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Information sheet

Australian Government
Department of Infrastructure and Regional Development
Bureau of Infrastructure, Transport and Regional Economics

Traffic and congestion cost trends for Australian capital cities

At a glance

This Bureau of Infrastructure, Transport and Regional Economics (BITRE) Information Sheet updates the results of a previous Bureau study (BTRE 2007, Working paper 71) identifying long-term trends in urban traffic growth and estimating the consequent impacts of that traffic growth on road network congestion levels within the Australian capital cities. Such studies attempt a suitable quantification of the aggregate social costs arising from those traffic congestion levels. Like Working paper 71 (BTRE 2007), this study presents order of magnitude estimates for the current (hypothetically avoidable) social costs of congestion, and describes possible base case, or 'business-as-usual' (BAU), projections of these congestion costs for Australian metropolitan road traffic trends.

- Total passenger travel in Australian cities has grown almost ten-fold over the last 70 years, with private road vehicles currently accounting for 87 per cent of the aggregate urban passenger task.
- Under currently expected patterns of metropolitan population growth, an overall trend of relatively linear increases in aggregate urban traffic is likely over the next decade and a half, with total vehicle-kilometres travelled (VKT) forecast to increase around 2 per cent per annum out to 2030 (roughly similar to the average historical trend experienced over the last three to four decades).
- BITRE estimates of the 'avoidable' social costs of congestion (where the benefits to road users of some travel in congested conditions are less than the costs imposed on other road users and the wider community) for the 8 Australian capitals (using an aggregate modelling approach) total approximately $16.5 billion for the 2015 financial year, having grown from about $12.8 billion for the 2010 financial year[1].
- This 2015 metropolitan total is comprised of approximately $6 billion in private time costs, $8 billion in business time costs, $1.5 billion in extra vehicle operating costs and $1 billion in extra air pollution costs.
- Under scenarios of future urban road provision roughly continuing at average historical levels, expected traffic increases would typically lead to average delays on metropolitan road networks continuing to increase at a fairly comparable rate to VKT (around 2 per cent per annum out to 2030; also roughly similar to the historical average trend).
- These traffic delay increases have BITRE base case projections of the avoidable social costs of metropolitan congestion rising to around $30 billion by 2030—with the various baseline modelling scenarios conducted giving aggregate 2030 results of between $27.7 and $37.3 billion, depending upon the chosen input assumptions.
- The upper value of this plausible range for BAU congestion cost increases (reaching $37.3 billion, totalled across all 8 Australian capital cities, by 2030) is composed of: estimates for Sydney rising from current (2015) levels of about $6.1 billion to approximately $12.6 billion by 2030; Melbourne values rising from around $4.6 billion (2015) to $10.2 billion (2030); Brisbane rising from $2.3 to $5.9 billion (2015–2030); Perth rising from $2 to $5.7 billion; Adelaide rising from $1.1 to $2.3 billion; Canberra rising from $0.2 to $0.4 billion; Hobart rising from $0.09 to $0.16 billion; and Darwin rising from $0.03 to $0.07 billion.

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[1] Real cost estimates are given in terms of 2010 Australian dollars throughout this Information Sheet since the most complete coverage of road user unit costs available at the time of the analysis (Austroads 2012) provided unit values in A$2010. This also happens to facilitate comparisons with several other relevant studies (such as Infrastructure Australia 2015, which provides estimates in terms of A$2011).

- These upper-range BAU costs represent a 2030 metropolitan average of about 19 cents per kilometre travelled (with the highest individual city value, for Sydney, at about 23 c/km).
- The estimates of future avoidable costs of congestion are sensitive to expected population projections and the assumed capacity added to urban transport networks over the next decade and a half.
- Technology options, such as the rapid deployment of semi or fully autonomous vehicles, have the potential to significantly reduce projected congestion costs.

Background

The BITRE study reported here has analysed a number of the underlying factors contributing to the growth in traffic volumes and congestion intensity across the metropolitan road networks, and the consequent impacts on traffic delays, travel reliability and congestion's spread in both area and duration. Essentially, the study's results provide some rough indications of the possible opportunity costs of growing time losses while travelling within our cities (through road traffic delays), and of other social and economic consequences of increasing urban traffic congestion.

The study estimates the level of average trip delay (and other social impacts) of current road congestion levels and forecasts how these will likely vary over time, depending on future movements in population levels, travel patterns, infrastructure provision and traffic management. A consistent aggregate methodology for estimating average avoidable social costs of congestion was developed for Working Paper 71 (BTRE 2007), as part of the Urban Congestion Review then commissioned by the Council of Australian Governments (COAG), and has been applied to this study. The development of this aggregate costing methodology relied on the results of previous detailed Bureau work using network models to estimate congestion impacts for Australian cities (such as described in Report 92, *Traffic Congestion and Road User Charges in Australian Capital Cities*, BTCE 1996). This latest work updates and revises previous congestion cost projections published by the Bureau – such as in Information Sheet 14 (BTE 1999) and Working Paper 71 (BTRE 2007).

It is important to stress that the approach used in this study (to estimate congestion impacts) is an *aggregate* modelling one. That is, like Working Paper 71, this study does not make direct use of detailed network models (which attempt to simulate the traffic flows on a city's road system in considerable detail, typically on a link by link basis); but aims to provide broad estimates of the scale of a city's congestion situation using aggregate indicators of a city's overall average traffic conditions.

The main advantage of such an aggregate approach relates to the ability to generate congestion cost estimates and scenario projections with much lighter computational and information resources than required by data intensive network or microsimulation models. Its main disadvantage relates to the highly approximate nature of such aggregate costings—with congestion being such a non-linear, inhomogeneous and stochastic process, that highly accurate, location-specific assessments of impacts can typically only be accomplished using intricate network models. Thus, the aggregate national congestion cost estimates derived here cannot replace the results of detailed traffic simulation modelling conducted at a jurisdictional level; but are intended as a complement to their more in-depth findings. The results presented in this report are therefore provided as 'order of magnitude' evaluations, to help with overall assessments of the aggregate costs of urban transport externalities for Australia and of likely future trends.

Due to the complexity of the congestion problem, and the difficulty in collating the requisite information to model every facet of road system performance, the modelling has had to include a variety of simplifying assumptions and approximations. Some of the major areas of modelling uncertainty surround issues of:

- The value of time—i.e. what exact worth or dollar value do different parts of the community place on their travel time. Not only is the level of such valuations (in dollars per hours lost) debateable, but there are also questions about how much the value changes with the travel circumstances (for example, whether people value reductions in waiting time more highly than improvements in trip time reliability; whether delays during various trip purposes or on various vehicle types are felt more strongly than during other travel; or whether the length of the delay and/or the trip alters the unit $/hour value). Basically, the main uncertainties here concern: choosing the most suitable dollar value for an hour of time lost to road congestion delay (either for business road use or for private travel); whether this unit rate also applies to small time losses; and the question of what proportions of urban trips are not highly time-sensitive.

- Future travel patterns (especially concerning whether per capita car use will most likely rise or fall over the medium to longer term) and possible structural changes to the transport system (such as could be caused by wider use of ride-sharing services or the deployment of autonomous road vehicles).
- Demographic effects—which can influence not only total travel demand levels but also elements of trip distribution and modal choice.
- The extent of possible peak-spreading of traffic volumes in the future, and the interactions of key network bottlenecks on travel choices of route and time of day (especially considering some major urban thoroughfares are already operating at close to full capacity during peak periods).
- Supply-side factors for urban road networks (such as likely trends in future network capacity expansion—including both further road construction and other transport infrastructure development—or medium to longer term plans for urban development, provision of transport services and travel demand management).
- Suitable comparison speed values. Even the determination of actual city-wide average traffic speeds is relatively inexact (often involving limited data from 'floating-car' surveys), though increasingly enhanced by the growing availability of real-time or crowd-sourced information from traffic authority road monitoring and in-car navigation/GPS systems. Yet when calculating how much delay a particular congestion occurrence has caused, the recorded average traffic speeds have to be compared with a less-congested benchmark speed—such as the *free-flow* speed (i.e. how fast a car is able to travel at, on a particular route, if no other vehicles are present) or *optimal* speed levels (i.e. the resulting speeds, for each road link, from traffic levels[2] that provide the most advantageous combination of traffic throughput and aggregate travel cost minimisation for all motorists). For actual road systems, the definition and estimation of such optimally-congested speeds is typically complex and fairly approximate.
- The possible flow-on effects of urban congestion. The costs presented in this report primarily relate to estimated valuations of excess travel time for road users (with some allowance for the inefficiency of vehicle engine operation under stop-start conditions, leading to higher rates of fuel consumption and pollutant emissions). However, there is a series of other possible consequences of urban congestion—ranging from business location impacts (due to restrictions on their operations from congestion delays), to widespread psychological stress and irritation from coping with heavy traffic levels, to reducing the efficiency of public transit and the attractiveness of transit or non-motorised transport options. Quantification of costs for such wider effects is beyond the scope of this particular study[3].

However, even with all such caveats, the aggregate projections modelling suggests an appreciable increase in the social costs of congestion should be anticipated over the next 15 years under business-as-usual trends; that is, unless suitable traffic management measures are enacted during the projection period to deal with increasing congestion incidence and intensity.

