calculate the cost of a composite vehicle type (*VOCcomp*) for both financial, and economic costs. This composite vehicle is made up of proportions of cars, rigid trucks and articulated vehicles. The formula is:

$$VOCcomp = \frac{Length * (perccar * VOCcar + percrig * VOCrig + percart * VOCart)}{100}$$

where $VOCcar$ VOC of cars

$VOCrig$ VOC of rigid trucks

$VOCart$ VOC of articulated vehicles

To make further analysis simpler, the composite vehicle results are presented as dollars per section length.

APPENDIX II EMPIRICAL SOCIAL COST BENEFIT ANALYSIS OF ROAD INFRASTRUCTURE

INTRODUCTION

In chapter two the theory of social cost benefit analysis was discussed. That exposition, however, outlined the theoretical ideal. The measurement difficulties associated with externalities means that some departures have to be made from the ideal for an empirical analysis to be possible. In this appendix, those departures are discussed and the empirical models used to analyse road infrastructure are explained.

A NON-OPTIMAL PRICING MODEL TO ASSESS ROAD CONSTRUCTION PROJECTS ON SINGLE ROADS

Non-optimal pricing

It is not currently possible to measure the cost of externalities such as vehicle emissions in a cost effective manner. They are therefore assumed to be zero. Furthermore, congestion taxes are not currently levied on users to ensure that each user pays the social marginal cost of using infrastructure.

In the absence of externality taxes, therefore, the additional user does not pay an amount equal to the extra cost that is imposed on society by that user's presence. All road users, including the additional user, equally share the extra cost caused by longer travel times. Users only pay the cost they bear directly. That is, the private marginal cost, which is, the average social cost, and their level of use is determined by this price. Average social cost therefore refers to the average social cost of users, and not society, because externalities such as vehicle emissions are ignored.

Non optimal pricing (average cost pricing) is therefore used to ration the use of road infrastructure. In the presence of congestion, this means that infrastructure use is above the optimal level of use. It is in this environment, however, that investment projects have to be evaluated. It is for these reasons, therefore, that the average social cost curves are used instead of the social marginal cost curves in empirical cost benefit analysis.

The non-optimal pricing model

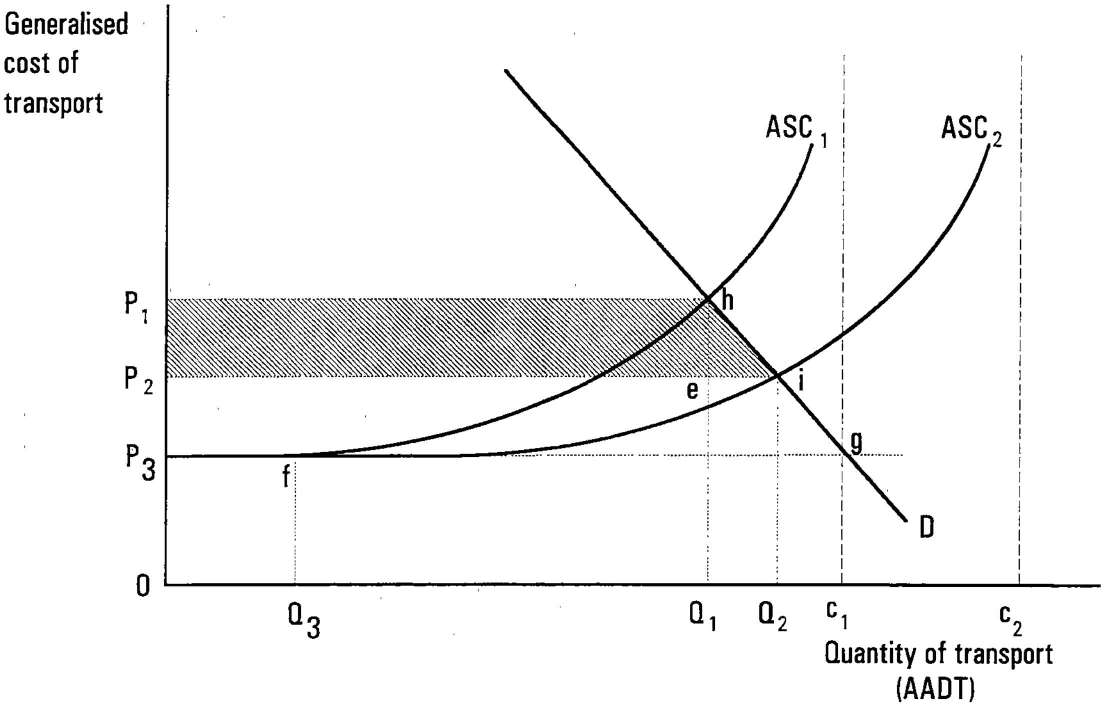


Figure II.1 **Benefits from capacity expanding investment with non-optimal (average cost) pricing.**

Figure II.1 is a graphical representation of the non-optimal pricing model. The short run marginal social cost curves have been replaced with the short run average social cost curves, but in most other respects, the model is analogous to the optimal pricing model discussed in chapter 2. The ASC_1 curve is the cost curve for the unimproved infrastructure, and the ASC_2 curve is the cost curve for the improved infrastructure. The net economic benefit that will be derived from a capacity expanding investment again has two principle components. First, the current quantity of travel will be consumed at a lower resource cost P_1 P_2 h e. This is the total social cost of consuming Q_1 on the old infrastructure less the total social cost of consuming Q_2 on the improved infrastructure. Second, the lower price of travel will induce Q_2-Q_1 extra vehicles a day to use the infrastructure. The net economic benefit of the extra travel is the triangle 'hei'. This is road users' increased willingness to pay Q_1 Q_2 h i, less the resource cost of the extra travel Q_1 Q_2 e i.

To simplify the diagram, this exposition assumes that users do not pay any sales taxes or excises on the resources they use. In the computer code for this model, however, fuel excise is deducted from vehicle operating costs to calculate the total social cost of travel. The change in willingness to pay is calculated at the market prices for resources, and these include sales taxes and excises.

It also needs to be pointed out that the net economic benefit illustrated in figure 1 (the trapezoid $P_1 P_2 h i$) only accounts for costs borne by users. Net savings on maintenance costs also have to be added to this benefit figure. It is possible for the net savings figure to be negative.

The computer model and its operation

To estimate a threshold AADT value for a given infrastructure improvement in a given set of traffic and terrain conditions, average social cost curves have to be generated for both the old infrastructure, and the new infrastructure given the defined traffic and terrain conditions. This is done with the HDM-C model that is described in appendix I.

A constant elasticity demand curve was used in this study. This type of demand curve has the following functional form:

$$Q = \frac{a}{P^b}$$

where Q is the quantity of travel, P is the price or average social cost, a is parameter, and b is the own price elasticity of demand defined as a positive number[1]. This was assumed to be 0.5 because available evidence suggests that 0.5 is a reasonable value for the own price elasticity of demand for road transport.

In a strategic assessment of whole corridors, it is not reasonable to assume that projects are implemented in isolation and to ignore complimentary effects between investment projects. Investment along one section of a highway may lead to an increase in traffic volume on that section. The extra vehicles may also travel over other sections of the same highway and bring forward the need for infrastructure investment along these other sections. If these complementary relationships between investments are ignored, the evaluation of projects in isolation will lead to an underestimate of total investment needs.

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[1] To express this demand function in this way b must be written as a positive number. The more common way to express the equation is: $Q=aP^{b}$. Expressed in this way, b is a negative number for a demand equation.

We were only able to examine short subsections of road in isolation, however, and had to approximate the complimentary effects of individual investment projects on corridor investment requirements. We achieved this by using the elasticity of demand estimate for long distance trips instead of the elasticity of demand for transport on individual road sections.

The demand for road transport over several sections of road considered together is more price sensitive than the demand for road transport over an individual road section. For example, assume road users travel 10 Km over ten sections of road, each of which is 1 Km in length and each of which imposes an equal cost on users. An examination of the data for these 10 sections may suggest that a 1 per cent fall in price of a journey over each of these sections, and thus a 1 per cent reduction in the cost of a trip over the 10 Km, leads to a 1 per cent increase in the number of road users that want to make the 10 Km trip over all sections. This gives an own price elasticity of demand for transport over the 10 Km of 1.0.

If the 1 percent cost reduction for the 10 Km trip is due to a project on an individual section of the road where 10 per cent of the total journey costs are incurred, the cost reduction over that individual section would have to be a reduction of 10 per cent. To the users travelling over all sections, however, this is still a 1 percent reduction to their travel costs and would induce the same 1 percent increase in vehicle numbers as a uniform 1 per cent reduction in costs over all the sections. If these data were then examined for the individual section being improved in isolation, the 10 per cent cost reduction for that section would show a 1 per cent increase in vehicle numbers, thus giving an own price elasticity of 0.1. This is much smaller than the elasticity estimate of 1.0 that was derived when all 10 sections of road were considered together.

