Bureau of Transport and Communications Economics

WORKING PAPER 35

ROADS 2020

The Bureau of Transport and Communications Economics undertakes applied economic research relevant to the portfolios of Transport and Regional Development, and Communications and the Arts. This research contributes to an improved understanding of the factors influencing the efficiency and growth of these sectors and the development of effective policies.

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PREFACE

A major rationale for the production of this Working Paper is to provide information to the Inquiry into Federal Road Funding by the House of Representatives Standing Committee on Communications, Transport and Microeconomic Reform. The analysis and results relate primarily to the non–urban sections of the federally funded National Highway System (NHS), but results are also provided for a set of roads nominated by individual States and Territories as being of national significance.

Although the modelling and assessment was undertaken by the Bureau of Transport and Communications Economics (BTCE), it benefited significantly from comments and suggestions by our colleagues in the States and Territories. The states and territories also generously provided data on their roads to enable the BTCE to update the database last used by it in work for the National Transport Planning Taskforce in 1994.

It is primarily in this spirit of cooperative effort that the BTCE has provided for the inclusion of unedited comment (appendix V) by each jurisdiction on the results. It is hoped that the transparency of the process established for this Working Paper will encourage enhanced cooperation in the future. Apart from improving the technical aspects of the modelling, the main aim would be to create a nationally consistent methodology—acceptable to all stakeholders—for the strategic assessment of non–urban road infrastructure on the NHS and possibly other nationally significant infrastructure.

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The BTCE team comprised Dr Mark Harvey and Dr David Gargett (team leaders), David Cosgrove, David Mitchell, Ben Wilson, Seu Cheng, Marion McCutcheon, Tony Carmody, and Dr Leo Dobes, with assistance from Sandra Collett and Karen Subasic.

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1 October 1997

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ABSTRACT

Using the BTCE's Road Infrastructure Assessment Model (RIAM), the *Roads 2020* study makes forecasts at a strategic level of expenditure needs for investment and maintenance between 1998 and 2005 and between 2005 and 2020. It also indicates the locations and types of these expenditures. The forecasts cover non-urban roads and bridges which are either part of the National Highway System or are considered to be of national significance by the States and Territories.

Expenditures predicted are upgrading road capacity (widening, adding lanes), town bypasses, maintenance, and bridge replacement. Some types of investment have been omitted because of data deficiencies or modelling difficulties. The exclusions are urban roads, flood mitigation projects, major realignment projects and widening roads used by road trains for safety reasons. Investments justified on social or equity grounds are also excluded.

Traffic levels were forecast using population projections and origin–destination data.

Total forecast expenditure needs for the National Highway System for the coming 22 year period have been estimated at $16.8 billion of which the backlog comprises $2.6 billion.

ABBREVIATIONS

AADT	Average Annual Daily Traffic
ABS	Australian Bureau of Statistics
ACT	Australian Capital Territory
ARRB	Australian Road Research Board
BTCE	Bureau of Transport and Communications Economics
NHS	National Highway System (roads listed in table 3.4)
NRM	NAASRA Roughness Meter
NRTC	National Road Transport Commission
NSW	New South Wales
NT	Northern Territory
QLD	Queensland
RIAM	Road Infrastructure Assessment Model (developed by BTCE)
SA	South Australia
SLA	Statistical Local Area
TAS	Tasmania
TRL	Terminal Roughness Level
VIC	Victoria
VKT	Vehicle Kilometres Travelled
WA	Western Australia

AT A GLANCE

The Bureau of Transport and Communications (BTCE) estimates that $16.8 billion will be required for non-urban sections of the National Highway System (NHS) from 2000 to 2020, with $2.6 billion of this amount warranted immediately. Its projections provide order of magnitude results, indicating areas where more detailed analysis is needed.

While the BTCE has recently enhanced its modelling by including overtaking lanes as an option to increase road capacity, and improved forecasts of car travel, it has not been able to include urban roads, flood mitigation works, or major realignment projects.

Economically warranted expenditure of $7 billion to the year 2020 is needed to widen NHS roads. Consistent with projected national population growth, over half is on the Sydney–Brisbane and Brisbane–Cairns corridors.

The States and Territories estimate that an additional $1 billion is needed to accommodate road trains, but cost-benefit analysis is required to test this.

About 34 bypasses of towns will be needed by 2020 at a cost of about $1.5 billion. About a third of this is warranted immediately. Most of the bypass expenditure is needed between Melbourne and Cairns.

Maintenance needs to 2020 are about $8 billion, spread fairly evenly across the NHS.

Most of the 1,976 bridges on the NHS are in good condition, but about $24 million would be required immediately to upgrade them if mass limits for heavy vehicles were increased from the current 42.5 tonnes to 45.5 tonnes for articulated trucks. Any increase in mass limits would also require expenditure on non-NHS roads, where costs could be expected to be much higher because bridges are not in as good a condition.

Other, non-NHS roads nominated by individual states and territories as nationally significant, have also been analysed by the BTCE (appendix III).

BTCE ESTIMATES OF EXPENDITURE NEEDS FOR NON-URBAN SECTIONS OF THE NATIONAL HIGHWAY SYSTEM

($ million, 1997–98 prices)

Road project type	*Backlog (1998)*	*1999-2005*	*2006-2020*	*Total*
Widening	1,928	721	4,317	6,967
Town bypasses	607	405	529	1,541
Maintenance	49	1,772	5,957	7,777
Bridge replacement	15	172	322	509
Total	*2,599*	*3,069*	*11,125*	*16,794*

Source BTCE.

CHAPTER 1 ASSESSMENT OF FUTURE INFRASTRUCTURE NEEDS FOR NON–URBAN ROADS

In 1994, the Bureau of Transport and Communications Economics (BTCE) undertook an assessment of the adequacy of transport infrastructure for the National Transport Planning Taskforce (BTCE 1994, 1995). The BTCE provided forecasts of future spending needs for the National Highway System (NHS) and the Pacific Highway for the 20 year period 1995 to 2015.

Since then, a number of significant improvements and extensions have been made to both data and modelling. Several of these improvements are due to the provision of data and advice from the various States and Territories.

Major improvements include:

- new sources of travel data
- an innovative methodology to forecast car traffic (developed by the BTCE);
- a more recent database of the NHS and other roads considered by the States and Territories to be of national significance (provided by road authorities);
- inclusion of overtaking lane standards as a modelling option in assessing potential investments;
- assessment of bridge replacement needs under three scenarios of increased vehicle mass limits;
- revised and updated vehicle operating cost model; and
- new road maintenance forecasting model.

SCOPE

Forecasts of future expenditure needs are divided into four categories:

- increased road capacity (essentially the width of the road);
- provision of town bypasses;
- road maintenance; and
- bridge replacement,

and for three time periods:

- as at 1 July 1998 (effectively the 'backlog' of investment expenditures already economically warranted as at that date);
- 1998–99 to 2004–2005 inclusive (a period of seven financial years); and
- 2005–06 to 2019–2020 inclusive (a period of 15 financial years).

The forecasts are straight additions of projected annual expenditures, not discounted present values, and are all in 1997–98 dollars.

GENERAL METHODOLOGY

The BTCE has recently obtained databases from the state road authorities describing the characteristics and traffic levels of the roads under study. The databases are composed of many thousands of road segments. Each segment has homogeneous characteristics for variables such as road width, surface type, roughness, traffic level and vehicle mix. SMEC Australia Ltd was engaged as a consultant to check the data and to consolidate it into a form suitable for the BTCE's computer models.

Road investment needs are largely driven by traffic levels and the proportions of heavy of vehicles using specific road sections. Forecasts of future traffic levels and vehicle mixes for 1998, 2005 and 2020 have been inserted into the database.

The BTCE has developed a computer model called the 'Road Infrastructure Assessment Model' (RIAM) to analyse the data. The model is written in the C++ computer language to ensure maximum processing speed. RIAM predicts future needs for road capacity, town bypasses and maintenance. It also generates estimates of the year in which expenditure would be optimal. A separate Working Paper describing the model in detail will be issued before the end of 1997.

STRATEGIC NATURE OF THE ANALYSIS

The strategic nature of the forecasts needs to be emphasised.

Economic worth of investment in road infrastructure can be tested properly only by undertaking a cost–benefit analysis for each road section. However, this would be a costly and time–consuming exercise, primarily because the NHS comprises over 18,000 kilometres of roads. Strategic analysis sacrifices detail to gain scope.

Results for individual sections of road, town bypasses or bridges may therefore be considerably under or over–stated. In the aggregate, however, the under and over–estimates should roughly cancel out.

The value of a strategic analysis is that it provides:

- broad orders of magnitude as to likely total future funding needs;

- broad indications of the locations and types of such needs; and
- results for a large amount of infrastructure in a timely and cost–effective manner.

That is, the BTCE analysis is intended to provide only indicative, order–of–magnitude results. The utility of these results lies in the fact that they can indicate readily to national, and State and Territory road authorities the major segments of roads that warrant more detailed study.

The BTCE's technique for strategic assessment of road infrastructure only requires data that can be obtained at a relatively low cost. There is no need for expensive on–site collection of road parameters. The investment project costs are generic for projects of a particular type. The bulk of the data requirements consist of information normally contained in the databases of state government road authorities.

However, this approach brings with it certain limitations.

QUALIFICATIONS TO ANALYSIS

Road authority databases do not normally contain information on curvatures and gradients of roads. Potential investment projects that result in major improvements in alignments therefore cannot be identified.

In the absence of information on flooding frequencies and on the economic benefits of improved flood immunity, flood mitigation projects are not included.

Road infrastructure needs within urban areas are excluded. The RIAM suite of models is set up only for non–urban roads. Urban roads require a completely different approach to modelling because of the need to take account of intersections, traffic lights and traffic flow interactions within networks.

The BTCE defines investment needs from a purely economic perspective. An investment is considered justified if the economic benefits exceed the costs. In practice, social and equity factors also play an important part in determining the pattern of road investment.

The net result of these limitations is that the BTCE's estimates of warranted expenditure should be regarded as a lower limit (underestimate) of funding needs for non–urban roads. However, the BTCE's research indicates clearly that its methodology provides forecasts of *most* of the road expenditures warranted on economic grounds. Additional expenditure on economically warranted flood mitigation schemes and major realignment projects, while important for expenditure totals for individual states and in specific years, are not expected to be large enough to cause any underestimate to be of major significance.

ROADS ASSESSED

States and Territories were requested to provide information on the characteristics of the NHS and any other roads that they considered to be of national significance. All of these roads have been assessed by the BTCE.

Because the NHS represents a defined set of roads for which the Commonwealth provides funding, results for NHS roads have been tabulated in the body of this Working Paper. Results for other roads nominated by individual States and Territories are presented separately in appendix III.

There is no agreed definition or set of roads considered to be of national significance. While the BTCE respects the judgment of the States and Territories on their choice of roads presented for analysis, the lack of a specific agreement between them, or between the Commonwealth and the States and Territories, means that it would be meaningless to aggregate the results. It would be similarly meaningless to add the results for the NHS to the results for the roads nominated by individual States and Territories.

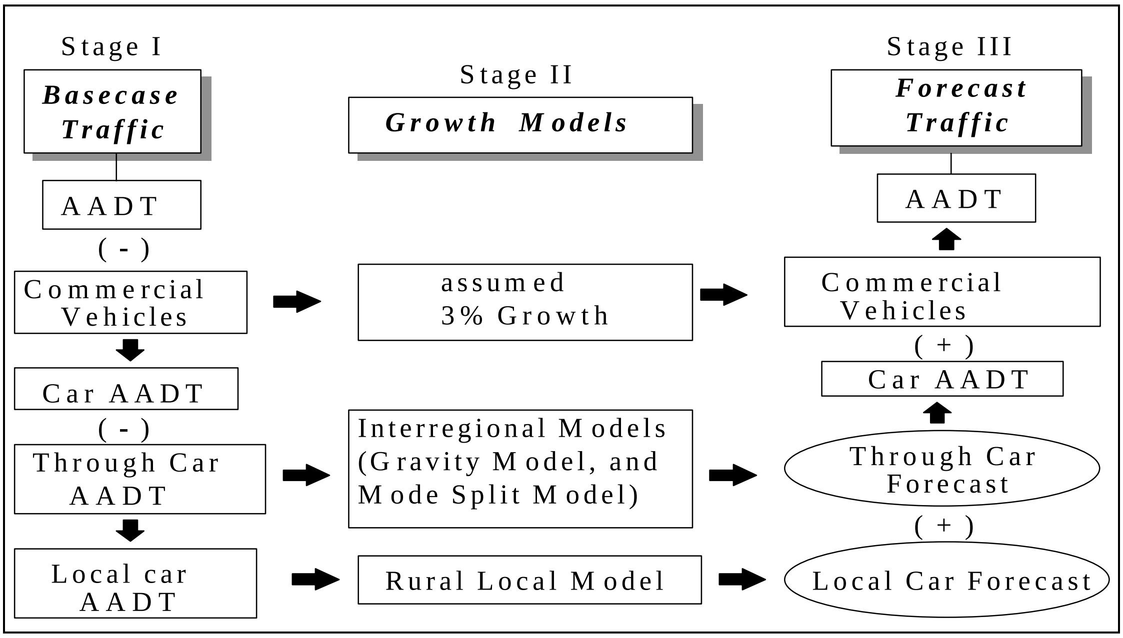
CHAPTER 2 TRAFFIC DEMAND FORECASTS

The BTCE has developed a procedure for predicting Annual Average Daily Traffic (AADT) on the nation's highways. This method was used to provide forecasts of traffic for use in the BTCE cost–benefit model of warranted road infrastructure investment, RIAM.

Three stages were involved in forecasting highway traffic (figure 2.1).

The first stage was to obtain the *basecase traffic* estimates for both the through car traffic and the rural local car traffic on each section of the NHS ('cars' was the term adopted for light vehicle traffic, which includes cars and light commercial vehicles such as utilities).

FIGURE 2.1 FORECASTING ANNUAL AVERAGE DAILY TRAVEL (AADT) ON EACH SECTION OF THE NATIONAL HIGHWAY SYSTEM



The second stage was to derive *growth models* for both through car traffic and for rural local car traffic. (Commercial vehicle traffic was not modelled in the recent study, and was assumed to grow at a rate of 3 per cent per year consistent with the approach of the National Transport Planning Taskforce in

1994.) Finally, in the third stage, the growth models were used to derive the *forecast traffic* (through car traffic and rural local car traffic). Aggregation of the various traffic components (that is, through car traffic, rural local car traffic, and commercial vehicle traffic) provided final forecasts of total traffic on each highway section.

A more detailed description of the modelling approach is expected to be released by the end of the year.

THROUGH CAR TRAFFIC

Car through–traffic by was estimated using two interregional travel demand models. The first model was a gravity model that explained the growth in total passenger travel between 10 pairs of interregional links: Sydney–Melbourne, Sydney–Canberra, Sydney–Brisbane, Sydney–Adelaide, Melbourne–Brisbane, Melbourne–Adelaide, Eastern Capitals–Perth, Melbourne and Sydney–Coolangatta, Eastern Capitals–Tasmania, Eastern Capitals–Northern Territory.

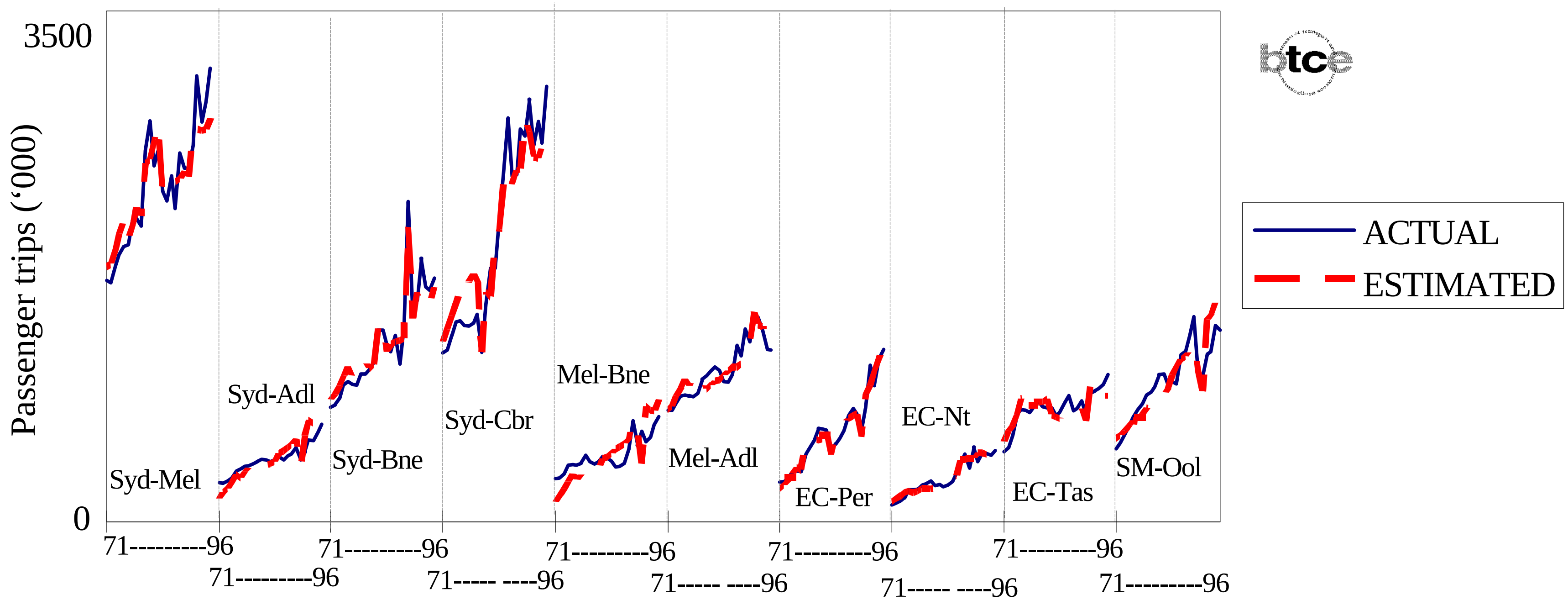
Two major factors that influenced interregional travel demand in the gravity model were the travel attraction of the populations in the origin (o) and destination (d) regions (adjusted for tourism specialisation), and the cost of travel. The cost of travel was measured as the ratio of generalised costs (including egress and access times, travel time, fares, and vehicle operating costs, etc.) to average weekly earnings per person. Both the generalised cost of travel and weekly earnings were deflated by consumer price index (1989–90=100) in order to express the values in real terms (which allowed separate forecasting treatment of cost and earnings). Based on these considerations, the gravity model is specified as follows:

$$Passenger\ Travel_{o-d} = \frac{(Population_o \times Population_d)^{0.5}}{(Real\ Generalised\ Travel\ Cost\ /\ Real\ Weekly\ Earnings)^{1.25}} \quad (1)$$

The model was estimated using cross–section and time series data between 1970–71 and 1995–96 for the 10 interregional links. This basic equation accounted for 85 per cent of the variation, with most of the residual variation being explained by some consistent differences between routes in levels of travel (not growth rates). By assigning dummy variables to fine tune levels in the corridors and to cater for special events (such as Expo in Brisbane (1988), the pilot strike (1990–91), etc.), the model explained about 97 percent of the variance in total passenger travel on the links (figure 2.2).

Having derived a gravity model to explain growth in *total* passenger travel, the second step was to account for the long–term trends in modal share. This allowed prediction of the relative share of car traffic in the total transport market (which includes air, rail, coaches, and/or ferry) between pairs of interregional links. Logistic–substitution models were derived to measure the relative shares of different transport modes over the period 1970–71 and 1995-96. The results

FIGURE 2.2 ACTUAL AND ESTIMATED INTERREGIONAL PASSENGER TRAVEL, 1970–71 TO 1995–96



Source BTCE estimates.

obtained from the models showed that travel on long routes is increasingly dominated by air transport, while shorter route travel is becoming dominated by cars. The BTCE's logistic–substitution modelling suggested the following 'rules of thumb' (table 2.1) for translating growth in *total* travel between two regions into growth in *car* travel.

TABLE 2.1 'RULES OF THUMB' USED TO TRANSLATE GROWTH IN TOTAL TRAVEL INTO GROWTH IN CAR TRAVEL

Distance category	*'Rules of thumb'*	*Car growth multiplier (Applied to predicted total growth)*
Long routes (> 800 km)	No growth in car travel	0.00
Medium routes (400–800 km)	Car gains some of total growth	0.70
Short routes (200–400 km)	Car winning mode share	1.25
Very short routes (< 200 km)	Mostly car already	1.00

Source BTCE.

LOCAL CAR TRAFFIC

The growth in local car traffic was assumed to be proportional to 'implied vehicle kilometres travelled (VKT)'. 'Implied VKT' was measured as a product of the population of rural Statistical Local Areas (SLAs), cars per person at a national level, and national level non–urban VKT. The model is specified as follows:

$$\begin{aligned} &\textit{Rural local VKT} \\ &\quad = \textit{Implied VKT} \\ &\quad = (\textit{Rural SLAs Population x National - level Cars Per Person x} \\ &\quad \textit{National - level Non - Urban VKT Per Car}) \end{aligned} \qquad (2)$$

The rationale for using the 'implied VKT' approach in modelling rural local travel relied upon two pieces of evidence. First, estimation conducted for urban VKT found that traffic in the cities is closely approximated by this model. Secondly, subtracting from the 1995 Survey of Motor Vehicle Usage estimate of non–urban VKT, the interregional VKT (derived from tourism data), results in a figure for rural local VKT quite close to the figure for 'implied VKT'.

THE FINAL TOTAL AADT FORECAST

The forecast of the final total AADT required forecasts of AADTs for both commercial vehicles and cars. In the absence of data or detailed forecasts, commercial vehicle AADT was assumed to grow at a rate of 3 per cent per year. The forecast of car AADT was obtained by adding up the forecasts of through car traffic as well as the rural local car traffic.

With respect to forecasting through car traffic, the growth in ***total*** travel between pairs of interregional links between 1996 and 2020 was based on the assumptions that:

- the product of the populations of the origin and destination interregional links is multiplied by 0.5. Population growth assumptions on an SLA base were supplied by the ABS (and averaged about 1.0 per cent per year nationally);
- there will be no change in real generalised costs of travel, and the growth in real average weekly earnings will be one per cent per year. Hence the denominator in equation (1) contributed 1.25 per cent per year to growth in total travel demand.

Growth in total passenger demand was converted to growth in car passenger demand by multiplying by the car growth multiplier matrix. The resulting forecast of car passenger movements was converted into a forecast origin–destination matrix of car trips using the assumption of 1.8 adults per car on long–distance trips. The car travel matrix was then assigned to the road network (using the TRANSCAD computer program) in order to produce forecasts of through car traffic on highway sections.

For the forecasting of rural local traffic, the major assumptions associated with the factors affecting rural local travel between 1996 and 2020 were as follows:

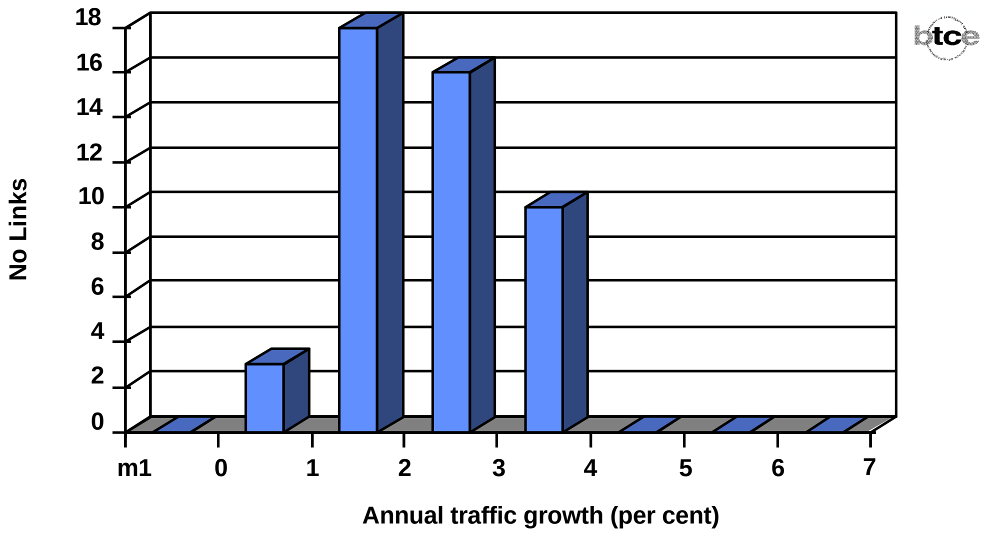
- ABS forecasts of growth of the population of rural SLAs (nationally about one per cent per year but varying by SLA) were used;
- the national–level non–urban VKT per vehicle was assumed to remain constant; and
- the national–level number of cars per person (cars plus light commercial vehicles) was assumed to grow at an average rate of 0.7 per cent per year.

Based on the assumptions adopted in the forecasting of through car traffic and rural local car traffic, the growth in the total light vehicle traffic therefore was estimated to be in the order of 2 per cent per year nationally.

Figure 2.3A shows the forecast distribution of non–urban road sections on the National Highway System in Western Australia by growth rate in AADT. The median growth forecast is about 2 percent growth as expected. Figure 2.3B shows the historical distribution of road sections in Western Australia by growth rate in AADT (1989–90 to 1995–96). It is similar to but somewhat higher than levels predicted for the next two decades. It must be borne in mind, however, that growth in both population and vehicles per person will be markedly slower over the next 20 years, and thus the forecast growth should indeed be somewhat lower than historical growth.

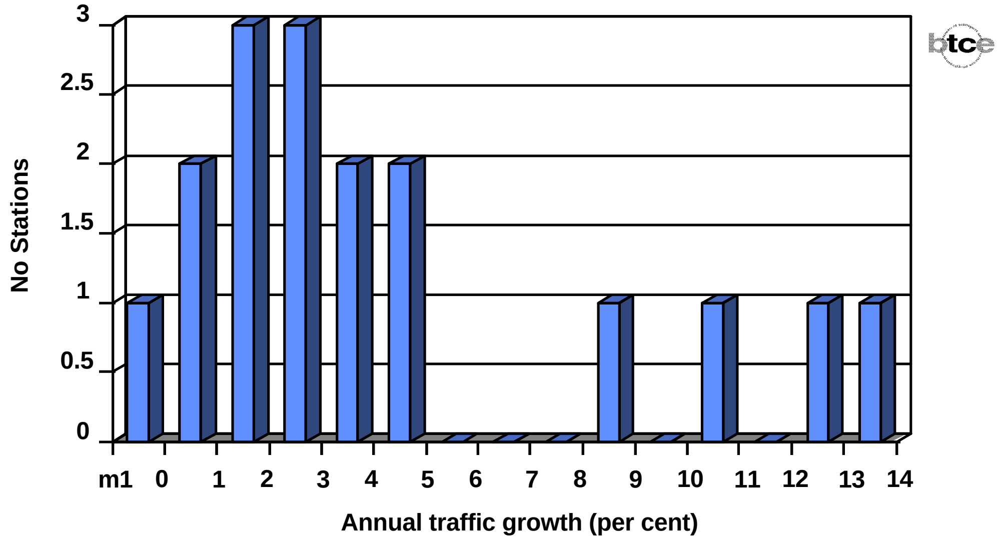
The final output of the forecast procedure was a file of predicted light and heavy vehicle traffic on each road section of the NHS. This was fed into the RIAM cost benefit model.

FIGURE 2.3A FORECAST TRAFFIC GROWTH ON WA NATIONAL HIGHWAY LINKS, 1996–2020



Source BTCE.

FIGURE 2.3B HISTORICAL TRAFFIC GROWTH AT WA NATIONAL HIGHWAY COUNT STATIONS, 1989–1996



Source WA Main Roads.

CHAPTER 3 ROAD CAPACITY

The capacity of a road to carry traffic depends on characteristics such as the number of lanes, lane widths, shoulder widths, curvature and gradient.

Where the traffic volume is small in relation to road capacity, vehicles can travel at their desired speed, free from interference from other road users. As traffic volume rises, vehicles begin to slow each other down. With further increases in traffic, congestion sets in. Investing in wider, straighter roads reduces congestion on a road for any given traffic volume, yielding benefits in terms of time, vehicle operating costs and accident cost savings.

However, the resulting benefits need to be compared to the costs of upgrading to test whether increasing road capacity is economically warranted.