Trends in urban traffic

Together with gradual expansions to capital cities' extent, population and road networks, total metropolitan travel in Australia has increased immensely over time—see Figure 1 for estimates[4] of the annual passenger task across the 8 State and Territory capital cities, displaying growth in passenger-kilometres (pkm) from a level of only about 3.5 billion in 1900 to almost 199 billion by 2014.

Through the latter stages of the 1800s, walking still accounted for the majority of urban trips in Australian cities (with most remaining passenger travel being performed by horse). However, by 1900 this had started to change quite dramatically—largely due to surging income levels, immigration and industrial development. With such stimuli to urban growth, and city areas now expanding at substantial rates, the development of effective transportation systems became a prominent part of furthering the urbanisation process. By the time of the First World War, urban public transport (UPT) services (in particular, trains and trams) had become the dominant form of passenger movement within our larger cities (see Figure 2).

During the 1920s and 1930s, private motor vehicle use started to grow rapidly in popularity, with its sharply rising trend in modal share only temporarily interrupted by the Great Depression and the Second World

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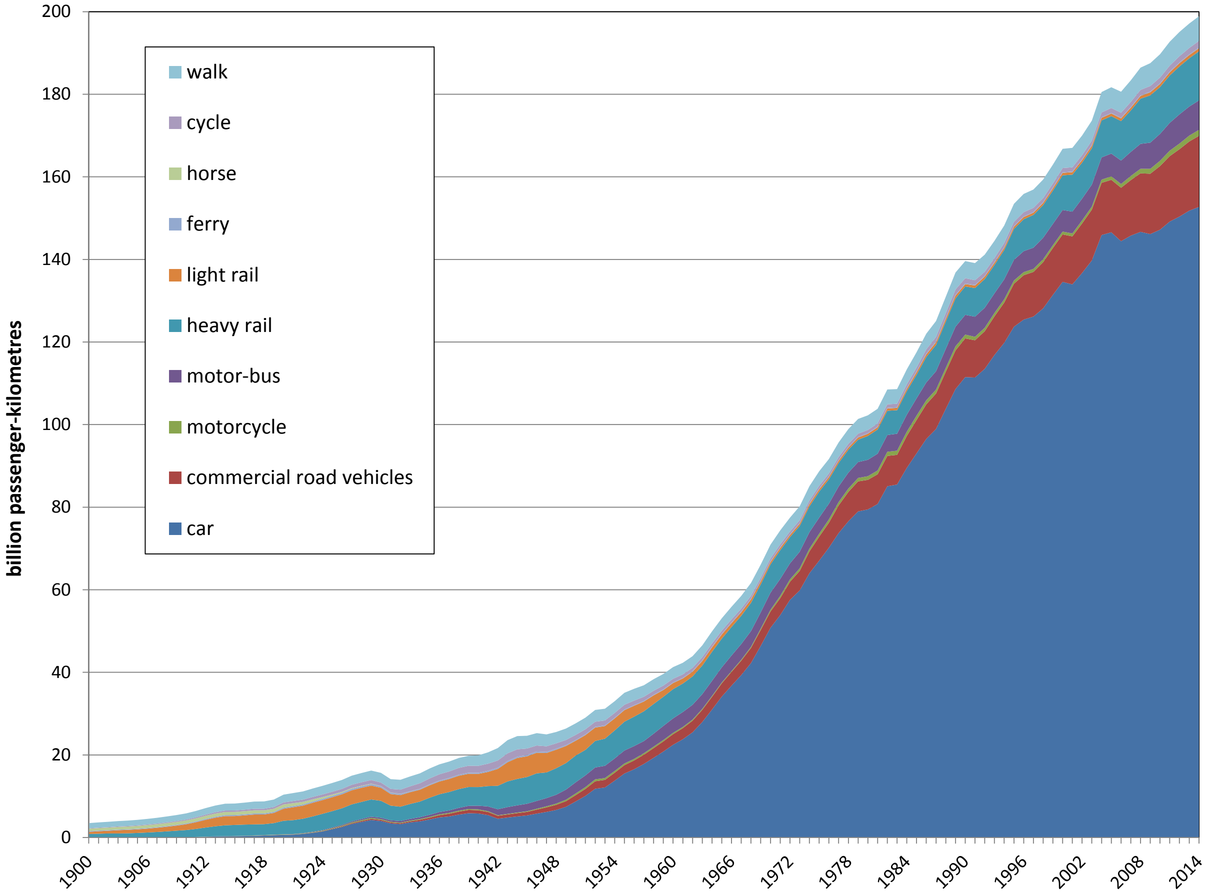
[2] That is, *optimal* traffic levels are those beyond which the full social costs of any further travel, entering an already congested traffic stream, would outweigh the social benefits of that extra travel.

[3] Note that Working Paper 71 (BTRE 2007) included some discussion around these issues of wider congestion effects.

[4] BITRE estimates provided in this Information Sheet generally relate to averages or totals over financial years—i.e. years ending June 30.

War (Figure 2). Motorised passenger travel within the capital cities has grown almost ten-fold since 1945, with most of that post-war growth coming from cars and other road vehicles (such as motorcycles and light commercial vehicles used for non-freight purposes), leading to the existing dominance of private motor vehicle travel (with modal share eventually accounting for almost 90 per cent of the urban passenger task). At the end of the Second World War, urban public transport still held the principal share of total passenger movement within the Australian capital cities. However, as post-war car travel grew strongly (especially following the cessation of war-induced petrol rationing by the end of the 1940s), the aggregate UPT mode share gradually declined, reaching around 10 per cent of total pkm (roughly equivalent to current levels) by about 1980.

Figure 1: Total metropolitan passenger task for Australia, across all modes, 1900–2014



Notes: Includes total annual passenger travel (for years ending 30 June) within the 8 State and Territory capital cities, across all available transport modes (including rough estimates of non-motorised travel).

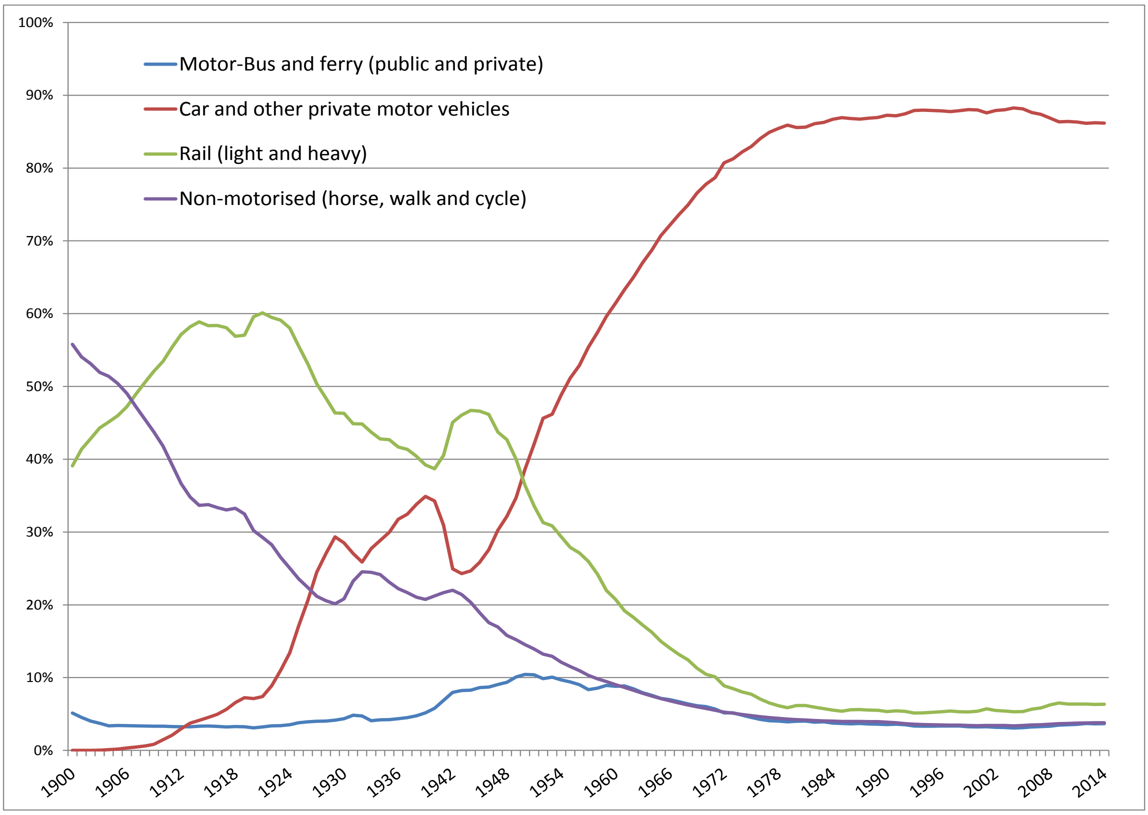
Values for 'motor-bus' include all motor vehicles with 10 or more seats (i.e. charter/hire buses and other private buses/minibuses, as well as UPT route buses). Values for 'commercial road vehicles' relate to non-freight use of such vehicles (primarily due to travel by light commercial vehicles such as utilities and panel vans).

Sources: Cosgrove (2011), Cosgrove & Gargett (2007), BTRE (2007), BITRE (2014a, 2014b) and BITRE estimates.