By using the elasticity of demand for long distance trips, this increases the estimated benefits for a particular project and approximates the complimentary effects of individual projects by bringing forward the optimal time to invest.

Other exogenous inputs to the model are the initial traffic volume, the annual traffic growth rate, the investment project's capital cost, and the discount rate. The discount rate used was the recommended Department of Finance rate of 8 per cent and the traffic growth rate was assumed to be 2 per cent. The capital costs are specific to the type of project and the terrain type.

The initial traffic volume in year t_0 ,Q_3, is set such that the demand curve passes through the ASC curves at point before congestion begins to force costs to rise (point f on figure 1). This point also gives the model an initial price value ,P_3. With a value for P, Q, and b, the model solves for the value of a that is consistent with the demand curve passing through f. It then evaluates the net economic benefit derived from the infrastructure improvement at the initial traffic volume, Q_3. At this point, the equilibrium point for the unimproved infrastructure is the same as that for the improved infrastructure (that is at point *f*), and therefore, the net benefit to users of the improvement is 0. This ensures that the optimal time to invest must be in a future time period and that the threshold AADT is not determined by the initial traffic volume given to the model. Since AADT measures traffic volumes on a daily basis, the net benefit calculations give a daily net benefit.

For the optimal timing condition to be satisfied, the daily net benefit must be greater than the hurdle amount, *H*, which is given by the following expression:

$H= (r/DAYS) * K$,

where r is the annual discount rate, K is the capital cost of the project, and $DAYS$ is the number of days in a year. $r/DAYS$ therefore gives the discount rate as a daily percentage rate. If this condition is not satisfied (as would not be in year t_0), the traffic volume for year t_1 is calculated using the following expression:

$AADT_t = Q_3 * e^{g*t}$,

where $AADT_t$ is the daily traffic volume in year t, Q_3 is the daily traffic volume in the year t_0, e' is the natural exponential, and g is the annual traffic growth rate. In figure 1 $AADT_1 = c_1$. To allow the model to solve for a new value for a, the price is initially held constant at P_3 so that the demand curve in t_1 passes through a point (g in figure 1) where both the price and quantity values are known. Once the new value of a is calculated, the new equilibrium points for the unimproved infrastructure (h in figure 1), and the improved infrastructure (i in figure 1) are solved for to give the new equilibrium prices and quantities (Q_1, P_1 for the old road, and Q_2, P_2 for the new road).

The daily net benefit of the investment project in the year t_1 is evaluated and compared with the hurdle amount. If the optimal timing condition is satisfied, the threshold AADT is the quantity demanded on the unimproved infrastructure, Q_1. If it is not satisfied, the model completes further iterations of the above process until it is.

The daily net benefit is given by the following expression:

$BENEFIT = DWTP + (SC_1-SC_2) +((FC_1-FC_2)/DAYS)$,

where $DWTP$ is road users change in willingness to pay, SC_1 is the total social cost of resources used prior to the investment, SC_2 is the total social cost of resources used after to the investment, FC_1 is the annual cost of maintenance on the old infrastructure and FC_2 the annual cost of maintenance on the new infrastructure. These maintenance costs are for recurring expenditures. The discounted value of periodic maintenance expenditures such as reconstruction are treated as part of the initial capital cost (see footnote 3 in chapter 2). These costs are exogenous inputs into the model.

The change in the willingness to pay is given by:

$$DWTP = \int_{Q_1}^{Q_2} \frac{a^{1/b}}{Q^{1/b}} dQ = a^{1/b}\left(\frac{b}{b-1}\right)\left(Q_2^{\frac{b-1}{b}} - Q_1^{\frac{b-1}{b}}\right),$$

which is the definite integral of the demand curve equation between the quantity of travel on the old infrastructure and that on the new infrastructure. Q_2 is the quantity of travel on the new infrastructure, Q_1 is the quantity of travel on the old infrastructure, and *a* and *b* are parameters in the demand equation.

The total social cost of resources used prior to the investment, SC_1, is given by:

$SC_1 = (P_1\text{-}TAX_1) * Q_1$,

and the total social cost of resources used after to the investment, SC_2, is given by:

$SC_2 = (P_2\text{-}TAX_2) * Q_2$

In both cases SC is equal to the market price that users pay (the average social cost) less any sales taxes multiplied by the quantity of travel.

The threshold AADT is estimated as the quantity of traffic *before* the upgrade takes place, Q_1 in figure II.1. Where investment is warranted immediately this does not cause a problem because the projected AADTs are not relied upon. However, where demand is not perfectly inelastic and costs not perfectly elastic, there is an inconsistency when threshold AADTs are compared with projected AADTs estimated on the assumption of a constant level of service (see figure 3.2). Congestion will choke off some demand causing the actual AADT (where the demand curve intersects the ASC_1 curve) to fall below the constant level of service projected AADT. The result will be an overestimate of future expenditure needs. The way to avoid this is to adjust the projected AADTs for the effects of congestion choking off demand. However, in the present exercise adjusting the demand projections was considered an unnecessary refinement because:

- the assumed demand elasticity of 0.5 is low;
- in the region of the threshold AADTs the elasticity of the ASC curve is not great; and,
- for the majority of the road sections requiring upgrading, AADTs at the beginning of the period exceed the thresholds so the projected AADTs are not relied upon.

A NON-OPTIMAL PRICING MODEL TO ASSESS BYPASS PROJECTS

The conceptual basis of the model

The bypass model is a non-optimal pricing model that is based on the same conceptual framework as the model that is used to assess open road projects. The assessment of town bypass projects, however, is complicated by the requirement to model the demand for travel on both a bypass road, and a road that passes through the town (referred to from herein as the town road). A graphical representation of the bypass model is shown in figure II.2.

The total demand curve, *D*, shows the quantity of travel through the town that is demanded at each price (generalised cost) level in the absence of a bypass. ASC_1 is the average social cost curve for the town road and ASC_2 is the average social cost curve for a bypass. In the absence of a bypass, the quantity of vehicles that pass through the town is Q_b, and the generalised cost to users is P_b.

Q_b vehicles, however, consists of two broad classes. First, vehicles that would use a bypass if one existed, and second, vehicles that would continue to use the town road even if a bypass was constructed.

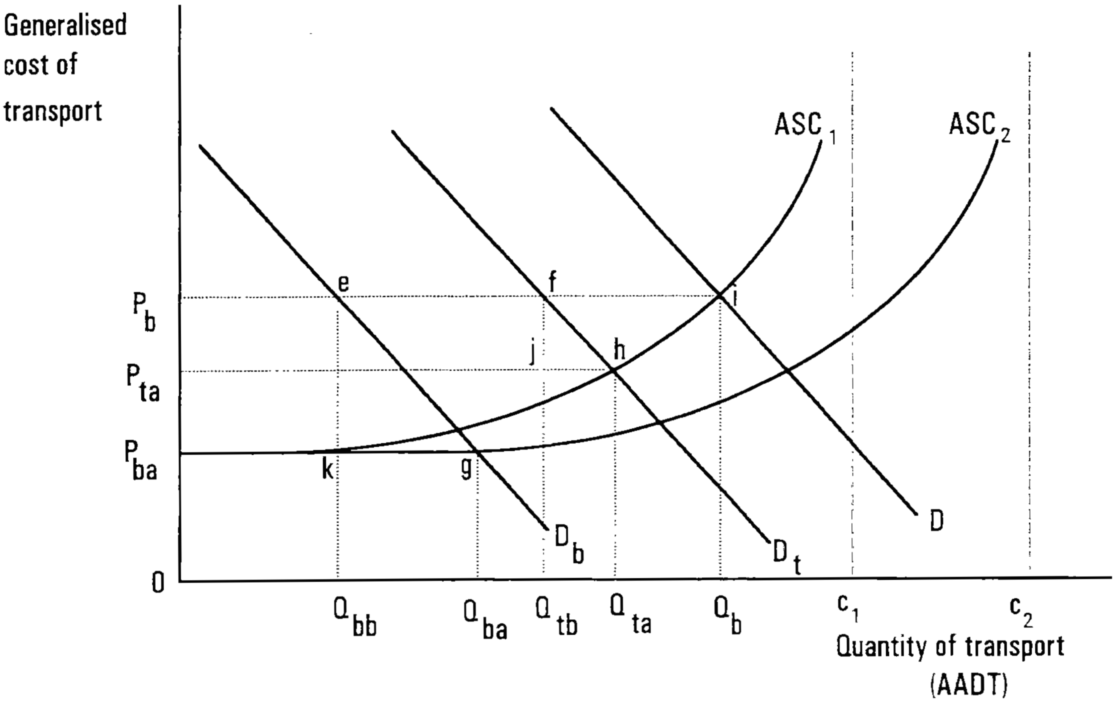

Figure II.2 Benefits from the construction of a bypass with non-optimal (average cost) pricing.