METHODOLOGY AND ASSUMPTIONS

In assessing the capacity of non–urban roads, the RIAM model recognises the series of discrete road standards shown in table 3.1. Each section of road in the database is assigned the standard that best approximates its current standard. Depending on the terrain, generic project construction costs are assumed (table 3.2) for upgrading from each standard to the next. These project costs include an allowance for upgrading of bridges and construction of interchanges. Expenditures required to replace existing bridges on the NHS are covered separately in chapter 6.

For each segment of road, the RIAM model tests whether, given the traffic level forecast, upgrading to higher standards is economically warranted. This is done by comparing the benefits from upgrades with the costs of upgrading. Benefits estimated are savings in vehicle operating costs, travel time, and accident costs. A large part of these benefits will be passed on to industries and consumers. Additional maintenance costs to the road authority are added in as a negative benefit. Assumptions employed in estimating benefits are given in appendix I.

TABLE 3.1 ROAD STANDARDS INCORPORATED IN BTCE RIAM MODEL

	Number of lanes	*Lane width (m)*	*Sealed shoulder width (m)*[a]	*Design speed (kph)*	*Average NRM over time*[b]
2 lane narrow, unsealed shoulders	2	3.0	0	100	100
2 lane narrow, sealed shoulders	2	3.0	3.0	100	100
2 lane wide	2	3.5	2.6	100	90
2 lanes with 1.2 km overtaking lanes every 20 kms	2	3.5	2.6	100	90
2 lanes with 1.2 km overtaking lanes every 10 kms	2	3.5	2.6	100	90
2 lanes with 1.2 km overtaking lanes every 5 kms	2	3.5	2.6	100	90
4 lane divided	4	3.5	6.0	110	80
6 lane divided	6	3.5	6.0	110	70
8 lane divided	8	3.5	6.0	110	70

Notes a. Sealed shoulder widths are the sum of sealed widths for both shoulders (eg. for a 2 lane road, left and right shoulders added together). Roads may also have unsealed shoulders but these are not specified because they are assumed to contribute to increasing the capacity of the road.

b. NRM = National Association of Australian State Road Authorities (NAASRA) Roughness Measure. Roughness levels can be as low as 20 NRM for a new pavement and will deteriorate with age. Eventually the road will be rehabilitated, returning it to the level for a new pavement. Higher standard roads are assumed to be rehabilitated more often and so have a lower average roughness over time.

Source BTCE.

TABLE 3.2 ASSUMED COST OF UPGRADING FROM ONE STANDARD TO THE NEXT

($'000 per kilometre)

		Terrain		
From standard	*To standard*	*Flat*	*Undulating*	*Mountainous*
2 lane narrow unsealed shoulders	2 lane narrow sealed shoulders	30	30	30
2 lane narrow, sealed shoulders	2 lane wide, sealed shoulders	200	200	200
2 lane wide	2 lanes with overtaking lanes every 20 kms	40	60	80
2 lanes with overtaking lanes every 20 kms	2 lanes with overtaking lanes every 10 kms	40	60	80
2 lanes with overtaking lanes every 10 kms	2 lanes with overtaking lanes every 5 kms	80	120	160
2 lanes with overtaking lanes every 5 kms	4 lane divided	2,900	4,300	5,800
4 lane divided	6 lane divided	4,300	6,400	8,600
6 lane divided	8 lane divided	4,300	6,400	8,600

Source BTCE based on information from various state and territory road authorities.

An allowance is made for new traffic generated as a result of improved road conditions. An upgrade is deemed likely to be warranted if its economically optimal implementation time occurs before the 'snapshot' dates used (1998, 2005 and 2020). Use of an optimal timing criterion ensures that the present value of net gains to Australia from road investment are maximised. If one upgrade is found to be justified, the model also tests whether upgrades to still higher standards are warranted.

The discount rate used was 7 per cent, in line with Austroads practice. Choice by the BTCE of a 7 per cent discount rate does not imply that it is the 'correct' rate to use to assess the viability of a road investment. It was used to facilitate any comparisons with other road studies, and work done for the National Planning Task Force (1994) by the BTCE.

The BTCE's RIAM model incorporates the vehicle operating cost component of the World Bank's Highway Design and Maintenance Standards Model (HDM–III) as revised for Australian conditions and updated by ARRB Transport Research Ltd (Thoresen and Roper 1996, Roper and Thoresen 1997). The BTCE has added a component that adjusts speed to take account of congestion for each level of hourly traffic volume throughout the year. The model also includes an algorithm to predict the effects of overtaking lanes on vehicle speeds.

Whether a length of road should be upgraded to a higher standard on economic grounds depends largely on the average annual daily traffic (AADT) level. The proportion of heavy vehicles is also quite influential. A truck creates more congestion than a car and, because trucks have higher operating and time costs than cars, benefits of road improvements are higher where there are greater numbers of heavy vehicles. Terrain has a significant effect because upgrading costs are higher in rougher terrain, but so also are the benefits to road users.

In order to confirm that the model is producing reasonable results, 'threshold AADTs' were estimated under a range of heavy vehicle proportion and terrain scenarios. The thresholds are the minimum AADT level at which it just becomes economic to upgrade from one standard to the next. These are presented in table I.1, in Appendix I. As an example, a road in flat terrain with 10 per cent of its AADT comprising heavy vehicles, would require at least an AADT of 1 981 vehicles per day to justify sealing the shoulders. Once the traffic volume reached 12 085, duplication (upgrading from two lanes with overtaking lanes to four lane divided) would be warranted. The values in the table appear to be reasonable.

TABLE 3.3 EXPENDITURE NEEDS FOR CAPACITY EXPANSION BY STATE AND TERRITORY: NATIONAL HIGHWAY SYSTEM

($ million)

State	*Length analysed (km)*	*Backlog (1998)*	*1999–2005*	*2006–2020*	*Total*
ACT	17	4	–	–	4
NSW	2,760	1,244	276	1,722	3,242
NT	2,620	–	–	–	–
QLD	3,820	338	253	1,492	2,083
SA	2,379	31	72	264	366
TAS	299	62	35	151	248
VIC	1,145	235	10	550	796
WA	4,523	14	76	139	229
Overall	*17,561*	*1,928*	*721*	*4,317*	*6,967*

Source BTCE, based on data generously provided by state and territory road authorities.

RESULTS FOR THE NHS

Table 3.3 shows the results aggregated by States and Territories. The total required expenditure for capacity upgrades of the type under consideration amounts to $7.0 billion over the 22 year forecast period. The backlog comprises 28 per cent of the total. New South Wales requires the largest share, accounting for 47 per cent of the total, followed by Queensland at 30 per cent. The model did not find any upgrading to be warranted (at the strategic level) for the Northern Territory.

A more detailed breakdown by corridor is provided in table 3.4. The two main east coast routes, Sydney–Brisbane (New England Highway) and Brisbane–Cairns (Bruce Highway) together account for more than half the forecast expenditures. This accords with forecasts that the largest population growths are likely to occur along the east coast.

Tables 3.5 and 3.6 show how the forecasts are split up between different types of upgrades by distance and cost. In terms of distance, addition of overtaking lanes predominates. They are a relatively inexpensive way to increase the capacity of two lane roads. The main expenditures, however, are for highway duplication because this is such a costly upgrading work.

A high proportion of the forecast expenditures occurs close to state capitals.

TABLE 3.4 EXPENDITURE NEEDS FOR CAPACITY EXPANSION BY CORRIDOR: NATIONAL HIGHWAY SYSTEM

($ million)

State	*Corridor*	*Length analysed (km)*	*Backlog (1998)*	*1999–2005*	*2006–2020*	*Total*
ACT	Canberra Connections	17	4	–	–	4
NSW	Canberra Connections	103	23	2	18	44
NSW	Melbourne to Brisbane	982	49	22	84	155
NSW	Melbourne to Sydney	474	416	150	306	872
NSW	Sydney to Adelaide	591	41	5	12	57
NSW	Sydney to Brisbane	609	715	96	1,302	2,113
NT	Adelaide to Darwin	1,717	–	–	–	–
NT	Brisbane to Darwin	434	–	–	–	–
NT	Perth to Darwin	469	–	–	–	–
QLD	Brisbane to Cairns	1,494	222	210	1,295	1,727
QLD	Brisbane to Darwin	1,893	15	39	134	188
QLD	Melbourne to Brisbane	218	1	0	2	3
QLD	Sydney to Brisbane	215	100	4	60	164
SA	Adelaide to Darwin	927	–	–	–	–
SA	Adelaide to Perth	954	15	8	23	47
SA	Melbourne to Adelaide	277	5	61	187	252
SA	Sydney to Adelaide	221	11	3	54	68
TAS	Hobart to Burnie	299	62	35	151	248
VIC	Melbourne to Adelaide	378	189	7	367	564
VIC	Melbourne to Brisbane	250	45	3	184	232
VIC	Melbourne to Sydney	284	–	–	–	–
VIC	Sydney to Adelaide	233	–	–	–	–
WA	Adelaide to Perth	1,391	12	24	111	147
WA	Perth to Darwin	3,132	3	52	28	82
Overall		*17,561*	*1,928*	*721*	*4,317*	*6,967*

Source BTCE estimates using RIAM model.

Table 3.7 shows that 27 per cent of the total forecast expenditure for capacity expansion occurs within 100 kilometres of Sydney, Melbourne, and Brisbane and within 50 kilometres of the other capital cities.

TABLE 3.5 LENGTHS OF NHS ROAD BY PROJECT TYPE WARRANTED BETWEEN 1998 AND 2020

(kilometres)

Project descriptions	*ACT*	*NSW*	*NT*	*QLD*	*SA*	*TAS*	*VIC*	*WA*	*Overall*
Seal shoulders	–	–	–	18	–	–	–	40	58
Seal shoulder and widen	–	–	–	17	–	–	–	–	17
Widen	–	–	–	12	20	–	5	2	39
Add overtaking lanes and widen/seal existing two lane road	–	28	–	74	4	–	10	–	116
Add overtaking lanes to two lane road	–	1,077	–	673	310	89	294	34	2,477
Duplicate (two lane to four lane)	–	350	–	131	15	50	49	33	628
Duplicate (two lane to six lane)	1	27	–	34	–	–	5	1	67
Duplicate (two lane to eight lane)	–	62	–	8	–	–	9	2	81
Four lane to six lane	–	41	–	23	13	–	4	1	83
Four lane to eight lane	–	12	–	85	11	–	20	4	132
Six lane to eight lane	–	–	–	1	–	–	–	–	1
No work	16	1,162	2,620	2,745	2,006	160	750	4,405	13,864
Length analysed for capacity expansion	17	2,760	2,620	3,820	2,379	299	1,145	4,523	17,561
Length within towns (analysed for bypasses)	–	208	47	268	42	16	30	59	669
Urban links not analysed	–	55	23	0	316	11	34	21	460
Total	*17*	*3,023*	*2,689*	*4,088*	*2,737*	*326*	*1,209*	*4,602*	*18,690*

Source BTCE using RIAM model.

TABLE 3.6 COSTS OF NHS ROAD BY PROJECT TYPE WARRANTED BETWEEN 1998 AND 2020

($ million, 1997–98 prices)

Project descriptions	*ACT*	*NSW*	*NT*	*QLD*	*SA*	*TAS*	*VIC*	*WA*	*Overall*
Seal shoulders	–	–	–	1	–	–	–	1	2
Seal shoulder and widen	–	–	–	4	–	–	–	–	4
Widen	–	–	–	3	4	–	1	1	8
Add overtaking lanes and widen/seal existing two lane road	–	7	–	28	2	–	4	–	41
Add overtaking lanes to two lane road	–	153	–	103	42	16	41	4	359
Duplicate (two lane to four lane)	–	1,459	–	489	63	224	210	117	2,563
Duplicate (two lane to six lane)	4	286	–	332	–	–	34	9	666
Duplicate (two lane to eight lane)	–	1,010	–	122	–	8	153	36	1,328
Four lane to six lane	–	193	–	101	96	–	15	5	411
Four lane to eight lane	–	133	–	897	159	–	336	56	1,581
Six lane to eight lane	–	–	–	4	–	–	–	–	4
Total	*4*	*3,242*	–	*2,083*	*366*	*248*	*795*	*229*	*6,967*

Source BTCE using RIAM model.

TABLE 3.7 QUASIURBAN DEVELOPMENT[a]

(Percentage of expenditure needs for capacity expansion)

State	*Backlog (1998)*	*1999–2005*	*2006–2020*	*Total*
ACT	100	n.a.	n.a.	100
NSW	7	1	12	9
NT	n.a.	n.a.	n.a.	n.a.
QLD	31	42	41	40
SA	56	82	74	74
TAS	0	1	0	0
VIC	0	0	59	41
WA	100	99	97	98
Overall	*10*	*34*	*33*	*27*

Note a. Quasiurban development is defined as development occurring within 100 kilometres of Sydney, Melbourne and Brisbane, and within 50 kilometres of the other capital cities.

Source BTCE estimates using RIAM model.

QUALIFICATIONS TO ANALYSIS

Major realignment and flood mitigation projects

Future expenditures for major realignment and flood mitigation projects could not be estimated. To a certain extent, however, these expenditures are already included, because higher construction costs are assumed for projects in rougher terrain and some bridge construction projects will improve immunity from flooding. Nevertheless, some underestimation of costs still occurs, although it is probably not very great in relation to the total.

Western Australia has informed the BTCE (David Rice, pers. comm. 19 September 1997) that it has significant flood problems to overcome in the Kimberley region, where road closures of one or two weeks per year still occur.

Provision by the States and Territories of detailed information such as flood frequency and intensity, duration of traffic disruption, cost of repairs etc would permit some assessment of potential mitigation projects. The BTCE would be happy to pursue such modelling enhancements in cooperation with the States and Territories.

Widening roads for road trains

Increasingly, double and triple road trains are being used to transport goods between Australia's western and northern states. State and Territory road authorities agree that road trains raise safety concerns on existing roads, which were built for standard truck configurations. The preferred solution is to widen roads to around 8 or 9 metres seal width.

The BTCE's modelling and analysis are based on economic criteria. To be consistent with the BTCE approach, a cost–benefit analysis of widening roads for road trains would need to be undertaken. The cost–benefit analysis would test whether the savings in accident costs as well as the other benefits arising from increased road capacity, were sufficient to cover the additional capital and maintenance costs. The BTCE has asked the road authorities concerned to provide estimates of the cost of raising their sections of the NHS to the standard they consider necessary to cater for road trains. Their estimates are set out in table 3.8. Western Australia and Queensland require the bulk of upgrading work necessary for road trains. Western Australia has more road length requiring upgrading than other states. Queensland's roads require complete rebuilding, as opposed to widening, which is sufficient in other states.

TABLE 3.8 SUMMARY OF STATE AND TERRITORY ROAD TRAIN REQUIREMENTS[a]

		Necessary upgrading work		
State	*Minimum standard for road trains*	*Rebuild*	*Widening & seal shoulder*	*Approximate cost ($ million)*
Northern Territory	8m seal	–	1170km	31
New South Wales		n.a.	n.a.	
Queensland	9m seal	632km	–	316
South Australia	8m seal	–	659km	98[b]
Western Australia	AADT<3000: 8m seal AADT>3000: 9m seal		2,318km 61km	619

Note a. The estimates in the table have not been subjected to cost–benefit analysis by the BTCE.

b. Includes $60 million for rebuilding and widening the Sturt Highway.

Sources pers. com. Phil Cross, Department of Transport and Works, Northern Territory, 17 September 1997; pers. com. Viv Manwaring, Roads and Traffic Authority, New South Wales, 17 September 1997; pers. com. Eddie Peters, Queensland Department of Main Roads, 19 September 1997; pers. com. Bert Rowe, Department of Transport, South Australia, 11 September 1997; pers. com. David Rice, Main Roads, Western Australia, 17 September 1997.

State and Territory estimates of the total cost of upgrading the NHS to take road trains are in the order of $1 billion. However, unqualified addition of this estimate to the BTCE's estimates of increased road capacity requirements is likely to involve some double counting, since RIAM's $7.0 billion estimate for capacity works includes some road widening. The Queensland costs include pavement reconstruction work which is already included in the BTCE's estimates of maintenance needs. Because the costs of widening for road trains have not been subjected to an economic test, they have not been added to the BTCE's totals. The economic viability of road upgrading depends to a large extent on traffic levels. For example, in Western Australia most of the NHS carries low levels of traffic (half of the length of NHS road in Western Australia assessed for capacity had AADT levels of less than 350 vehicles per day as at 1998), so it is probable that much of the widening work suggested for road trains would not pass a cost–benefit test. However, the information in table 3.8 is useful in that it provides an indication of the likely magnitude of the cost of widening roads for road trains.

SENSITIVITY TESTS

Sensitivity tests have been undertaken for varying forecast traffic levels, the discount rate, construction costs, and the annual hourly volume distribution. The results of these tests are presented in table 3.9. The table shows the percentage changes from the basecase presented above, for expenditure totals for each state and for the total of all states.

There is fair amount of variability between states. If a significant proportion of a state's road system has traffic levels close to threshold levels for upgrading to higher standards, small changes in assumptions can lead to large movements across thresholds and hence large effects on forecast expenditure needs. The less the length of road being analysed in a state or territory, the more pronounced these effects can be, as seen by the Australian Capital Territory results. The tests show that for the Northern Territory, traffic levels fall well short of thresholds.

The expenditure forecasts are very sensitive to traffic level forecasts, but less so for construction costs. Increasing construction costs lowers threshold AADT levels, thus reducing the total distance upgraded but raises the required expenditures for the remaining upgrades. In most cases, the latter effect predominates. The change in expenditure levels from increasing the discount is not very great considering the size of increase in the discount rate: from 7 to 12 per cent.

Congestion along a road varies throughout the day, week and year. RIAM models congestion on the basis of hourly traffic volumes. The model needs to assume a distribution of these volumes across all the hours of the year. Two distributions are employed, 'rural' and 'quasiurban'. The quasiurban distribution is slightly flatter and is used for roads close to capital cities. The Western Australian annual hourly volume distribution is a composite of a number of distributions supplied to the BTCE by Main Roads WA. All three distributions are presented in appendix I.

Two sensitivity tests were undertaken with respect to the hourly volume distributions: one replacing only the rural distribution and one replacing both the rural and quasiurban distributions. The Western Australian distribution is quite different in character from the rural and quasiurban distributions and can have a marked effect on the results for individual states.

TABLE 3.9 SENSITIVITY TESTS FOR CAPACITY EXPANSION FORECASTS

	Per cent change in results								
Sensitivity Test	*ACT*	*NSW*	*NT*	*QLD*	*SA*	*TAS*	*VIC*	*WA*	*Total*
+20% AADT in 2020	290	58	0	82	86	61	118	59	66
-20% AADT in 2020	0	-34	0	-15	-63	-51	-46	-21	-40
12% discount rate[a]	0	-23	0	20	-23	-47	-16	-10	-22
+20% construction costs	20	18	0	55	15	19	9	12	15
-20% construction costs	160	-7	0	29	-1	-17	1	-19	-7
WA hourly volume distribution: rural only	0	-3	0	27	-1	-29	-10	0	-7
WA hourly volume distribution: rural and quasiurban	225	-1	0	39	30	-29	-6	21	0

Note a. 7 per cent discount rate used as default in RIAM.

Source BTCE estimates using RIAM model.

CHAPTER 4 TOWN BYPASSES

Traffic passing through a town experiences delays itself, while generating congestion for local traffic within the town. Construction of a town bypass therefore benefits both through–traffic and local traffic. In much the same manner as for capacity expansion projects, the RIAM model is able to test whether or not construction of town bypasses is warranted.

METHODOLOGY AND ASSUMPTIONS

For each town bypass assessed by RIAM, the length of the bypass has been taken as the total distance of road sections in and around the town with legal speed limits of less than 100 kilometres per hour. The construction cost has been estimated from the generic costs per kilometre presented in table 4.1. The Queensland Department of Main Roads supplied their own estimates of lengths and costs for the bypasses assessed on national highways in Queensland. These lengths and costs were used in place of the RIAM estimates.

TABLE 4.1 ASSUMED COSTS FOR TOWN BYPASS CONSTRUCTION

($'000 per kilometre)

	Terrain		
	Flat	*Undulating*	*Mountainous*
Two lane bypass	2,300	2,900	5,300
Four lane bypass	4,100	5,300	9,300

Source BTCE estimates.

The model distinguishes between through–traffic and local traffic. For cars, through–traffic is estimated from the interregional traffic flow generated during the course of developing the total AADT forecasts. For trucks, it is estimated from the traffic counts in the database. Not all of the through–traffic would use a bypass. It is assumed that a certain proportion will continue to use the town road despite construction of the bypass.

As the basecase, the model estimates the vehicle operating, time and accident costs along the town sections of the road in the absence of a bypass. Then, assuming that a bypass existed, the model estimates these costs along the town and bypass roads and combines the results. Allowance is made for traffic generated by the project. Additional maintenance costs to the road authority are added in as a negative benefit. The difference between costs without and with the bypass is the benefit of constructing the bypass. Benefits are compared with costs using the same optimal timing criterion as for the capacity assessment (chapter 3) to test whether the economically optimal implementation time occurs before the date of the traffic forecast. If a two lane bypass is found to be warranted, the model tests whether a four lane bypass may be justified.

As in the capacity analysis, it is possible to confirm that the results produced by the model are reasonable by examining ‘threshold AADTs’. The ‘threshold AADTs’ were estimated for a range of heavy vehicle proportions, and town road traffic levels. The thresholds are the minimum AADT levels that would be required to travel on the bypass for a given level of town road traffic. They are presented in table II.2, in Appendix II. As an example, for a road passing through a town having 20 per cent of its AADT heavy vehicles, and local traffic of 5 500 vehicles per day, there would need to be a through–traffic of at least 4 800 vehicles per day to justify building a two lane bypass.

RESULTS FOR THE NHS

The results of the bypass assessment for the NHS are presented in table 4.2 by state and territory and by corridors within states and territories in table 4.3. A total of 90 possible town bypasses were assessed for NHS roads, of which the model suggests 34 are warranted by 2020. The backlog is 13 bypasses, with a further 4 being warranted between 1999 and 2005, and 17 between 2006 and 2020. There is also some expenditure for upgrading two lanes bypasses in the backlog and 1999-2005 groups to four lane bypasses.

In common with the capacity forecasts, the corridors with the largest bypass needs are the Bruce (Brisbane–Cairns) and New England (Sydney–Brisbane) Highways. The Newell Highway (Melbourne–Brisbane) in New South Wales also has very significant bypass needs. The predominance of the New England and Newell Highways means that almost half of forecast bypass needs are in New South Wales. The backlog accounts for 39 per cent of the total, which is somewhat higher than for capacity where it was 28 per cent.

At the request of the states and territories, at a meeting with the BTCE on 19 August 1997, individual town bypasses have not been identified in order to avoid raising expectations unnecessarily.

TABLE 4.2 EXPENDITURE NEEDS FOR TOWN BYPASSES BY STATE AND TERRITORY: NATIONAL HIGHWAY SYSTEM

($ million)

State	*Number of bypasses assessed*	*Number of bypasses warranted*	*Backlog*	*1999–2005*	*2006–2020*	*Total*
NSW	22	14	412	117	171	700
NT	5	–	–	–	–	–
QLD	24	10	195	288	190	673
SA	11	2	–	–	27	27
TAS	4	3	–	–	45	45
VIC	6	5	–	–	96	96
WA	18	–	–	–	–	–
Overall	*90*	*34*	*607*	*405*	*529*	*1,541*

Source BTCE using RIAM model.

TABLE 4.3 EXPENDITURE NEEDS FOR TOWN BYPASSES BY CORRIDOR: NATIONAL HIGHWAY SYSTEM

($ million)

State	*Corridor*	*Number of bypasses assessed*	*Number of bypasses warranted*	*Backlog*	*1999–2005*	*2006–2020*	*Total*
NSW	Melbourne to Brisbane	9	4	92	117	21	229
NSW	Melbourne to Sydney	1	1	145	–	–	145
NSW	Sydney to Adelaide	3	1	40	–	–	40
NSW	Sydney to Brisbane	9	8	136	–	150	286
NT	Adelaide to Darwin	5	0	–	–	–	–
QLD	Brisbane to Cairns	8	7	55	167	171	393
QLD	Brisbane to Darwin	14	2	140	110	11	261
QLD	Sydney to Brisbane	2	1	–	11	9	20
SA	Adelaide to Darwin	1	0	–	–	–	–
SA	Adelaide to Perth	3	0	–	–	–	–
SA	Melbourne to Adelaide	3	0	–	–	–	–
SA	Sydney to Adelaide	4	2	–	–	27	27
TAS	Hobart to Burnie	4	3	–	–	45	45
VIC	Melbourne to Adelaide	5	4	–	–	90	90
VIC	Melbourne to Brisbane	1	1	–	–	7	7
WA	Adelaide to Perth	8	0	–	–	–	–
WA	Perth to Darwin	10	0	–	–	–	–
Overall		*90*	*34*	*607*	*405*	*529*	*1,541*

Source BTCE using RIAM model.

SENSITIVITY TESTS

The same sensitivity tests have been undertaken as for the capacity analysis. The results are presented in table 4.4. As with capacity, the bypass expenditure needs forecasts are very sensitive to the demand forecasts, but less so for the discount rate and construction costs. The South Australian results are particularly sensitive because of the low basecase, for which only two bypasses are warranted.

TABLE 4.4 SENSITIVITY TESTS

	Percentage change in expenditure needs for town bypasses								
Sensitivity Test	*ACT*	*NSW*	*NT*	*QLD*	*SA*	*TAS*	*VIC*	*WA*	*Total*
+20% AADT in 2020	na	14	0	15	317	48	17	0	12
-20% AADT in 2020	na	-47	0	-7	-100	-100	-56	0	-67
12% discount rate	na	0	0	-12	-100	-53	-35	0	-20
+20% construction costs	na	20	0	13	-100	-28	5	0	0
-20% construction costs	na	-20	0	-6	1	-20	-7	0	-28
WA hourly volume distribution: rural only	na	0	0	0	-100	-53	-20	0	-18
WA hourly volume distribution: rural and quasimodal	na	0	0	0	-100	-53	-20	0	-18

Note na not applicable because no bypasses were assessed for the ACT.

Source BTCE using RIAM model.

CHAPTER 5 MAINTENANCE

When a flexible pavement reaches the end of its life it needs to be 'rehabilitated'. This could involve reconstruction (usually recycling the existing pavement materials) or applying an asphalt overlay. Flexible pavements require resealing roughly every 7 to 15 years. Bitumen is sprayed on the surface and a thin layer of crushed rock applied. This seals cracks and so keeps out moisture which could weaken the pavement. Regular expenditures necessary for minor maintenance works such as cutting grass, repair and replacement of signs, repairing shoulders and patching potholes are included under the heading 'routine maintenance'.

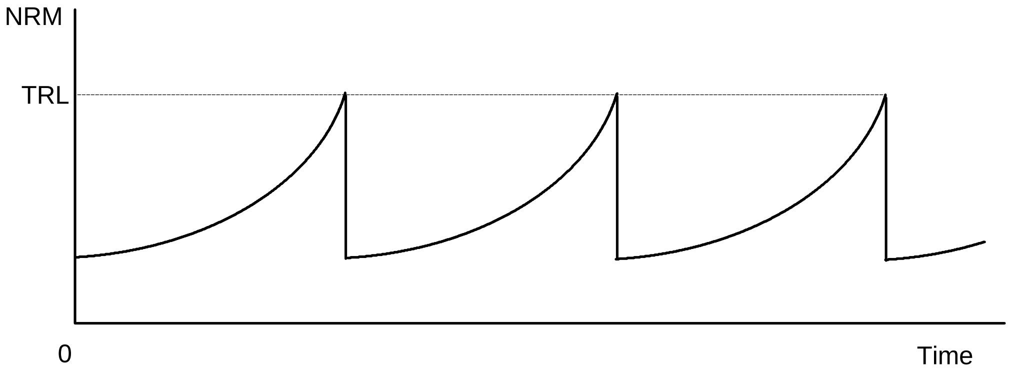
METHODOLOGY AND ASSUMPTIONS

RIAM estimates maintenance costs for three categories: rehabilitation, resealing and routine maintenance.

Rehabilitation

The indicator of when rehabilitation is needed is the roughness of a road. Roughness is measured in NAASRA Roughness Meter (NRM) units. Figure 5.1 shows a roughness profile for a road section. Roughness increases over time as a pavement deteriorates. Once it reaches a 'terminal roughness level' (TRL) the pavement is rehabilitated and the cycle starts again.

FIGURE 5.1 PAVEMENT LIFE–CYCLES



To estimate how roughness changes over time, RIAM employs an algorithm developed by ARRB Transport Research Ltd (Martin, T.C. 1996). The rate of pavement deterioration in the ARRB algorithm depends on pavement strength, pavement age, the standard of maintenance (reseals and patching), weather and the amount of truck traffic (cars do negligible damage to pavements).