Despite some recent increases in UPT modal share, metropolitan passenger travel remains dominated by private road vehicles (see Figure 2); with such vehicles (cars, motorcycles and the non-freight use of commercial road vehicles) accounting for approximately 171.4 billion pkm across the 8 capitals in 2014 (about 86.2 per cent of total travel). Adding in bus passengers takes the total 2014 metropolitan road task to approximately 178.5 billion pkm (accounting for 90 per cent of all capital city passenger travel).

During most of the first half of the 20th century, the typical amount of time spent on day-to-day travel by a capital city resident was a little over an hour each day (averaging approximately 64 minutes/day per capita). Yet with the speed advantages then offered by car use (accompanied by considerable improvement and spread of city road systems and an even faster expansion in car ownership), the post-war period saw this average daily travel time decline throughout the late 1940s and the 1950s, eventually falling almost as low as 50 minutes/day per capita by the mid-1960s. However, as the major cities were by then growing strongly outwards, often leading to longer and longer average trip lengths, and the mounting popularity of car travel started contributing to busier and busier roads, the daily travel average climbed back over the hour mark during the 1970s. Daily time spent travelling kept climbing throughout most of the rest of the century, and the existing combination of network congestion and increased trip distances have contributed to current levels for urban travel time (which have averaged around 85 minutes/day per capita over last decade) being significantly above the long-term historical norm.

Figure 2: Modal shares for various metropolitan travel choices, 1900–2014



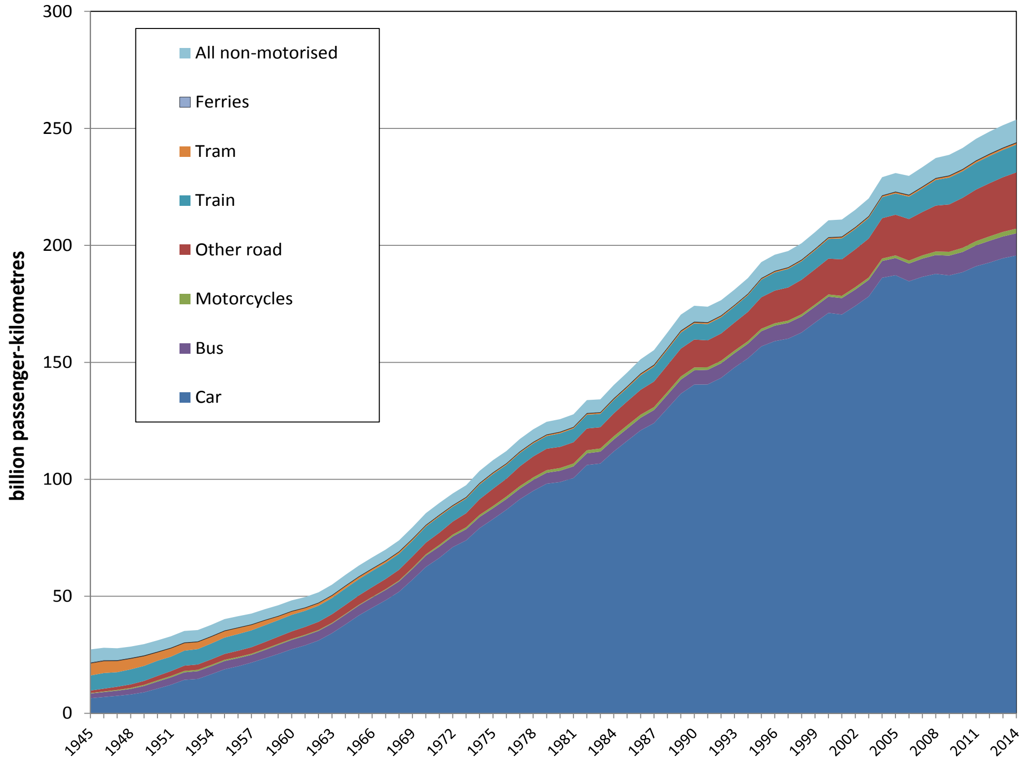
Notes: Share of total metropolitan passenger-kilometres (for years ending 30 June, within the State and Territory capital cities, including rough estimates of the contribution from non-motorised travel): with values for 'light rail' including steam, cable and electric powered trams (as well as the Sydney Monorail); values for 'horse' include all horse use for urban passenger transport (both saddle horses and harness horses—for all horse-drawn carriage use, horse trams and horse buses); values for 'motor-bus' include all motor vehicles with 10 or more seats (i.e. charter/hire buses and other private use, as well as UPT-route buses, and include trolley-buses).

Sources: Cosgrove (2011), Cosgrove & Gargett (2007), BITRE (2014a, 2014b), BTRE (2007) and BITRE estimates.

Note that the current methodology addresses estimated traffic congestion costs purely for metropolitan areas—i.e. for each Greater Capital City Statistical Area (GCCSA) of the eight State/Territory capitals, as defined by the Australian Bureau of Statistics (ABS)—with the worst congestion incidence typically concentrated in the major state centres. The estimates would be higher to some extent if all regional urban areas (such as Newcastle, Wollongong, Geelong or the non-Brisbane parts of South-East Queensland) were also included. For example, Figure 3 provides estimates of the passenger task trends for aggregate Australian urban travel, with annual volumes being noticeably higher than the respective *metropolitan* pkm totals plotted in Figure 1.

The modal share patterns for the total urban passenger task are given in Figure 4, for both the historical trends and the base case scenario projections. Under business-as-usual trends, some mode share could shift further from private vehicles to UPT over time. However, even though UPT always accounts for an important component of aggregate city pkm (and urban rail typically a major share of radial movements into the Central Business Districts of the larger cities), the bulk of urban passenger travel will still be performed on the road system, largely by private motor vehicles (as displayed in Figure 4), for the foreseeable future. Also, practically all of intra-urban freight (with a national 2015 task level of about 59 billion tonne-kilometres, growing in the order of 3 per cent per annum) is moved by road. The expected increases in Australian capital city traffic volumes (such as implied by ABS mid-range population projections) are thus liable to lead to increasing levels of aggregate social costs due to road network delays, at least over the medium term.

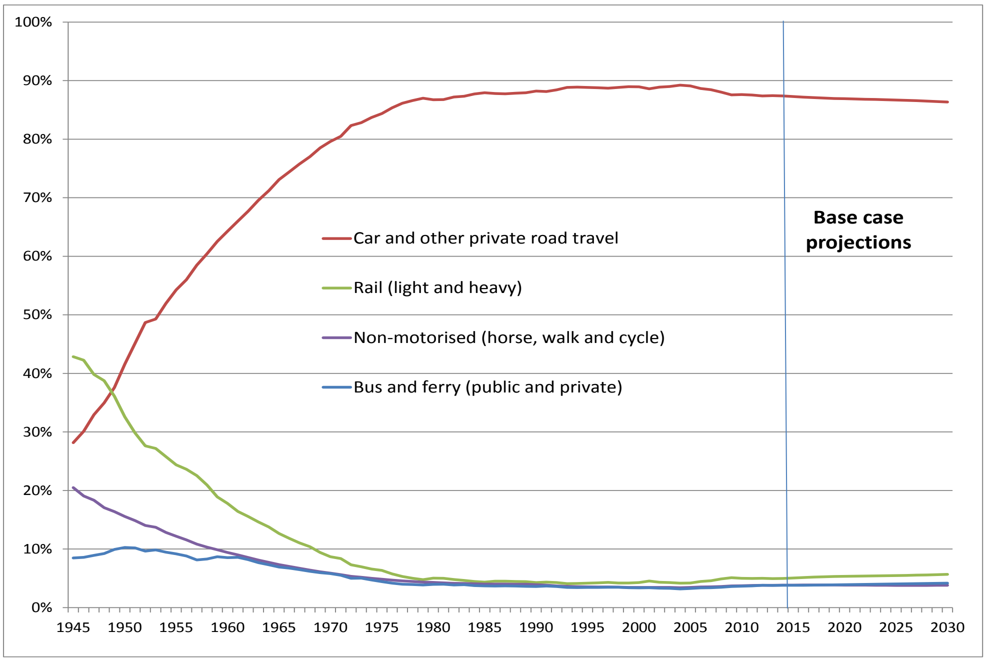
Figure 3: Total urban passenger task for Australia, across all modes, 1945–2014



Notes: Includes total annual passenger travel (for years ending 30 June), across all available transport modes (including rough quantification of non-motorised travel), for estimated pkm within Australian urban areas—including Greater Capital City Statistical Areas (GCCSA) and those Significant Urban Areas (SUAs, regional cities) with a population of 40,000 or more (using ABS population geographies)—based on a rough scaling of aggregate task estimates for the capital cities. Values for 'Bus' include all motor vehicles with 10 or more seats (i.e. charter/hire buses and other private buses/minibuses, as well as UPT route buses). Values for 'Other road' relate primarily to non-freight use of light commercial vehicles.

Sources: Cosgrove (2011), Cosgrove & Gargett (2007), BTRE (2007), BITRE (2014a, 2014b) and BITRE estimates.

Figure 4: Baseline modal share projections for total urban travel to 2030



Note: Share of total urban pkm (for years ending 30 June, within Australian urban areas with a population of 40,000 or more), including rough estimates of the contribution from non-motorised travel.

Sources: Cosgrove (2011), Cosgrove & Gargett (2007), BITRE (2010, 2014a, 2014b), BTRE (2007) and BITRE estimates.