This means that for any prevailing price level (P_b in figure II.2);

$Q_b = Q_{tb} + Q_{bb},$

where Q_{bb} is quantity of vehicles that would use the bypass if it existed and Q_{tb} is the quantity of vehicles that would use the town road.

That is, the total demand curve, *D*, is the horizontal summation of the demand for travel on the town road, D_t, and the demand for travel on a bypass road, D_b.

Prior to a bypass when all users pay the same price (that is P_b) for using the town road, potential bypass users will be at position *e* on the D_b demand curve, and town road users will be at position *f* on the D_t demand curve. After a bypass is built, bypass users will travel on a higher capacity road at a lower price and town road users will travel on the same road at a lower price because of reduced congestion. Unless the demand curves are perfectly inelastic, the reduced price on both roads will induce a greater number of vehicles to use them (Q_{ba}-Q_{bb} vehicles on the bypass and Q_{ta}-Q_{tb} on the town road).

With this knowledge, the net economic benefit of constructing a bypass may be estimated in an analogous manner as that for capacity expanding projects on a single road. For the bypass, there is the cost reduction for existing users:

$P_b\ e\ k\ P_{ba} = P_b\ e\ Q_{bb}\ 0 - P_{ba}\ k\ Q_{bb}\ 0,$

and there is the net economic benefit of the extra travel;

$e\ k\ g = e\ Q_{bb}\ Q_{ba}\ g - Q_{bb}\ Q_{ba}\ g\ k.$

For the town road, there is also the cost reduction for existing users;

$P_b\ f\ j\ P_{ta} = P_b\ f\ Q_{tb}\ 0 - P_{ta}\ j\ Q_{tb}\ 0,$

and the net economic benefit of the extra travel;

$f\ j\ h = Q_{tb}\ Q_{ta}\ h\ f - Q_{tb}\ Q_{ta}\ h\ j.$

The sum of these benefits, $P_b\ P_{ta}\ h\ f + P_b\ P_{ba}\ g\ e$, plus the net savings on maintenance costs, annual savings/DAYS, is the daily net economic benefit in the year t, and for the optimal timing condition to be satisfied it must be greater than the hurdle amount (that is H = r/DAYS * K).

The computer bypass model and its operation

The general algebraic formulation of these benefit calculations is identical to that for the open road case, except now, two sets of calculations are necessary, one for the town road, and one for the bypass. The logical operation of the computer model, however, is more complicated because of the need to model the use of two roads.

The town demand curve, D_t, is fixed such that it passes through the ASC_T curve at a point such as *h* and this means there is enough information for the model to solve for the *a* parameter of the town demand curve (that is, Q_{ta}, P_{ta} and *b* are known). The total demand curve is initially assumed to be in the same position as the town road demand curve, and then, it is shifted rightward along the P_{ta} price line by a given quantity amount. The model has enough information to solve for the value of the *a* parameter of the total demand curve that is consistent with its new position. The total quantity of traffic going through the town prior to the construction of a bypass, *Qb*, and the price that all users have to pay, *Pb*, are then calculated by solving for the equilibrium point that exists prior to the construction of a bypass (that is point i in figure II.2) This gives the model enough information to solve for the amount of traffic that would continue to use the town road at price *Pb* even if the bypass existed (that is, it finds Q_{tb} by solving for the Q that satisfies the town demand equation at *f*). The quantity of traffic that would use a bypass at the price that all users of the town road currently pay (Q_{bb} at price P_b) is found by making use of the following relationship:

$$Q_{bb} = Q_b - Q_{tb}.$$

The model now has enough information to solve for the value of the *a* parameter of the bypass demand curve, D_b, that is consistent with it passing through point *e*. The equilibrium point (*g* in figure II.2) for the bypass road is then solved for to find the quantity of traffic that would use the bypass, Q_{bb}, and the new lower price level that the bypass users would have to pay, P_{ba}, if it was constructed. Now the benefit calculations described earlier may be made to see if the optimal timing condition is satisfied. If it is, Q_{ba} is recorded as the level of bypass traffic that would make a bypass economically justifiable if the town traffic volume was Q_{ta} after the bypass was built (these are the threshold AADT values used to screen the actual data base). If it is not, the total demand curve is again shifted to the right along the P_{ta} price line and the above processes repeat themselves. This continues until the minimum quantity of vehicles that must use the bypass to make it economically justifiable given a town traffic level of Q_{ta}, is found.

This process is repeated for several values of Q_{ta} so that threshold AADT values are estimated for a wide range of town traffic levels.

APPENDIX III RESULTS OF INFRASTRUCTURE ASSESSMENT BY LINK

This appendix contains tables that presents the infrastructure assessment results on a link basis for each corridor.

TABLE III.1 SYDNEY - MELBOURNE

Link	*LOS score*[*]		*Forecast investment*[**]
	1995-96	*2014-15*	*($M)*
Liverpool - Goulburn	35	60	250.4
Goulburn - Sturt Highway	42	58	355.5
Sturt Highway - Victorian border	53	68	231.3
NSW border - Seymour	9	30	151.8
Seymour - Melbourne	36	75	288.0
Expenditure outside towns			1277.0
Bypass expenditure			68.6
Corridor results	34	55	1345.6

Source BTCE

[*] LOS scores includes roads through towns

[**] Bypass expenditure excluded from link estimates

TABLE III.2 SYDNEY - BRISBANE (NEW ENGLAND HWY)

Link	*LOS score*[*]		*Forecast investment*[**]
	1995-96	*2014-15*	*($M)*
Hornsby - Minmi	55	83	377.9
Minmi - Aberdeen	59	77	267.3
Aberdeen - Armidale	56	79	525.9
Armidale - Queensland border	61	80	487.5
NSW border - Ipswich	47	69	354.3
Expenditure outside towns			2012.8
Bypass expenditure			100.9
Corridor results	55	77	2113.7

Source BTCE

[*] LOS scores includes roads through towns

[**] Bypass expenditure excluded from link estimates

TABLE III.3 SYDNEY - BRISBANE (PACIFIC HWY)

Link	*LOS score*[*]		*Forecast investment*[**]
	1995-96	*2014-15*	*($M)*
Minmi - Port Macquarie	78	94	930.1
Port Macquarie - Grafton	92	99	1267.1
Grafton - Queensland border	91	99	1114.3
NSW border - Brisbane	98	100	479.7
Expenditure outside towns			3791.2
Bypass expenditure			462.7
Corridor results	89	98	4253.9

Source BTCE

[*] LOS scores includes roads through towns

[**] Bypass expenditure excluded from link estimates

TABLE III.4 CANBERRA CONNECTIONS

Link	*LOS score*[*]		*Forecast investment*[**]
	1995-96	*2014-15*	*($M)*
Federal Highway	34	38	107.3
Barton Highway	79	91	148.8
Expenditure outside towns			256.1
Bypass expenditure			0.0
Corridor results	51	57	256.1

Source BTCE

[*] LOS scores includes roads through towns

[**] Bypass expenditure excluded from link estimates

TABLE III.5 MELBOURNE - ADELAIDE

Link	*LOS score*[*]		*Forecast investment*[**]
	1995-96	*2014-15*	*($M)*
Melbourne - Ballarat	18	42	141.0
Ballarat - SA border	30	48	32.4
Victorian border - Tailem Bend	30	40	7.2
Tailem Bend - Adelaide	16	23	114.6
Expenditure outside towns			295.2
Bypass expenditure			44.8
Corridor results	26	42	340.0

Source BTCE

[*] LOS scores includes roads through towns

[**] Bypass expenditure excluded from link estimates

TABLE III.6 SYDNEY - ADELAIDE

Link	*LOS score*[*] *1995-96*	 *2014-15*	*Forecast investment*[**] *($M)*
Sturt Highway - Narrandera	28	41	28.2
Narrandera - Victorian border	9	23	6.7
NSW border - SA border	11	25	0.0
Victorian border - Adelaide	34	47	193.5
Expenditure outside towns			228.4
Bypass expenditure			31.4
Corridor results	19	33	259.8