For each section of road, the model fits a deterioration curve to the roughness level recorded in the database in the particular year it was measured. The assumed starting level for a new or rehabilitated pavement is 50 NRM. Because no information on pavement strength is available, the model estimates this from heavy vehicle traffic, under the assumption that pavements met Austroads design standards when built. (The assumed Austroads design standards are based on traffic levels at the estimated rehabilitation time in the past). Growth rates are expolated backwards in time to obtain the estimate of past design traffic. Weather is taken into account using the ‘Thornthwaite Index’. Values of this index were assigned to each section of road in the database using information from a map in Aitchison and Richards (1965).

The model estimates the optimal times to undertake rehabilitations, minimising the discounted present value of combined road authority and road users’ costs. In determining the optimal rehabilitation times, the model is constrained so that, if the model has not found an optimum TRL below 160 NRM, rehabilitation automatically occurs once the pavement reaches 160 NRM. The constraint has been imposed because of advice that once roughness exceeds 160 NRM, the deterioration rate accelerates and the pavement will soon break up (pers. comm. Jon Roberts, ARRB Transport Research Ltd, 11 September 1997). Where a rehabilitation is found to be warranted within the forecast period, the cost is added to the total.

Forecast rehabilitation costs depend principally on traffic levels (higher vehicle numbers justify lower TRLs), climate (wetter climate leads to higher deterioration rates), and current roughness. If a pavement has a low roughness level, which indicates that it is relatively new, the pavement may not require rehabilitation before 2020, particularly if the traffic level is low and the climate dry. The model found large numbers of sections of road falling into this category.

Resealing

If a rehabilitation is predicted to occur within a forecast period, the model in turn predicts when reseals could occur. Once a pavement has been rehabilitated, there will be no need for a reseal for some years. It would also be wasteful to reseal within several years prior to a rehabilitation. Where there are no rehabilitations within the forecast period, the model assumes that reseals occur every 10 years and allocates one tenth of the resealing cost to each year.

Routine maintenance

Routine maintenance is simply estimated on the basis of an amount per square metre per annum. Routine maintenance includes cutting grass, repair and replacement of signs, filling potholes, and so on.

Cost assumptions

For all three types of maintenance, generic costs per square metre of pavement are assumed for each standard of road established for the capacity analysis. Unsealed shoulders are costed at different rates from the sealed road surface. Higher road capacity standards are associated with higher rehabilitation costs per square metre owing to greater traffic levels. Table 5.1 shows the cost assumptions used by the BTCE.[1]

In order to test the model, optimal TRLs were obtained for the road standards recognised by RIAM over large range of AADT levels. These are presented as charts in appendix II. For example, assuming 6 per cent rigid trucks and 18 per cent articulated trucks (the averages for the NHS), two lane roads with AADT levels below 1000 vehicles per day would be rehabilitated when they reached 160 NRM, the maximum allowed by the model. At 2000 vehicles per day, the TRL falls to around 135 NRM. For two lane roads having 10 000 vehicles per day, the TRL is around 95 NRM. For four lane roads with 10 000 vehicles per day, the TRL is 128 NRM. Higher traffic levels lead to lower TRLs because the greater the number of vehicles, the greater the benefits of smoother pavements. Higher rehabilitation costs will lead to higher TRLs because of the greater cost to road authorities of providing smoother pavements. This is the reason for the higher TRL on a four lane road having the same AADT as two lane road.

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1 Higher cost assumptions were employed for the ACT at the request of the ACT Department of Urban Services. It argued that greater costs are incurred because of lack of economies of scale. The effect on the total forecasts is minuscule because the ACT only accounts for 17 kilometres of the NHS.

TABLE 5.1 COSTS ASSUMED FOR MAINTENANCE ASSESSMENT

($ per square metre of pavement area)

	Rehabilitation		*Reseals*		*Routine maintenance*	
Standard	*Sealed*	*Unsealed shoulder*	*Bitumen surface*	*Asphalt*	*Sealed*	*Unsealed shoulder*
2 lane narrow, unsealed shoulders	30.00	20.00	2.50	12.50	1.00	1.25
2 lane narrow, sealed shoulders	30.00	20.00	2.50	12.50	1.00	1.25
2 lane wide (including standards where there are overtaking lanes)	30.00	20.00	2.50	12.50	1.00	1.25
4 lane divided	60.00	20.00	2.50	12.50	1.00	1.25
6 lane divided	60.00	20.00	2.50	12.50	1.00	1.25
8 lane divided	60.00	20.00	2.50	12.50	1.00	1.25

Note Reseals are assumed to occur every 10 years except when a rehabilitation occurs.

Source BTCE estimates, based on advice by State and Territory road authorities.

RESULTS FOR THE NHS

Forecast expenditure needs are shown by state and territory in table 5.2 and by corridor in table 5.3. No backlog has been assumed for resealing and routine maintenance as these expenditures occur with much greater frequency than for rehabilitation. Resealing and routine maintenance costs are roughly proportional to the length of road analysed (width is also a factor).

There is very little backlog for rehabilitation except for the Brisbane-Darwin corridor in Queensland, but even then it is small. The implication is that there are significant lengths of road with roughness levels currently above economical terminal roughness levels. For total rehabilitation costs, the major costs occur along the main east coast corridors where traffic levels are higher and deterioration rates are higher because of the wetter climate.

On an annual basis, the resealing and routine maintenance costs are similar from year to year. However, rehabilitation costs per year are considerably higher for all states and territories during the 2006–2020 period compared with the 1999–2005 period plus the backlog. This suggests that pavements are generally in good condition at present, but that later in the forecast period, a significant amount of pavement will need rehabilitating. Growth in traffic volumes would also be a contributing factor to this unevenness in annual rehabilitation needs.

QUALIFICATIONS TO ANALYSIS

RIAM allows for only one kind of treatment (rehabilitation) which could mean either a reconstruction or a thick overlay. There is a range of possible maintenance strategies involving thinner overlays which are cheaper, but less effective than a thicker overlay. Thinner overlay options have not been considered because, where a number of alternative treatments are available, determining the optimum treatment and timing vastly increases the complexity of the optimisation problem. The results would also be very sensitive to the assumed costs of the various treatments. The purpose of strategic models such as RIAM is primarily to draw attention to the need for closer investigation, while providing an approximate estimate of costs.

Concrete pavements have not had any maintenance costs attributed to them in the RIAM model. They have much longer lives than flexible pavements, but, because they are a relatively recent phenomenon, there is great uncertainty about just how they will last. Routine maintenance costs for concrete pavements are quite small, so no allowance has been made for this.

The forecasting of future capacity upgrading and town bypass needs has been carried out separately from the forecasting of future maintenance needs. Maintenance costs of additional road pavement created over the coming 22 years to increase capacity have not been included. Being new, the additional pavements are unlikely to require rehabilitation during the forecast period. There will still be a need for routine maintenance and, in some cases, a reseal. However, these additional costs will be minor in relation to the total.

In practice, a rehabilitation and upgrading to a higher standard would often be undertaken at the same time. A model that allowed for combined upgrading and rehabilitations would require a much more complex algorithm than currently used for RIAM. The effect on results is considered too small to justify the necessary resources.

SENSITIVITY TESTS

Sensitivity tests have been undertaken, as for the capacity analysis, with the addition of variations in the rate of change in roughness and the maximum TRL. The results are presented in table 5.4. They have been presented for rehabilitation costs only. Changes in the costs will affect resealing and routine maintenance costs proportionately but changes in the other variables in the table will have no effect whatsoever.

Rehabilitation costs are quite sensitive to the deterioration rate. Increasing rehabilitation costs can cause forecast expenditure needs to change in either direction. Higher rehabilitation costs per square metre of pavement lead to

TABLE 5.2 EXPENDITURE NEEDS FOR MAINTENANCE BY STATE AND TERRITORY: NATIONAL HIGHWAY SYSTEM

($ million, 1997–98 prices)

		Rehabilitation				*Resealing and routine maintenance*[a]			*All maintenance*			
State	*Length of road analysed (km)*	*Backlog (1998)*	*1999–2005*	*2006–2020*	*Total*	*1999–2005*	*2006–2020*	*Total*	*Backlog (1998)*	*1999–2005*	*2006–2020*	*Total*
ACT	17	0	1	10	11	3	5	8	0	4	15	19
NSW	2,968	6	86	902	994	202	416	618	6	288	1,318	1,612
NT	2,666	1	2	117	120	195	435	630	1	197	551	750
QLD	4088	31	93	818	942	364	791	1155	31	457	1,609	2,097
SA	2,421	0	3	93	96	226	525	751	0	229	618	847
TAS	316	0	1	127	128	38	74	111	0	39	201	239
VIC	1,177	6	26	385	418	127	297	425	6	153	683	842
WA	4,581	3	11	105	120	394	858	1,252	3	405	963	1,372
Overall	*18233*	*49*	*224*	*2,556*	*2,829*	*1,548*	*3,401*	*4,949*	*49*	*1,772*	*5,957*	*7,777*

Notes a. No backlog has been assumed for resealing and routine maintenance as these expenses are incurred with greater frequency than rehabilitations.

Source BTCE using RIAM model.

TABLE 5.3 EXPENDITURE NEEDS FOR MAINTENANCE BY CORRIDOR: NATIONAL HIGHWAY SYSTEM

($ million, 1996–1997 prices)

		Length of road	*Rehabilitation*				*Resealing and routine maintenance*[a]			*All maintenance*			
State	*Corridor*	*analysed (km)*	*Backlog*	*1999–2005*	*2006–2020*	*Total*	*1999–2005*	*2006–2020*	*Total*	*Backlog*	*1999–2005*	*2006–2020*	*Total*
ACT	Canberra Connections	17	0	1	10	11	3	5	8	0	4	15	19
NSW	Canberra Connections	103	0	2	59	60	10	20	29	0	11	78	90
NSW	Melbourne to Brisbane	1,059	3	53	169	225	61	122	183	3	114	291	408
NSW	Melbourne to Sydney	510	0	4	326	330	47	104	151	0	51	430	481
NSW	Sydney to Adelaide	609	3	4	118	125	37	70	107	3	40	189	232
NSW	Sydney to Brisbane	687	0	23	231	254	48	99	147	0	71	330	401
NT	Adelaide to Darwin	1,763	0	0	97	98	132	293	425	0	132	390	522
NT	Brisbane to Darwin	434	0	0	5	5	34	72	106	0	34	78	111
NT	Perth to Darwin	469	1	2	14	17	30	69	99	1	32	83	117
QLD	Brisbane to Cairns	1680	7	47	551	606	166	350	516	7	213	902	1122
QLD	Brisbane to Darwin	1950	18	30	168	216	158	350	508	18	188	518	725
QLD	Melbourne to Brisbane	223	2	4	32		17	38	55	2	21	70	93
QLD	Sydney to Brisbane (inland route)	234	4	12	66	81	23	52	75	4	35	118	157
SA	Adelaide to Darwin	930	0	0	3	3	86	185	271	0	86	188	273
SA	Adelaide to Perth	965	0	0	16	16	88	193	281	0	88	209	297
SA	Melbourne to Adelaide	286	0	0	44	44	32	99	131	0	32	144	175
SA	Sydney to Adelaide	240	0	3	30	33	20	48	68	0	23	78	101
TAS	Hobart to Burnie	316	0	1	127	128	38	74	111	0	39	201	239
VIC	Melbourne to Adelaide	408	2	13	142	157	44	95	139	2	57	238	296
VIC	Melbourne to Brisbane	252	4	10	53	66	18	42	60	4	28	94	126
VIC	Melbourne to Sydney	284	0	1	164	165	49	125	174	0	50	290	339
VIC	Sydney to Adelaide	233	1	3	26	29	16	35	51	1	19	61	80
WA	Adelaide to Perth	1,421	2	7	68	77	117	259	376	2	124	327	453
WA	Perth to Darwin	3,160	1	4	37	43	277	599	876	1	281	636	919
Overall		*18,233*	*49*	*224*	*2,556*	*2,829*	*1,548*	*3,401*	*4,949*	*49*	*1,772*	*5,957*	*7,777*

Notes a. No backlog has been assumed for resealing and routine maintenance as these expenses are incurred with greater frequency than rehabilitations.

Source BTCE using RIAM model.

higher economically optimal TRLs which pushes rehabilitation times into the future. When rehabilitation times shift beyond 2020, the forecasts fall. For some states, such as South Australia, this effect outweighs higher unit rehabilitation costs.

The final sensitivity test shown in the table involves reducing the maximum roughness constraint from 160 NRM to 130 NRM. According to RIAM, there is no economic warrant for this, but it might be advocated for social or equity reasons. This has a large effect on the Northern Territory, Western Australia and South Australia where low traffic levels lead to high economically optimal TRLs.

TABLE 5.4 SENSITIVITY TESTS: REHABILITATION COSTS

	Per cent change in results								
Sensitivity Test	*ACT*	*NSW*	*NT*	*QLD*	*SA*	*TAS*	*VIC*	*WA*	*Total*
+20% AADT in 2020	5	3	0	8	26	8	31	13	10
-20% AADT in 2020	-14	-9	-4	-12	-21	-11	-25	-20	-13
12% discount rate	0	-10	-3	-16	-28	-16	-31	-30	-17
+20% deterioration rate	10	8	77	263	86	15	52	42	106
-20% deterioration rate	-16	-22	-74	-23	-45	-19	-39	-34	-28
+20% rehabilitation costs	3	16	16	8	-4	7	0	0	9
-20% rehabilitation costs	-12	-17	-19	-11	16	-12	7	-6	-10
WA hourly volume distribution	0	0	0	0	2	0	0	1	0
TRL constrained to maximum of 130 NRM	0	0	299	14	65	3	1	93	24

Source BTCE using RIAM model.

CHAPTER 6 INCREASED VEHICLE WEIGHTS AND BRIDGE REPLACEMENT

Bridges are relatively more expensive to construct than road pavements, and are therefore designed for a longer service life. Failure of a bridge also has more severe transport consequences than a pavement failure, illustrated spectacularly by the loss of three spans of the Tasman Bridge in Hobart because of a ship collision.

The range of ages and strengths in Australia’s bridges reflects their longer service life as well as the increase over time in the mass and number of heavy vehicles. For example, some bridges presently in service on national highways were designed and constructed over 50 years ago for loads half of those carried today. It is the design limits of these older bridges that limits potential productivity gains from increasing current limits on the weight of heavy vehicles.

The BTCE therefore commissioned Dr Rob Heywood (Queensland University of Technology) and Bob Pearson (Pearsons Transport Resource Centre P/L) to analyse the adequacy of bridges on the NHS and other primary roads, including the costs of replacement if current mass limits on heavy vehicles were increased in the future. Their report is reproduced with minor editing at appendix IV.

BRIDGES ON THE NATIONAL HIGHWAY SYSTEM

The consultants analysed bridges on both the NHS and on a number of other primary roads (listed in table 2.1, appendix IV), but only the results for the NHS are reported in this chapter. The major source of data used was an earlier survey of bridges as part of the National Road Transport Commission’s (NRTC) Mass Limits Review in 1996. The data collected by the NRTC is in aggregated form and does not permit the identification of specific bridges.

There are about 1 976 bridges on the NHS network, of varying types, ages and spans. The superstructure material is predominantly concrete, almost 20 per cent is steel, and there are still some timber bridges.

Design standard was used by the consultants as a surrogate for age as well as the fundamental indicator of bridge strength. Three design load groupings were considered, each designated by a design code:

- bridges built since 1976, referred to as T44, forming about 43 per cent of bridges on the NHS;
- MS18 denotes bridges built between 1948 and 1976. Bridges of this design grouping form about 46 per cent of NHS bridges; and
- the 11 per cent of pre–MS18 bridges which were built before 1948.

The Northern Territory has the highest proportion of bridges built to T44 standard, but also the highest percentage of pre–1948 bridges. Victoria and Tasmania have the lowest proportion of modern bridges. South Australia has the lowest proportion of pre–1948 bridges.

ANALYSIS

Bridges were assessed for their capacity to withstand loads under three scenarios of possible mass limits in the future for articulated vehicles (table 3.1, appendix IV provides detail):

- Scenario 1: gross mass increased from current level of 42.5 tonnes to 45.5 tonnes, with no further increases;
- Scenario 2: gross mass increased to 45.5 tonnes in 1997, further increased to 52 tonnes in 2010, with no further increases; and
- Scenario 3: as for scenario 2, but with a further increase to 58 tonnes in 2020.

The model used by the consultants estimates bending of bridges under various vehicle weights, and compares them to design standards for the bridge type under consideration. The model applies engineering judgement about the remaining life of a bridge, taking account of worst case truck loadings, ageing, traffic growth, environmental effects and the observed better than expected performance of bridges compared with the original design calculations. A bridge is deemed to need replacing once the risk of failure reaches an unacceptable level.

Replacement costs were estimated from the deck area of the existing bridge using a generic cost per square metre. It was assumed that replacement bridges are of concrete or steel at the T44 standard. There was no allowance made for the additional costs of constructing wider, longer bridges with improved alignments. These costs were allowed for in the capacity analysis through use of higher generic costs per kilometre than would be required for construction in the absence of bridges and interchanges.

Strengthening of bridges was not considered as an option. Hence the costs presented below are likely to be overestimates. Overestimation may have also occurred where bridges have been replaced or strengthened since the collection of the data set used.

RESULTS

Costs of bridge replacement were estimated for four time periods: now (the 1998 backlog), 1998–2005, 2006–2020, and 2021–2030. Estimates for the NHS are presented in table 6.1

The analysis shows that an immediate expenditure of $24 million is needed on the NHS. Victorian bridges would require attention much earlier than those in other states. However, substantial expenditure would be required in Queensland and New South Wales in the early part of next century.[2]

The bridges on the NHS are generally in good condition, with almost half having been built in the last 20 years. It should be borne in mind that the forecast bridge replacement costs for the NHS are not representative of the wider population of Australian bridges. The results obtained cannot therefore be extrapolated to Australia as a whole.

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2 It is not possible to make comparisons with the NRTC Mass Limits Review (National Road Transport Commission, 1996). The estimates above are costs of bridge replacement in 1996-97 dollars, whereas the Mass Limits Review costs were estimates of the cost of bringing forward reconstruction, and it did not consider the cost of replacing bridges already considered deficient under existing mass limits.

TABLE 6.1 COSTS TO REPLACE BRIDGES UNDER DIFFERENT LOADING SCENARIOS ON THE NATIONAL HIGHWAY SYSTEM

($million, 1997–98 prices)

	Scenario 1				*Scenario 2*				*Scenario 3*			
Corridor	*now*	*1998–2005*	*2006–2020*	*2021–2030*	*now*	*1998–2005*	*2006–2020*	*2021–2030*	*now*	*1998–2005*	*2006–2020*	*2021–2030*
Sydney–Melbourne	4.3	5.9	10.7	8.5	4.3	5.9	26.2	13.7	4.3	5.9	26.2	56.0
Canberra connections	0.0	0.0	0.2	0.8	0.0	0.0	1.2	0.2	0.0	0.0	1.2	3.7
Sydney–Brisbane (New England Hwy)	0.2	0.1	2.2	8.1	0.2	0.1	17.1	4.2	0.2	0.1	17.1	41.8
Sydney–Adelaide (Sturt Hwy)	0.1	0.2	4.8	5.3	0.1	0.2	12.4	3.8	0.1	0.2	12.4	38.8
Melbourne–Adelaide	1.3	1.9	6.6	4.4	1.3	1.9	14.1	6.4	1.3	1.9	14.1	37.3
Melbourne–Brisbane (Newell Hwy)	1.2	1.4	3.7	6.6	1.2	1.4	17.4	6.2	1.2	1.4	17.4	37.6
Brisbane–Cairns	1.2	0.8	2.8	10.0	1.2	0.8	47.3	15.5	1.2	0.8	47.3	66.1
Adelaide–Perth	0.1	0.2	0.8	0.7	0.1	0.2	3.2	1.2	0.1	0.2	3.2	5.6
Adelaide–Darwin	2.8	1.7	0.6	0.6	2.8	1.7	7.3	0.5	2.8	1.7	7.3	4.8
Perth–Darwin	1.2	1.2	1.3	1.1	1.2	1.2	12.8	4.5	1.2	1.2	12.8	9.7
Brisbane–Darwin	0.9	0.5	0.3	1.2	0.9	0.5	7.0	1.8	0.9	0.5	7.0	7.7
Hobart–Burnie	10.6	1.1	0.9	0	10.6	1.1	5.5	1.2	10.6	1.1	5.5	12.1
Total	*23.9*	*15.0*	*34.9*	*47.3*	*23.9*	*15.0*	*171.5*	*59.2*	*23.9*	*15.0*	*171.5*	*321.2*

Source BTCE, see appendix IV.

CHAPTER 7 AGGREGATED RESULTS

Tables 7.1 and 7.2 show the aggregated results for the four types of expenditure considered for the NHS and for other roads considered to be of major significance by the state and territory road authorities. Expenditure to widen roads to allow for road trains has been excluded.

Bridge replacement costs have been included, assuming the highest cost vehicle mass limits scenario. Although an increase in mass limits to only 45.5 tonnes is currently under discussion, it is highly likely that any bridges that are replaced would be designed to far more than for an additional 3 tonne load. This is primarily because the marginal cost of building a bridge to a higher standard is fairly low.

The total expenditure for the NHS for the 22 year forecast period is almost $17 billion. This is higher than the 1995–2015 forecast of $12.9 billion developed by the BTCE for the National Transport Planning Taskforce. The backlog comprises 15.5 per cent of the total. Counting town bypass construction as a type of capacity expansion and bridge replacement as a type of maintenance, there is roughly a 50:50 split between forecast capacity expansion and maintenance expenditures.

New South Wales and Queensland have the largest expenditure needs. Together they account for two–thirds of the total. For these two states, forecast capacity expenditure exceeds maintenance expenditure. For the more sparsely populated states and territories, South Australia, Western Australia and the Northern Territory, forecast maintenance needs far outweigh capacity needs.

TABLE 7.1 AGGREGATED RESULTS FOR THE NATIONAL HIGHWAY SYSTEM

($ million, 1997–1998 prices)

	ACT	*NSW*	*NT*	*QLD*	*SA*	*TAS*	*VIC*	*WA*	*Total*
BACKLOG									
Capacity	4	1,244	0	338	31	62	235	14	1,928
Bypasses	0	412	0	195	0	0	0	0	607
Maintenance	0	6	1	31	0	0	6	3	49
Bridges[a]	0	0	3	1	0	1	9	1	15
Total	*4*	*1,663*	*4*	*565*	*31*	*63*	*250*	*19*	*2,599*
2005									
Capacity	0	276	0	253	72	35	10	76	721
Bypasses	0	117	0	288	0	0	0	0	405
Maintenance	4	288	197	457	229	39	153	405	1,772
Bridges[a]	0	31	9	65	22	6	26	13	172
Total	*4*	*712*	*206*	*1,063*	*323*	*79*	*189*	*494*	*3,069*
2020									
Capacity	0	1,722	0	1,492	264	151	550	139	4,317
Bypasses	0	171	0	190	27	45	90	0	529
Maintenance	15	1,318	551	1,609	618	201	683	963	5,957
Bridges[a]	0	94	0	91	71	12	43	11	322
Total	*15*	*3,304*	*552*	*3,382*	*979*	*408*	*1,373*	*1,113*	*11,125*
TOTAL									
Capacity	4	3,242	0	2,083	366	248	796	229	6,967
Bypasses	0	700	0	673	27	45	90	0	1,541
Maintenance	19	1,612	750	2,097	847	239	842	1,372	7,777
Bridges[a]	0	126	12	157	93	19	78	26	509
Total	*22*	*5,679*	*762*	*5,009*	*1,333*	*551*	*1,812*	*1,626*	*16,794*

Note a. Bridge replacement costs assume an increase in the gross mass limit from 45.5 to 52 tonnes in 2010.

Source BTCE using RIAM.

TABLE 7.2 AGGREGATED RESULTS FOR NON–NATIONAL HIGHWAYS

($ million, 1997–1998 prices)

	ACT	*NSW*	*NT*	*QLD*	*SA*	*TAS*	*VIC*	*WA*	*Total*
BACKLOG									
Capacity	0	505	0	701	0	3	181	46	1,437
Bypasses		155					14	18	187
Maintenance	0	27	0	5	4	1	15	1	53
Bridges[a]		0					3	2	5
Total	*0*	*687*	*0*	*706*	*4*	*4*	*213*	*68*	*1,682*
2005									
Capacity	0	510	0	218	8	14	60	65	875
Bypasses		38				20	14	55	127
Maintenance	9	377	32	152	98	25	216	559	1,469
Bridges[a]		0					2	3	5
Total	*9*	*926*	*32*	*371*	*105*	*59*	*292*	*682*	*2,476*
2020									
Capacity	31	1,634	0	155	5	14	1,067	666	3,573
Bypasses		265				16	71	95	448
Maintenance	38	1,059	93	472	281	108	883	1,581	4,515
Bridges[a]		42					8	3	53
Total	*69*	*3,000*	*93*	*627*	*286*	*139*	*2,030*	*2,346*	*8,590*
TOTAL									
Capacity	31	2,649	0	1,075	13	32	1,308	777	5,885
Bypasses	0	458	0	0	0	36	100	168	762
Maintenance	46	1,463	125	630	383	134	1,115	2,142	6,038
Bridges[a]	0	42	0	0	0	0	13	9	64
Total	*78*	*4,612*	*125*	*1,704*	*396*	*201*	*2,535*	*3,096*	*12,748*

Note a. Bridge replacement costs assume an increase in the gross mass limit from 45.5 to 52 tonnes in 2010. The non-National Highway roads examined by the bridge consultants do not match the roads listed in appendix III assessed using RIAM.

Source BTCE using RIAM.

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APPENDIX I MISCELLANEOUS ASSUMPTIONS

Changes in ongoing road authority costs and accident costs are included in the economic analysis.

Table I.1 shows the fixed annual costs per kilometre that are incurred by road authorities to maintain roads of given standards. The fixed annual costs include routine annual maintenance costs, and the annualised discounted present value of future reseals and rehabilitations.

Typical routine maintenance costs include: pothole repair, minor pavement resealing of limited thickness and length, edge repair, shoulder regrading, minor pavement repairs, roadside maintenance, drainage clearance, grass cutting, sign cleaning, minor bridge and culvert maintenance.

TABLE I.1 FIXED ANNUAL COSTS

($ per kilometre)

Standard	*Cost*
2 lane narrow, unsealed shoulders	13,900
2 lane narrow, sealed shoulders	19,100
2 lane wide	20,100
2 lanes with 1.2 km overtaking lanes every 20 kms	20,400
2 lanes with 1.2 km overtaking lanes every 10 kms	20,800
2 lanes with 1.2 km overtaking lanes every 5 kms	21,500
4 lane divided	49,500
6 lane divided	65,000
8 lane divided	80,500

Notes a. Fixed annual costs consist of annual routine maintenance plus the annualised discounted present value of rehabilitation and resealing costs.

b. The increase in fixed annual costs from having a higher standard road is included in the capacity model as a negative benefit.

Source BTCE estimates.

TABLE I.2 ACCIDENT COSTS

(cents per vehicle kilometre)

Standard	*Costs*
2 lane narrow, unsealed shoulders	3.95
2 lane narrow, sealed shoulders	3.16
2 lane wide	2.20
2 lanes with 1.2 km overtaking lanes every 20 kms	2.17
2 lanes with 1.2 km overtaking lanes every 10 kms	2.12
2 lanes with 1.2 km overtaking lanes every 5 kms	2.02
4 lane divided	0.78
6 lane divided	0.48
8 lane divided	0.48

Source BTCE estimates.

The accident costs in table I.2 are presented in terms of cents per vehicle kilometre. They were derived from looking at accident frequencies by type on the different road standards, and the average social costs of each type of accident. When a road is upgraded, there are generally lower accident costs per vehicle, but higher traffic levels, so accident cost changes are included in the economic analysis as either a positive or negative benefit.

Table I.3 shows the unit costs used in the road user cost component of RIAM. Financial costs (costs paid by road users) are used for estimating demand generated by the improved roads. Economic costs (costs to society, excluding fuel excise, sales taxes and import duties) are used to estimated the benefits of road improvements in cost–benefit analyses.

State and territory road authority databases do not generally include road alignment data. They do however indicate whether the terrain is flat, undulating or mountainous. RIAM makes assumptions about average road gradients and curvatures based on these three terrain types, as shown in table I.4.