Projections of capital city vehicle use levels

A basic structural relationship underlying many BITRE projections of historical passenger task trends into the future (e.g. see BITRE 2014c, BITRE 2012a and BITRE 2012b) concerns the connection between rising income levels and per capita travel, and implied eventual 'saturation' levels (i.e. stages beyond which average per capita annual travel becomes practically constant from year to year). Historically, as income levels (and motor vehicle affordability) tended to increase over time, average travel per person also tended to increase. However, there are limits to how far this growth can continue and eventually people are spending as much time on daily travel as they are willing to commit; and are loath to spend any more of their limited time budgets on yet more travel, even if incomes do happen to rise further.

For daily transport in Australia, the (per capita) passenger-kilometre versus average income trend-curve started flattening out during the 1990s; see Figure 5—reproducing Figure 6 of BITRE (2014b) Information Sheet 60—which plots around seven decades of per capita task estimates for Australian metropolitan passenger travel against the average income level at which that aggregate transport activity was undertaken. Curve-fitting models imply that saturation in per capita day-to-day urban travel could be virtually achieved in Australia by around 2020. Thereafter, future increases in Australian urban passenger travel are likely to be more dependent on the rate of population increase and less dependent on increases in general prosperity levels—and growth in per capita travel (and subsequent intensity of urban car use) is thus likely to be lower in the future than for the long-term historical trend.

Despite average daily travel behaviour having generally followed such identified saturating trends for many years, making medium-term projections of future travel levels may not, however, necessarily be clear-cut. Significant structural changes to urban transport systems (or large enough shifts in underlying price and income levels) are capable of displacing such latent trends. For example, after aggregate travel per person peaked somewhat above the long-term trend, during 2004–2005 (for the impact on car use, see Figure 6), rising fuel prices contributed to falls over subsequent years. Then the economic slowdown following the Global Financial Crisis (GFC, in late calendar 2008) caused average travel volumes to shift further downwards; such that per capita values for recent years have been well below the previous trend-line.

Going forward, the main possibilities over the next few decades essentially cover a sizeable range, from relatively high to low travel volumes, of:

1) average urban pkm per capita gradually returning to levels of a pre-GFC trend-line, as any residual socio-economic effects on travel behaviour fade over time (as in the Figure 6 'High VKT' scenario);
2) per capita pkm continuing over the medium to longer term at around current levels, perhaps with a slight rebound before stabilisation, with the post-GFC slowdown period having changed Australian social composition enough to effectively establish a new (lower) saturation level (as in the 'Median' scenario displayed in Figure 6, which forms the basis for the 'upper baseline' congestion projections to follow[5]); or
3) the downwards movement of recent years persists, and urban pkm per capita (especially for car travel) continues falling for some time yet, before reaching a new (even lower) equilibrium level (as per the 'Low VKT' scenario for car use in Figure 6).

For the main analysis of future vehicle use within the congestion cost projections, BITRE has chosen the middle possibility (option 2 above) for the baseline projection scenarios. Note that, for future Australian car use, some of the literature makes an argument for behaviour akin to option 3 being as likely, with certain researchers considering various social developments—such as younger people tending to delay (or even refrain from) getting a driver's licence; replacing some travel with the communication options allowed by modern information technologies; and commonly preferring modes, such as public transit, more compatible with mobile IT/social media use than vehicle driving—as capable of decreasing overall urban car use[6]. The high VKT possibility (option 1) is perhaps now looking relatively less likely; unless some further structural change, such as more widespread adoption of innovations in vehicle sharing/booking alternatives, serves to boost per capita vehicle use (while re-shaping car ownership patterns).

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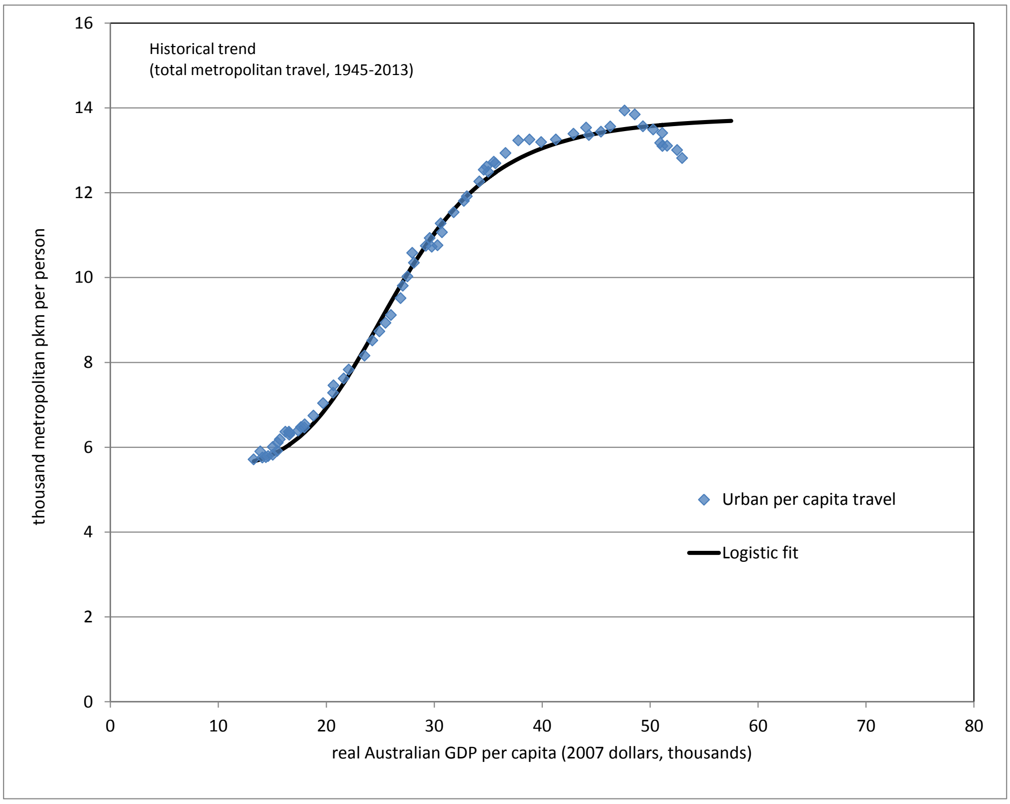
[5] Note that due to the inherent uncertainties of parts of the estimation/projection methodology, most 'base case' projection results for congestion effects, appearing in following sections of this Information Sheet, are presented as plausible ranges—with values varying between 'upper baseline' levels (which use the blue projections trend-line from Figure 6 as the car VKT parameter input) and 'lower baseline' values (based on the slightly more conservative input assumption of per capita car VKT staying constant at 2015 levels).

[6] E.g. see discussions of 'Peak Car' issues; such as in Goodwin 2012, Newman & Kenworthy 2011, and Pearce 2011.

Figure 5: Relationship of per capita Australian urban travel to per capita income levels



Notes: For each data point: y-axis value refers to total annual passenger travel (in pkm, including non-motorised travel) within the State and Territory capital cities, divided by the resident metropolitan population (as at each year ending 30 June, totalled across the capital city areas, GCCSAs); x-axis value refers to a proxy for average Australian income levels, calculated here as national GDP for the relevant year, divided by the national population level.

Sources: Cosgrove (2011), Cosgrove & Gargett (2007), ABS (2014), BTRE (2002, 2007), BITRE (2010, 2014a, 2014b) and BITRE estimates.

Figure 6 displays the range of these possibilities for future per capita saturation levels in Australian car use, along with the median values used within the (upper) baseline projection scenario. A reasonably wide spread of urban traffic outcomes would be encompassed by these potential VKT trends; effectively depending on whether, before ultimate stabilisation, the current trend of year on year decreases in car km per person continues, halts or even reverses for a period.

Figure 7 shows the resulting projections for aggregate capital city vehicle kilometres travelled (VKT) after applying the relevant per capita curves (as shown in Figure 6) to projections of Australian metropolitan population out to 2030. Three of the potential BAU VKT trends plotted in Figure 7 use the most recently published ABS population projections (see ABS 2013a), where the *upper baseline* travel estimates are the result of the ABS medium population growth scenario, 'Series B'—defined by the ABS as projections of resident population assuming "medium levels of fertility, overseas migration, life expectancy, and interstate migration flows"—applied to the intermediate per capita VKT (blue trend-line from Figure 6). The high and low VKT scenarios result from applying ABS high and low population scenarios[7]—respectively, Series A and Series C—to the high and low per capita VKT trends from Figure 6.

Of course, whether a particular pattern of forecast VKT growth actually ensues will be largely contingent on the underlying projection assumptions (e.g. around fuel prices, employment levels and residual effects of the Global Financial Crisis) holding. In particular, these three VKT forecast scenarios, outlined so far, are highly dependent on the relatively strong population growth within the latest ABS projection series. For example, the latest United Nations population projections (UN 2015) include series for Australia considerably lower than the comparable ABS values—with the *high growth* scenario in the UN projections quite similar to the medium ABS Series B, whereas the UN *medium growth* scenario has about 5 per cent lower national population levels by 2030 than Series B.