Source BTCE

[*] LOS scores includes roads through towns

[**] Bypass expenditure excluded from link estimates

TABLE III.7 MELBOURNE - BRISBANE

Link	*LOS score*[*] *1995-96*	 *2014-15*	*Forecast investment*[**] *($M)*
Seymour - NSW border	41	56	34.1
Victorian border - Narrandera	31	50	8.6
Narrandera - Dubbo	36	54	29.8
Dubbo - Narrabri	46	64	115.4
Narrabri - Queensland border	50	70	118.3
NSW border - Toowoomba	12	32	6.6
Expenditure outside towns			312.6
Bypass expenditure			308.6
Corridor results	32	56	621.2

Source BTCE

[*] LOS scores includes roads through towns

[**] Bypass expenditure excluded from link estimates

TABLE III.8 BRISBANE - CAIRNS

Link	*LOS score*[*]		*Forecast investment*[**]
	1995-96	*2014-15*	*($M)*
Brisbane - Gympie	55	88	480.2
Gympie - Rockhampton	49	67	194.7
Rockhampton - Townsville	36	52	271.0
Townsville - Cairns	48	66	257.5
Expenditure outside towns			1203.4
Bypass expenditure			168.3
Corridor results	44	62	1371.7

Source BTCE

[*] LOS scores includes roads through towns

[**] Bypass expenditure excluded from link estimates

TABLE III.9 ADELAIDE - PERTH

Link	*LOS score*[*]		*Forecast investment*[**]
	1995-96	*2014-15*	*($M)*
Adelaide - Port Augusta	25	40	14.4
Port Augusta - WA border	11	18	0.0
SA border - Norseman	4	8	0.0
Norseman - Perth	19	30	65.5
Expenditure outside towns			79.9
Bypass expenditure			19.2
Corridor results	13	20	99.1

Source BTCE

[*] LOS scores includes roads through towns

[**] Bypass expenditure excluded from link estimates

TABLE III.10 ADELAIDE - DARWIN

Link	*LOS score*[*]		*Forecast investment*[**]
	1995-96	*2014-15*	*($M)*
Port Augusta - NT border	4	7	0.8
SA border - Katherine	1	2	0.0
Katherine - Darwin	9	13	38.8
Expenditure outside towns			39.6
Bypass expenditure			0.0
Corridor results	3	5	39.6

Source BTCE

[*] LOS scores includes roads through towns

[**] Bypass expenditure excluded from link estimates

TABLE III.11 PERTH - DARWIN

Link	*LOS score*[*]		*Forecast investment*[**]
	1995-96	*2014-15*	*($M)*
Perth - Meekatharra	24	28	73.6
Meekatharra - Port Hedland	0	0	0.0
Port Hedland - Broome turn off	0	0	0.0
Broome turn off - NT border	2	4	0.0
WA border - Katherine	3	5	0.0
Expenditure outside towns			73.6
Bypass expenditure			0.0
Corridor results	6	7	73.6

Source BTCE

[*] LOS scores includes roads through towns

[**] Bypass expenditure excluded from link estimates

TABLE III.12 BRISBANE - DARWIN

Link	*LOS score*[*]		*Forecast investment*[**]
	1995-96	*2014-15*	*($M)*
Ipswich - Toowoomba	35	63	207.6
Toowoomba - Barcaldine	9	17	37.1
Barcaldine - Cloncurry	1	1	0.0
Cloncurry - NT border	6	9	9.8
Queensland border - Stuart Highway	0	0	0.0
Expenditure outside towns			254.5
Bypass expenditure			89.5
Corridor results	6	11	344.0

Source BTCE

[*] LOS scores includes roads through towns

[**] Bypass expenditure excluded from link estimates

TABLE III.13 HOBART - BURNIE

Link	*LOS score*[*]		*Forecast investment*[**]
	1995-96	*2014-15*	*($M)*
Hobart - Launceston	36	52	45.1
Launceston - Devonport	39	52	33.4
Devonport - Burnie	46	55	62.8
Expenditure outside towns			141.2
Bypass expenditure			12.0
Corridor results	38	52	153.2

Source BTCE

[*] LOS scores includes roads through towns

[**] Bypass expenditure excluded from link estimates

APPENDIX IV ESTIMATING THE COST OF ASSET PRESERVATION

THE PAVEMENT DETERIORATION MODEL

Using data from Brazil and several other countries, Paterson (1987) developed the following aggregate model for the relationship between roughness and several key explanatory variables:

$$R(t) = [\, R_o + 725(SNC + 1)^{-4.99}\, NE4_t \,]\, e^{0.0153\, t}$$

where $R(t)$ = roughness at time t (measured in IRI units)

R_o = roughness at time zero, ie. initial roughness

SNC = modified structural number

$NE4_t$ = equivalent standard axles until time t (in million ESAL/lane)

The time variable, t , does not represent time on an absolute scale, instead it is more useful to think of it as the *effective age* of the pavement. By performing appropriate rehabilitation work, the clock can be wound back to reduce the pavement's effective age. According to BTCE (1990), the conversion between IRI units and NAASRA roughness meter (NRM) counts can be performed using the following formulas

$$NRM = 26.49\, IRI - 1.27 \qquad \text{and} \qquad IRI = 0.0378\, NRM + 0.048$$

For practical purposes, the intercepts can be ignored and it can be assumed that NRM is simply a multiple of IRI and hence that the Paterson formulation is equally applicable to NRM counts.

The Paterson formula provides a useful starting point but in the form shown above, it proved impractical for forecasting deterioration of the intercapital road network because of gaps in the data. Information on initial roughness and year in which the road was constructed (or reconstructed) was not available for most links, and data for the structural number and reliable traffic ESAL estimates were not available for many links. As a result, it was necessary to simplify the formula in line with limitations in data availability.

It was assumed that traffic volume has been constant over the period so that we may write:

$$NE4_t \alpha t.$$

Further, SNC is a design constant so the expression for roughness progression can be represented in the general form:

$$R(t) = [R_0 + k . t] e^{mt} = R_0 . e^{mt} + k . t e^{mt}$$

where m is an environmental parameter and the units can be either IRI or NRM as required. In other words, roughness progression can be expressed as:

R(t) = {Environmental deterioration} + {Structural deterioration due to traffic}

In relation to the above formula and experimental results, Paterson (1986) noted that "pavements structurally designed for their traffic loadings suffer only very small amounts of roughness progression from structural causes and that roughness in these cases is largely a function of surface defects and environmental factors". Surface defects are largely random and unpredictable, so it is reasonable to simplify the formula to

$$R(t) = \beta . e^{mt}$$

where β is a *constant* that is largely determined by the initial roughness and construction characteristics of the road segment. The influence of random surface defects, deviations from designed traffic loading and other uncertainties can be captured in the pavement deterioration model by considering β to be specified by a probability distribution rather than a point estimate. This gives rise to a family of roughness progression curves, as shown in Figure IV.1.

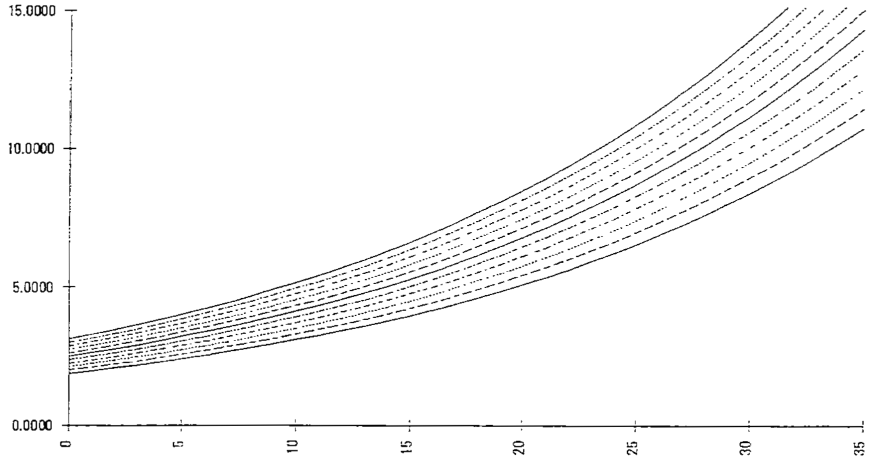

Figure IV.1 Family of Pavement Deterioration Curves

The roughness of a particular road segment will evolve along one of the curves, but precisely which curve is not known. Note that this formulation also predicts the observed phenomenon that the standard deviation in observed pavement roughness increases with pavement age.