Congestion depends on the volume of traffic passing at a particular point in time so the annual traffic volume alone provides insufficient information to estimate the effects of congestion on vehicle speeds. It necessary to know the distribution of traffic volumes throughout the year. Actual distributions are rarely available so the model uses two standard distributions, one applied generally to non-urban roads and the other to roads close to major cities and other roads where there is an extremely high proportion of local traffic. The quasiurban histogram is flatter than the rural histogram because of the greater numbers of regular commuters. These distributions are specified as histograms of hourly traffic volumes as percentages of AADT given for each of the 8766 hours of the average year (allowing for leap years). For example, on the rural histogram, the three most highly trafficked hours each have a volume of 22 per cent of AADT, the next three have 20 per cent, the next ten have 18 per cent and so on for the 8766 hours in the average year.

TABLE I.3 UNIT COSTS

	Cars		*Rigid Trucks*		*Articulated vehicles*	
Cost	*Financial*	*Economic*	*Financial*	*Economic*	*Financial*	*Economic*
Fuel ($/litre)	0.760	0.328	0.745	0.319	0.700	0.275
Oil ($/litre)	4.09	3.35	3.82	3.13	3.56	2.92
Value of vehicle ($)	26,202	22,977	141,391	123,952	223,136	195,562
Maintenance labour ($/hr)	50	50	50	50	50	50
Tyre ($/tyre)	120.10	83.70	666.60	546.40	548.30	449.40
Time ($/hr/person)[a]	11.14	11.14	na	na	na	na
Crew ($/hour)	na	na	15.08	15.08	16.15	16.15
Freight time ($/hr/veh)	na	na	10.69	10.69	13.24	13.24
Overhead (%)	na	na	10%	10%	10%	10%
Registration ($/year)	na	na	1,323	na	4,782	na

Notes na not applicable

a. There are assumed to be 1.6 persons on average in each car, including the driver.

Source BTCE estimates, based on: ABS 1992, Thoresen and Roper 1996, Roper and Thoresen 1997.

Table I.5 shows the two standard distributions that were used in the main analysis, and a third alternative traffic distribution based on data provided by Western Australia that was used in the sensitivity tests.

The BTCE's analysis only covers non-urban roads. Table I.6 shows the assumed boundaries around capital cities where the roads analysed end.

TABLE I.4 ROAD ALIGNMENT ASSUMPTIONS

General Terrain	*Gradient (rise and fall in metres per km[a])*	*Curvature (degrees per km[b])*
Flat	6.5	11.72
Undulating	20.5	15
Mountainous	36.3	20

Notes a. The gradient is expressed as the average rise plus fall, defined as the sum of absolute values in metres of all ascents and all descents along a section, divided by the length of the section in kilometres (Watanada et al., p. 154). See Watanada et al. p. 155 for a diagramatic explanation.

b. The average horizontal curvature is defined as the sum of the absolute values of angular deviations in degrees of sucessive tangent lines of the road alignment when travelling in one direction, divided by the section (arc not chord) length in kilometres (Watanada et al., p. 154). See Watanada et al. p. 155 for a diagramatic explanation.

Source BTCE 1995.

TABLE I.5 HOURLY TRAFFIC VOLUME DISTRIBUTIONS

(hours in year)

Percentage of AADT	*Rural Distribution*	*Quasi-urban distribution*	*Western Australian distribution*
22	3	–	–
20	3	–	–
18	10	–	–
17	–	–	1
16	17	3	2
15	18	3	6
14	30	7	12
13	45	13	12
12	71	26	42
11	107	48	92
10	161	90	174
9	241	185	420
8	354	309	842
7	509	546	1,029
6	714	848	974
5	967	1,252	424
4	1,242	1,640	394
3	1,467	1,736	588
2	1,482	1,375	954
1	1,017	600	1,875
0	308	85	925
Total	*8,766*	*8,766*	*8,766*

Source BTCE estimates.

TABLE I.6 URBAN BOUNDARIES

State	*Highway*	*Defined urban boundary*
ACT	All roads treated as non-urban	
NSW[a]	Pacific Highway	Berowra
NSW[a]	Princes Highway	Heathcote
NSW[a]	Hume Highway	Campbelltown Offramp at Raby Road
NSW[a]	Great Western Highway	Nepean River Bridge
NT	Stewart Highway	Howard Springs turn off
QLD	Bruce Highway	Pine River Bridge
QLD	Warrego Highway	Cunningham Arterial Road, Dinmore
QLD	Cunningham Highway	Brisbane City Boundary, Goodna
QLD	Pacific Highway	Underwood Road, Eight Mile Plains
SA	Port Augusta-Port Wakefield Road	Waterloo Corner Road
SA	Sturt Highway	Gawler River Bridge
TAS	Midland Highway	Rifle Range Road
TAS	Tasman Highway	Shark Point Road
TAS	Huon Highway	Summerleas Road
VIC	Princes Highway West	Berwick Beaconsfield Road, Narewarren
VIC	Princes Highway East	Western Interchange, Werribee Main Road, Werribee
VIC	Calder Highway	Melton Highway
VIC	Hume Highway	Craigeburn Road, Craigeburn
VIC	Western Highway	Melton-Werribee Road, Deer Park
WA	Albany Highway	Bedford Dale Hill
WA	Perth-Bunbury Highway	Spearwood Avenue, Hamilton Hill
WA	Great Eastern Highway	Old York Road, Greenmount
WA	Southwestern Highway	Keates Road, Armidale
WA	Wanneroo Road	Town Boundary, north of Wanneroo
WA	Brookton Highway	Hawkestone Road, Roleystone

Note a. For NSW, the BTCE was forced to use the Auslig statistical definition of 'Built Up Area'. This corresponds broadly with the locations mentioned above.

APPENDIX II RIAM TEST RESULTS

A number of tests were performed on the models to confirm that they were producing reasonable results.

Table II.1 shows average threshold AADT levels for a range of heavy vehicle proportions and for the three terrain types. Derivation of threshold AADTs serves as check to ensure the model is producing reasonable results for the capacity assessment.

TABLE II.1 AVERAGE THRESHOLD AADTS FOR ROAD CAPACITY

10 per cent heavy vehicles (as proportion of total traffic)

Upgrading		*Terrain*		
from	*to*	*Flat*	*Undulating*	*Mountainous*
2 lane narrow, unsealed shoulders	2 lane narrow, sealed shoulders	1,981	1,752	1,556
2 lane narrow, sealed shoulders	2 lane wide	3,083	3,430	4,495[a]
2 lane wide	2 lanes with overtaking lanes every 20 kms	5,610	4,867	4,495[a]
2 lanes with overtaking lanes every 20 kms	2 lanes with overtaking lanes every 10 kms	6,015	5,569	5,252
2 lanes with overtaking lanes every 10 kms	2 lanes with overtaking lanes every 5 kms	6,605	6,204	5,830
2 lanes with overtaking lanes every 5 kms	4 lane divided	12,085	11,398	10,313
4 lane divided	6 lane divided	41,308	33,396	28,599
6 lane divided	8 lane divided	61,543	49,297	42,178

TABLE II.1 (CONTINUED)

20 per cent heavy vehicles (as proportion of total traffic)

Upgrading		*Terrain*		
from	*to*	*Flat*	*Undulating*	*Mountainous*
2 lane narrow, unsealed shoulders	2 lane narrow, sealed shoulders	1,894	1,575	1,358
2 lane narrow, sealed shoulders	2 lane wide	2,887	3,063	3,662[a]
2 lane wide	2 lanes with overtaking lanes every 20 kms	4,938	3,831	3,662[a]
2 lanes with overtaking lanes every 20 kms	2 lanes with overtaking lanes every 10 kms	5,402	4,470	3,925
2 lanes with overtaking lanes every 10 kms	2 lanes with overtaking lanes every 5 kms	5,966	5,018	4,372
2 lanes with overtaking lanes every 5 kms	4 lane divided	11,100	9,844	8,683
4 lane divided	6 lane divided	36,663	25,331	19,918
6 lane divided	8 lane divided	54,564	36,207	28,988

30 per cent heavy vehicles (as proportion of total traffic)

Upgrading		*Terrain*		
from	*to*	*Flat*	*Undulating*	*Mountainous*
2 lane narrow, unsealed shoulders	2 lane narrow, sealed shoulders	1,810	1,452	1,243
2 lane narrow, sealed shoulders	2 lane wide	2,716	2,786	3,059[a]
2 lane wide	2 lanes with overtaking lanes every 20 kms	4,415	3,195	3,059[a]
2 lanes with overtaking lanes every 20 kms	2 lanes with overtaking lanes every 10 kms	4,918	3,800	3,163
2 lanes with overtaking lanes every 10 kms	2 lanes with overtaking lanes every 5 kms	5,446	4,245	3,585
2 lanes with overtaking lanes every 5 kms	4 lane divided	10,212	8,759	7,608
4 lane divided	6 lane divided	32,937	20,502	15,494
6 lane divided	8 lane divided	48,987	30,173	22,216

TABLE II.1 (CONTINUED)

40 per cent heavy vehicles (as proportion of total traffic)

Upgrading		*Terrain*		
from	*to*	*Flat*	*Undulating*	*Mountainous*
2 lane narrow, unsealed shoulders	2 lane narrow, sealed shoulders	1,731	1,354	1,159
2 lane narrow, sealed shoulders	2 lane wide	2,566	2,562	2,637[a]
2 lane wide	2 lanes with overtaking lanes every 20 kms	3,995	2,775	2,637[a]
2 lanes with overtaking lanes every 20 kms	2 lanes with overtaking lanes every 10 kms	4,518	3,310	2,687
2 lanes with overtaking lanes every 10 kms	2 lanes with overtaking lanes every 5 kms	5,008	3,689	3,051
2 lanes with overtaking lanes every 5 kms	4 lane divided	9,567	7,903	6,817
4 lane divided	6 lane divided	29,885	17,116	12,609
6 lane divided	8 lane divided	44,426	25,245	18,355

50 per cent heavy vehicles (as proportion of total traffic)

Upgrading		*Terrain*		
from	*to*	*Flat*	*Undulating*	*Mountainous*
2 lane narrow, unsealed shoulders	2 lane narrow, sealed shoulders	1,564	1,266	1,086
2 lane narrow, sealed shoulders	2 lane wide	2,435	2,366	2,225[a]
2 lane wide	2 lanes with overtaking lanes every 20 kms	3,650	2,467	2,225[a]
2 lanes with overtaking lanes every 20 kms	2 lanes with overtaking lanes every 10 kms	4,179	2,933	2,350
2 lanes with overtaking lanes every 10 kms	2 lanes with overtaking lanes every 5 kms	4,636	3,266	2,666
2 lanes with overtaking lanes every 5 kms	4 lane divided	9,065	7,219	6,253
4 lane divided	6 lane divided	27,340	14,644	10,762
6 lane divided	8 lane divided	40,632	21,650	15,628

Note a. The RIAM model indicates that overtaking lanes every 20 kilometres are warranted at the same time as widening in mountainous terrain.

Source BTCE estimates using RIAM model.

Table II.2 shows the threshold AADT levels necessary to warrant a town bypass, for a range of heavy vehicle percentages, and levels of local traffic.

The thresholds denote the minimum AADT for through–traffic that would be required to make a bypass economically justified under the methodology and assumptions employed by RIAM. As for the capacity assessment, the derivation of threshold AADTs serves as check to ensure the model is producing reasonable results.

Figures II.1 and II.2 plot economically optimal terminal roughness levels (TRLs) against AADT for a range of the road standards recognised by RIAM. The charts show the same data, but figure II.1 makes it easier to see the TRLs for roads with traffic levels below 10 000 vehicles per day.

As noted in chapter 5, TRL is constrained so that rehabilitation must occur automatically once roughness reaches 160 NRM. The curves are not smooth because RIAM optimises rehabilitation times in whole years, not in NRM units, and because the hypothetical database used to derive the curves consisted of road sections ascending in steps of 250 vehicles. The plots assume a vehicle mix of 6 per cent rigid trucks and 18 per cent articulated trucks, average levels for 1998 in the NHS database.

TABLE II.2 THRESHOLDS REQUIRED FOR THROUGH–TRAFFIC LEVELS FOR TOWN BYPASSES

Two lane bypass

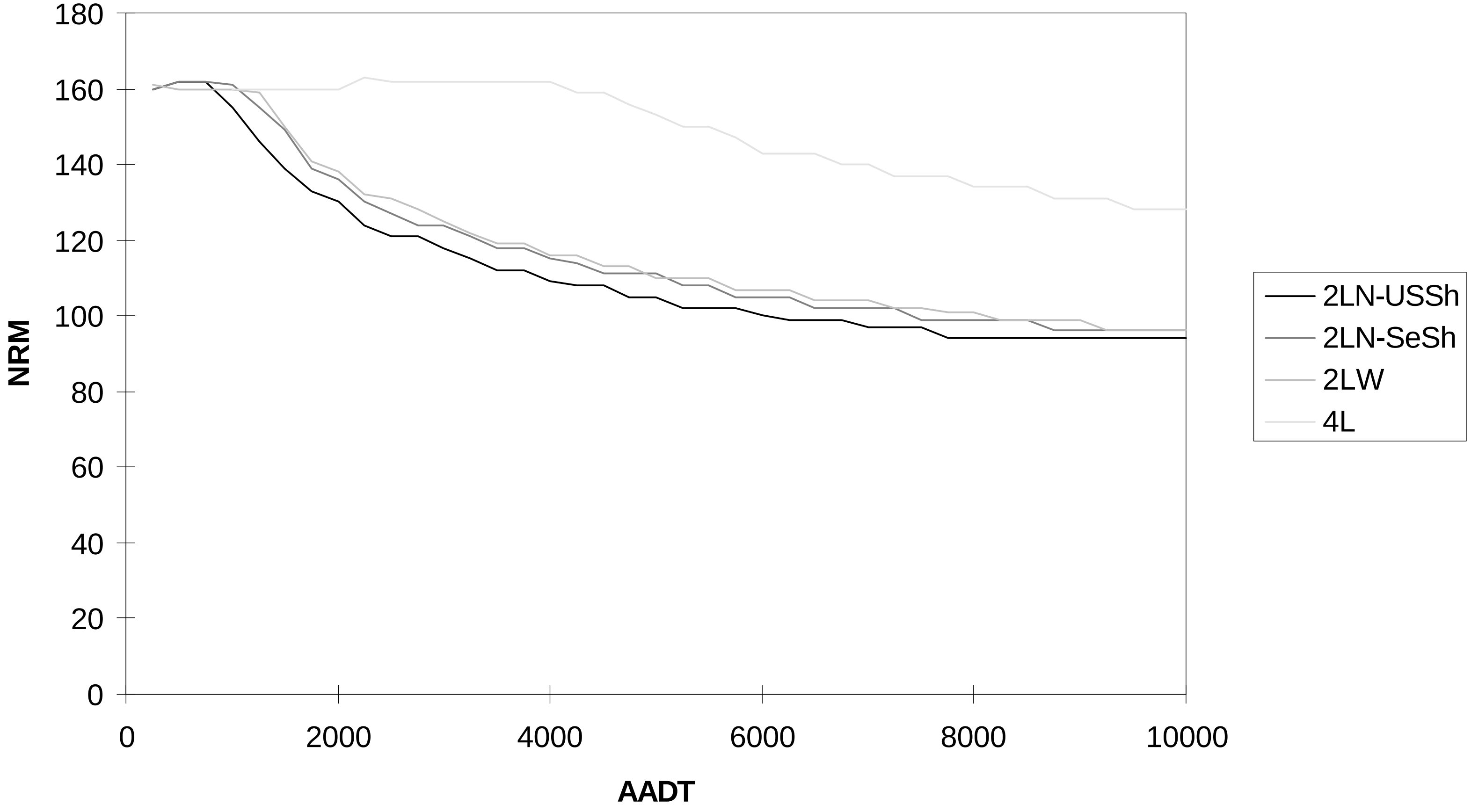
	Local traffic (AADT)			
Per cent heavy vehicles	*500*	*5,500*	*10,500*	*15,500*
20	3,500	3,500	2,000	700
30	3,200	3,100	1,500	700
40	3,000	2,700	1,000	500
50	2,800	2,300	800	400

Four lane bypass

	Local traffic (AADT)			
Per cent heavy vehicles	*500*	*5,500*	*10,500*	*15,500*
20	5,200	4,800	3,000	1,400
30	4,800	4,300	2,100	1,100
40	4,500	3,800	1,600	800
50	4,300	3,400	1,200	600

Source BTCE estimates using RIAM model.

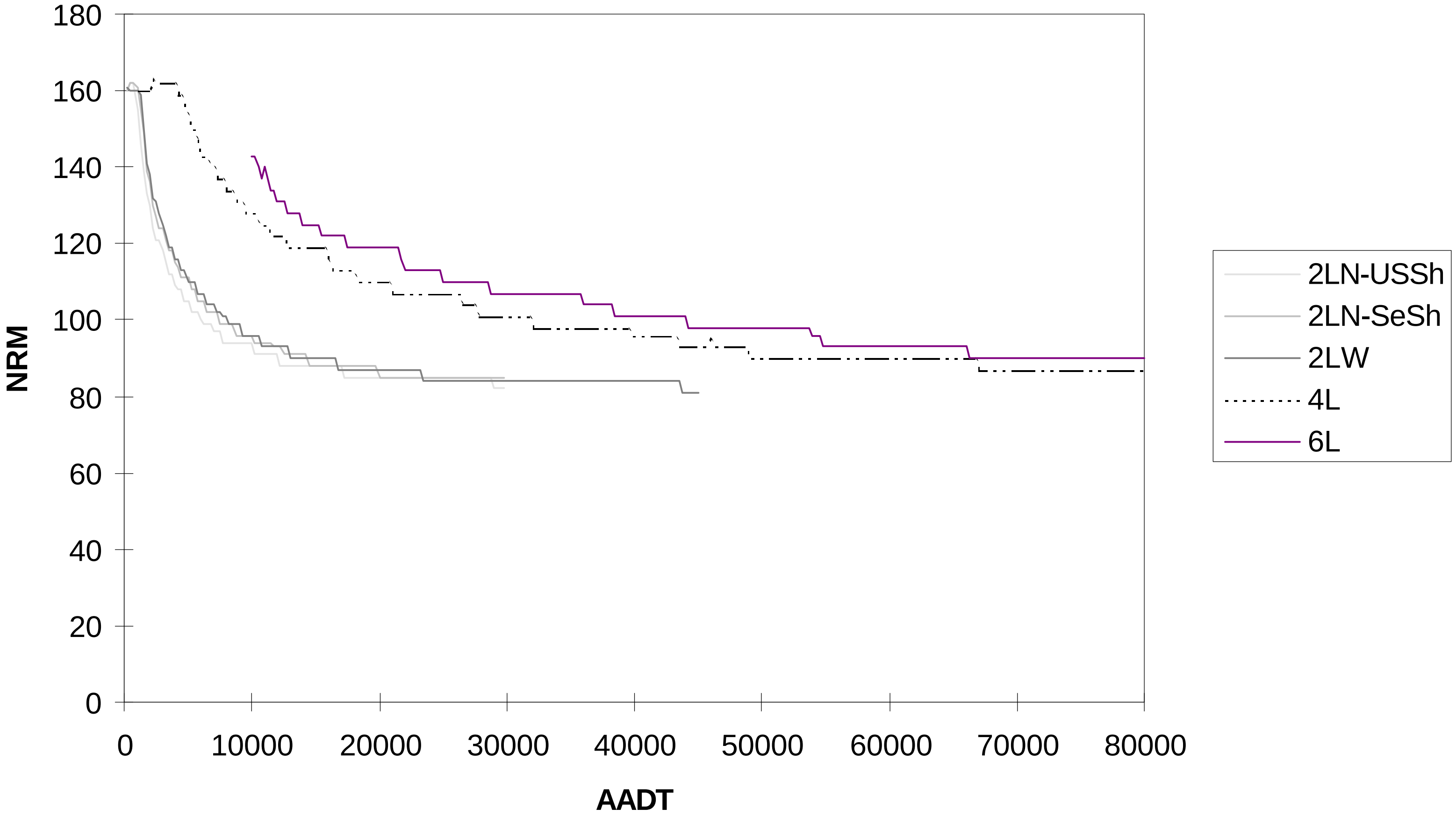
FIGURE II.1 OPTIMAL TERMINAL ROUGHNESS LEVELS



Note Abbreviations are: 2LN-USSh = two lane narrow, unsealed shoulder; 2LN-SeSh = two lane narrow, sealed shoulder; 2LW = two lane wide; 4L = four lane.

Source BTCE.

FIGURE II.2 OPTIMAL TERMINAL ROUGHNESS LEVELS



Note Abbreviations are: 2LN-USSh = two lane narrow, unsealed shoulder; 2LN-SeSh = two lane narrow, sealed shoulder; 2LW = two lane wide; 4L = four lane; 6L = six lane.

Source BTCE.

APPENDIX III EXPENDITURE NEEDS FOR NON–NHS ROADS

In addition to the National Highway analysis contained in the main body of the Working Paper, an analysis of future rural road infrastructure needs was performed on non-National Highway roads that were nominated by the individual States and Territories as being of national significance.

Road capacity, bypass and maintenance needs have been estimated, using the same methodology and assumptions as used for the National Highway system.

It is important to reiterate that direct comparisons cannot be made between the funding needs of different states for non-NHS roads because there is no agreed definition or set of roads considered to be of national significance.

CAPACITY

Expenditure needs for capacity expansion on the non-NHS roads are presented in table III.1 by state and III.2 by corridor. Over half of the expenditure needs for capacity is for the Pacific Highway in NSW and Queensland.

TABLE III.1 EXPENDITURE NEEDS FOR CAPACITY EXPANSION BY STATE AND TERRITORY: NON-NHS ROADS

($ million)

State	*Length analysed[a] (km)*	*Backlog (1998)*	*1999–2005*	*2006–2020*	*Total*
ACT	46	0	0	31	31
NSW	3,179	505	510	1,634	2,649
NT	470	0	0	0	0
QLD	1,434	701	218	155	1,075
SA	999	0	8	5	13
TAS	242	3	14	14	32
VIC	2,100	181	60	1,067	1,308
WA	7,382	46	65	666	777
Overall	*15,852*	*1,437*	*875*	*3,573*	*5,885*

Note a. Roads included in this table are listed in table III.1.

Source BTCE, based on information generously provided by state and territory road authorities.

TABLE III.2 EXPENDITURE NEEDS FOR CAPACITY EXPANSION BY CORRIDOR: NON-NHS ROADS

($ million)

State	*Corridor*[a]	*Length analysed (km)*	*Backlog (1998)*	*1999–2005*	*2006–2020*	*Total*
ACT	Canberra Connections	2	0	0	0	0
ACT	Kings Highway	8	0	0	0	0
ACT	Monaro Highway	36	0	0	31	31
NSW	Adelaide to Nyngan	631	9	0	0	9
NSW	Bathurst to Cunnamulla	799	3	3	17	23
NSW	Kings Highway	127	4	5	15	24
NSW	Melbourne to Sydney (coastal route)	385	165	111	267	544
NSW	Monaro Highway	200	1	0	9	10
NSW	Newcastle to Dubbo (Golden Hwy)	308	4	0	87	92
NSW	Sydney to Bathurst	78	36	3	2	41
NSW	Sydney to Brisbane (Pacific Highway)	651	283	388	1236	1907
NT	Arnhem Hwy	223	0	0	0	0
NT	Stuart Hwy to Ayers Rock	247	0	0	0	0
QLD	Brisbane to Darwin	14	0	0	0	0
QLD	Rockhampton to Barcaldine	575	0	0	4	4
QLD	Sydney to Brisbane (Pacific Highway)	83	701	218	149	1069
QLD	Townsville to Cloncurry	763	0	0	2	2
SA	Adelaide to Nyngan	368	0	0	0	0
SA	Melbourne to Keith	225	0	7	3	10
SA	Pimba to Olympic Dam	94	0	0	0	0
SA	Port Lincoln to Port Augusta	312	0	0	2	3
TAS	Cygnet to Hobart	46	0	0	0	1
TAS	Hobart to Smithtown	92	3	14	13	29
TAS	Launceston to George town	47	0	0	0	0
TAS	Triabunna to Hobart	57	0	0	1	1
VIC	Geelong to Benalla (Midland Hwy)	386	25	1	9	35
VIC	Melbourne to Keith	402	24	1	329	354
VIC	Melbourne to Mildura	520	102	49	386	537
VIC	Melbourne to Sydney (coastal route)	458	29	9	343	381
VIC	Portland to Sunraysia Hwy	334	1	0	0	1
WA	000H006 to Broome (Broome Highway)	42	0	0	2	3
WA	000H006 to Derby (Derby Highway)	43	0	0	0	0
WA	000H006 to Port Hedland (Port Hedland Road)	10	0	0	0	0
WA	000H007 to Karratha (Point Samson to Roebourne Road)	18	0	0	0	0

TABLE III.2 (CONTINUED)

State	*Corridor*	*Length analysed (km)*	*Backlog (1998)*	*1999–2005*	*2006–2020*	*Total*
WA	000H011 to Wyndham (Great Northern Highway)	123	0	0	0	0
WA	000M050 to Pannawonica (Pannawonica Road)	46	0	0	0	0
WA	00H007 to Dampier (Dampier Road)	26	0	0	0	0
WA	Albany Port Road	7	0	0	0	0
WA	Albany to Perth	367	5	6	9	20
WA	Augusta to Bunbury	135	6	1	56	63
WA	Bunbury to Perth	142	30	16	240	286
WA	Carnarvon Road	5	0	0	3	3
WA	Collie to Bunbury	36	0	0	0	0
WA	Esperance to Bunbury	954	3	24	263	289
WA	Esperance to H003 (Coolgardie to Esperance Highway)	201	0	0	0	0
WA	Kalgoolie to Coolgardie	40	0	0	0	0
WA	Kambalda to Meekatharra	793	0	0	0	0
WA	Laverton to Leonora	124	0	0	0	0
WA	Marvel Loch	33	0	0	0	0
WA	Minilya to Exmouth	212	0	0	0	0
WA	Mount Magnet to Geraldton	334	0	2	6	9
WA	Munjina to Nanatarra Road House	417	0	0	0	0
WA	Narrogin to Williams	31	0	0	0	0
WA	Newman to Port Hedland	434	0	0	0	0
WA	Perth to Port Hedland	1,643	1	0	38	39
WA	Pinjarra to Mandurah	17	1	7	17	25
WA	Ravensthorpe to Perth	494	0	0	0	0
WA	Roebourne to Wittenoom Rd	259	0	0	0	0
WA	Tom Price to Paraburdoo	151	0	0	0	0
WA	Warneroo Road	23	1	8	30	39
WA	Woodie Woodie Rd	223	0	0	0	0
Overall		*15,852*	*1,437*	*875*	*3,573*	*5,885*

Note a. Roads were selected by individual states and territories on the basis of perceived national significance.

Source BTCE estimates using RIAM model.

TOWN BYPASSES

Expenditure requirements for town bypasses are presented in table III.3, by State, and table III.4, by corridor.

MAINTENANCE

Tables III.5, and III.6 show maintenance expenditure needs on the non-NHS roads nominated by the states and territories for analysis.

TABLE III.3 EXPENDITURE NEEDS FOR TOWN BYPASSES BY STATE AND TERRITORY: NON–NHS ROADS

($ million)

State	*Number of bypasses assessed*[a]	*Number of bypasses warranted*	*Backlog*	*1999–2005*	*2006–2020*	*Total*
NSW	30	10	155	38	265	458
NT	0	0	0	0	0	0
QLD	0	0	0	0	0	0
SA	6	0	0	0	0	0
TAS	1	1	0	20	16	36
VIC	22	6	14	14	71	100
WA	24	8	18	55	95	168
Overall	*83*	*25*	*187*	*127*	*448*	*762*

Note a. Roads included in this table are listed in table III.1.

Source BTCE using RIAM model.