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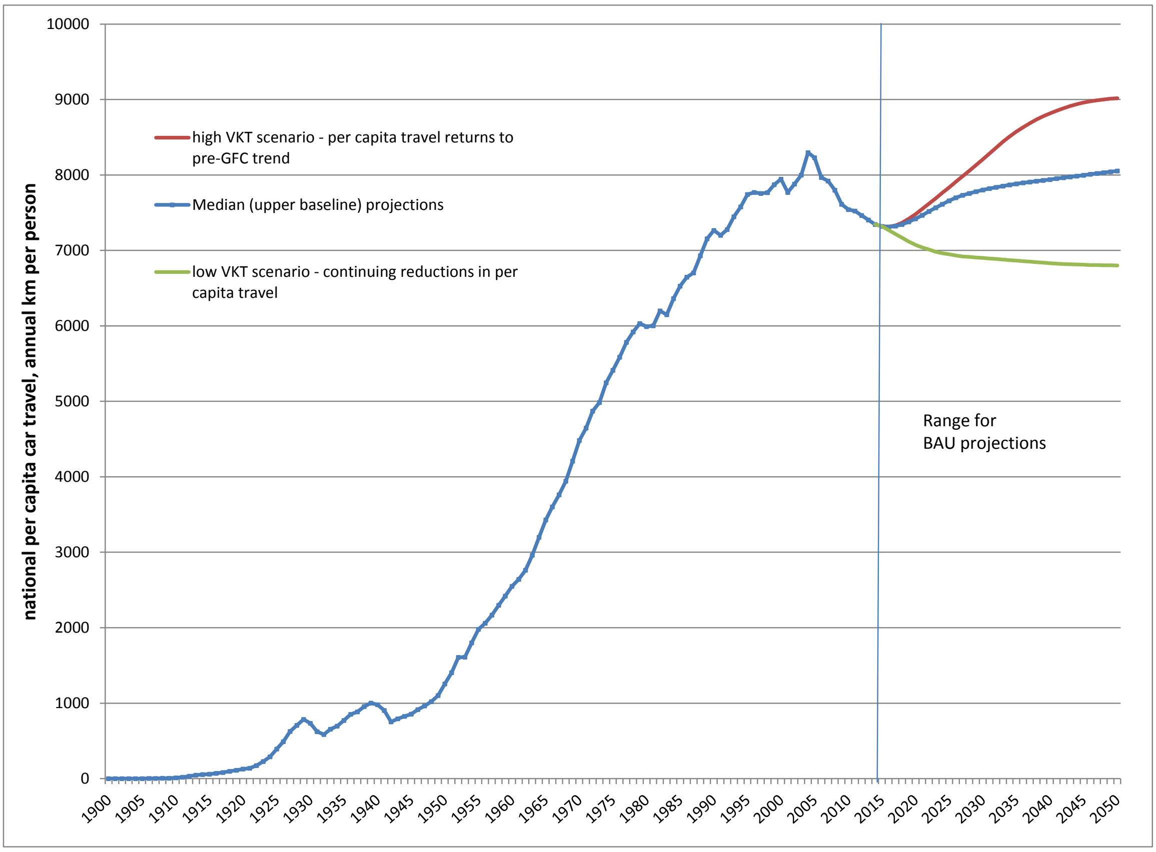
[7] ABS (2013a) states that, for Australia, "Series B largely reflects current trends in fertility, life expectancy at birth and NOM [net overseas migration], whereas Series A and Series C are based on high and low assumptions for each of these variables respectively."

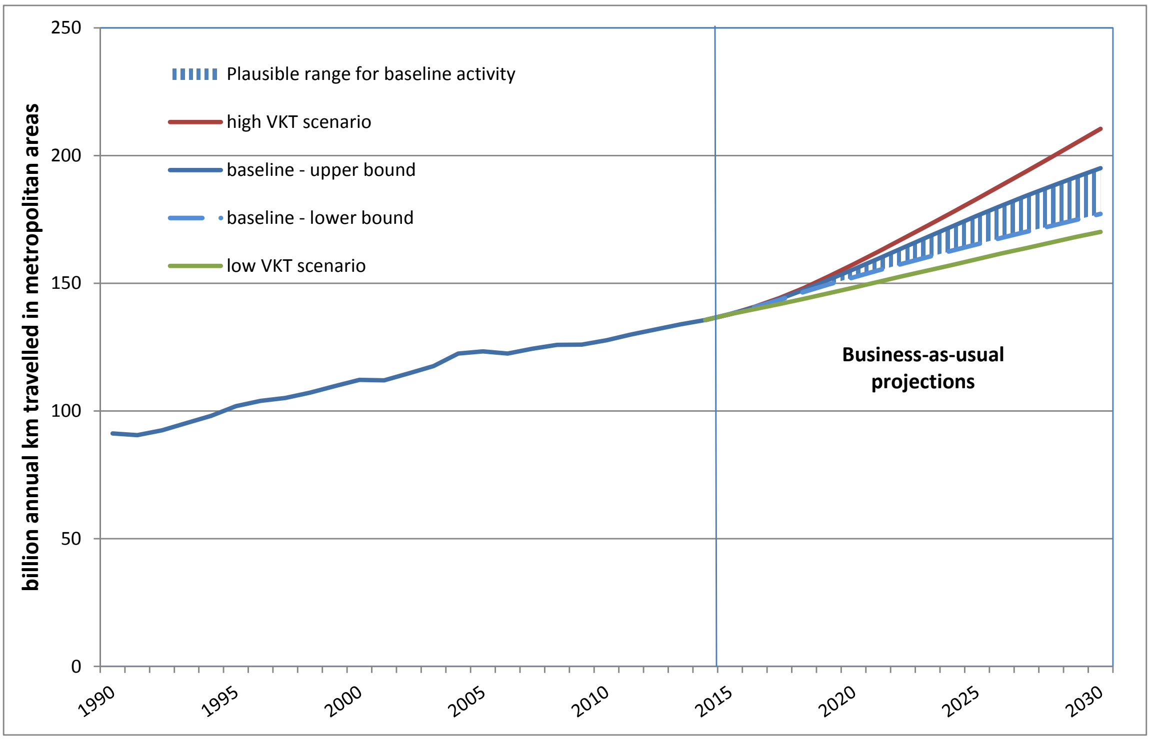
Figure 6: Base case long-term projections of per capita car use in Australia



Note: 'Median' projection trend is used for setting the 'upper baseline' congestion scenario input levels for car VKT (while such parameter inputs for 'lower baseline' values—not displayed here—set future per capita car VKT constant at 2015 levels).

Sources: BITRE & CSIRO (2008), ABS (2014, 2013a, 2013b), BTRE (2007), BITRE (2010, 2014a, 2014b, 2014c) and BITRE estimates.

Figure 7: Base case projections of metropolitan vehicle use in Australia, to 2030



Sources: BITRE (2010, 2014a, 2014b, 2014c) and BITRE estimates.

The fourth of the distinct BAU VKT trends plotted in Figure 7—the *lower baseline* scenario—is derived by using the UN (2015) *medium growth* scenario for Australian population, applied to values for annual per capita car VKT kept constant at 2015 levels.

Due to the high relative uncertainties inherent to the forecasting of traffic congestion effects, 'base case' projection results are typically presented here as plausible ranges, with expected values likely to fall between 'upper baseline' levels (such as formed by the solid blue trend-line in Figure 7) and 'lower baseline' levels (such as the dashed blue trend-line in Figure 7). Where detailed plots or tabular results might appear too cluttered, or difficult to interpret, if attempting to display the full array of such baseline outcomes (such as in Figure 8 or Table 2), the *upper baseline* scenario estimates are given, to serve as representative of the highest traffic or congestion levels within the plausible BAU range.

Sensitivity testing on a wider range of possible outcomes (such as the high and low VKT scenarios given in Figure 7) are also presented in following sections of this Information Sheet. Given such lower population projections within the literature as the latest UN (2015) results, and how far current per capita car use is below pre-GFC levels (see Figure 6), actual aggregate VKT outcomes falling between the chosen baseline range (blue hatched area of Figure 7) and the lower scenario (green trend-line of Figure 7) should probably be regarded as having a higher BAU likelihood than future values above the baseline range (i.e. between the upper baseline bound—blue trend-line in Figure 7—and the 'high VKT' scenario given by the red trend-line of Figure 7).

Under the currently expected patterns of population growth, an overall trend of relatively linear increases in *aggregate* metropolitan traffic (i.e. across all 8 capital cities) is projected as likely over the next decade and a half, with total vehicle-kilometres travelled forecast to increase around the order of 2 per cent per annum out to 2030 (with the upper baseline scenario exhibiting growth from 2015 levels of about 138 billion kilometres to 2030 levels of 195 billion kilometres—averaging an increase of around 2.3 per cent per annum; and the lower baseline growing to 2030 levels of about 177 billion kilometres—averaging around 1.7 per cent per annum).

Base case commercial vehicle traffic (such as vans, trucks and buses) is forecast to grow substantially more strongly (being more closely linked to increases in economic activity, with metropolitan VKT averaging growth in the range of 2.5–2.9 per cent per annum, for the lower to upper baseline scenario range) than private car traffic (at 1.4–2.1 per cent per annum) over the projection period to 2030 (see Table 2).