The simplified deterioration formula allows the current effective age of the pavement to be estimated from its current roughness. At time T, inverting the formula gives:

$$T = (1/m) \,.\, \ln[R(T)/\beta\,]$$

Let R_c be the critical roughness at which some form of major maintenance (reconstruction or rehabilitation) will take place. The corresponding effective pavement age is:

$$T_c = (1/m) \,.\, \ln[R_c/\beta\,]$$

If the current roughness of a particular pavement is R' then its implied effective age is:

$$T' = (1/m) \,.\, \ln[R'/\ \beta]$$

and the time until it reaches critical roughness, that is, the *life expectancy* of the pavement is:

$$T_c - T' = (1/m) \,.\{\ln[R_c/\ \beta] - \ln[R'/\ \beta]\,\}$$

or:

$$T_c - T' = (1/m) \,.\, \ln[R_c/R']$$

This is an extremely useful result because the predicted pavement life expectancy is independent of the initial state of the pavement. It is only dependent on the current roughness (R'), the specified critical roughness (R_C), and the environmental parameter (m). This implies that the subsequent evolution of the pavement depends on its current roughness, not on how it got to that state or on its original condition. That is, the life expectancy does not depend on the parameter β or its probability distribution.

In a recent study by the BTCE (1990) a value of 0.016 was recommended for the environmental co-efficient for all States. However this value was set on the basis that the effect of traffic volume has been included in the calculation. Having omitted the traffic volume term, it may be appropriate to increase the value of the environmental constant to capture the small additional roughness progression induced by traffic flow. On the basis of roughness deterioration curves in recent studies by the BTCE (1990, 1992), and Paterson's recommended values, it appears that a value in the range 0.020-0.025 is more appropriate. Adopting a value of 0.020, it follows that the pavement life expectancy, that is, the time until the next major reconstruction, can be written as:

$$T_C - T' = 50 \ln[R_C/R']$$

This result can be used as the basis for a pavement maintenance costing model that has minimal data demands.

In a BTCE (1992) study it was demonstrated that the optimal balance of vehicle operating costs and pavement lifecycle costs is achieved by initiating road reconstruction at a range of different roughness levels. For road links with heavy traffic volume, reconstruction should take place when roughness reaches around 110 NRM whereas for road links with low traffic volumes, a critical roughness of 150 NRM is more appropriate. If AADT estimates are available for the road links then the model can be extended by varying the critical roughness (R_C) according to the traffic volume on the link.

Procedure for estimating the cost of road asset preservation

Step 1. Prepare database of roughness, AADT and pavement area of road segments.

Step 2. Prepare reference table of maintenance measures and associated costs and intervention triggers.

Step 3. Select an appropriate value of the environmental parameter. The value could be set on a national basis, or varied according to location and prevailing environmental conditions.

Step 4. For each road segment, calculate number of years until reconstruction using current and critical roughness as specified in Step 2 and the life expectancy formula developed above. Record year and cost.

Step 5. Starting from the projected year of reconstruction as calculated in Step 4, calculate and record a resealing schedule using the triggers specified in Step 2.

Step 6. Apply routine maintenance in all years in which resealing or reconstruction does not take place.

Step 7. Calculate cost of maintenance for each road segment, each year and the total for system.

Parameters

In order to calculate maintenance expenditures, it was necessary to derive values for the model parameters and make certain assumptions about maintenance regimes. The key parameters and assumptions are:

- the critical roughness for a given road segment is determined by its traffic load according to the optimum trigger roughness derived in BTCE 1992 (see table 2.9 p14). The roughness triggers are
  - 150 NRM for AADT<800
  - 120 NRM for 800<AADT<2000
  - 110 NRM for AADT>2000
- maintenance cost estimates are based on the following unit costs
  - Rehabilitation @ \$600,000/km
  - Resealing @ \$2/m^2
  - Resealing with shape correction @ \$15/m^2
  - Routine maintenance @ \$6/m
  - *Source* : Ove Arup National Highway Strategy Study
- resealing is assumed to take place at 10 year intervals with shape correction 100% of the time on high volume East Coast corridors, 50% of the time on other Eastern States corridors and 25% of the time on corridors with low traffic volumes to the north and west of Adelaide.
- a value of 0.020 has been used for the environmental parameter, m, for all States. This is a mid-range value in line with the recommended values for Australian climatic conditions, see Table 4.4 of BTCE (1990). It implies an expected life of some 50 years for a new pavement.

APPENDIX V DEMAND PROJECTIONS

The following table provides details of both the projected 1995-96 populations, and the projected population growth to 2014-15 for major Australian centres. Since there are a large number of locations involved, the table only contains the first ten centres in each state. Populations, both current and for three growth scenarios, are tabulated for both zones (ABS statistical local areas) and nodes (ABS urban centres and localities).

TABLE V.1 PROJECTED POPULATION GROWTH: 1995-96 TO 2014-15

	1995-96		*2014-15 Population (000's)*								
	Population(000's)		*Low growth*			*Medium growth*			*High growth*		
Location	*Zone*	*Node*	*Zone*	*Node*	*% pa from '95-96*	*Zone*	*Node*	*% pa from '95-96*	*Zone*	*Node*	*% pa from '95-96*
NSW											
Albury	66.3	66.0	76.1	75.9	0.7%	83.0	82.7	1.2%	89.6	89.3	1.6%
Armidale	22.0	22.0	21.7	21.7	-0.1%	23.4	23.4	0.3%	24.9	24.9	0.7%
Ballina	34.5	16.7	50.8	24.7	2.1%	55.5	26.9	2.5%	60.0	29.1	2.9%
Balranald	2.3	1.3	2.0	1.1	-0.8%	2.1	1.2	-0.5%	2.3	1.3	-0.1%
Barham	3.6	1.2	2.7	0.9	-1.5%	2.9	1.0	-1.1%	3.1	1.0	-0.8%
Barraba	2.5	1.4	1.9	1.1	-1.3%	2.1	1.2	-0.8%	2.2	1.3	-0.6%
Batemans Bay	30.8	23.6	48.0	36.7	2.4%	51.0	38.9	2.7%	53.7	41.0	3.0%
Bathurst	27.8	25.2	27.4	24.9	-0.1%	29.4	26.7	0.3%	31.1	28.3	0.6%
Bega	30.8	20.0	42.6	27.7	1.7%	44.3	28.8	1.9%	47.7	31.0	2.3%
Berrigan	8.3	5.6	7.3	5.0	-0.6%	7.8	5.3	-0.3%	8.4	5.7	0.1%
VICTORIA											
Ararat	12.5	8.0	12.1	7.7	-0.2%	13.6	8.7	0.4%	15.1	9.6	1.0%
Bacchus Marsh	13.4	10.9	24.3	19.8	3.2%	27.3	22.3	3.8%	30.4	24.7	4.4%
Baimsdale	19.2	11.5	22.3	13.4	0.8%	25.1	15.0	1.4%	27.8	16.7	2.0%
Ballarat	116.2	68.5	113.6	67.0	-0.1%	127.5	75.2	0.5%	141.6	83.5	1.0%
Benalla	15.0	8.9	17.5	10.5	0.8%	19.7	11.8	1.5%	21.9	13.1	2.0%
Bendigo	71.1	60.6	61.6	52.5	-0.8%	69.2	59.0	-0.1%	76.8	65.5	0.4%
Castlemaine	7.4	7.4	8.0	8.0	0.5%	9.0	9.0	1.1%	10.0	10.0	1.6%
Colac	16.7	10.7	15.3	9.8	-0.5%	17.2	11.0	0.1%	19.1	12.2	0.7%
Echuca	15.7	15.7	19.0	19.0	1.0%	21.4	21.4	1.6%	23.7	23.7	2.2%
Geelong	212.9	133.1	208.6	130.4	-0.1%	234.2	146.5	0.5%	260.1	162.6	1.1%

TABLE V.1 PROJECTED POPULATION GROWTH: 1995-96 TO 2014-15 (CONTINUED)