TABLE III.4 EXPENDITURE NEEDS FOR TOWN BYPASSES BY CORRIDOR: NON–NHS ROADS

($ million)

State	*Corridor*[a]	*Number of bypasses assessed*	*Number of bypasses warranted*	*Backlog*	*1999–2005*	*2006–2020*	*Total*
NSW	Adelaide to Nyngan	3	0	0	0	0	0
NSW	Bathurst to Cunnamulla	4	1	0	0	23	23
NSW	Kings Highway	1	0	0	0	0	0
NSW	Melbourne to Sydney (coastal route)	7	0	0	0	0	0
NSW	Monaro Highway	2	0	0	0	0	0
NSW	Newcastle to Dubbo (Golden Hwy)	3	0	0	0	0	0
NSW	Sydney to Bathurst	2	1	0	0	42	42
NSW	Sydney to Brisbane (Pacific Highway)	8	8	155	38	201	393
SA	Adelaide to Nyngan	2	0	0	0	0	0
SA	Melbourne to Keith	3	0	0	0	0	0
SA	Port Lincoln to Port Augusta	1	0	0	0	0	0
TAS	Hobart to Smithtown	1	1	0	20	16	36
VIC	Geelong to Benalla (Midland Hwy)	8	1	0	0	6	6
VIC	Melbourne to Keith	2	0	0	0	0	0
VIC	Melbourne to Mildura	8	3	9	8	57	74
VIC	Melbourne to Sydney (coastal route)	3	2	5	7	9	20
VIC	Portland to Sunraysia Hwy	1	0	0	0	0	0
WA	Albany to Perth	3	0	0	0	0	0
WA	Augusta to Bunbury	2	0	0	0	0	0
WA	Bunbury to Perth	2	2	18	14	21	54
WA	Esperance to Bunbury	11	5	0	14	53	67
WA	Esperance to H003 (Coolgardie to Esperance Highway)	1	0	0	0	0	0
WA	Perth to Port Hedland	4	1	0	27	21	48
WA	Ravensthorpe to Perth	1	0	0	0	0	0
Overall		*83*	*25*	*187*	*127*	*448*	*762*

Note a. Roads included in this table are listed in table III.1.

Source BTCE using RIAM model.

TABLE III.5 EXPENDITURE NEEDS FOR MAINTENANCE BY STATE AND TERRITORY: NON–NHS ROADS

($ million, 1997–98 prices)

		Rehabilitation				*Resealing and routine maintenance[a]*			*All maintenance*			
State	*Length of road analysed[c] (km)*	*Backlog (1998)*	*1999–2005*	*2006–2020*	*Total*	*1999–2005*	*2006–2020*	*Total*	*Backlog (1998)*	*1999–2005*	*2006–2020*	*Total*
ACT	46	–	2	19	22	6	18	25	–	9	38	46
NSW	3,300	27	178	626	832	199	433	632	27	377	1,059	1,463
NT	470	–	–	22	22	32	70	102	–	32	93	125
QLD	1,434	5	33	215	253	120	257	377	5	152	472	630
SA	1,023	4	6	77	87	92	204	296	4	98	281	383
TAS	247	1	4	65	70	21	43	64	1	25	108	134
VIC	2,186	15	52	511	577	165	373	537	15	216	883	1,115
WA[d]	7,467	1	29	415	446	530	1,166	1,697	1	559	1,581	2,142
Overall	*16,172*	*53*	*304*	*1,951*	*2,308*	*1,165*	*2,564*	*3,729*	*53*	*1,469*	*4,515*	*6,038*

Notes a. No backlog has been assumed for resealing and routine maintenance as these expenses are incurred with greater frequency than rehabilitations.

b. Dashes mean that expenditure needs are zero for the maintenance type.

c. List of routes detailed in table III.6

d. There were no roughness data for 202.09 kilometres of Western Australian non–NHS roads. Resealing and routine maintenance costs have been estimated for these sections, but not rehabilitation costs. The lengths of road lacking roughness data are: Albany to Perth 0.74km; Augusta to Bunbury 17.37km; Bunbury to Perth 32.53km; Collie to Bunbury 6.5km; Esparence to Bunbury 21.1km; Kalgoorlie to Coolgardie 0.09km; Kambalda to Meekatharra 2.62km; Mount Magnet to Geraldton 8.71km; Munjina to Nanatarra Road House 2.45km; Narrogin to Williams 2.18km; Newman to Port Hedland 8.13km; Perth to Port Hedland 0.05km; Ravensthorpe to Perth 84.33km; and Roebourne to Wittenoom Rd 15.29km.

Source BTCE using RIAM model.

TABLE III.6 EXPENDITURE NEEDS FOR MAINTENANCE BY CORRIDOR: NON–NHS ROADS

($ million, 1996–1997 prices)

			Rehabilitation				Resealing and routine maintenance[a]			All maintenance			
State	*Corridor*[c]	*Length of road analysed (km)*	*Backlog*	*1999–2005*	*2006–2020*	*Total*	*1999–2005*	*2006–2020*	*Total*	*Backlog*	*1999–2005*	*2006–2020*	*Total*
ACT	Canberra Connections	2	–	–	2	2	1	1	1	–	1	3	3
ACT	Kings Highway	8	–	–	1	1	1	3	4	–	1	3	4
ACT	Monaro Highway	36	–	2	17	19	5	15	20	–	7	31	39
NSW	Adelaide to Nyngan	631	2	0	10	11	32	69	102	2	32	79	113
NSW	Bathurst to Cunnamulla	801	4	10	65	79	40	89	129	4	50	154	208
NSW	Kings Highway	128	3	5	29	36	9	18	27	3	14	47	63
NSW	Melbourne to Sydney (coastal route)	429	5	38	161	203	30	65	95	5	68	226	299
NSW	Monaro Highway	206	1	3	37	40	14	30	44	1	17	67	84
NSW	Newcastle to Dubbo (Golden Hwy)	313	–	9	54	64	16	35	51	–	26	89	115
NSW	Sydney to Bathurst	91	–	7	41	48	9	19	27	–	15	60	75
NSW	Sydney to Brisbane (Pacific Highway)	700	13	107	229	348	49	108	157	13	156	337	505
NT	Arnhem Hwy	223	–	–	22	22	15	34	48	–	15	56	71
NT	Stuart Hwy to Ayers Rock	247	–	–	–	–	17	37	54	–	17	37	54
QLD	Brisbane to Darwin	14	–	–	–	1	1	2	3	–	1	3	4
QLD	Rockhampton to Barcaldine	575	1	9	65	75	41	90	130	1	50	155	206
QLD	Sydney to Brisbane (Pacific Highway)	83	3	21	108	131	25	44	69	3	46	152	200
QLD	Townsville to Cloncurry	763	1	2	42	45	53	121	174	1	55	163	219
SA	Adelaide to Nyngan	380	1	2	11	13	33	74	108	1	35	85	121
SA	Melbourne to Keith	232	–	2	50	52	22	49	71	–	24	99	123
SA	Pimba to Olympic Dam	94	–	–	–	–	9	20	29	–	9	20	29

TABLE III.6 (CONTINUED)

State	Corridor	*Length of road analysed (km)*	*Rehabilitation*				*Resealing and routine maintenance[a]*			*All maintenance*			
			Backlog	*1999–2005*	*2006–2020*	*Total*	*1999–2005*	*2006–2020*	*Total*	*Backlog*	*1999–2005*	*2006–2020*	*Total*
SA	Port Lincoln to Port Augusta	317	3	2	16	21	27	61	89	3	29	77	110
TAS	Cygnet to Hobart	46	–	1	14	15	5	9	13	–	5	23	28
TAS	Hobart to Smithtown	97	–	1	23	24	8	16	24	–	9	39	48
TAS	Launceston to Georgetown	47	–	1	17	17	4	10	14	–	5	26	31
TAS	Triabunna to Hobart	57	–	2	12	14	4	9	13	–	6	21	27
VIC	Geelong to Benalla (Midland Hwy)	420	4	9	60	74	29	66	95	4	38	126	168
VIC	Melbourne to Keith	410	2	8	104	114	31	71	102	2	39	175	216
VIC	Melbourne to Mildura	548	5	10	101	117	39	89	129	5	49	191	246
VIC	Melbourne to Sydney (coastal route)	470	3	22	230	255	46	101	148	3	68	332	403
VIC	Portland to Sunraysia Hwy	337	1	2	15	18	20	44	64	1	22	60	82
WA	000H006 to Broome (Broome Highway)	42	–	–	4	4	3	6	9	–	3	10	14
WA	000H006 to Derby (Derby Highway)	43	–	–	1	1	3	7	10	–	3	7	10
WA	000H006 to Port Hedland (Port Hedland Road)	10	–	–	–	–	1	2	3	–	1	2	3
WA	000H007 to Karratha (Point Samson to Roebourne Road)	18	–	–	–	–	2	3	5	–	2	3	5
WA	000H011 to Wyndham (Great Northern Highway)	123	–	–	4	4	9	21	30	–	9	24	34
WA	000M050 to Pannawonica (Pannawonica Road)	46	–	–	–	–	4	8	11	–	4	8	11

TABLE III.6 (CONTINUED)

			Rehabilitation				*Resealing and routine maintenance*[a]			*All maintenance*			
State	*Corridor*	*Length of road analysed (km)*	*Backlog*	*1999–2005*	*2006–2020*	*Total*	*1999–2005*	*2006–2020*	*Total*	*Backlog*	*1999–2005*	*2006–2020*	*Total*
WA	00H007 to Dampier (Dampier Road)	26	–	–	1	1	2	5	7	–	2	6	8
WA	Albany Port Road	7	–	–	–	–	1	1	2	–	1	1	2
WA	Albany to Perth[d]	374	–	1	59	61	33	76	109	–	34	136	170
WA	Augusta to Bunbury[d]	141	–	4	42	45	17	38	55	–	20	80	100
WA	Bunbury to Perth[d]	155	–	2	79	81	17	36	52	–	19	115	134
WA	Carnarvon Road	5	–	–	1	1	1	2	3	–	1	3	4
WA	Collie to Bunbury[d]	36	–	–	8	8	4	9	13	–	5	17	22
WA	Esperance to Bunbury[d]	987	1	19	129	148	74	161	235	1	92	290	383
WA	Esperance to H003	205	–	–	2	2	17	38	55	–	17	40	57
WA	Kalgoolie to Coolgardie[d]	40	–	–	–	–	4	9	14	–	4	9	14
WA	Kambalda to Meekatharra[d]	793	–	–	2	3	45	97	142	–	45	100	145
WA	Laverton to Leonora	124	–	–	–	–	10	21	31	–	10	21	31
WA	Marvel Loch	33	–	–	3	3	2	5	7	–	2	8	10
WA	Minilya to Exmouth	212	–	–	–	–	17	36	53	–	17	36	53
WA	Mount Magnet to Geraldton[d]	334	–	–	7	7	26	56	82	–	26	63	89
WA	Munjina to Nanatarra Road House[d]	417	–	–	–	–	19	41	60	–	19	41	60
WA	Narrogin to Williams[d]	31	–	–	1	1	3	6	8	–	3	7	10
WA	Newman to Port Hedland[d]	434	–	–	–	–	7	16	23	–	7	16	23
WA	Perth to Port Hedland[d]	1,662	–	2	47	49	140	308	449	–	142	356	498
WA	Pinjarra to Mandurah	17	–	–	11	11	9	20	30	–	9	31	40
WA	Ravensthorpe to Perth[d]	495	–	–	8	8	32	70	102	–	32	78	110
WA	Roebourne to Wittenoom Rd[d]	259	–	–	–	–	–	–	–	–	–	–	–

TABLE III.6 (CONTINUED)

State	*Corridor*	*Length of road analysed (km)*	*Rehabilitation*				*Resealing and routine maintenance*[a]			*All maintenance*			
			Backlog	*1999–2005*	*2006–2020*	*Total*	*1999–2005*	*2006–2020*	*Total*	*Backlog*	*1999–2005*	*2006–2020*	*Total*
WA	Tom Price to Paraburdoo	151	–	–	–	–	10	22	33	–	10	22	33
WA	Warneroo Road	23	–	–	6	6	2	5	7	–	2	11	13
WA	Woodie Woodie Rd	223	–	–	–	–	17	40	57	–	17	40	57
Overall		*16,172*	*53*	*304*	*1,951*	*2,308*	*1,165*	*2,564*	*3,729*	*53*	*1,469*	*4,515*	*6,038*

Notes a. No backlog has been assumed for resealing and routine maintenance as these expenses are incurred with greater frequency than rehabilitations.

b. Dashes mean that expenditure needs are zero for the maintenance type.

c. List of routes detailed in table III.6

d. There were no roughness data for 202.09 kilometres of Western Australian non–NHS roads. Resealing and routine maintenance costs have been estimated for these sections, but not rehabilitation costs. The lengths of road lacking roughness data are: Albany to Perth 0.74km; Augusta to Bunbury 17.37km; Bunbury to Perth 32.53km; Collie to Bunbury 6.5km; Esparence to Bunbury 21.1km; Kalgoorlie to Coolgardie 0.09km; Kambalda to Meekatharra 2.62km; Mount Magnet to Geraldton 8.71km; Munjina to Nanatarra Road House 2.45km; Narrogin to Williams 2.18km; Newman to Port Hedland 8.13km; Perth to Port Hedland 0.05km; Ravensthorpe to Perth 84.33km; and Roebourne to Wittenoom Rd 15.29km.

Source BTCE using RIAM model.

APPENDIX IV ADEQUACY OF AUSTRALIAN BRIDGES

The material in this appendix is reproduced with minor editorial changes from a report prepared under contract to the BTCE by Dr Rob Heywood (Queensland University of Technology) and Bob Pearson (Pearsons Transport Resource Centre P/L).

Except for those spanning significant geographic features, bridges tend to attract little interest from road users. However, they are more numerous than commonly supposed and are an essential component of the road infrastructure.

Bridges are relatively more expensive to construct than road pavements, and are therefore designed for a longer service-life. Failure of a bridge has more severe consequences than a road failure, none more spectacularly illustrated than by the loss of 3 spans of the Tasman Bridge in Hobart because of a ship collision in 1975.

The range of ages and strengths in Australia's bridge infrastructure reflects the longer service life of bridges and the increase over time in the mass and number of heavy vehicles. For example, bridges presently in service on national highways were designed and constructed over 50 years ago for loads half the size of the loads applied by contemporary heavy vehicles. It is the strength of these older bridges that limits the potential productivity enhancements associated with increased heavy vehicle weights.

CHARACTERISTICS OF BRIDGES ANALYSED

Designated Network

The analysis was undertaken on a designated primary road network. The network consisted of National Highways and other primary rural roads as listed in table 2.1

The bridge inventory available was a combination of selected parts of the bridge inventory collected for the Mass Limits Review (NRTC 1996a) and data collected specifically for the project.

TABLE 2.1 PRIMARY ROAD NETWORK

National Highways [1]		
Corridor	*Total length (km)*	*Note*
Sydney-Melbourne	804	
Canberra connections	121	
Sydney-Brisbane (New England Hwy)	914	
Sydney-Adelaide (Sturt Hwy)	1,001	Tarcutta (Hume Hwy) to Adelaide (Cavan)
Melbourne-Adelaide	716	
Melbourne-Brisbane (Newell Hwy)	1,441	Seymour to Toowoomba
Brisbane-Cairns	1,699	
Adelaide-Perth	2,671	
Adelaide-Darwin	2,695	Port Augusta to Darwin
Perth-Darwin	3,708	Midland (Perth) to Katherine
Brisbane-Darwin	2,433	Brisbane to Threeways Roadhouse (Tennant Creek)
Hobart-Burnie	333	The route length between Hobart and Burnie is 320km. There is also 13km of parallel roadway declared as a National Highway
Total	*18,536*	
Other primary roads		
Corridor	*Total length (km)*	*Note*
Sydney-Melbourne (Princes Hwy)	975	
Sydney-Brisbane (Pacific Hwy)	794	Newcastle (Hexham) to Brisbane
Sydney-Adelaide (via Broken Hill)	1,093	NSW highways only
Melbourne-Mt Gambier	385	Princes Hwy West in Victoria only
Melbourne-Mildura	535	
Perth-Port Hedland (via Geraldton)	1,704	North West Coastal Hwy & Brand Hwy
Perth-Coolgardie (via Albany)	1,204	
Total	*6,690*	

Note 1. Excludes any national highways in the urban area.

Source Table 2.7 BTCE (1994) and consultants' derivation.

The Mass Limits Review inventory was not road or bridge specific, but aggregated data by State and Territory in the categories of National Highways and Rural Arterials with traffic volumes greater than 5,000 vehicles per day (vpd). Where assessment of specific corridors was required, estimates were made based on:

- number of bridges or deck area in each corridor (where available); or
- carriageway length adjusted by type of terrain.

TABLE 2.2 NUMBERS OF BRIDGES IN THE PROJECT INVENTORY

	State								
	NSW	*VIC*	*QLD*	*SA*	*WA*	*TAS*	*NT*	*ACT*	*Aust*
National Highways	462	255	681	328[1]	105	73	72	0	1976
Other primary roads	209	162	0	0	101	0	0	0	472

Note 1. Including 205 'bridges' in South Australia which have spans less than 5m.

Bridge Inventory on Designated Network

The inventory contains information on 2448 bridges in all States and the Northern Territory (table 2.2). It should be noted that the majority of the bridges in the South Australian bridge inventory have spans less than 5 m (205

or 63 per cent) whereas the inventory in all other states shows much smaller numbers in this span range. This is a reflection of varying policies regarding the definition of what constitutes a bridge with many States regarding these structures as culverts.

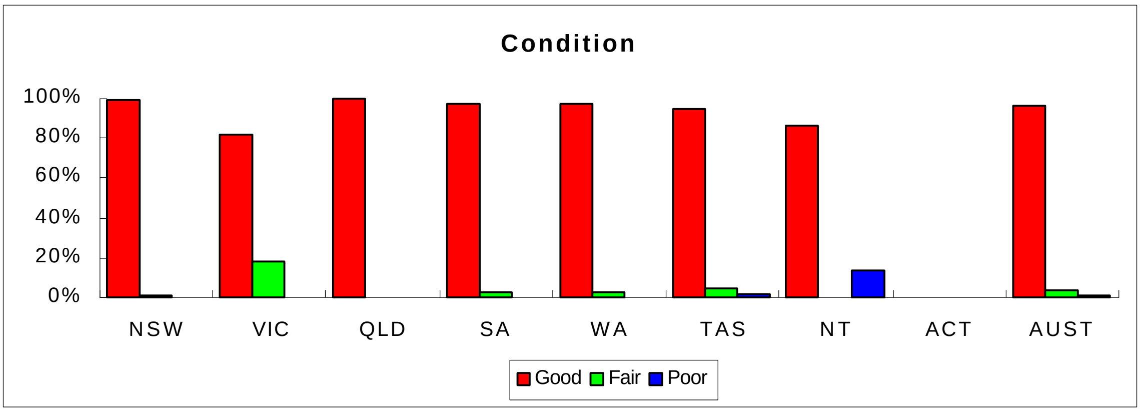
The bridges included in the inventory represent a total deck area of 1,553,000 m^2 with an estimated replacement cost of $1,900 million, of which $1,500 million is for national highways.

The inventory contained information on numbers of bridges and deck areas in the following categories:

- road classification;
- superstructure material;
- type of superstructure;
- simply supported or continuous;
- span length of the maximum span;
- design load (a surrogate for age); and
- condition.

A distinction was made between simply supported and continuous bridges because of the differences in the way that they respond to modern vehicles. Simply supported bridges have beam elements which span between piers with a joint over each pier. In contrast the beam elements of continuous bridges continue over each pier thus eliminating the joint but introducing another region which is sensitive to modern vehicles which are both heavier and longer than the original design loads.

FIGURE 2.1 BRIDGE CONDITION ON RURAL NATIONAL HIGHWAYS - PERCENTAGE BY NUMBER



Bridges on National Highways

Condition

Bridges on National Highways are generally in good condition, with 94 per cent classified in this category. Figure 2.1 shows that New South Wales, Queensland, Western Australian and South Australian bridges are virtually all in good, condition. Victoria has the lowest proportion of bridges in good condition being 82 per cent, while Northern Territory has the highest proportion of bridges in poor condition.

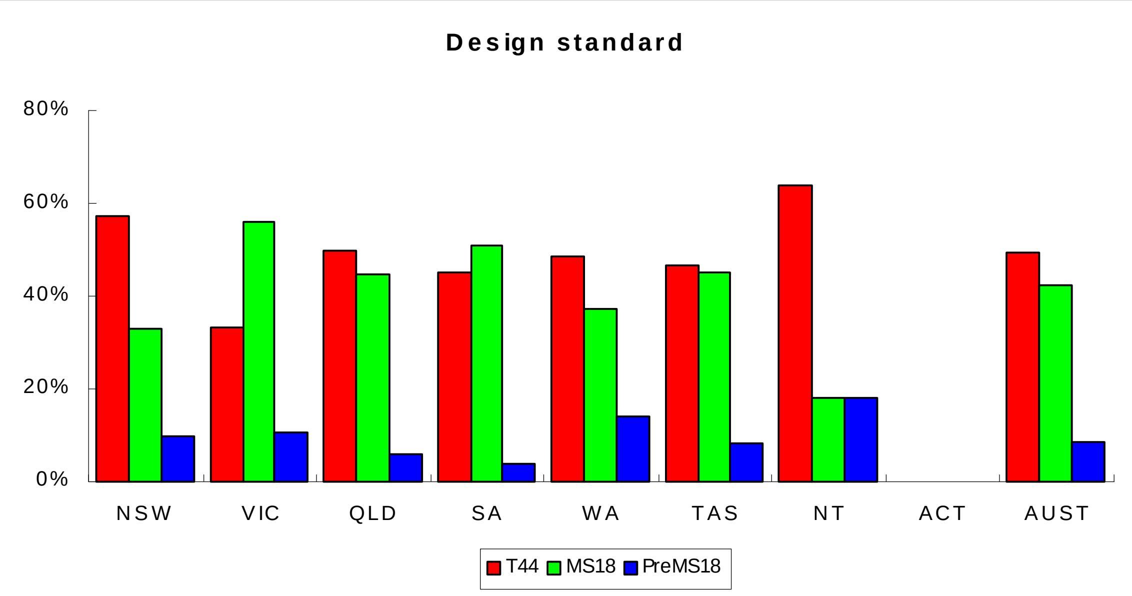
Design standard (Age)

The design standard is used as a surrogate for age as well as the fundamental indicator of bridge strength. Three design load groupings are considered. They are denoted by the nomenclature used in the appropriate bridge design code. T44 denotes bridges built since 1976, MS18 denotes bridges built between 1948 and 1976, and pre MS18 are pre 1948 bridges. The latter group covers a wide variety of design standards, a history of which can be found in the Review of Road Vehicle Limits (NAASRA 1985). The T44, MS18 and other related bridge design loads are summarised in Appendix A.

On National Highways, 43 per cent of bridges were designed and built in the last 20 years to T44 design standard. Of the remainder, 46 per cent were built to MS18 and 11 per cent to earlier standards.

The Northern Territory has the highest percentage of bridges built to T44 (64 per cent) and also the highest percentage of pre 1948 bridges (18 per cent). As illustrated in figure 2.2, Victoria and Tasmania have the lowest proportion of modern bridges (less than 40 per cent) and are the only States less than the national average. In each case, they also have the highest proportion of MS18 bridges at 56 per cent. South Australia has the lowest proportion of pre 1948 bridges at 4 per cent.

FIGURE 2.2 DESIGN STANDARDS (AGE) OF STATE/TERRITORY BRIDGES ON RURAL NATIONAL HIGHWAYS - PERCENTAGE BY NUMBER



Span length

Apart from the Northern Territory, the span lengths of bridges exhibit a reasonably consistent pattern. In the Northern Territory, 69 per cent of bridges are in the range 9m to 11m. No other State or Territory has any one span range represented in more than 30 per cent of bridges. New South Wales, Victoria and South Australia have the highest proportion (>19 per cent) of bridges with more than 30m spans. On a national basis, the highest proportion of bridges (22 per cent) is in the 9m to 11m range, with Tasmania, Queensland, New South Wales and of course Northern Territory all having high proportions of bridges in this range.

However, when deck area is used as the measurement parameter, the longer spans take on more prominence. Sixty percent of the deck area of Australia's bridges on National Highways span more than 20m compared to 35 per cent of the bridge population. table 2.3 shows the position.

TABLE 2.3 BRIDGES BY SPAN AND STATE

(per cent)

	NSW		*VIC*		*QLD*		*SA*[1]		*WA*		*TAS*		*NT*		*Aust*	
	N	*DA*	*N*	*DA*	*N*	*DA*	*N*	*DA*	*N*	*DA*	*N*	*DA*	*N*	*DA*	*N*	*DA*
≤5m	0	0	7	2	1	0	7	4	3	1	11	1	0	0	5	1
5-7m	9	4	7	3	4	1	6	2	25	13	14	4	0	0	9	3
7-9m	10	6	5	1	6	3	9	4	11	10	14	8	0	0	9	5
9-11m	19	13	16	12	22	14	6	4	21	14	23	19	69	51	22	15
11-13m	8	4	11	11	14	11	6	4	5	6	7	6	1	1	9	7
13-15m	7	5	7	9	19	18	15	7	3	2	5	7	8	3	10	9
15-20m	16	16	16	21	14	16	19	18	30	49	12	22	11	11	15	19
20-30m	20	21	12	27	18	27	23	31	2	5	12	23	7	28	15	24
>30m	9	31	9	14	2	10	10	26	0	0	3	11	3	7	5	17
Unknown	-	-	11	-	-	-	-	-	-	-	-	-	-	-	1	-

Notes N = number

DA = deck area

1. excluding the 205 culverts

FIGURE 2.3 SUPERSTRUCTURE MATERIAL

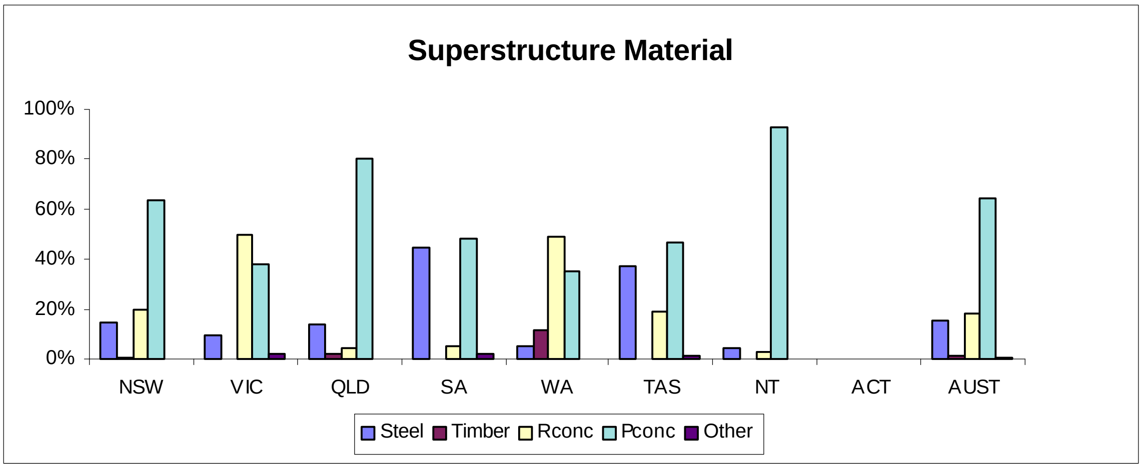


TABLE 2.4 COMPARISON OF BRIDGES ON NATIONAL HIGHWAYS WITH OTHER BRIDGES ON THE DESIGNATED NETWORK

(per cent)

	Design standard			*Condition*		
	T44	*MS18*	*pre MS18*	*good*	*fair*	*poor*
National Highways	43	46	11	94	5	1
Other primary roads	35	44	22	85	14	1

Superstructure material

Concrete is the predominant superstructure material, with more than 60 per cent of Australian bridges on National Highways being constructed of prestressed concrete and 20 per cent of reinforced concrete. New South Wales, Queensland and Northern Territory all have more than 80 per cent of their bridges made of concrete. Steel comprises 18 per cent of superstructure material and timber 3 per cent when measured by bridge numbers.

Bridges on other primary roads

In general, bridges on other primary roads are older, not in as good a condition and have similar span lengths and construction materials. The comparison of design standard (age) and condition is given in table 2.4.

Bridge Loading

The bridge analysis considered three different mass limit scenarios. In determining these scenarios, historical trends in mass limits were examined.

Each State and Territory prescribes the maximum legal limits for the allowable mass on road vehicles. Limits are placed on each axle, axle group and the gross or total laden vehicle mass. Up until 1977, every State and Territory had different allowable mass limits. Following the NAASRA Economics of Road Vehicle Limits Study (Fry et al 1975), the eastern and western regions of Australia were basically uniform within each region but with the western States being higher. Only in 1988 were the legal mass limits for heavy vehicles uniform across Australia when the 42.5 tonne gross mass limit of option C of the RoRVL Study (NAASRA 1986a) was adopted.

The types of vehicles have also changed over recent years. Up until 1976, triaxles were rare, and the basic long distance vehicle was either a 4 or 5 axle articulated. Since 1977, the 6 axle articulated vehicle has been the common long distance eastern seaboard vehicle, with double or triple road trains operating in more remote parts of the nation.