Figure 8 displays the resulting long-term trend in metropolitan VKT (by vehicle type) for the upper baseline scenario, with relevant numerical values provided in Table 1 (for historical VKT) and Table 2 (for projected VKT). Table 3 provides the disaggregation of the total metropolitan VKT between the various capital cities, and Figure 9 shows the resulting estimates for city-by-city traffic levels (in terms of passenger car equivalent units, PCU-kilometres) for the upper baseline scenario. The base case scenario projections have city-wide annual VKT levels[8] for Sydney rising from current (2015) levels of about 40.81 billion kilometres to between 50.26 (lower baseline estimate) and 55.57 billion kilometres (upper baseline estimate) by 2030; Melbourne rising from around 40.38 billion kilometres (2015) to between 51.86 and 57.05 billion (2030); Brisbane rising from about 21.60 billion kilometres to 29.02–32.10 billion kilometres (2015–2030); Adelaide rising from 10.39 to 12.10–13.47 billion kilometres; Perth rising from 17.80 to 25.54–27.62 billion kilometres; Hobart rising from 1.98 to 2.22–2.47 billion kilometres; Darwin rising from 1.05 to 1.32–1.47 billion kilometres; and Canberra rising from 3.90 to 4.85–5.26 billion kilometres[9].

For the VKT projection values (such as those shown in Figure 8), and in fact for much of the analysis herein, the results would be quite different if estimated under the assumption of any significant structural change within the projection period, either to Australian society or its transport systems (e.g. one example of a credible future 'disruptive' technology concerns the possible widespread use of autonomous vehicles). Some considerations around possible major divergences from *business-as-usual* trends are also discussed in following sections (dealing with sensitivity scenario testing). Evidently, if actual VKT happens to differ substantially in the future from the baseline projections (e.g. as given in Figure 7), then the corresponding estimates of traffic congestion impacts will be similarly affected.

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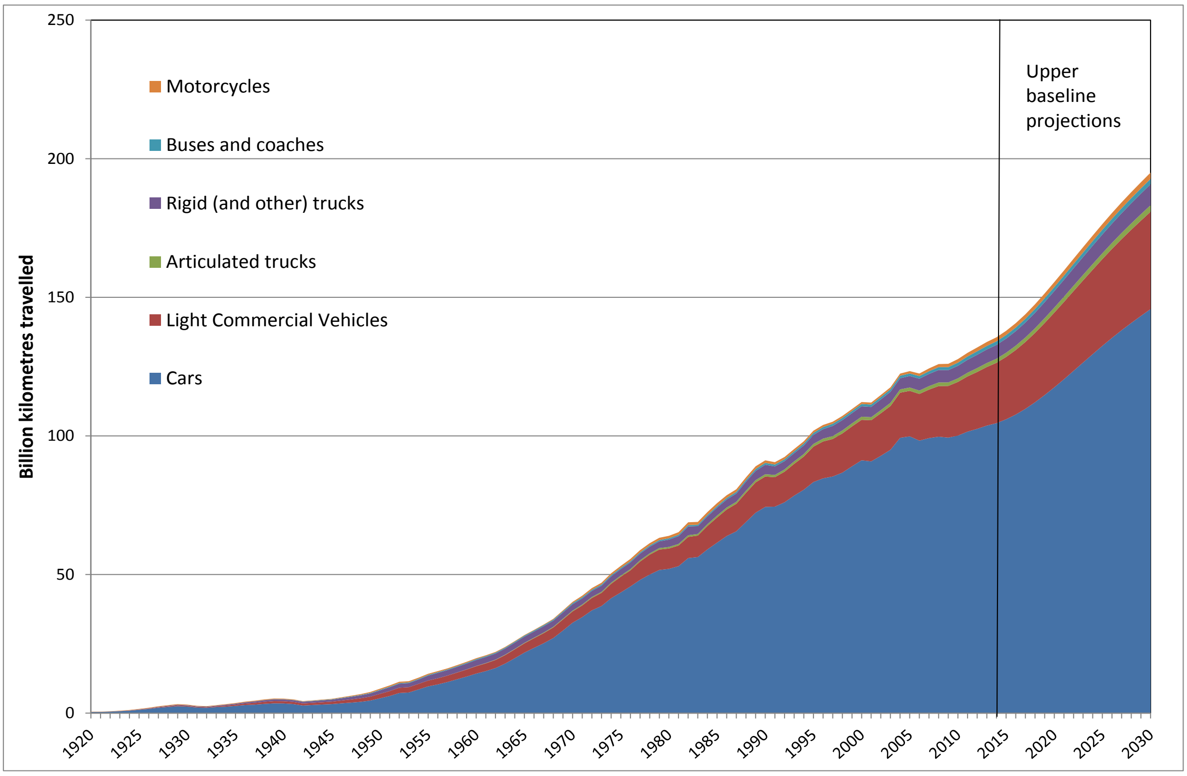
[8] Refer to Table 3 for the upper baseline trend data.

[9] Detailed long-term trend series for city-by-city VKT are available in spreadsheet form on the BITRE website.

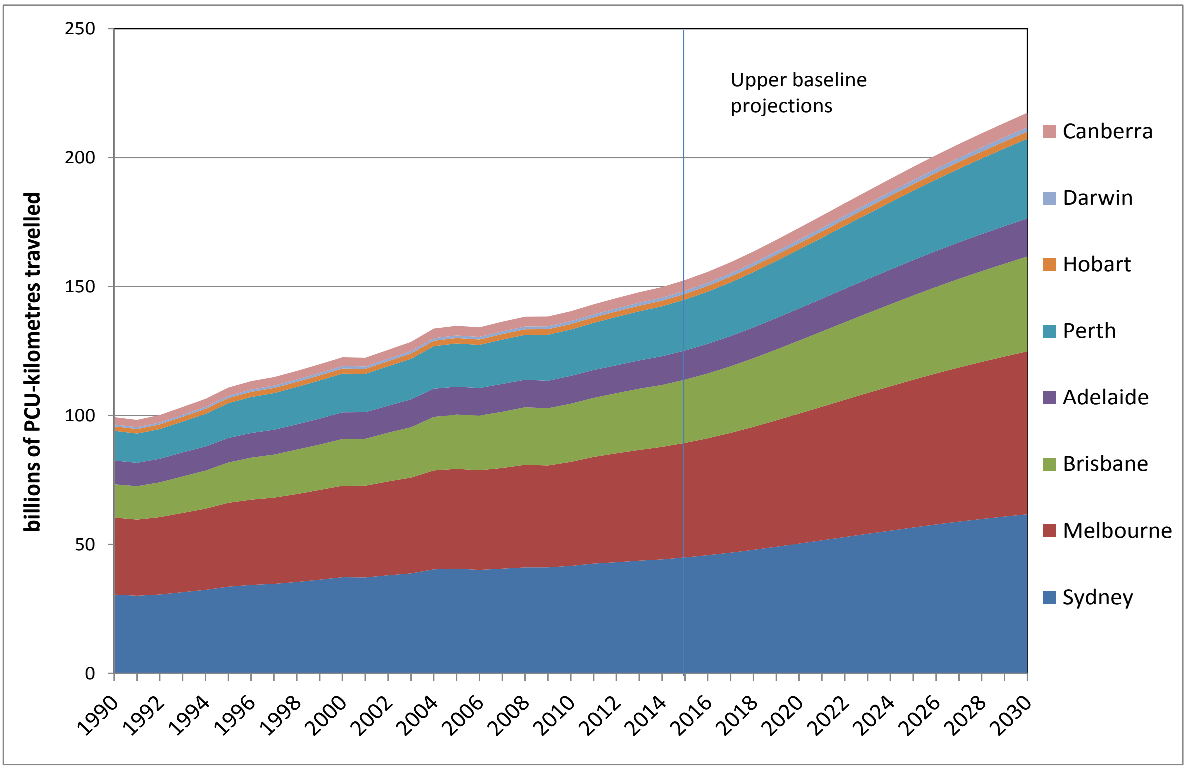
Figure 8: Long-term metropolitan VKT trends and base case projections to 2030



Notes: Includes total annual vehicle travel (for years ending 30 June) within the 8 State and Territory capital cities, across all vehicle types, for the 'upper baseline' VKT scenario (using ABS median population projections).

Sources: BITRE & CSIRO (2008), ABS (2013a, 2013b), BTRE (2007), BITRE (2010, 2014a, 2014b, 2014c) and BITRE estimates.

Figure 9: Total projected traffic for Australian capital cities to 2030, upper baseline scenario



Note: Passenger car equivalent km (PCU-km) estimates calculated using rough traffic contribution values (relative to passenger car = 1) of: LCV = weighted sum of standard light commercials (PCU=1) and large vans (PCU=1.5); Rigid truck = 2; Articulated truck = weighted sum of standard 6-axle semitrailer (PCU=3) and B-doubles (PCU=4); Motorcycle = 0.5; and Bus = 2.

Sources: ABS (2013a, 2013b), BTRE (2007), BITRE (2010, 2014a, 2014b, 2014c) and BITRE estimates.