	1995-96		*2014-15 Population (000's)*								
	Population(000's)		*Low growth*			*Medium growth*			*High growth*		
Location	*Zone*	*Node*	*Zone*	*Node*	*% pa from '95-96*	*Zone*	*Node*	*% pa from '95-96*	*Zone*	*Node*	*% pa from '95-96*
QUEENSLAND											
Ayr	9.3	9.3	11.6	11.6	1.1%	12.0	12.0	1.3%	12.6	12.6	1.6%
Barcaldine	1.6	1.6	1.5	1.5	-0.5%	1.6	1.6	-0.1%	1.6	1.6	0.2%
Beaudesert	42.2	10.4	81.9	20.1	3.6%	91.1	22.3	4.1%	99.6	24.4	4.6%
Blackwater	6.8	6.8	6.5	6.5	-0.2%	6.8	6.8	0.0%	6.8	6.8	0.0%
Brisbane	1275.5	1275.5	1649.2	1649.2	1.4%	1781.8	1781.8	1.8%	1927.3	1927.3	2.2%
Bundaberg	53.6	42.1	55.6	43.7	0.2%	60.7	47.7	0.7%	62.0	48.7	0.8%
Cairns	74.0	74.0	90.8	90.8	1.1%	96.4	96.4	1.4%	99.8	99.8	1.6%
Charleville	5.3	3.5	5.3	3.5	0.1%	5.6	3.7	0.3%	5.7	3.7	0.4%
Charters Towers	9.4	9.4	10.8	10.8	0.7%	11.2	11.2	0.9%	12.4	12.4	1.5%
Chinchilla	3.4	3.4	3.8	3.8	0.7%	4.0	4.0	1.0%	4.2	4.2	1.1%
SOUTH AUST											
Adelaide	1000.0	1000.0	1061.4	1061.4	0.3%	1123.6	1123.6	0.6%	1249.3	1249.3	1.2%
Barmera	1.9	1.9	1.8	1.8	-0.5%	2.0	2.0	0.1%	2.2	2.2	0.7%
Berri	3.8	3.8	3.6	3.6	-0.3%	4.0	4.0	0.3%	4.5	4.5	0.9%
Bordertown	2.2	2.2	2.0	2.0	-0.4%	2.3	2.3	0.2%	2.6	2.6	0.8%
Ceduna	2.7	2.7	2.5	2.5	-0.4%	2.8	2.8	0.2%	3.1	3.1	0.7%
Clare	4.0	2.7	4.2	2.8	0.3%	4.8	3.2	0.9%	5.3	3.5	1.5%
Coober Pedy	2.5	2.5	2.2	2.2	-0.6%	2.5	2.5	0.0%	2.8	2.8	0.6%
Gawler	14.8	14.8	18.3	18.3	1.1%	20.6	20.6	1.7%	22.9	22.9	2.3%
Keith	1.2	1.2	1.1	1.1	-0.6%	1.2	1.2	0.0%	1.3	1.3	0.6%
Mount Barker	19.8	7.0	24.8	8.8	1.2%	27.9	9.9	1.8%	31.0	11.0	2.4%
WEST AUST											
Broome	10.6	10.6	15.3	15.3	2.0%	17.8	17.8	2.8%	20.7	20.7	3.6%
Carnarvon	7.2	7.2	8.0	8.0	0.6%	9.3	9.3	1.4%	10.3	10.3	1.9%
Coolgardie	1.2	1.2	1.2	1.2	0.2%	1.5	1.5	1.1%	1.7	1.7	1.9%
Cunderdin	0.7	0.7	0.6	0.6	-0.7%	0.7	0.7	0.0%	0.8	0.8	0.6%
Derby	3.4	3.4	3.2	3.2	-0.3%	3.7	3.7	0.5%	4.3	4.3	1.3%
Fitzroy Crossing	1.2	1.2	1.0	1.0	-0.8%	1.2	1.2	0.0%	1.4	1.4	0.8%
Geraldton	25.0	25.0	25.1	25.1	0.0%	28.9	28.9	0.8%	32.0	32.0	1.3%
Halls Creek	1.4	1.4	1.2	1.2	-0.8%	1.4	1.4	0.0%	1.6	1.6	0.8%
Kalgoorlie	35.3	34.1	34.0	32.9	-0.2%	40.4	39.0	0.7%	47.5	45.9	1.6%
Karratha	13.8	13.8	17.8	17.8	1.4%	19.0	19.0	1.7%	19.9	19.9	1.9%
TASMANIA											
Beaconsfield	17.8	4.9	19.4	5.3	0.5%	19.5	5.3	0.5%	19.6	5.4	0.5%
Bridgewater	13.3	9.2	17.4	12.0	1.4%	17.7	12.2	1.5%	17.6	12.2	1.5%
Burnie	20.7	20.7	22.5	22.5	0.4%	22.6	22.6	0.5%	22.9	22.9	0.5%
Devonport	24.8	22.9	27.3	25.2	0.5%	27.3	25.2	0.5%	27.2	25.1	0.5%
George Town	7.2	5.2	7.4	5.3	0.2%	7.6	5.5	0.3%	7.8	5.7	0.5%
Hobart	170.6	147.0	170.8	147.1	0.0%	176.3	151.9	0.2%	180.4	155.5	0.3%
Launceston	69.3	69.3	73.3	73.3	0.3%	74.3	74.3	0.4%	74.3	74.3	0.4%
New Norfolk	10.3	6.0	10.9	6.3	0.3%	11.0	6.4	0.4%	11.1	6.4	0.4%
Queenstown	8.0	5.2	9.8	6.3	1.1%	9.8	6.3	1.0%	9.9	6.4	1.1%
Smithton	8.3	3.5	9.0	3.8	0.5%	8.9	3.8	0.4%	9.1	3.9	0.5%
NORTH TERR											
Alice Springs	29.3	23.4	34.6	27.6	0.9%	38.9	31.0	1.5%	43.2	34.5	2.1%
Borroloola	0.7	0.7	0.9	0.9	1.6%	0.9	0.9	1.6%	0.9	0.9	1.6%
Darwin	78.3	75.9	126.9	122.3	2.6%	126.9	122.3	2.6%	126.9	122.3	2.6%
Elliott	0.4	0.4	0.6	0.6	1.6%	0.6	0.6	1.6%	0.6	0.6	1.6%
Katherine	7.9	7.9	7.2	7.2	-0.5%	8.1	8.1	0.1%	9.0	9.0	0.7%
Ngukurr	0.9	0.9	1.0	1.0	0.7%	1.0	1.0	0.7%	1.0	1.0	0.7%
Tennant Creek	4.3	4.3	6.0	6.0	1.8%	6.0	6.0	1.8%	6.0	6.0	1.8%
Yulara	3.9	3.9	3.8	3.8	-0.1%	4.3	4.3	0.5%	4.8	4.8	1.1%
ACT	305.4	305.4	398.9	398.9	1.4%	423.3	423.3	1.7%	435.0	435.0	1.9%

The following table provides information on the projected traffic volumes for 1995-96, and 2014-15, for the three different growth scenarios. Since the

Bureau's data-base contained a large number of records, the table only contains the first five links on each corridor.

TABLE V.2 PROJECTED GROWTH IN TRAFFIC VOLUMES: 1995-96 TO 2014-15

Link		*Dist*	*Estimated 1995-96 Traffic*					*2014-15 Low growth*		*2014-15 Med growth*		*2014-15 High growth*	
				Light vehicles		*Heavy*		*Heavy*		*Heavy*		*Heavy*	
From	*To*	*km*	*Model*	*Local*	*Total*	*vehs*	*AADT*	*vehs*	*AADT*	*vehs*	*AADT*	*vehs*	*AADT*
SYDNEY	**MELBOURNE**												
Liverpool	Mittagong	76	8944	12654	21598	4119	25717	6708	35209	7222	37906	7766	40761
Mittagong	Hume/Illawarra Hwys	13	10061	6607	16668	3934	20602	6391	28705	6898	30983	7456	33489
Hume/Illawarra Hwys	Marulan	32	10754	3547	14301	3707	18008	6000	24811	6500	26878	7003	28959
Marulan	Goulbum	28	11669	2136	13805	3666	17471	5935	23848	6428	25830	6905	27747
Goulbum	Hume/Federal Hwys	10	9546	2422	11968	3419	15387	5523	20735	5995	22507	6425	24122
SYDNEY	**BRISBANE 1**												
Hornsby	Calga	45	34019	17658	51677	4634	56311	7612	72457	8125	77342	8633	82181
Calga	Ourimbah	17	24067	13281	37348	3604	40952	5911	52818	6319	56461	6720	60047
Ourimbah	Wyong/fwy	9	25955	6803	32758	3089	35847	5057	46301	5416	49589	5768	52808
Wyong/fwy	Freemans W'hole	33	13312	14877	28189	2677	30866	4327	41284	4694	44783	5048	48157
Freemans W'hole	Hexham Junction	24	10409	12859	23268	2471	25739	3984	34744	4332	37775	4667	40694
SYDNEY	**BRISBANE 2**												
Hexham Junction	Hexham	5	22910	2646	25556	3089	28645	5069	36667	5416	39174	5744	41549
Hexham	Raymond Terrace	16	15829	2088	17917	793	18710	1288	24521	1390	26462	1488	28336
Raymond Terrace	Karuah	20	9414	2055	11469	720	12189	1164	16625	1262	18030	1356	19372
Karuah	Bulahdelah	43	8257	1016	9273	684	9957	1102	13932	1199	15157	1291	16316
Bulahdelah	Taree	77	5803	1768	7571	551	8122	878	11809	966	12988	1049	14103
FEDERAL	**HWY**												
Hume/Federal Hwys	Canberra	91	5290	1820	7110	896	8006	1468	10985	1571	11753	1651	12349
BARTON	**HWY**												
Yass	Murrumbatm'n	32	4496	520	5016	659	5675	1055	7678	1155	8406	1235	8987
Murrumbatm'n	Canberra	25	5502	5957	11459	762	12221	1202	16261	1336	18074	1413	19118
MELBOURNE	**BRISBANE**												
Seymour	Shepparton	80	2424	903	3327	1060	4387	1619	5383	1858	6177	2100	6982
Shepparton	Strathmerton	49	1203	521	1724	679	2403	1037	2901	1190	3328	1350	3776
Strathmerton	MVHwy/Newell	14	1238	2075	3313	839	4152	1284	4888	1471	5600	1669	6354
MV Hwy/Newell	Tocumwal	15	1272	511	1783	932	2715	1422	3360	1634	3861	1855	4383
Tocumwal	Finley	21	1272	89	1361	617	1978	940	2419	1081	2781	1227	3157
SYDNEY	**ADELAIDE**												
Hume/Sturt Hwys	Wagga Wagga	48	2113	441	2554	494	3048	786	3544	866	3904	946	4266
Wagga Wagga	Collingullie	26	2025	219	2244	679	2923	1079	3344	1190	3689	1301	4034
Collingullie	Narrandera	72	985	329	1314	314	1628	498	1813	550	2001	600	2184
Narrandera	Darlington Pt	59	176	754	930	267	1197	414	1344	468	1519	517	1679
Darlington Pt	Carrath Rd	58	123	726	849	205	1054	305	1250	359	1470	424	1735