Since their introduction in the 1980s, B-doubles have taken an increasing proportion of the long distance eastern seaboard freight and now carry an estimated 15 per cent of this traffic.

From a bridge perspective, the critical vehicle depends upon the span of the bridge. The spans and the critical axle groups on vehicles are:

- less than 13m triaxles;
- 13m to 30m 6 axle articulated vehicles; and
- above 30m B-double.

The historical trend in legal gross mass in Victoria for articulated vehicles is illustrated in figure 2.4. These trends are generally representative of limits in the eastern states and, while pre 1988 limits were lower than the western region of Australia, are sufficiently representative to make predictions of future limits (see Section 3.4). It is interesting to contrast the changes in limits to the changes in bridge design loads (figures 2.5 and 2.6).

FIGURE 2.4 TREND IN VICTORIAN MASS LIMITS **(TONNES)**

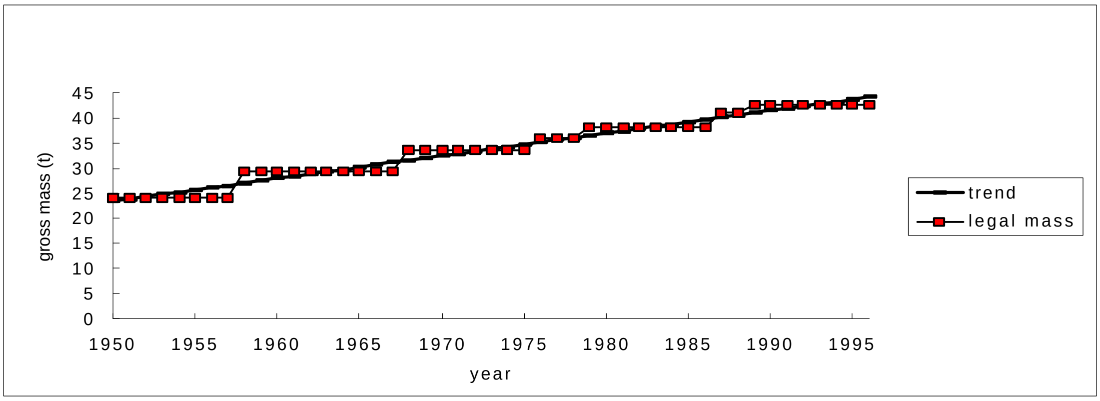


FIGURE 2.5 TRENDS IN BRIDGE DESIGN LOADS IN AUSTRALIA - COMPARISON OF BENDING MOMENTS INDUCED IN A 15 M SIMPLE SPAN

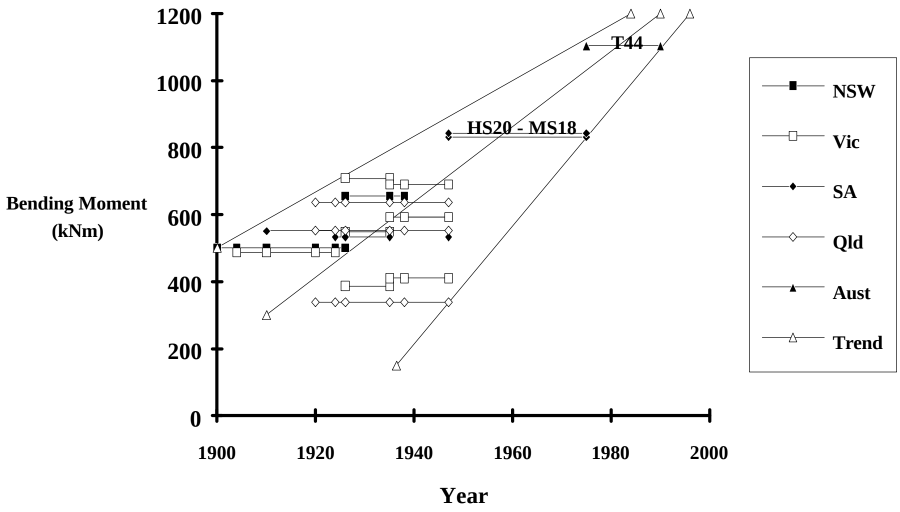


FIGURE 2.6 COMPARISON OF SELECTED BRIDGE DESIGN LOADS WITH CURRENT T44 BRIDGE DESIGN LOAD

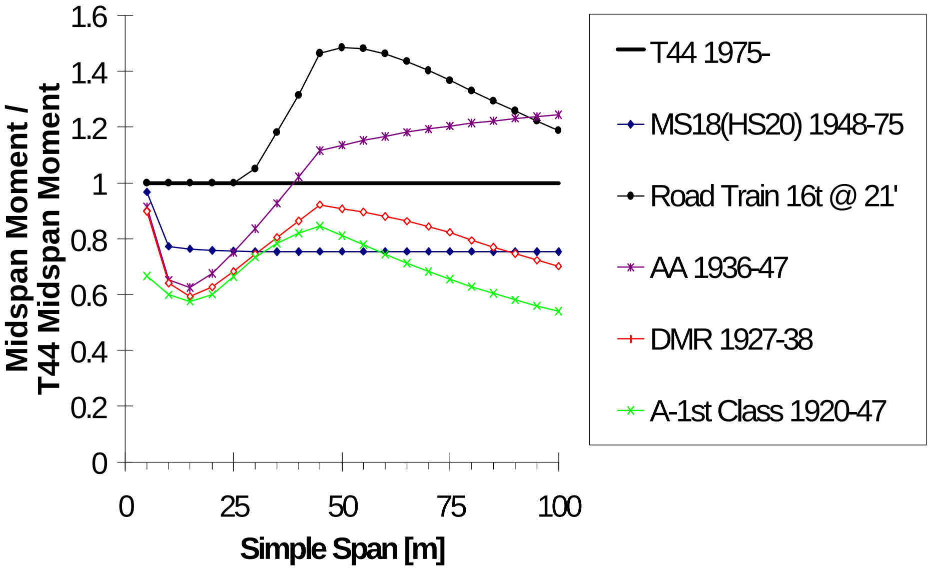


Figure 2.5 compares the bridge design loads on the basis of the effects (bending moments) they induce in a 15 m span. Figure 2.6 shows that ratio of effects induced by different design loads to the current T44 bridge design load varies significantly with span.

Bridge Expenditure

Maintenance

Maintenance costs are associated with a broad range of activities. These include periodic inspections, painting, waterway clearing, guardrail repair, deck joint maintenance, replacement of elements damaged by impact of vehicles and the like.

The maintenance cost varies dramatically with construction material and to a lesser extent with geographical location. The maintenance costs associated with timber bridges are very significant as a major deck rehabilitation is usually required every 7 to 10 years. Consequently the maintenance cost of traditional timber girder bridges is at least an order of magnitude larger than those associated with reinforced concrete bridges for example. The number of bridges that are included in the inventory associated with this project is small (4 per cent by number) and they are identified for replacement relatively quickly. Thus it is assumed that the timber bridges will be replaced rather than maintained leaving the inventory with lower maintenance bridges.

The maintenance cost will be substantially lower on the major highways due to the fact that the bridges are newer. The bridge replacement model developed for this project also assumes that bridges are replaced rather than accept an increased maintenance/strengthening scenario. In this way the bridge inventory will remain in good condition and the maintenance costs low.

Based on discussions with road authorities, maintenance costs of bridges in good condition have been estimated at approximately $600 per bridge per year with an accuracy of ±20 per cent.

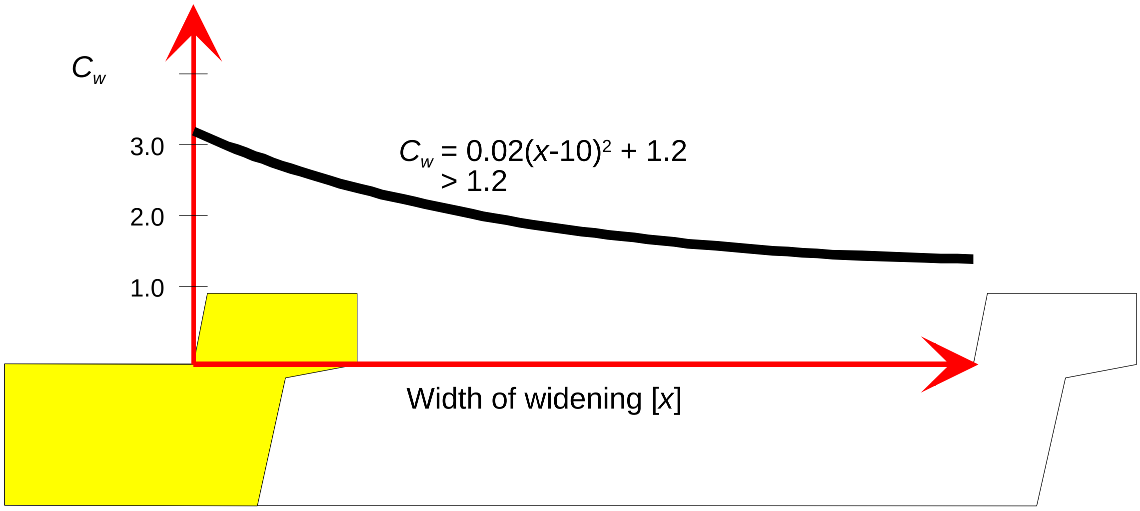
Widening

Bridge widening is a relatively expensive activity from a bridge standpoint but is sometimes the most cost effective solution compared with a new bridge. The reduced cost of approaches plays a significant part in the savings. The increased costs are associated with need to break into existing construction, to operate under and near traffic together with the limited opportunities for economies of scale.

The general preference is not to widen bridges. The cost of widening is not well documented and varies significantly from bridge to bridge. The relationship for widening costs presented in figure 2.7 has been normalised against the cost of the equivalent new construction of the structure being widened. The economies of scale improve with the width of the widening. The widening cost index C_W is defined as follows:

FIGURE 2.7 COST OF BRIDGE WIDENING

$$C_W = \frac{Cost\ of\ widening\ per\ m^2}{Cost\ of\ new\ construction\ per\ m^2}$$



Hence the cost of widening can be estimated as follows:

$$Cost\ of\ widening\ = C_w\ x\ Area\ of\ widening\ x\ Unit\ rate\ for\ the\ equivalent\ new\ construction$$

The costs associated with widening have not been included in the costs of upgrading the bridge infrastructure.

EVALUATING BRIDGES

The database for the bridge evaluation model was a modified version of the inventory used in the National Road Transport Commission (NRTC) Mass Limits Review last year. It covered bridges on the following roads:

- National Highways;
- Rural Arterials carrying more than 5000 vehicles per day; and
- other roads where information was provided by States.

The data is disaggregated by:

- road classification;
- superstructure material;
- type of superstructure;
- simply supported or continuous;
- span length of the maximum span;
- design load (a surrogate for age); and
- condition.

For more details of the disaggregation, refer to pp B.4 and B.5 of NRTC (1996b).

Loading Scenarios

The history of mass limits for trucks in Australia (outlined above) was used to develop three different mass limit scenarios used in the bridge analysis.

It appears likely that option F of the Mass Limits Review (NRTC 1996) will be adopted in the relatively near future. The articulated vehicle limits of 45.5 tonnes for option F was therefore adopted as the base case.

For the purposes of assessing future limits, the recent trend to increase mass limits every decade provides the basis for the three scenarios adopted. These scenarios are:

Scenario 1: gross mass 45.5 tonnes, no future increases;

Scenario 2: gross mass 45.5 tonnes, increasing to 52 tonnes in 2010, no other increases; and

Scenario 3: as for scenario 2, but a further increase to 58 tonnes for articulated vehicles in 2020.

These scenarios are for bridge impact calculations only and increments between these years will have a minimal effect on the results.

The 58 tonne limit is slightly in excess of the trend line but was chosen because it coincides with a mass for which independent cost estimates will be available (Pearson and Bayley 1997).

The detailed scenarios are as given in table 3.1 and illustrated in figure 3.1.

The reporting periods for the cost of bridge replacements are also indicated in figure 3.1 by the vertical lines. The four costing periods are defined as follows:

1. Current (1997);
2. 1998 - 2005;
3. 2006 - 2020; and
4. 2021 - 2030.

Pavement implications have not been considered in this exercise. It is possible that additional axles may be necessary to reduce pavement wear, but for the majority of cases little effect results for bridge costs.

Other important assumptions were that:

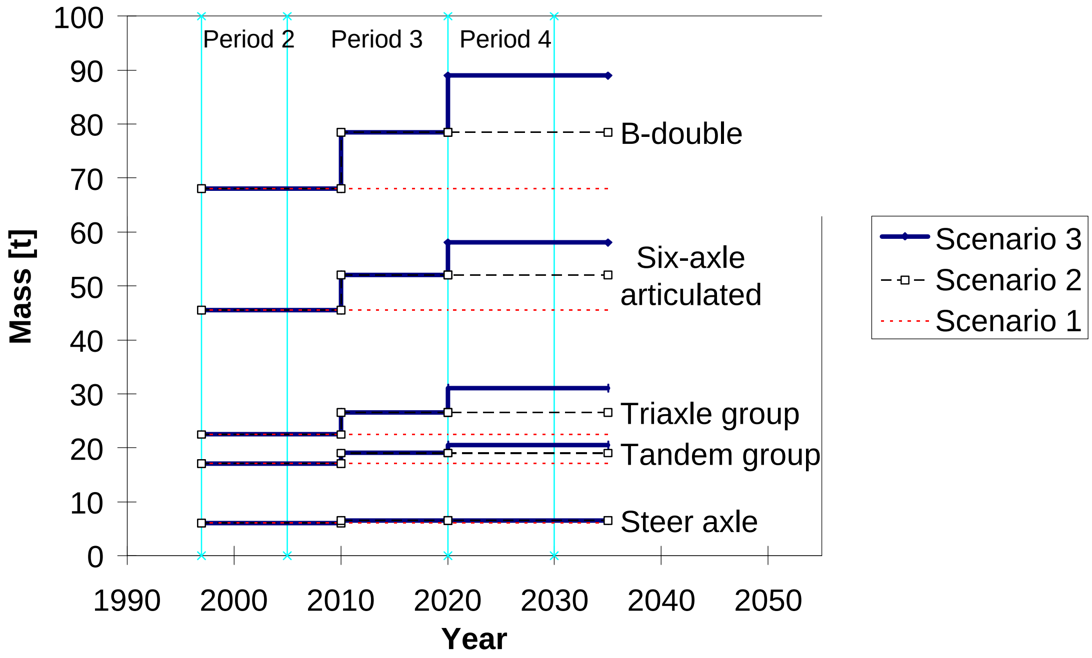
- greater increases are assigned to triaxles compared to tandem axles so that load per axle is approaching the same for tandem and triaxles;
- tyre capacities are available to carry the loads; and

- both air suspensions and mechanical suspensions will be represented in the fleet in future years (important for bridge dynamic effects).

TABLE 3.1 BRIDGE LOADING SCENARIOS

Scenario	*Years*	*Design Vehicle*				
1	1997 on	Artic	**0** 6	**00** 17	**000** 22.5	
		B-double	**0** 6	**00** 17	**000** 22.5	**000** 22.5
2	1997 to 2010	Artic	**0** 6	**00** 17	**000** 22.5	
		B-double	**0** 6	**00** 17	**000** 22.5	**000** 22.5
	2010 on	**Artic**	**0** 6.5	**00** 19	**000** 26.5	
		B-double	**0** 6.5	**00** 19	**000** 26.5	**000** 26.5
3	1997 to 2010	as above				
	2010 to 2020	as above				
	2020 on	Artic	**0** 6.5	**00** 20.5	**000** 31	
		B-double	**0** 6.5	**00** 20.5	**000** 31	**000** 31

FIGURE 3.1 BRIDGE LOADING SCENARIOS AND COSTING PERIODS



Bridge Evaluation Model

The model used to predict the remaining life of Australia's bridges is an adaptation of the model developed by R. Wedgwood and the AUSTROADS team for the Mass Limits Review. It is based largely on limit state design concepts, historical information, research findings and knowledge relating to the performance of bridges over the years. Like most complex models, it involves many approximations and general assumptions. More sophisticated methods applied to individual bridges could well extend or reduce the life of an individual bridge compared with the model. However, the model is considered to provide an acceptable indication of the expenditure required for Australian bridges.

Bridges can fail in many ways. However, they are usually designed so that should they fail then the failure will occur in a controlled ductile manner. Ductile failures are generally associated with bending effects and thus a well designed bridge will fail in bending first. As a consequence, the bridge evaluation model is based around the bending effects induced by traffic.

Bending moments in bridges are calculated from the wheel loads applied to the bridge. Consider the simple span and the vehicle illustrated in figure 3.2. The internal shear (V) and bending moments (M) can be calculated at a point (A-A) from the calculated reactions (R) and the positions (a_1, a_2, a_3, b) of the wheel loads (P_1, P_2, P_3) as follows:

$$V = R - P_1 - P_2 - P_3$$

$$M = Rb - (P_1a_1 + P_2a_2 + P_3a_3)$$

The bridge evaluation model includes a comparison of the bending moments induced by current or future heavy vehicles compared with the bending moments that the bridge was designed to resist.

Australian bridge design codes have adopted the limit state concept for bridge design since 1976. Prior to this time, bridges were designed based on working stress methods. In this case the dead load (or self weight effects) plus the live load (or traffic) effects were not permitted to exceed an allowable stress which was typically some form of yield strength reduced by a factor of safety or safety margin. Thus the safety margin was the same for the dead load and the live load.

FIGURE 3.2 BENDING MOMENTS AND SHEARS INDUCED IN SIMPLY SUPPORTED BRIDGES

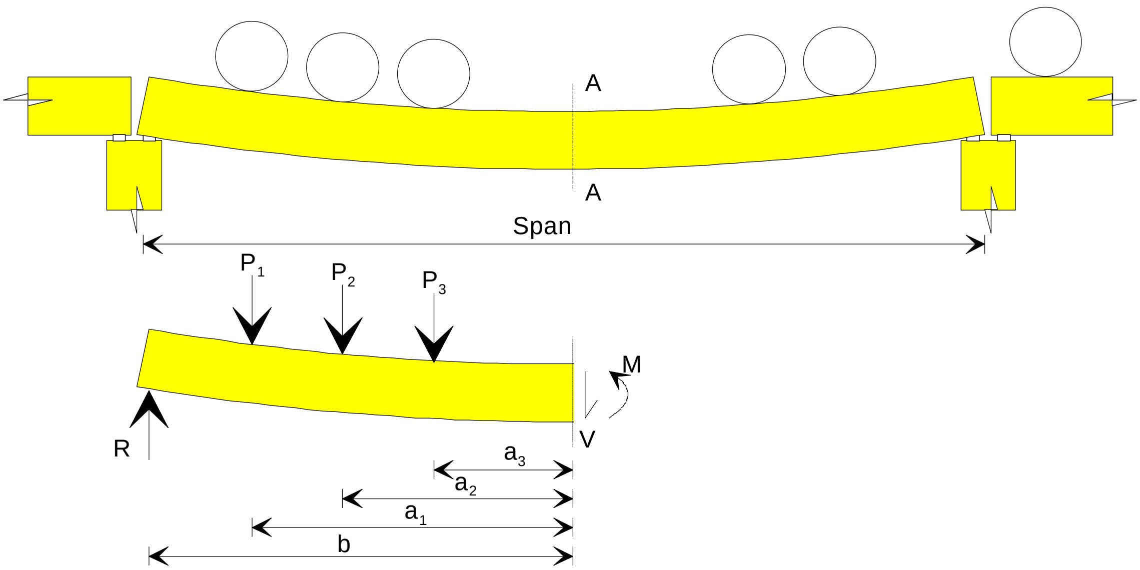
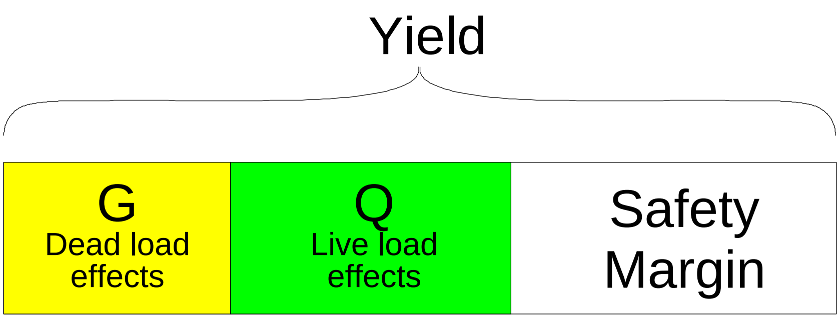


FIGURE 3.3 WORKING STRESS DESIGN METHODS USED PRIOR TO 1976 (I.E. MS18 LOADS AND EARLIER)



The objective of bridge design and the limit state concept is to ensure that the bridge fulfils its purpose and ensures that the probability of failure is acceptable. The AUSTROADS Bridge Design Code expresses this in terms of the load and resistance (strength) of the bridge. The probability of failure is deemed to be acceptable if the estimated extreme event during the life time of the bridge is smaller than a lower bound estimate of the strength of the bridge. Mathematically this limit state equation is expressed as follows:

Extreme loading £ *lower bound estimate of strength*

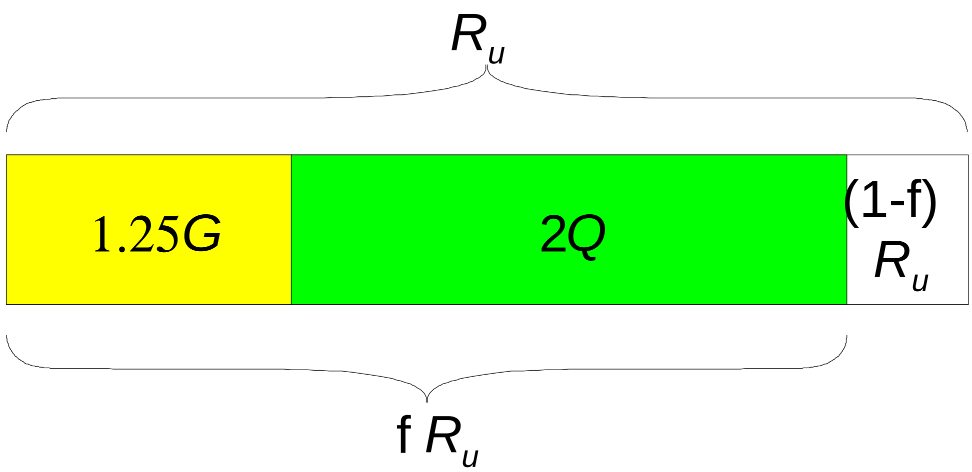
$a_G G + a_Q Q$ £ fR_u

where:

- a_G load factor for dead load (1.25 typically)
- G effects induced by dead loads (including an allowance for superimposed dead loads such as asphalt surfacing)
- a_Q load factor for live load (2.0 for traffic loads)
- Q effects induced by live load (including the dynamic load allowance)
- f strength reduction factor
- R_u ultimate strength (characteristic)

In limit state design the safety margins associated with dead load are substantially smaller than that associated with live loads. This contrasted with older working stress design methods which effectively allocated the same safety margin to both dead and live loads. Thus the introduction of limit state design concepts permitted an increase in live loading for existing bridges.

FIGURE 3.4 LIMIT STATE DESIGN CONCEPTS USED SINCE 1976 (I.E. T44 LOADING)



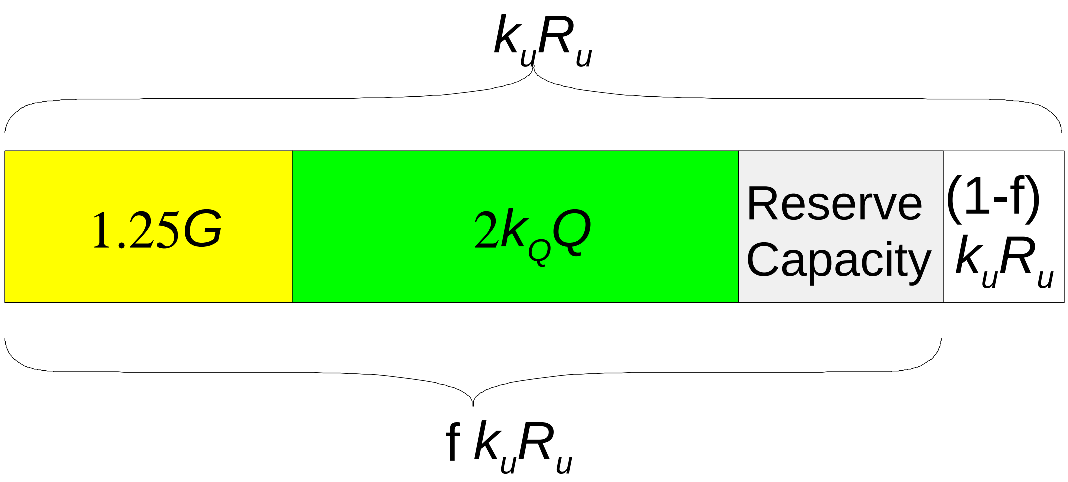
In addition, experience has shown that the performance of bridges in good condition is often better than was anticipated based on the original design calculations. For example, a recent test of a Victorian bridge to failure showed that the bridge was substantially stronger than the original calculations indicated. Also the actual effects induced in the bridge by the traffic are different to those predicted by the appropriate bridge design load. These two groups of influences can be included in the limit state equation through the application of a live load modification factor (k_Q) and a resistance modification factor (k_u):

$$a_G G + a_Q k_Q Q \;£\; f k_u R_u$$

Through the adoption of safe but conservative assumptions during the design phase, the resistance is often greater than expected (i.e. $k_u > 1.0$). Likewise the actual effects induced by the traffic loading are generally smaller than those induced (by theoretical calculation) by the design loading (i.e. $k_Q < 1.0$). The result is some reserve capacity when a structure is new.

Over time, the traffic loads increase and the strength of the structure can deteriorate due to corrosion and the like. As a consequence the live load modification factor (k_Q) increases and the resistance modification factor (k_u) reduces. Figure 3.6 presents this scenario for a particular value of the live load factor a_Q that satisfies the limit state equation. The value of this live load factor is then used to determine the remaining life of the structure.

FIGURE 3.5 NEW BRIDGES OFTEN HAVE RESERVE CAPACITY AVAILABLE THAT CAN FACILITATE INCREASES IN LOAD CARRYING CAPACITY



By dividing the limit state equation by ($G+Q$) and noting that:

$$F_G = G/(G+Q)$$

$$F_Q = Q/(G+Q) \quad \text{gives:}$$

$$a_G F_G + a_Q k_Q F_Q \leq f k_u R_u/(G+Q)$$

This equation can be re-arranged to give the live load factor a_Q which usually has a value $a_Q \approx 2$ assuming the bridge design live load is representative of the traffic loading.

$$a_Q \leq \frac{k_u f R_u}{k_Q F_Q (G+Q)} - \frac{a_G F_G}{k_Q F_Q}$$

The model used to determine the remaining life of the bridge is derived from the value of a_Q. The live load modification factor (k_Q) and a resistance modification factor (k_u) are detailed below.

Live load modification factor (k_Q)

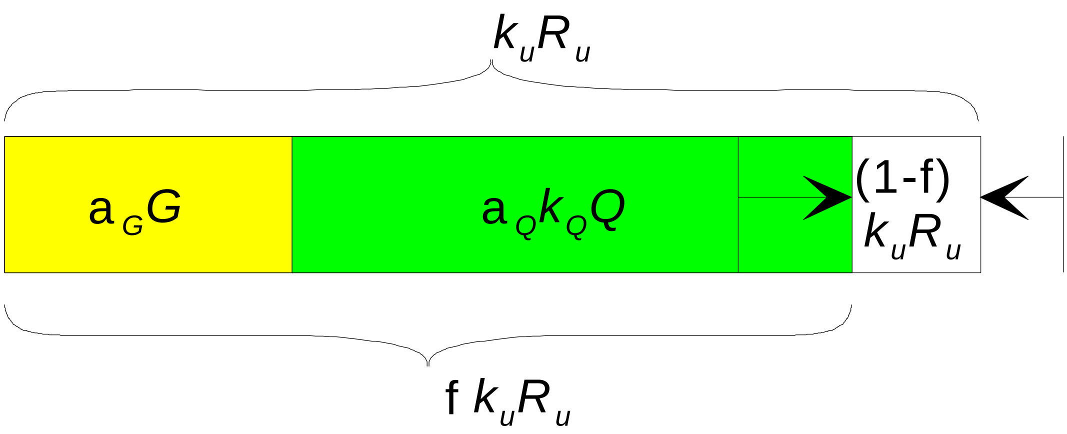
The live load modification factor (k_Q) is expressed as follows:

$$k_Q = k_{Q1}\, k_{Q1c} k_{Q2} k_{Q3} k_{Q4}\, k_{Q5}$$

where the sub-factors are described below and then defined.