Table 1: Total motor vehicle use, within all Australian capital cities, 1930–2015

Year ending 30 June	Cars	Light Commercial Vehicles	Articulated trucks	Rigid and other trucks	Motor-bus	Motorcycles	Total motor vehicles
			(billions of annual metropolitan vehicle kilometres travelled)				
1930	2.34	0.27	0.00	0.20	0.03	0.20	3.05
1940	3.48	0.81	0.00	0.64	0.07	0.22	5.21
1950	5.32	1.60	0.00	1.25	0.22	0.40	8.78
1960	14.24	2.68	0.07	2.17	0.32	0.32	19.80
1970	32.59	4.10	0.28	2.29	0.43	0.42	40.12
1980	52.03	7.35	0.56	2.65	0.48	0.89	63.95
1981	52.99	7.45	0.57	2.84	0.49	0.93	65.27
1982	55.91	7.65	0.60	3.17	0.50	1.01	68.84
1983	56.29	7.74	0.59	2.82	0.51	1.02	68.97
1984	59.06	8.46	0.65	2.79	0.52	1.04	72.54
1985	61.48	9.08	0.69	2.89	0.54	1.07	75.75
1986	63.88	9.58	0.71	2.89	0.56	0.99	78.60
1987	65.57	9.94	0.72	2.98	0.59	0.96	80.75
1988	68.94	10.51	0.78	3.26	0.62	0.94	85.05
1989	72.29	10.94	0.80	3.33	0.65	1.01	89.03
1990	74.37	10.97	0.82	3.42	0.67	0.92	91.18
1991	74.48	10.62	0.82	3.08	0.68	0.85	90.52
1992	76.03	11.04	0.83	2.98	0.67	0.84	92.39
1993	78.44	11.47	0.89	2.96	0.67	0.83	95.27
1994	80.58	11.95	0.93	3.08	0.71	0.81	98.05
1995	83.35	12.77	0.99	3.24	0.74	0.79	101.88
1996	84.68	13.31	1.03	3.41	0.76	0.75	103.95
1997	85.35	13.52	1.06	3.66	0.77	0.75	105.11
1998	86.73	14.15	1.09	3.71	0.80	0.71	107.19
1999	89.01	14.39	1.10	3.69	0.81	0.68	109.69
2000	91.19	14.62	1.13	3.76	0.83	0.69	112.21
2001	90.81	14.84	1.11	3.71	0.86	0.71	112.03
2002	92.81	15.35	1.14	3.86	0.86	0.75	114.77
2003	94.99	15.80	1.16	3.98	0.88	0.74	117.55
2004	99.30	16.30	1.18	4.03	0.90	0.78	122.49
2005	99.84	16.42	1.20	4.15	0.92	0.84	123.37
2006	98.29	16.85	1.22	4.28	0.96	0.91	122.51
2007	99.20	17.51	1.26	4.39	0.99	1.01	124.35
2008	99.71	18.27	1.29	4.51	1.03	1.11	125.92
2009	99.37	18.66	1.27	4.42	1.09	1.19	126.01
2010	100.11	19.36	1.29	4.53	1.15	1.28	127.71
2011	101.53	19.92	1.34	4.65	1.21	1.32	129.98
2012	102.53	20.53	1.41	4.78	1.27	1.37	131.91
2013	103.72	21.14	1.44	4.88	1.28	1.42	133.88
2014	104.59	21.77	1.48	4.98	1.28	1.47	135.57
2015	105.98	22.50	1.52	5.09	1.30	1.52	137.90

Notes: 'Motor-bus' comprises all motor vehicles with 10 or more seats. 'Cars' include all-terrain wagons and sports utility vehicles (SUVs). 2015 values are preliminary estimates.

Sources: Cosgrove (2011), ABS (2013b), BTRE (2007), BITRE (2014a, 2014b) and BITRE estimates.

Table 2: Base case projections of road vehicle use, within all Australian capital cities, to 2030

Year ending 30 June	Cars	Light Commercial Vehicles	Articulated trucks	Rigid and other trucks	Motor-bus	Motorcycles	Total motor vehicles
	(billions of annual metropolitan vehicle kilometres travelled)						
2015	105.98	22.50	1.52	5.09	1.30	1.52	137.90
2016	107.69	23.28	1.57	5.23	1.32	1.57	140.66
2017	109.74	24.13	1.63	5.39	1.35	1.62	143.87
2018	112.10	25.04	1.69	5.57	1.39	1.67	147.47
2019	114.72	26.00	1.76	5.76	1.43	1.72	151.39
2020	117.49	26.97	1.82	5.94	1.48	1.77	155.47
2021	120.40	27.89	1.88	6.11	1.52	1.82	159.64
2022	123.45	28.78	1.94	6.28	1.57	1.87	163.90
2023	126.49	29.64	2.00	6.45	1.62	1.93	168.13
2024	129.51	30.49	2.06	6.62	1.67	1.98	172.31
2025	132.49	31.31	2.11	6.79	1.72	2.03	176.45
2026	135.38	32.11	2.17	6.96	1.76	2.08	180.45
2027	138.14	32.89	2.22	7.11	1.81	2.12	184.29
2028	140.76	33.65	2.27	7.27	1.85	2.17	187.97
2029	143.29	34.38	2.32	7.42	1.89	2.22	191.52
2030	145.76	35.11	2.37	7.58	1.93	2.26	195.01

Notes: ‘Motor-bus’ comprises all motor vehicles with 10 or more seats. ‘Cars’ include all-terrain wagons and sports utility vehicles (SUVs). 2015 values are preliminary estimates. Projection values relate to the ‘upper baseline’ scenario.

Sources: Cosgrove (2011), ABS (2013b), BTRE (2007), BITRE (2014a, 2014b) and BITRE estimates.

Average network performance

High levels of traffic and traffic growth typically impose strains on the capacity of urban roads, and can lead to significant levels of urban congestion, degrading average network performance (in terms of vehicle speeds or lane flow-rates)—especially in peak travel periods—unless appropriate traffic management processes are in place; which imposes considerable costs on those affected by delays, increased average fuel consumption and increased air pollution levels.

The Australian capital cities generally exhibit varying levels of population growth (and consequently, the VKT projections in Table 3 have differing growth rates between the cities; being significantly higher, than the metropolitan average, for Perth and Brisbane). Under the currently projected patterns of median population growth, aggregate metropolitan traffic (in terms of passenger car equivalents) is anticipated to increase from estimated 2015 levels of about 152.5 billion PCU-kilometres to around the order of 200 PCU-kilometres annually by 2030 (with estimated results for the lower baseline scenario reaching 198 PCU-km, and the upper baseline scenario reaching about 217 PCU-km, by 2030). By city, the projected PCU-km increases between 2015 and 2030 (using the upper baseline input assumptions) are about 37 per cent for Sydney, 42 per cent for Melbourne, 50 per cent for Brisbane, 30 per cent for Adelaide, 57 per cent for Perth, 25 per cent for Hobart, 40 per cent for Darwin and 35 per cent for Canberra.

The cities also vary greatly in size, composition and road network design—so should not be expected to exhibit totally equivalent congestion responses to an equivalent increase in VKT volume. The most direct response to VKT increases (or more specifically, to increases in the volume/capacity ratios of urban roads) is typically interruptions to traffic flow, lengthening average journey times and making trip travel times more variable. One standard congestion indicator used for reporting on road network performance is extra vehicle travel time, per unit distance, compared with freely-flowing traffic conditions (i.e. the minutes lost per kilometre driven while travelling in a particular stream of traffic, relative to the time that same trip would have taken under less congested conditions, such as might occur during the night).

Table 3: Base case projections of total vehicle kilometres travelled, by city, to 2030

Year ending 30 June	Sydney	Melbourne	Brisbane	Adelaide	Perth	Hobart	Darwin	Canberra	Metropolitan total
			(billions of annual metropolitan vehicle kilometres travelled)						
1990	28.05	27.38	11.77	8.52	10.57	1.60	0.65	2.64	91.18
1991	27.76	27.11	11.88	8.41	10.44	1.59	0.65	2.66	90.52
1992	28.25	27.59	12.38	8.51	10.63	1.63	0.67	2.75	92.39
1993	29.10	28.23	12.99	8.67	11.03	1.70	0.69	2.86	95.27
1994	29.89	28.88	13.50	8.71	11.66	1.75	0.71	2.94	98.05
1995	30.95	29.81	14.23	8.85	12.45	1.79	0.76	3.03	101.88
1996	31.45	30.34	14.77	8.87	12.83	1.82	0.79	3.08	103.95
1997	31.69	30.68	15.05	8.94	13.03	1.82	0.82	3.09	105.11
1998	32.30	31.31	15.52	9.08	13.25	1.79	0.84	3.11	107.19
1999	33.12	32.03	15.83	9.34	13.55	1.78	0.85	3.17	109.69
2000	33.97	32.70	16.31	9.61	13.75	1.79	0.86	3.23	112.21
2001	33.89	32.80	16.38	9.57	13.62	1.75	0.84	3.18	112.03
2002	34.65	33.53	16.99	9.74	13.97	1.79	0.85	3.25	114.77
2003	35.30	34.21	17.54	10.05	14.37	1.85	0.87	3.36	117.55
2004	36.88	35.35	18.66	10.18	15.08	1.94	0.90	3.50	122.49
2005	37.12	35.65	18.90	10.03	15.35	1.92	0.89	3.51	123.37
2006	36.64	35.50	18.95	9.90	15.22	1.90	0.90	3.49	122.51
2007	37.04	35.79	19.47	10.01	15.64	1.94	0.93	3.54	124.35
2008	37.44	36.42	19.90	9.84	15.84	1.95	0.97	3.57	125.92
2009	37.47	36.17	19.77	9.81	16.27	1.94	0.99	3.59	126.01
2010	37.98	36.89	20.04	9.94	16.31	1.93	0.99	3.62	127.71
2011	38.78	37.77	20.28	9.94	16.59	1.94	1.00	3.68	129.98
2012	39.18	38.50	20.59	9.93	17.00	1.94	1.01	3.76	131.91
2013	39.72	39.12	20.95	10.07	17.23	1.94	1.02	3.82	133.88
2014	40.12	39.74	21.16	10.24	17.49	1.94	1.04	3.86	135.57
2015	40.81	40.38	21.60	10.39	17.80	1.98	1.05	3.90	137.90
2016	41.54	41.20	22.10	10.56	18.21	2.01	1.07	3.96	140.66
2017	42.38	42.18	22.69	10.75	18.69	2.05	1.10	4.04	143.87
2018	43.34	43.26	23.35	10.94	19.24	2.09	1.12	4.12	147.47
2019	44.38	44.44	24.06	11.16	19.86	2.12	1.15	4.22	151.39
2020	45.45	45.65	24.80	11.38	20.51	2.16	1.18	4.32	155.47
2021	46.56	46.90	25.54	11.61	21.18	2.20	1.21	4.43	159.64
2022	47.70	48.16	26.30	11.85	21.88	2.23	1.24	4.53	163.90
2023	48.81	49.41	27.05	12.08	22.60	2.27	1.27	4.63	168.13
2024	49.91	50.64	27.80	12.30	23.33	2.30	1.30	4.73	172.31
2025	51.00	51.81	28.56	12.52	24.06	2.34	1.33	4.83	176.45
2026	52.06	52.94	29.30	12.73	24.78	2.37	1.36	4.92	180.45
2027	53.04	54.02	30.02	12.93	25.50	2.39	1.39	5.01	184.29
2028	53.94	55.06	30.72	13.11	26.21	2.42	1.41	5.09	187.97
2029	54.77	56.06	31.41	13.29	26.92	2.45	1.44	5.17	191.52
2030	55.57	57.05	32.10	13.47	27.62	2.47	1.47	5.26	195.01