TABLE V.2 PROJECTED GROWTH IN TRAFFIC VOLUMES: 1995-96 TO 2014-15 (CONTINUED)

Link		*Dist*	*Estimated 1995-96 Traffic*					*2014-15 Low growth*		*2014-15 Med growth*		*2014-15 High growth*	
				Light vehicles		*Heavy*		*Heavy*		*Heavy*		*Heavy*	
From	*To*	*km*	*Model*	*Local*	*Total*	*vehs*	*AADT*	*vehs*	*AADT*	*vehs*	*AADT*	*vehs*	*AADT*
MELBOURNE	**ADELAIDE**												
Melbourne	Melton	40	27903	5421	33324	4485	37809	6935	60135	7864	68194	8819	76472
Melton	BacchusMarsh	16	21372	7431	28803	3604	32407	5426	60230	6319	70144	7259	80583
Bacchus Marsh	Ballarat	55	10388	4001	14389	2204	16593	3362	21105	3864	24256	4390	27558
Ballarat	Ararat	91	2664	749	3413	1472	4885	2258	6080	2581	6949	2944	7927
Ararat	Stawell	31	2157	2536	4693	1416	6109	2144	7346	2482	8504	2875	9850
ADELAIDE	**PERTH**												
Adelaide	Port Wakefield	93	749	953	1702	494	2196	774	2469	866	2763	974	3107
Port Wakefield	Port Pirie	127	731	969	1700	494	2194	773	2456	866	2752	977	3104
Port Pirie	Port Augusta	99	475	1810	2285	628	2913	972	3223	1101	3650	1253	4153
Port Augusta	Iron Knob	26	385	1173	1558	540	2098	824	2272	946	2609	1118	3084
Iron Knob	Ceduna	444	49	211	260	185	445	278	697	324	812	408	1023
BRISBANE	**DARWIN**												
Toowoomba	Dalby	83	964	2776	3740	823	4563	1358	6145	1443	6529	1541	6972
Dalby	Chinchilla	125	206	885	1091	231	1322	383	1786	405	1887	431	2009
Chinchilla	Miles	45	139	957	1096	231	1327	387	1719	405	1800	433	1923
Miles	Roma	140	94	743	837	211	1048	354	1386	369	1446	403	1578
Roma	Morven	176	31	532	563	139	702	230	901	243	951	262	1024
ADELAIDE	**DARWIN**												
Port Augusta	Pimba	173	53	482	535	180	715	274	809	315	930	362	1068
Pimba	Coober Pedy	362	20	195	215	139	354	204	429	243	511	282	593
Coober Pedy	Erldunda	484	10	201	211	92	303	124	335	161	435	198	535
Erldunda	Alice Springs	199	19	382	401	185	586	262	705	324	872	374	1007
Alice Springs	Tennant Creek	506	21	294	315	139	454	222	702	243	768	257	812
PERTH	**DARWIN**												
Midland	Upper Swan	13	7558	4596	12154	1544	13698	2429	22528	2707	25104	2995	27778
Upper Swan	Bullsbrook	15	2535	3751	6286	720	7006	1123	10635	1262	11954	1410	13354
Bullsbrook	Muchea	11	470	2954	3424	463	3887	750	5616	811	6070	874	6541
Muchea	Wubin	215	48	289	337	82	419	134	576	143	613	158	677
Wubin	Mount Magnet	310	42	142	184	56	240	93	333	98	352	108	388
BRISBANE	**CAIRNS**												
Brisbane	Nambour	99	8632	2520	11152	1750	12902	2712	22724	3068	25706	3344	28021
Nambour	Gympie	68	2910	4391	7301	1076	8377	1684	12070	1886	13517	2020	14479
Gympie	Maryborough	87	1884	1043	2927	514	3441	814	4802	901	5317	960	5664
Maryborough	Childers	63	1342	1478	2820	453	3273	721	4490	794	4944	848	5279
Childers	Gin Gin	56	689	1471	2160	468	2628	761	3736	820	4027	892	4381
BURNIE	**HOBART**												
Burnie	Ulverstone	39	1613	2478	4091	793	4884	1379	6461	1390	6513	1402	6568
Ulverstone	Devonport	24	4198	5028	9226	1163	10389	2028	13295	2039	13366	2046	13414
Devonport	Deloraine	50	915	2970	3885	746	4631	1293	5967	1308	6037	1317	6080
Deloraine	Launceston	51	915	4999	5914	736	6650	1275	8391	1290	8490	1299	8550
Launceston	Oatlands	117	1241	1156	2397	437	2834	753	3557	766	3618	774	3655

PROJECTED INTERCAPITAL LIGHT VEHICLE MOVEMENTS

While estimating future demand for travel, the gravity model was run specifically to examine traffic movements between the capital cities and other important centres. This gave a greater insight into the origins and destinations of traffic on the National Highway system. The results of this work are tabulated below. Table V.3 shows the projected traffic volumes for light vehicles between each mainland capital city pair (and Alice Springs) for 1995-96.

TABLE V.3 PROJECTED TWO-WAY LIGHT VEHICLE TRIPS PER DAY: 1995-96

	Sydney	*Melbourne*	*Brisbane*	*Adelaide*	*Perth*	*Darwin*	*Canberra*
Melbourne	790						
Brisbane	560	90					
Adelaide	100	370	30				
Perth	10	10	4	7			
Darwin	1	1	1	1	0		
Canberra	3450	230	40	20	1	0	
Alice Springs	1	2	0	2	0	10	0

Table V.4 contains the projected volumes of heavy vehicle traffic between each mainland capital city pair (and Alice Springs) for 1995-96.

TABLE V.4 PROJECTED TWO-WAY HEAVY VEHICLE TRIPS PER DAY: 1995-96

	Sydney	*Melbourne*	*Brisbane*	*Adelaide*	*Perth*	*Darwin*	*Canberra*
Melbourne	970						
Brisbane	380	260					
Adelaide	230	390	80				
Perth	40	60	10	40			
Darwin	2	6	10	20	2		
Canberra	60	40	8	6	1	0	
Alice Springs	0	0	0	6	0	10	0

Table V.5 shows the projected volumes for all vehicles between each mainland capital city pair (and Alice Springs) for 1995-96.

TABLE V.5 PROJECTED TWO-WAY VEHICLE TRIPS PER DAY: 1995-96

	Sydney	*Melbourne*	*Brisbane*	*Adelaide*	*Perth*	*Darwin*	*Canberra*
Melbourne	1760						
Brisbane	940	350					
Adelaide	330	760	110				
Perth	50	70	14	47			
Darwin	3	7	11	21	2		
Canberra	3510	270	48	26	2	0	
Alice Springs	1	2	0	8	0	20	0

Table V.6 shows the projected volumes of light vehicle traffic between each mainland capital city pair (and Alice Springs) for 2014-15 for the medium growth scenario.