- k_{Q1} Bridge design vehicle factor
- k_{Q1c} Continuity load factor
- k_{Q2} Legal load factor
- k_{Q3} Bridge response factor

FIGURE 3.6 THE STRENGTH LIMIT STATE INCORPORATING ALLOWANCES FOR INCREASED LOADS AND DETERIORATION IN THE STRENGTH



- k_{Q4} Bridge design code factor
- k_{Q5} Bridge profile and truck suspension factor.

These factors are designed firstly to investigate the effects of increases in loads on the bridges and secondly to incorporate some factors that have been observed in the field that help explain the often enhanced performance compared with bridge design code provisions. These are detailed below:

k_{Q1} Bridge design load factor

This factor allows for the increases in design load used to design the bridge to the current traffic loading (refer figure 2.5 and 2.6). This involves an adjustment due to increases in bridge design load and a factor relating to the fact that the current traffic loading (RoRVL C) is not uniformly represented by the T44 design vehicle (Heywood, 1993 & 1995).

TABLE 3.2 BRIDGE DESIGN LOAD FACTOR (K_{Q1})

Span (m)	*Pre MS18*	*MS18*	*T44*
<5	1.38	1.16	1.10
5-7	1.50	1.17	1.05
7-9	1.47	1.14	0.97
9-11	1.43	1.17	0.90
11-13	1.42	1.16	0.88
13-15	1.43	1.13	0.86
15-20	1.42	1.16	0.88
20-30	1.36	1.27	0.95
>30	1.25	1.33	1.00
Unknown	-	-	-

$$k_{Q1} = \frac{\text{Effects induced in simply supported bridges by RoRVL C traffic}}{\text{Effects induced in simply supported bridges by the bridges' design load}}$$
$$= \text{function of (Bridge Design Load, Span)}$$

As with the Mass Limits Review, three categories of bridge design load have been adopted. The recommended values for k_{Q1} are as follows. (Please note that the values for spans larger than 30 m can vary quite significantly. A conservative value has been adopted. It should be further noted that the number of bridges in this category that will require replacement is relatively small although their cost impact could be significant.)

TABLE 3.3 CRITICAL DESIGN LOADS AND K_{Q2} FACTORS BY SPAN

	Truck configurations and loads					*Critical design loads by span*		
	o	*oo*	*ooo*	*o oo ooo*	*o oo ooo ooo*	*<13*	*13-30*	*>30*
A42.5	6.0	16.5	20.0	42.5	62.5	20.0	42.5	62.5
A45.5	6.0	17.0	22.5	45.5	68.0	22.5	45.5	68.0
A52.0	6.5	19.0	26.5	52.0	78.5	26.5	52.0	78.5
A58.0	6.5	20.5	31.0	58.0	89.0	31.0	58.0	89.0
						k_{Q2} by span		
A42.5	6.0	17.0	22.5	45.5	68.0	1.00	1.00	1.00
A45.5	6.0	17.0	22.5	45.5	68.0	1.13	1.07	1.09
A52.0	6.5	19.0	26.5	52.0	78.5	1.33	1.22	1.26
A58.0	6.5	20.5	31.0	58.0	89.0	1.55	1.36	1.42

TABLE 3.4 BRIDGE RESPONSE FACTOR (K_{Q3})

	Span (m)	*Timber*	*Timber Truss*	*Reinforced Concrete*	*Prestressed Concrete*	*Steel*	*Steel Truss*
1	<5	.90	1.0	.90	.90	.90	.95
2	5-7	.90	1.0	.90	.90	.90	.95
3	7-9	.90	1.0	.90	.90	.90	.95
4	9-11	.90	1.0	.90	.90	.90	.95
5	11-13	.90	1.0	.90	.90	.90	.95
6	13-15	.90	1.0	.95	.95	.95	.95
7	15-20	1.0	1.0	.95	.95	.95	1.00
8	20-30	1.0	1.0	.95	.95	.95	1.00
9	>30	1.0	1.0	1.00	1.00	1.00	1.00
10	Unknown		-	-	-		

k_{Q1c} Bridge design load continuity factor

The effects induced in short span continuous bridges have traditionally been underestimated in comparison to the effects induced by legal vehicles. This effect is included in the model through the adoption of the continuity factor (Fcont) from the Mass Limits Review.

k_{Q2} Legal load factor

$$k_{Q2} = \frac{\text{Effects induced by proposed legal vehicles}}{\text{Effects induced by the RoRVL C legal vehicles}}$$
$$= \text{function of (Span, Gross vehicle mass, Axle group loads, axle spacing)}$$

This factor incorporates the increases in legal loads over time by scaling the live load up in comparison to the RoRVL C limits (the limits adopted following the Review of Road Vehicle Limits Study in 1985). The scaling factor is based on the axle group loads which are critical for the span under consideration. The values of k_{Q2} are summarised in table 3.3.

k_{Q3} Bridge response factor

$$k_{Q3} = \frac{\text{Actual bridge response}}{\text{Theoretical bridge response}}$$
$$= \text{function of (Structure type, span, bearing restraint, membrane action, analytical model...)}$$

k_{Q4} Bridge design code factor

This factor is designed to compensate for the fact that bridge design code provisions are based around heavily trafficked routes rather than the mostly lightly trafficked highways in Australia. The assumptions relating to the number of vehicles present on a bridge at any one instant and their positioning requirements are compensated for as a function of traffic volume. The type of highway is used here as a surrogate for traffic volume although there are some parts of the national highway which are less heavily trafficked than the major arterial roads.

$$k_{Q4} = \frac{\text{Actual effects induced by traffic stream}}{\text{Estimated effects induced by traffic stream (Code approx)}}$$
$$= \text{function of (Span, Traffic volume, lateral position, multiple presence...)}$$

= 0.95 for National Highways

= 0.90 for Major Arterial Roads

= 0.80 for lightly trafficked local roads

k_{Q5} Bridge profile and truck suspension factor.

$$k_{Q5} = \frac{\text{Actual dynamic effects induced by traffic stream}}{\text{Estimated effects induced by traffic stream (Code approx)}}$$
$$= \text{function of (Road profile; vehicle suspension; bridge frequency, stiffness \& damping)}$$
$$\approx \text{function of (Road Class, vehicle suspension, bridge type, bridge span)}$$

TABLE 3.5 VALUES OF K_{Q5} USED IN THE EVALUATION MODEL

Span (m)	*Timber (non-composite)*		*Steel (composite) average damping*		*Steel (non-composite) v. strong damping*		*Reinforced concrete strong damping*		*Prestressed concrete average damping*	
	*S**	*R**	*S*	*R*	*S*	*R*	*S*	*R*	*S*	*R*
<7	-	-	-	-	-	-	-	-	-	-
7-13	-	-	1.07	1.17	-	-	1.05	1.14	1.08	1.19
13-30	-	-	-	-	-	-	-	-	-	-
30-60	-	-	-	-	-	-	-	-	-	-
60-120	-	-	1.02	-	-	-	1.00	-	1.03	-

Note S* and R* denote ‘smooth’ and ‘rough’ surface profiles.

Source Based on table 9 in Heywood, 1996.

Research associated with the OECD DIVINE project and the Mass Limits Review concluded that the introduction of air suspensions would be beneficial to most bridges but it could result in detrimental effects in short span bridges rough road profiles. To take account of the penetration of air suspensions and the continuing role of conventional steel leaf springs a conservative approach has been adopted for the k_{Q5} factor. It has been given the value of 1.0 except where increased effects are likely to be generated by air suspensions.

For this study it has been assumed that the national highways are ‘smooth’ and the balance of the system is ‘rough’.

Resistance modification factor (k_u)

The resistance modification factor (k_u) is expressed as follows:

$$k_u = k_{u1}k_{u2}$$

where the sub-factors are described below and then defined.

k_{u1} Element strength factor

k_{u2} Condition factor

k_{u1} Element strength factor

$$k_{u1} = \frac{\text{Actual section strength}}{\text{Theoretical section strength}}$$

$$= \text{function of (Material propoerties, as built dimensions...)}$$

Material	k_{u1}
Timber	1.5
Reinforced Concrete	1.2
Prestressed Concrete	1.1
Steel	1.1

k_{u2} Condition factor

$$k_{u2} = \frac{\text{Strength in corroded state}}{\text{Strength in 'as new' condition}}$$
$$= \text{function of (Amount of corrossion, type of structure)}$$

Material	*Good*	*Fair*	*Poor*	*Unknown*
Timber	1.0	0.75	0.50	-
Reinforced Concrete	1.0	0.90	0.75	-
Prestressed Concrete	1.0	0.90	0.75	-
Steel	1.0	0.90	0.75	-

Strength to load ratio

The remaining unknown is the value of $fR_u/(G+Q)$ which has been taken as ≈ 0.8/0.5 = 1.6. This is based on (i) f a factor of 0.8, (ii) permissible stresses are limited to $0.6f_y$ and (iii) the fact that the plastic capacity is somewhat larger than the yield moment (i.e. 0.5 instead of 0.6).

Estimating remaining bridge life

The live load factor a_Q can be estimated for each of the groups of bridges by applying the above model. As the live load factor a_Q reduces, the risk of failure increases. Values of a_Q were examined and compared to threshold limits. If the value exceeded 2.0 (the bridge design standard), the bridge was classified as satisfactory. If the value of a_Q fell between 1.5 and 2.0 it was postulated that the bridge life will be shortened. If the value of a_Q fell below 1.5, the bridge should be strengthened or replaced in the short term as the probability of failure was deemed to be unsatisfactory.

For a_Q factors between 1.5 and 2.0, the remaining life (L_R years to replacement) of the bridge was represented by a curve as shown in figure 3.7. The curve takes account of many issues which individually cannot be quantified, such as increased traffic growth, wear effects and environmental effects. The curve is based on the average expected lives for the bridges of each design load category (90 years for T44, 67 years for MS18, and 37 years for pre MS18). The equation for remaining life L_R was developed as part of the Mass Limits Review. Its basis is largely engineering judgement.

Costing of Bridges Requiring Replacement

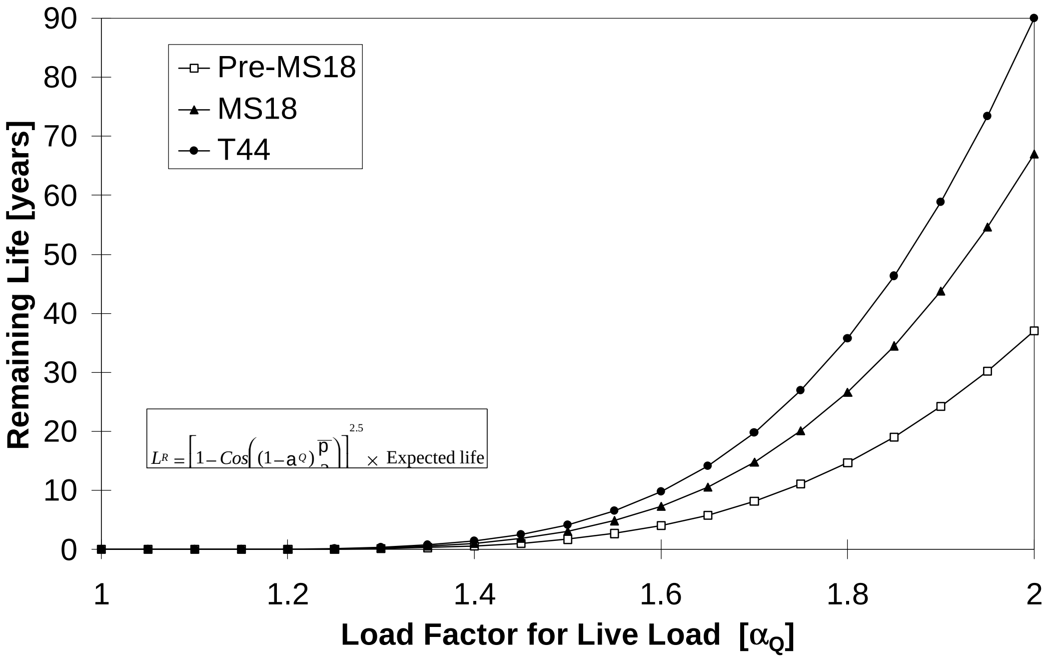
As noted above, if the a_Q value was less than 2.0, the bridge needed to be replaced. The replacement cost of the bridge (R_c) was the product of the deck area of the bridge by R_{ub}, the unit replacement cost for that type of bridge, i.e.:

$$R_c = \text{deck area} * R_{ub}$$

The unit replacement cost for bridges (R_{ub}) used in this study is based on the unit rates used in the Mass Limits Review increased to 1996-97 prices. It is included in Appendix B. Note that timber bridges are replaced by either concrete or steel bridges and costs are based on replacement with bridges capable of withstanding at least T44 loads.

In the Mass Limits Review, additional costs were assigned to bridges which required replacement to represent new construction policies. From experience, it is found that when a bridge is replaced it is wider, longer and placed on an improved alignment which requires additional approach costs. Factors applied to national highways and State arterials were 1.8 for extra width and length and 1.5 for improved approaches, giving a combined increased cost factor of 2.7.

FIGURE 3.7 RELATIONSHIP BETWEEN THE BRIDGE LIVE LOAD A_Q AND BRIDGE REPLACEMENT TIME



Equivalent combined increased cost factor for local road bridges was 1.32 (1.20 x 1.10). These factors were **not** applied in this analysis because of the BTCE methodology for traffic capacity enhancement projects.

RESULTS OF ANALYSIS

The analysis was constrained by a number of factors outlined earlier, but worth repeating again. Bridge inventory data varies in quality throughout the different States and Territories. The time scale for this project required the data collected for the Mass Limits Review to be used. The Mass Limits Review inventory is aggregated data and some judgement was necessary in assigning costs to the different corridors. On the other hand, judgement cannot be applied to the need to replace individual bridges and therefore is likely to overestimate demand, particularly when alternative management methods are available like strengthening or rehabilitation and more sophisticated methods of evaluation that can be applied to individual bridges.

Despite these reservations, the results reproduced in this section are certainly robust and reflect the expenditure necessary to ensure Australia's bridge stock is adequate to carry economically beneficial increased loads.

Costs in this project cannot be compared to the costs from the Mass Limits Review. In this project, costs are capital costs of replacement in 1996–97 dollars, whereas the Mass Limits Review costs were economic impacts, or the costs to bring forward reconstruction, not the capital cost. A further point is that the Mass Limits Review did not include bridges considered deficient under existing mass limits whereas these costs have been included in this project.

The costs for bridge upgrading under the three scenarios and four cost periods are presented in the following Sections. Points relevant to the analysis include:

- when a bridge has been replaced, it is considered adequate to carry all higher loads in the future;
- costs are likely to be at the upper bound because individual bridges may have been strengthened to a standard higher than the original design standard, or have been replaced since most of the inventory was collected in 1995, or alternative management methods may produce a satisfactory results.

Progressive replacement costs

The progressive (total cost up to a given year) bridge replacement costs on the designated network by State/Territory and for Australia are given in figures 4.1, 4.2, 4.3 and 4.4, and the progressive bridge replacement costs for national highways are given in figures 4.5 to 4.8. For example, in Scenario 3 (figure 4.7) the total cost in Victoria for national highways to 2010 would be $20 million, to 2020 would be $41 million and the total cost until 2030 would be $83.5 million.

The graphs are characterised by relatively steady gradients with occasional steps. The steps correspond to a particular family of bridges reaching an age and load carrying capacity which necessitates their replacement. In reality, differences in traffic volumes and environmental conditions would result in a substantial ‘smoothing’ of the steps. When summed across Australia these steps seem to average out into a fairly steady expenditure demand (figures 4.4 and 4.8).

The rate of expenditure for the first scenario is fairly constant over the period. The second and third scenarios show increased rates of expenditure associated with the times at which the loads are increased. These kinks are particularly evident in figure 4.4 where the total expenditure on the highways considered in the model have been summed for Australia for each of the three loading scenarios. The rate of replacement expenditure is closely related to the loading level adopted.

The variability between states is a result of the many differences in the history of the road network and bridge replacement / maintenance policies. The model is also indicating an immediate expenditure requirement of approximately $30m.

The costs associated with loading scenarios 1, 2 and 3 are presented for the national highways by State in figures 4.5, 4.6, 4.7 and 4.8. These show that Victorian national highway bridges have the greatest immediate need. If the loading continues to increase in accordance with historical need then substantial effort will be required on Queensland, New South Wales and South Australian bridges in the early part of next century.

In table 4.1, the costs for each State and the Northern Territory are given for each scenario and costing period, broken into national highways and other primary roads.