TABLE V.6 PROJECTED TWO-WAY LIGHT VEHICLE TRIPS PER DAY: 2014-15 (MEDIUM GROWTH)

	Sydney	*Melbourne*	*Brisbane*	*Adelaide*	*Perth*	*Darwin*	*Canberra*
Melbourne	1046						
Brisbane	902	149					
Adelaide	133	488	41				
Perth	16	16	8	11			
Darwin	1	2	1	1	1		
Canberra	5089	349	75	33	2	0	
Alice Springs	2	2	1	3	0	15	0

Table V.7 shows the projected volumes of heavy vehicle traffic between each mainland capital city pair (and Alice Springs) for 2014-15 for the medium growth scenario.

TABLE V.7 PROJECTED TWO-WAY HEAVY VEHICLE TRIPS PER DAY: 2014-15 (MEDIUM GROWTH)

	Sydney	*Melbourne*	*Brisbane*	*Adelaide*	*Perth*	*Darwin*	*Canberra*
Melbourne	1700						
Brisbane	660	450					
Adelaide	410	680	150				
Perth	70	110	20	70			
Darwin	3	10	16	40	4		
Canberra	110	80	15	10	1	0	
Alice Springs	0	0	0	11	0	18	0

Table V.8 shows the projected volumes for all vehicles between each mainland capital city pair (and Alice Springs) for 2014-15 for the medium growth scenario.

TABLE V.8 PROJECTED TWO-WAY TOTAL VEHICLE TRIPS PER DAY: 2014-15 (MEDIUM GROWTH)

	Sydney	*Melbourne*	*Brisbane*	*Adelaide*	*Perth*	*Darwin*	*Canberra*
Melbourne	2746						
Brisbane	1562	599					
Adelaide	543	1168	191				
Perth	86	126	28	81			
Darwin	4	12	17	41	5		
Canberra	5199	429	90	43	3	0	
Alice Springs	2	2	1	14	0	33	0

Tables V.9 to V.11 contains the resulting average annual low, medium and high growth rates for the city pair light vehicle traffic.

TABLE V.9 ANNUAL LIGHT VEHICLE GROWTH: 1995-96 TO 2014-15 (LOW GROWTH)

per cent

	Sydney	*Melbourne*	*Brisbane*	*Adelaide*	*Perth*	*Darwin*	*Canberra*
Melbourne	0.9						
Brisbane	2.0	1.8					
Adelaide	1.1	0.8	1.7				
Perth	2.7	2.4	3.0	1.9			
Darwin	0.0	0.0	0.0	0.0	na		
Canberra	1.7	1.6	2.5	1.6	3.7	na	
Alice Springs	0.0	0.0	na	0.0	na	2.4	na

The following table is derived from tables V.3 and V.6 and presents the annual growth in light vehicle traffic for the medium growth scenario.

TABLE V.10 ANNUAL LIGHT VEHICLE GROWTH: 1995-96 TO 2014-15 (MEDIUM GROWTH)

per cent

	Sydney	*Melbourne*	*Brisbane*	*Adelaide*	*Perth*	*Darwin*	*Canberra*
Melbourne	1.5						
Brisbane	2.6	2.6					
Adelaide	1.5	1.4	2.2				
Perth	3.1	3.1	3.7	2.4			
Darwin	0.0	3.7	0.0	0.0	na		
Canberra	2.1	2.3	3.1	2.2	3.7	na	
Alice Springs	3.7	0.0	na	2.2	na	2.7	na

TABLE V.11 ANNUAL LIGHT VEHICLE GROWTH: 1995-96 TO 2014-15 (HIGH GROWTH)

per cent

	Sydney	*Melbourne*	*Brisbane*	*Adelaide*	*Perth*	*Darwin*	*Canberra*
Melbourne	2.1						
Brisbane	3.0	3.3					
Adelaide	2.1	2.3	2.8				
Perth	3.7	3.7	4.9	3.3			
Darwin	0.0	3.7	0.0	0.0	na		
Canberra	2.3	2.8	3.5	2.6	6.0	na	
Alice Springs	3.7	2.2	na	2.2	na	3.1	na

APPENDIX VI DATA REQUIREMENTS FOR FUTURE INFRASTRUCTURE STUDIES

In this study the limited data that was available for all four modes was often fragmented. The lack of reliable statistics on demand, usage, condition and extent of the physical infrastructure, meant that a disproportionate amount of effort was required to gather information.

Policy formulation for transport infrastructure improvements should be based on the highest quality information. For instance the use of this data in the NTPT study has shown that though large sections of national highway have no capacity problems, as the highways approach capital cities, improvements will be needed to maintain acceptable levels of service. The study has also shown that critical problems may exist in urban areas for freight movement, but the lack of data, limited the analysis of these areas.

Consistent, uniform data are essential for evaluating transport infrastructure on an equitable basis throughout the nation. Otherwise solutions may be biased in favour of more articulated and active participants. This can result in under utilised infrastructure in some parts of the nation, built at great expense to the community, while congestion is occurring in other areas.

Within Australia various transport agencies are bidding for funds for the improvement of infrastructure. These agencies should be responsible for collecting and updating necessary data for evaluation of potential improvements to infrastructure and also to gauge its success.

ROAD DATA REQUIREMENTS FOR STRATEGIC STUDIES

It is pointless collecting data for the sake of collection. Prior to gathering data, the following questions should be addressed:

- what assessment methodology will be used;
- how is the data going to be used;

- what results will this data produce;
- what methods will be employed to check the data accuracy; and,
- who will maintain the currency of data and what data should be maintained.

On the basis that a similar methodology to that employed for the NTPT study will be adopted for future studies, the following proposed national highway data collection is recommended.

Description of road inventory (for each section)

Location details

- State code
- Name of corridor (or Identification of corridor)
- Highway name or number
- Location of towns and major centres on the route (to and from)
- Link number (in sequential order)
- Section number (in sequential order)
- Length of Section (Sections need to be identified sequentially from *start* to *end* of the corridor) *
- Geographic details

Pavement information

- Divided or undivided *
- Number of carriageways on the section
- Number of traffic lanes available *
- Actual lane widths *
- Pavement type +
- Pavement width (number of lanes if width data is not available)
- Surface type +
- Surface width +
- Number of shoulders
- Shoulder average width *
- Shoulder surface type

Pavement condition information

- Average NRM for all lanes on the section +
- NRM year of measurement +
- Per cent crack with severity +
- Per cent rutting with severity +

Usage information

- AADT on the section *
- AADT year of count *
- Per cent of commercial vehicles in the AADT (by type: Rigid %, Articulated %, Road Trains %) *
- Percentage of section length with no Passing Zone (Length with double line %)
- Any hourly AADT profiles that are available *
- AADT counts for a number of years for the route as a whole or for different sections (used for demand projection)

Geometric information

- Average change in grade *
- Terrain characteristics *
- Percentage length of curves on the section with speed limit restrictions or number of curves with maximum 4.5 degree (ie. minimum radius 385 metres)

Safety information.

- Accidents by type: **Fatal, Injury, Property damage** (year of record)
- Legal speed limit (or Advisory speed limit where this is less than the Legal speed limit) *
- Number of intersections (by type)
- Average travel speed during peak hour

Cost information

- Routine maintenance cost ($ per square metre of pavement)
- Reseal cost ($ per square metre of pavement)
- Asphalt overlay cost ($ per square metre of pavement with thickness information)
- Pavement reconstruction cost ($ per square metre of pavement)
- Pavement widening cost ($ per lane km with width information)

Other information

- Altitude above mean sea level *

Note * Necessary items for technical and economic adequacy (level of service) assessments

+ Additional items for maintenance adequacy measures assessments

Other items are needed for location identification, state classification, etc.

Data for urban and rural sections of national highway should be kept separately.

Description of structure's inventory (for each structure)

- Location details as above
- Usage details as above
- Deficiency status (such as load carrying capacity)
- Cost details

REFERENCES

ABBREVIATIONS

ABS	Australian Bureau of Statistics
AGPS	Australian Government Publishing Service
ARRB	Australian Road Research Board
BTCE	Bureau of Transport and Communications Economics
NAASRA	National Association of Australian State Road Authorities

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ABBREVIATIONS

AADT	Average annual daily traffic volume or the average number of vehicles that uses a road each day of the year
ABS	Australian Bureau of Statistics
ARRB	Australian Road Research Board
ASC	Average social cost curve
BCR	Benefit cost ratio
BTCE	Bureau of Transport and Communications Economics
BTE	Bureau of Transport Economics
CGE	Computable general equilibrium models
CPI	Consumer price index
GDP	Gross domestic product
LOS	Level of service
NHS	National Highway System
NRM	National Association of State Road Authorities roughness measure
NTPT	National Transport Planning Taskforce
PCU	Passenger car unit
SRMC	Short run marginal social cost curve
VCR	Vehicle capacity ratio
VOC	Vehicle operating cost