FIGURE 4.1 SCENARIO 1 — PROGRESSIVE REPLACEMENT COST VERSUS YEAR FOR THE DESIGNATED NETWORK

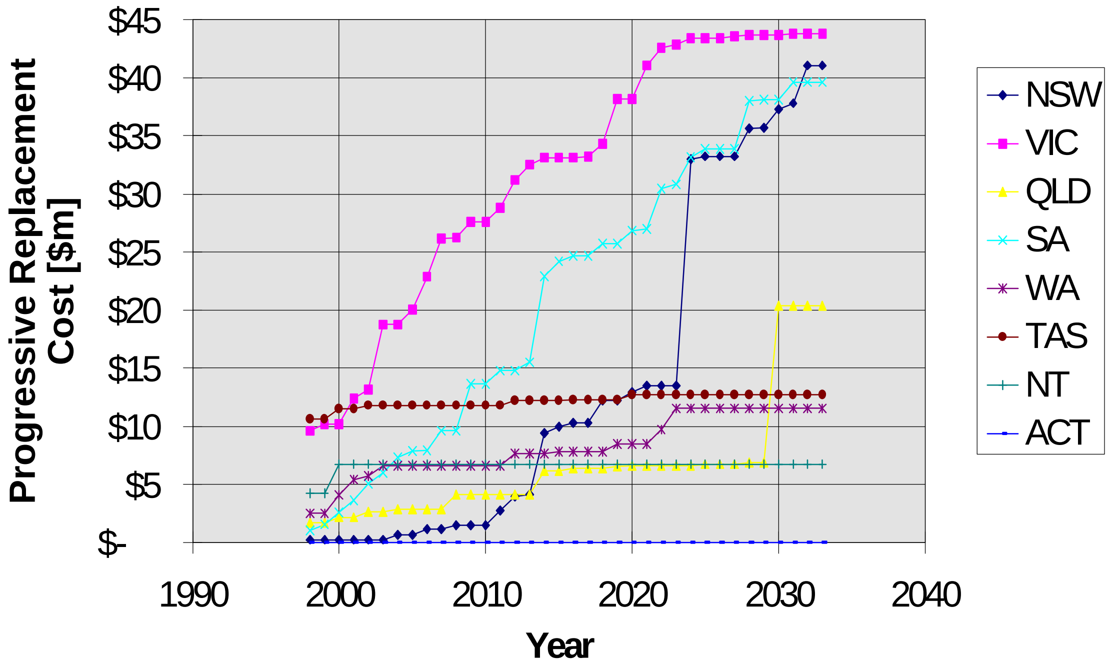


FIGURE 4.2 SCENARIO 2 — PROGRESSIVE REPLACEMENT COST VERSUS YEAR FOR THE DESIGNATED NETWORK

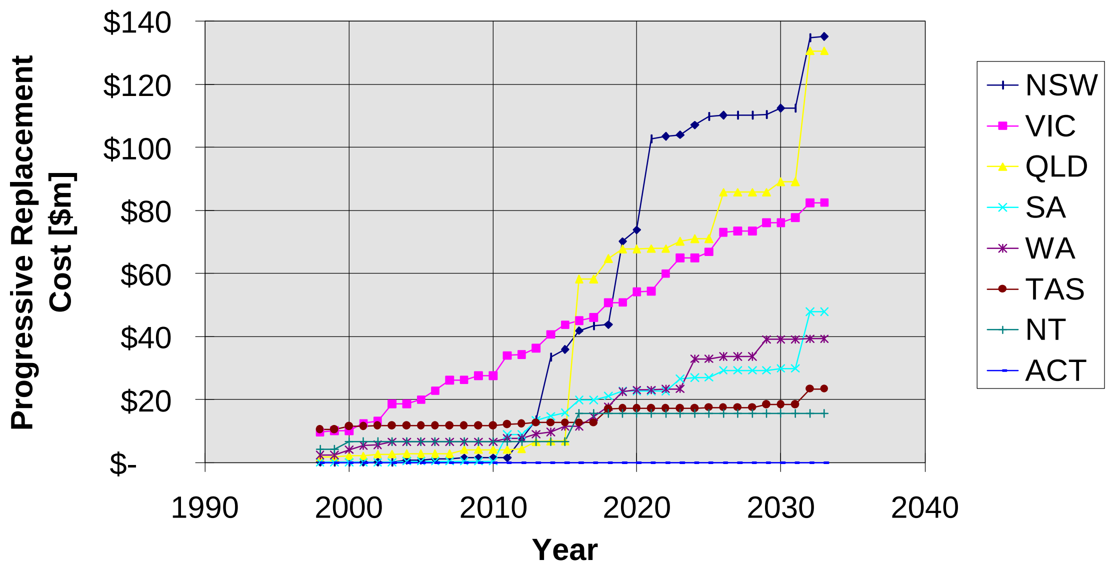


FIGURE 4.3 SCENARIO 3 — PROGRESSIVE REPLACEMENT COST VERSUS YEAR FOR THE DESIGNATED NETWORK

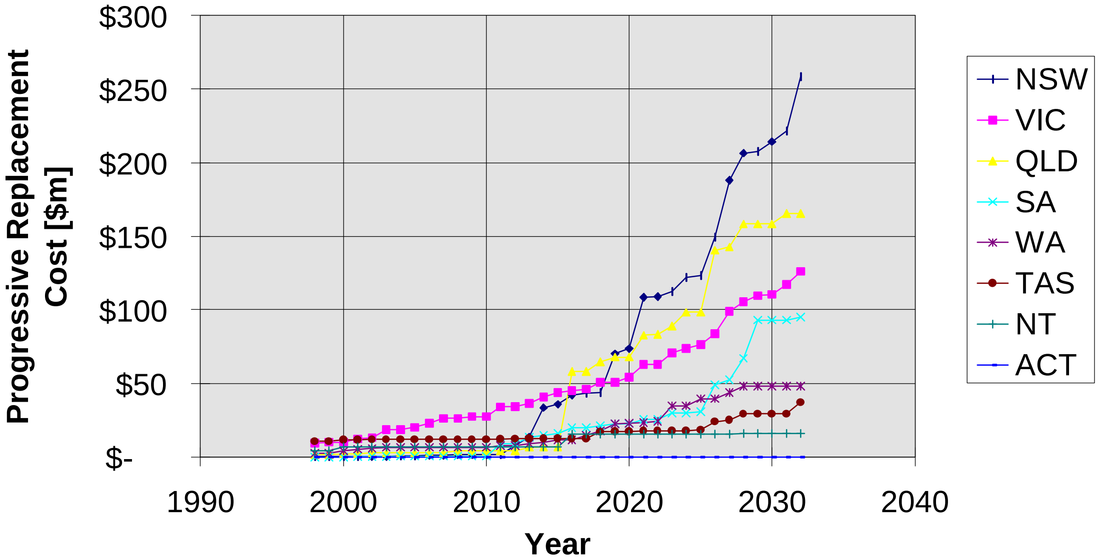


FIGURE 4.4 PROGRESSIVE REPLACEMENT COST VERSUS YEAR FOR AUSTRALIA - LOADING SCENARIOS 1, 2 & 3

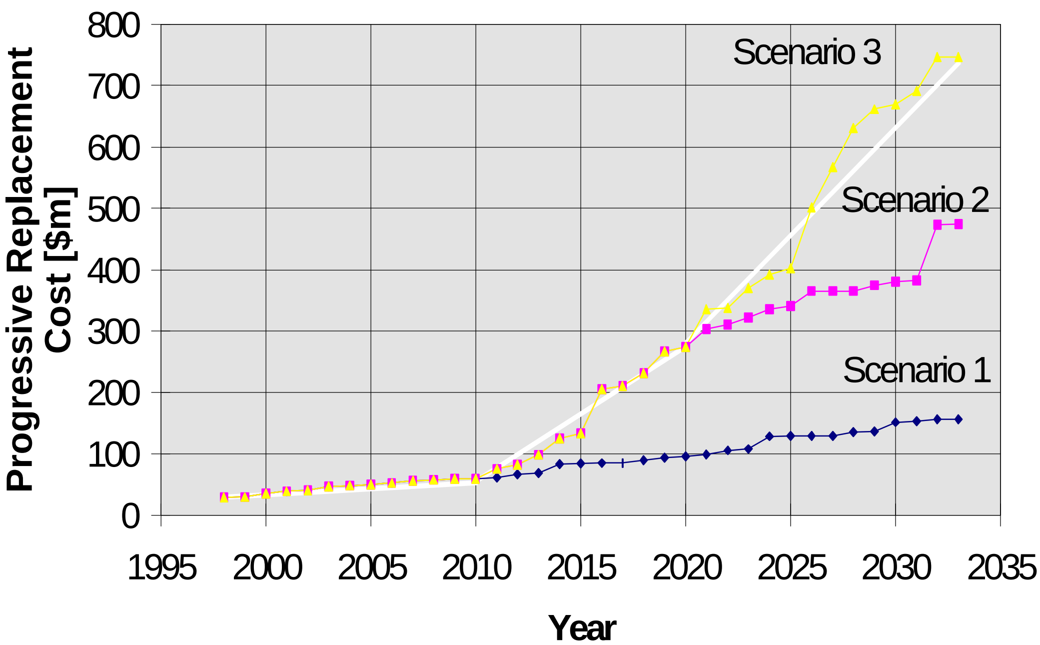


FIGURE 4.5 SCENARIO 1 — PROGRESSIVE REPLACEMENT COST VERSUS YEAR FOR NATIONAL HIGHWAYS BY STATE/TERRITORY

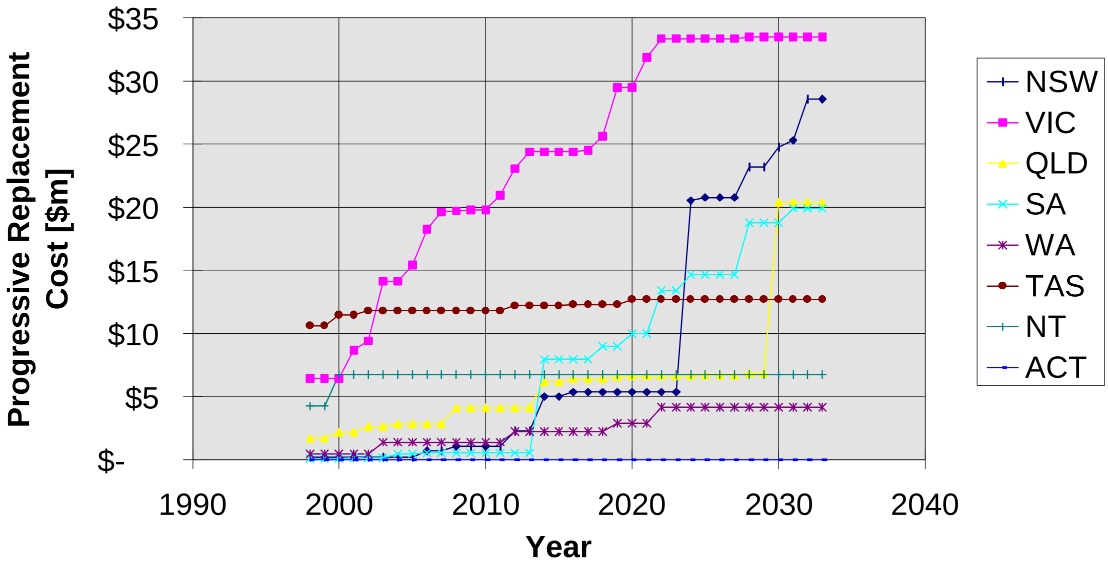


FIGURE 4.6 SCENARIO 2 — PROGRESSIVE REPLACEMENT COST VERSUS YEAR FOR NATIONAL HIGHWAYS BY STATE/TERRITORY

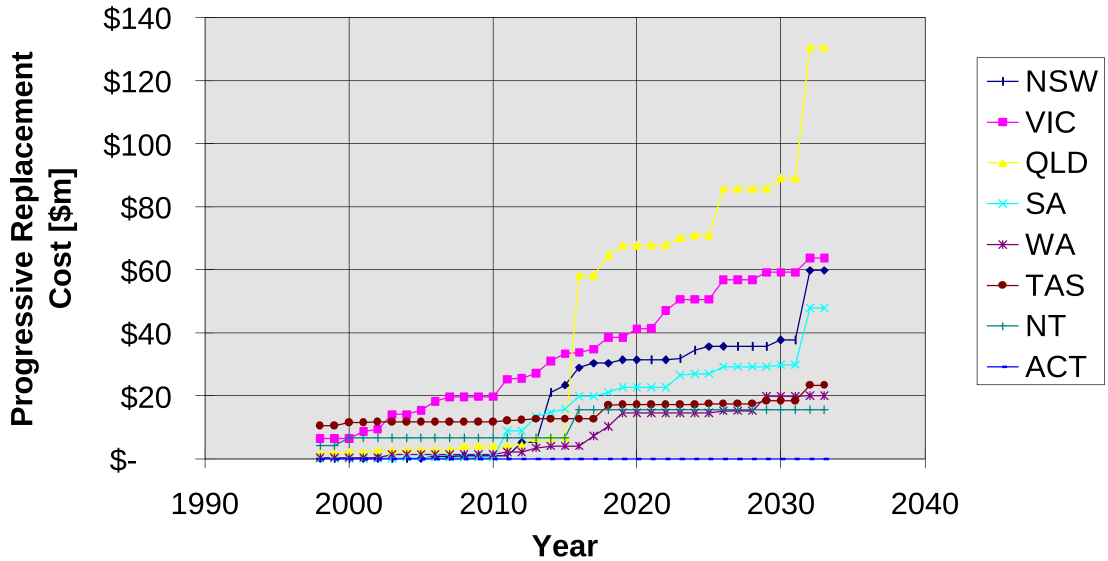


FIGURE 4.7 SCENARIO 3 — PROGRESSIVE REPLACEMENT COST VERSUS YEAR FOR NATIONAL HIGHWAYS BY STATE/TERRITORY

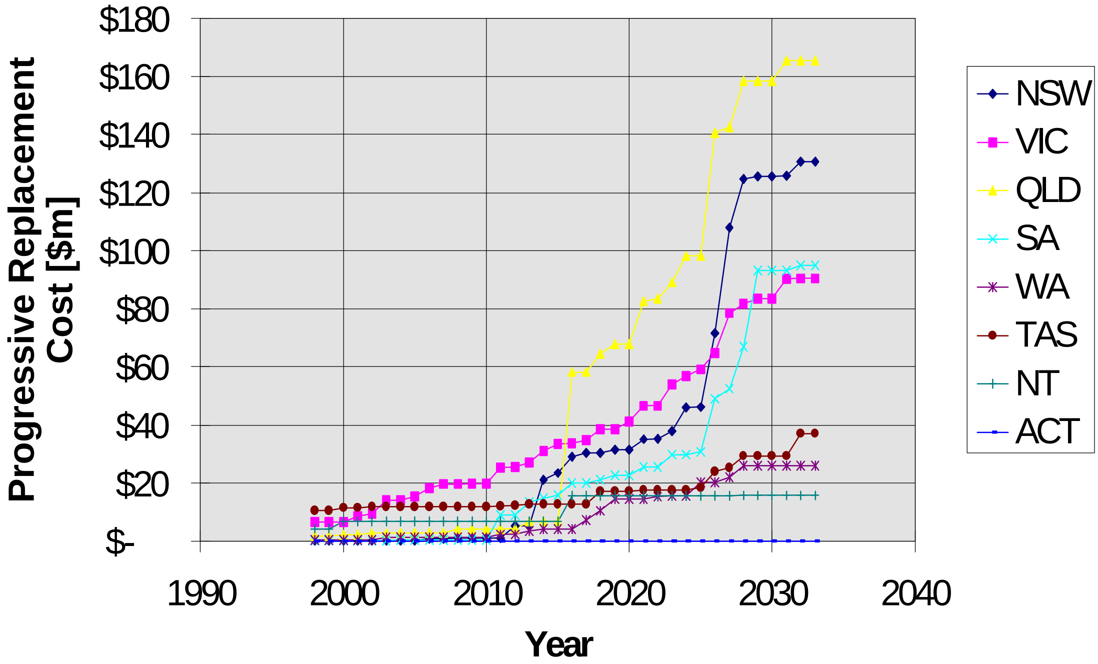


FIGURE 4.8 PROGRESSIVE REPLACEMENT COST VERSUS YEAR FOR NATIONAL HIGHWAYS - LOADING SCENARIOS 1, 2 & 3

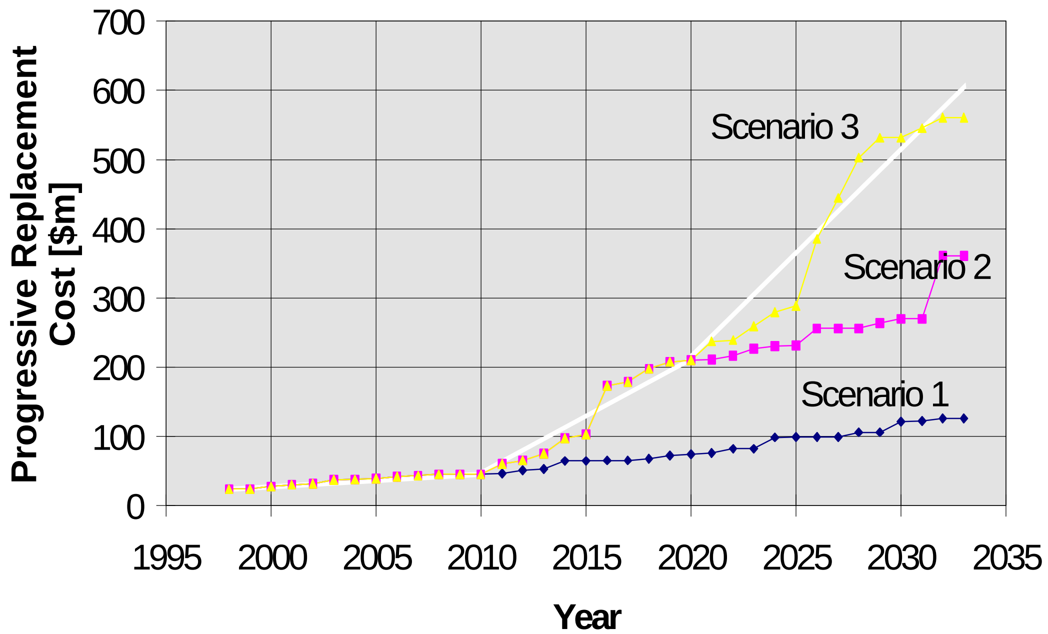


TABLE 4.1 STATE COSTS TO REPLACE BRIDGES UNDER DIFFERENT LOADING SCENARIOS

($million 1996–97 prices)

	Scenario 1				*Scenario 2*				*Scenario 3*			
Corridor	*now*	*1998 to 2005*	*2006 to 2020*	*2021 to 2030*	*now*	*1998 to 2005*	*2006 to 2020*	*2021 to 2030*	*now*	*1998 to 2005*	*2006 to 2020*	*2021 to 2030*
National Highways												
New South Wales	0.2	0	5.2	19.4	0.2	0	31.2	6.3	0.2	0	31.2	94.1
Victoria	6.5	9.0	14.0	4.0	6.5	9.0	25.7	18.0	6.5	9.0	25.7	42.3
Queensland	1.7	1.1	3.8	13.8	1.7	1.1	64.9	21.3	1.7	1.1	64.9	90.7
South Australia	0.1	0.4	9.5	8.8	0.1	0.4	22.2	7.1	0.1	0.4	22.2	70.5
Western Australia	0.5	0.9	1.5	1.3	0.5	0.9	13.2	5.3	0.5	0.9	13.2	11.4
Tasmania	10.6	1.1	0.9	0	10.6	1.1	5.5	1.2	10.6	1.1	5.5	12.0
Northern Territory	4.3	2.5	0	0	4.3	2.5	8.8	0	4.3	2.5	8.8	0.2
Total	*23.9*	*15.0*	*34.9*	*47.3*	*23.9*	*15.0*	*171.5*	*59.2*	*23.9*	*15.0*	*171.5*	*321.2*
Other primary roads												
New South Wales	0	0.4	7.1	4.9	0	0.4	41.8	32.4	0	0.4	41.8	46.5
Victoria	3.2	1.5	4.1	1.5	3.2	1.5	8.3	4.0	3.2	1.5	8.3	13.9
Queensland	0	0	0	0	0	0	0	0	0	0	0	0
Western Australia	2.0	3.2	0.3	1.8	2.0	3.2	3.3	10.7	2.0	3.2	3.3	13.6
Total	*5.2*	*5.1*	*11.5*	*8.2*	*5.2*	*5.1*	*53.4*	*47.1*	*5.2*	*5.1*	*53.4*	*74.0*

TABLE 4.2 AVERAGE ANNUAL EXPENDITURE FOR THE PRIMARY ROAD NETWORK CORRESPONDING TO CHANGES IN LOADING FOR SCENARIO 3

($million 1996/97 prices)

	Initial Expenditure		*Average Annual Expenditure 1998-2010*		*2011-2020*		*2021-2030*	
	$m	*%*	*$m*	*%*	*$m*	*%*	*$m*	*%*
National Highways	23.9	1.6	1.8	0.1	16.5	1.1	26.9	1.8
Other primary roads	5.2	1.4	0.7	0.2	5.0	1.4	9.6	2.6
Total	29.1	1.5	2.5	0.1	21.5	1.1	36.5	1.9

A trend line for scenario 3 has been superimposed on figures 4.4 and 4.8. This is characterised by the initial replacement expenditure followed by steady expenditure rates for each segment of the loading scenario. Note that the slope of the line represents the average annual expenditure which is summarised in table 4.2 for scenario 3.

The initial replacement expenditure is $23.9m for national highways and $29.1m for the total designated network. This represents 1.6 per cent and 1.5 per cent respectively of the inventory. The model predicts an increasing rate of replacement with increasing vehicle loading. The maximum replacement rate is 2.5 per cent per year for the other parts of the primary network under the highest level of loading. Given that the notional design life of a bridge is 50 years it is not an unreasonable expectation to be replacing 2 per cent of the bridge infrastructure each year. At the 45.5 tonne load levels, replacement for strength requirements will be low (replacement rate of 0.1 per cent to 0.2 per cent per year which corresponds to an average life of 500 to 1000 years) and the bridges would need to be replaced because of deterioration issues rather than for strength reasons.

Costs by Corridor

The costs for bridge upgrading under the three scenarios and four cost periods are presented in table 4. 3[A].

Costs for some corridors are relatively higher, reflecting the relative age and condition of bridges in these corridors. The major initial cost occurs in the Hobart-Burnie corridor, where the Bridgewater Bridge over the Derwent River contributed $10.5 million of the present deficiencies. Although strengthened in 1988, this bridge is in relatively poor condition. This case highlights two issues. Firstly, the costs in the model reflected normal bridge costs, but this bridge also carries a railway and incorporates a lift-span, and actual replacement will be in the order of $40 million. Secondly, the model calculated that the bridge needed replacement now, but substantial maintenance expenditure may prolong its life for a few years.

The results for scenario 1, with a constant loading regime, reflect the need to replace older bridges as they reach the end of their service life because of general age and deterioration. By 2030, any pre MS18 bridges would be at least 80 years old.

As noted previously, costs are increased significantly in scenarios 2 and 3 as bridges require replacement with increased loadings.

TABLE 4.3[A] CORRIDOR COSTS TO REPLACE BRIDGES UNDER DIFFERENT LOADING SCENARIOS

($million 1996–97 prices)

	Scenario 1				*Scenario 2*				*Scenario 3*			
Corridor	*now*	*1998 to 2005*	*2006 to 2020*	*2021 to 2030*	*now*	*1998 to 2005*	*2006 to 2020*	*2021 to 2030*	*now*	*1998 to 2005*	*2006 to 2020*	*2021 to 2030*
National Highways												
Sydney-Melbourne	4.3	5.9	10.7	8.5	4.3	5.9	26.2	13.7	4.3	5.9	26.2	56.0
Canberra connections	0	0	0.2	0.8	0	0	1.2	0.2	0	0	1.2	3.7
Sydney-Brisbane (New England Hwy)	0.2	0.1	2.2	8.1	0.2	0.1	17.1	4.2	0.2	0.1	17.1	41.8
Sydney-Adelaide (Sturt Hwy)	0.1	0.2	4.8	5.3	0.1	0.2	12.4	3.8	0.1	0.2	12.4	38.8
Melbourne-Adelaide	1.3	1.9	6.6	4.4	1.3	1.9	14.1	6.4	1.3	1.9	14.1	37.3
Melbourne-Brisbane (Newell Hwy)	1.2	1.4	3.7	6.6	1.2	1.4	17.4	6.2	1.2	1.4	17.4	37.6
Brisbane-Cairns	1.2	0.8	2.8	10.0	1.2	0.8	47.3	15.5	1.2	0.8	47.3	66.1
Adelaide-Perth	0.1	0.2	0.8	0.7	0.1	0.2	3.2	1.2	0.1	0.2	3.2	5.6
Adelaide-Darwin	2.8	1.7	0.6	0.6	2.8	1.7	7.3	0.5	2.8	1.7	7.3	4.8
Perth-Darwin	1.2	1.2	1.3	1.1	1.2	1.2	12.8	4.5	1.2	1.2	12.8	9.7
Brisbane-Darwin	0.9	0.5	0.3	1.2	0.9	0.5	7.0	1.8	0.9	0.5	7.0	7.7
Hobart-Burnie	10.6	1.1	0.9	0	10.6	1.1	5.5	1.2	10.6	1.1	5.5	12.1
Total	*23.9*	*15.0*	*34.9*	*47.3*	*23.9*	*15.0*	*171.5*	*59.2*	*23.9*	*15.0*	*171.5*	*321.2*
Other primary roads												
Sydney-Melbourne (Princes Hwy)	1.5	0.7	4.1	2.3	1.5	0.7	17.7	12.4	1.5	0.7	17.7	21.9
Sydney-Brisbane (Pacific Hwy)	0	0	3	2.3	0	0	19.8	15.0	0	0	19.8	21.6
Sydney-Adelaide (via Broken Hill)	0	0.4	2	1.0	0	0.4	8.3	7.0	0	0.4	8.3	9.7
Melbourne-Mt Gambier	0.9	0.5	1.1	0.4	0.9	0.5	2.2	1.0	0.9	0.5	2.2	3.7
Melbourne-Mildura	0.8	0.3	1.0	0.4	0.8	0.3	2.2	1.0	0.8	0.3	2.2	3.5
Perth-Port Hedland (via Geraldton)	0.8	1.3	0.1	1.8	0.8	1.3	2.1	0.2	0.8	1.3	2.1	0.6
Perth-Coolgardie (via Albany)	1.2	1.9	0.2	0	1.2	1.9	1.1	10.5	1.2	1.9	1.1	13.0
Total	*5.2*	*5.1*	*11.5*	*8.2*	*5.2*	*5.1*	*53.4*	*47.1*	*5.2*	*5.1*	*53.4*	*74.0*

Results of Other Analyses

Costs relative to superstructure material show that steel bridges have costs disproportionate to their relative population. As noted in Section 2.2.1, steel bridges comprise 18 per cent of the bridge stock, but replacement of steel bridges accounted for 38.6 per cent of the total costs. The lower replacement costs for prestressed concrete bridges reflected their relative recent construction and therefore higher strength. Overall results are shown in table 4.3[B].

TABLE 4.3[B] RELATIONSHIP BETWEEN SUPERSTRUCTURE MATERIAL AND REPLACEMENT COST

Superstructure materials	*% of bridges*	*% of costs*
Steel	18	38.6
Timber	3	5.4
Reinforced concrete	18	26.8
Prestressed concrete	61	29.2

CONCLUDING COMMENTS

The adequacy of Australian bridges on a primary road network under three different loading scenarios has been evaluated in this project. A bridge evaluation model refined for this project was used to estimate costs to replace bridges considered deficient either presently or under the different loading scenarios.

Costs could be more accurately defined if:

- the model could be calibrated against work presently underway by road authorities following the Mass Limits Review;
- more accurate bridge inventory information was available;
- load testing on representative bridges had been undertaken to identify any reserve strength which might be available; and
- information was available from which the model could be further refined, such as the effects of traffic volumes.

Nevertheless, the costs are robust within these constraints. The replacement costs represent a small proportion of the value of the bridges on the network studied.

The bridge evaluation model used in this project was designed to identify and cost broad trends associated with increasing loads on bridges. The model is based on sound engineering principles but, by necessity, involves many approximations that are applied across the network. Consequently it is a macro planning tool and cannot replace examination of individual bridges.

New technologies are continually being fostered which will improve the reliability of bridge evaluation technologies. Improved analytical procedures, models that incorporate site specific loading information and field testing activities such as proof load testing, behavioural testing, and bridge health monitoring will all assist in ensuring the maximum productivity is achieved from the bridge infrastructure in a manner that is consistent with public safety.

Some of the key observations made in this study of a primary road network defined in table 1 are summarised below:

No. of bridges	1,976 on national highways (6.5 per cent of the estimated number of bridges in the national inventory) and a total of 2,448 on the designated primary network	
Replacement value:	$1,500 million for all national highways ($1,900 million for the primary network)	
Condition:	Generally good	
Superstructure material:	79 per cent concrete, 18 per cent steel, 3 per cent timber	
Age:	>50 per cent designed to a standard less than Australia's current bridge design standard	
Heavy vehicle loads:	Steady trend towards heavier vehicles for most of this century	
Loading scenarios:	Articulated vehicles with gross mass between 44.5 tonne and 58 tonne were considered	
Analysis period:	1998 to 2030	
Bridge evaluation model:	Limit State model developed from the Mass Limits Review model	
Immediate expenditure:	National highways	$24 million (1.6 per cent of replacement value)
	Other highways	$5 million (1.4 per cent of replacement value)
Maximum expenditure to 2030:	National highways	$532 million
	Other highways	$138 million
	Total	$670 million
Rate of expenditure per year:	At current load levels	$1.8 million (0.1 per cent)

	— national highways $2.5 million (0.1 per cent) — primary network
At future load levels	$26.9 million (1.8 per cent) — national highways $36.5 million (1.9 per cent) — primary network

This study has been based on approximately 8 per cent of Australia’s bridges. This is the best maintained and strongest group of bridges in the network. The bridges on the secondary and local roads that feed the primary network are generally older and weaker and thus would show much higher replacement rates if the above model was applied across the entire bridge infrastructure.

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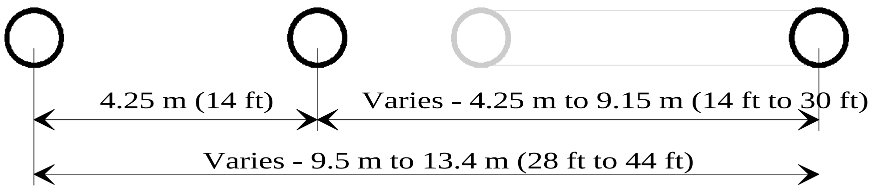
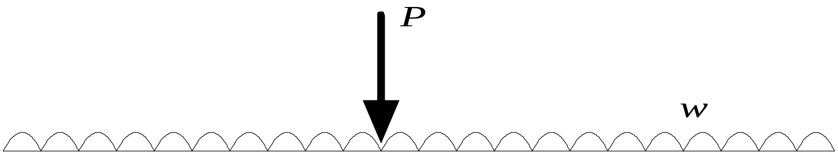
ATTACHMENT A MS18 AND T44 BRIDGE DESIGN LOADS

FIGURE A.1 THE USA AND AUSTRALIAN H AND HS SERIES OF BRIDGE DESIGN LIVE LOADS AND THEIR M AND MS METRIC EQUIVALENTS.

HS20, MS18	8,000 lb, 36kN	32,000 lb, 144kN	32,000 lb, 144kN
HS15, MS13.5	6,000 lb, 27 kN	24,000 lb, 108 kN	24,000 lb, 108 kN
H20, M18	8,000 lb, 36 kN	32,000 lb, 144 kN	32,000 lb, 144 kN
H15, M13.5	6,000 lb, 27 kN	24,000 lb, 108 kN	zero
H10, M9	4,000 lb, 18 kN	16,000 lb, 72 kN	zero



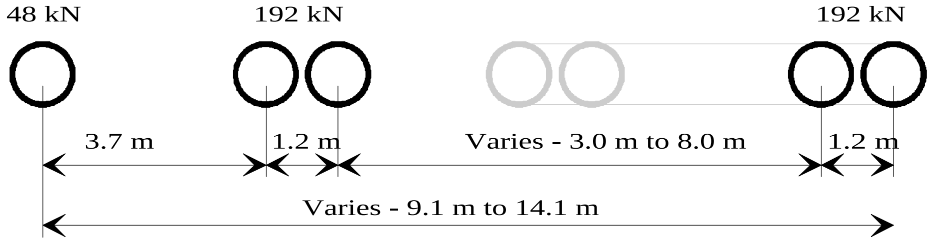
(a) Truck loadings



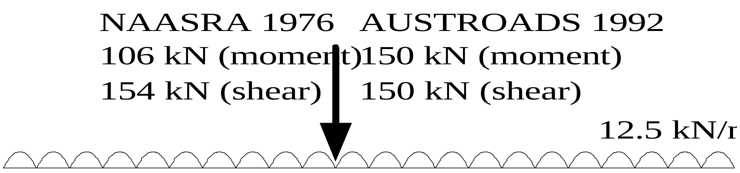
Design loading	P moment (shear) [lb]	P moment (shear) [kN]	w [lb/ft]	w [kN/m]
H20, HS20, M18 & MS18	18 000 (26 000)	80 (116)	640	9.4
H15, HS15, M13.5 & MS13.5	13 500 (19 500)	60 (87)	480	7.0
H10, M9	9 000 (13 000)	40 (58)	320	4.7

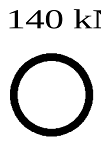
(b) Lane loadings

FIGURE A.2 THE AUSTRALIAN T44 LOADING. (1976 TO PRESENT)



(a) T44 truck loading





(b) T44 lane loading

(c) A14 standard vehicle loading

ATTACHMENT B BRIDGE REPLACEMENT COSTS

($ per square metre of deck area)

	Configuration				
Span (m)	*Steel-Beam-SS*	*Steel-Beam-Cont*	*Steel-Truss*	*Timber-Beam-SS*	*Timber-Truss/arch*
<=5	1291	1237	1237	1184	1506
5-7	1291	1237	1237	1184	1506
7-9	1345	1237	1237	1237	1506
9-11	1345	1291	1291	1291	1506
11-13	1399	1291	1291	1345	1506
13-15	1399	1345	1345	1399	1506
15-20	1453	1345	1345	1453	1506
20-30	1506	1399	1399	1506	1506
>30	1937	1829	1829	1829	1829
Unknown	-	-	-	-	-

	Configuration					
Span (m)	*Rconc-Slab-SS*	*Rconc-Slab-Cont*	*Rconc-Beam-SS*	*Rconc-Beam-Cont*	*Rconc-Box-SS*	*Rconc-Box-Cont*
<=5	1076	1022	1076	1022	1184	1130
5-7	1076	1022	1076	1022	1184	1076
7-9	1130	1076	1130	1076	1237	1184
9-11	1130	1076	1130	1076	1237	1184
11-13	1184	1076	1184	1130	1291	1184
13-15	1184	1184	1184	1130	1291	1237
15-20	1184	1237	1237	1237	1234	1291
20-30	1291	1237	1291	1506	1399	1345
>30	1614	1506	1614	1506	1722	1614
Unknown	-	-	-	-	-	-

	Configuration						
Span (m)	*Pconc-Slab-SS*	*Pconc-Slab-Cont*	*Pconc-Beam-SS*	*Pconc-Beam-Cont*	*Pconc-Box-SS*	*Pconc-Box-Cont*	*Other*
<=5	1076	1022	1076	1022	1184	1076	-
5-7	1076	1022	1076	1022	1184	1076	-
7-9	1130	1076	1130	1076	1237	1130	-
9-11	1130	1076	1130	1076	1237	1130	-
11-13	1184	1130	1184	1130	1291	1184	-
13-15	1184	1130	1184	1130	1291	1184	-
15-20	1237	1237	1237	1184	1345	1291	-
20-30	1291	1506	1291	1237	1399	1345	-
>30	1614	1506	1614	1506	1722	1668	-
Unknown	-	-	-	-	-	-	-

APPENDIX V COMMENTS BY STATE AND TERRITORY ROAD AUTHORITIES

States and territories were invited by the BTCE to comment on the BTCE's methodology and results. This appendix contains all responses received at the time of printing. Responses have not been edited.

These comments are available from the BTCE upon request.

APPENDIX VI BTCE RESPONSE TO COMMENTS FROM STATES AND TERRITORIES IN APPENDIX V

The BTCE again acknowledges with gratitude the cooperation of the various jurisdictions in providing data and comment in the modelling exercise undertaken to provide input to the Committee of Inquiry into Federal Road Funding.

The draft provided to the States and Territories on 26 September did not include final results for some jurisdictions because not all the necessary data were available to the BTCE at the time. While this was unavoidable, it may have disadvantaged those states in providing considered comment to the BTCE.

Rather than addressing all the points made by individual jurisdictions, only a number of the more substantive issues raised have been addressed below under generic headings. Factual errors made by some jurisdictions in their comments have been ignored in the interests of maintaining discussion on concrete issues.

COST ESTIMATES USED BY THE BTCE

Some jurisdictions considered BTCE estimates of unit and total costs for areas such as maintenance to be too low. Others held the opposite view. Differences were also apparent on the issue of desirable frequency of resealing of road pavement, and hence the figure used in the BTCE model.

These differences highlight different conditions due to Australian geography, as well as differences in maintenance practices by the various road authorities. The BTCE considers that the use of averaged cost and other data is not desirable because it cannot provide accurate estimates of overall expenditure needs, and may disadvantage some jurisdictions (while advantaging others). If resources and data were to become available, this aspect of the modelling could easily be rectified.

STRATEGIC NATURE OF BTCE MODEL

A related issue is the ‘strategic’ nature of the output. The BTCE agrees that its output cannot provide a guide to specific projects. Indeed, it is not intended to do so. Its purpose is to identify sections of road that warrant more detailed cost-benefit analysis by individual road authorities which have local expertise. The BTCE modelling also provides indicative figures for road expenditure required in the future to assist in budgetary planning.

ROUGHNESS INTERVENTION LEVELS

Following advice from ARRB Transport Research Ltd., a maximum roughness constraint of 160 NRM was imposed in the model. However, most intervention levels derived by the BTCE model are well below this figure.

FLOODING, TOWN BYPASSES, BRIDGES AND ROADTRAINS

The BTCE acknowledges fully in several parts of its study that further work is required on flood mitigation works, town bypasses, bridge needs if mass limits are increased, and roadtrain requirements. Apart from resource issues in terms of BTCE capability, however, it is also necessary to bear in mind that credible estimates in these areas would require provision by the jurisdictions of highly detailed data.

Rigorous cost-benefit analysis would be required before any estimates were made and published by the BTCE. In some instances, preliminary work by the BTCE suggests that estimated expenditure needs may not be significant, particularly when compared with other modelling and data uncertainties.

FORECASTS OF ROAD USAGE

A number of jurisdictions have commented on the simplicity of using an assumption that freight traffic will grow by 3 per cent per annum. The BTCE endorses this position.

However, cost-benefit modelling of road infrastructure requires forecasts of traffic growth for individual sections of each road. While most jurisdictions are able to provide global estimates of freight growth (presumably based on forecasts of economic growth in the state or territory), the BTCE did not have available to it the more detailed figures required to carry out its analysis on a nationally consistent basis.

ROADS ANALYSED

A meeting of State and Territory officials with the BTCE in Canberra on 19 August agreed that the BTCE should analyse roads identified in 1996 as being of national importance by a working party (Infrastructure and Policy Planning, IAPP) established under the aegis of the Australian Transport Council. However, the BTCE was not able to obtain from the IAPP Secretariat a list of the roads that its members had identified, and did not have the time or resources to draw up a list itself from a map supplied by the IAPP Secretariat.

The BTCE itself makes no judgement on which non-NHS roads are of national significance.

CONCLUSION

The BTCE is committed to transparency in its research. It has therefore acknowledged above and elsewhere a number of the qualifications identified by the States and Territories. We again stress that the strategic character of the modelling means that figures for individual sections of road should be regarded as indicative, not conclusive.

1 October 1997

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