Notes: Values include use of all vehicle types, for travel on the road networks of the capital cities. 2015 values are preliminary estimates. Projection values relate to the ‘upper baseline’ scenario.

Sources: Cosgrove (2011), ABS (2013b), BTRE (2007), BITRE (2014a) and BITRE estimates.

The BITRE congestion-estimation models have been calibrated against aggregate network performance data collected by the various state road authorities (including the annual statistics reported to the Austroads *National Performance Indicators*—with NPI charts/tables available at http://algin.net/austroads/site/index.asp). Various jurisdictions' on-going 'Traffic Systems Performance Monitoring' processes collect a reasonable amount of useful congestion-related data (such as details on average traffic flows or speeds on certain major urban road links, and consequent delay levels relative to posted speeds); and such data are utilised for model input parameter setting wherever feasible. For example, as well as contributing to the Austroads NPI, VicRoads has also systematically collected and published traffic performance information on major freeways and selected arterial roads in Melbourne for the last couple of decades—with the most recent release of the annual VicRoads *Performance Monitoring Information Bulletin* being *Traffic Monitor 2012-13* (issued March 2015).

Given the importance of emerging real-time traffic performance information systems, capable of utilising massive crowd-sourced data-sets[10] (generated by GPS/location-based navigation systems, cell-phones and other GPS-equipped devices), the BITRE modelling has also employed further parameter adjustment using the TomTom Traffic Index (a set of travel time indicators for major cities, derived from their large database recording real-world driving patterns—such as published in the 2013 *TomTom Australian & New Zealand Traffic Index* and recently updated at https://www.tomtom.com/en_au/trafficindex/#/list).

Such procedures allow the BITRE aggregate congestion models to be suitably benchmarked against records of actual on-road traffic flow conditions for our major cities (though reiterating that such aggregate—citywide averaged—methods are very blunt instruments for estimating and projecting congestion occurrence).

The reported network performance data and the results of the aggregate modelling imply that current (2015) overall traffic delay (relative to free flow), averaged across all 8 metropolitan road networks for all times of day, stands at about 0.34 minutes lost per kilometre driven. Assuming a free-flow speed in the order of 60 km/hr leads to an equivalent statement of this average congestion level as: urban trips performed throughout the day, which would take an hour during uncongested times, take on average about 20 minutes longer due to traffic delays. Note that during off-peak periods typical delay levels will be well below such average daily intensities, while during peak travel periods (especially in the larger cities) the usual time losses will be substantially above the daily average (see Figure 10 for an illustration of the typical variation of current delay intensity throughout the day). The road networks of the larger capitals (such as Sydney or Melbourne) generally have average daily delay levels two to three times higher than that of the smaller capitals (such as Hobart or Canberra).

Figure 11 displays the typical spread of urban vehicle travel throughout the average weekday, with the morning and evening peak traffic volumes resulting from current standard commuting patterns—in turn producing the sharply peaked delay response obvious in the indicator values plotted in Figure 10, with average network performance for most urban road systems dropping significantly for approximately 1–2 hours during both of the day's peak periods.

Figure 12 goes on to show the resulting daily distribution of total metropolitan road delay (citywide person-hours lost to daily traffic congestion) from the combination of these two elements: VKT performed during each hour of the day (hourly profile given in Figure 11) multiplied by the specific intensity of traffic delay experienced during that hour (indicator of hourly variation given in Figure 10). The hourly plot in Figure 12 demonstrates not only how strongly overall urban delay is concentrated within the peak periods, but also how the total hours lost to delay (by the full road vehicle fleet) are dominated by the car travel component.

Assuming future urban road provision roughly continues at average historical levels, the projected traffic increases within the upper baseline scenario lead to the modelled delays on metropolitan road networks continuing to increase over the projection period, with the national average estimates reaching levels of around 0.47 minutes lost per kilometre driven by 2030 (i.e. urban routes traversed in an hour during uncongested times, taking on average about 28 minutes longer due to daily traffic congestion)[11].

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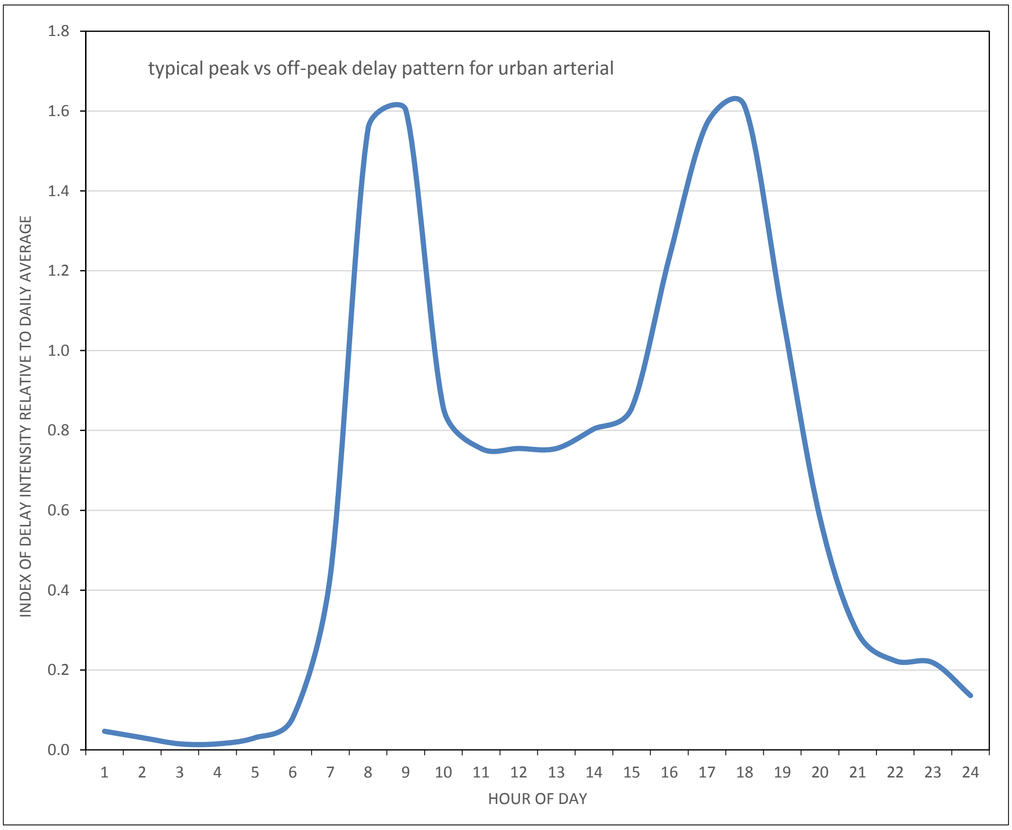
[10] Examples of IT applications dealing with the processing of real-time traffic flow information include Google Traffic and INRIX Traffic.

[11] The recorded average traffic speeds over the *monitored* networks of the larger capitals have tended to be around the 40km/hr mark over recent years (Austroads 2015)—while the distributed traffic data available from the TomTom Traffic Index indicates that average road travel speeds across the *entire* city networks (where the monitored portions typically concentrate on major arterials) are likely to be around 10 per cent higher—and in the upper baseline scenario, modelled average speeds on such monitored networks decline to around 36 km/hr by 2030.

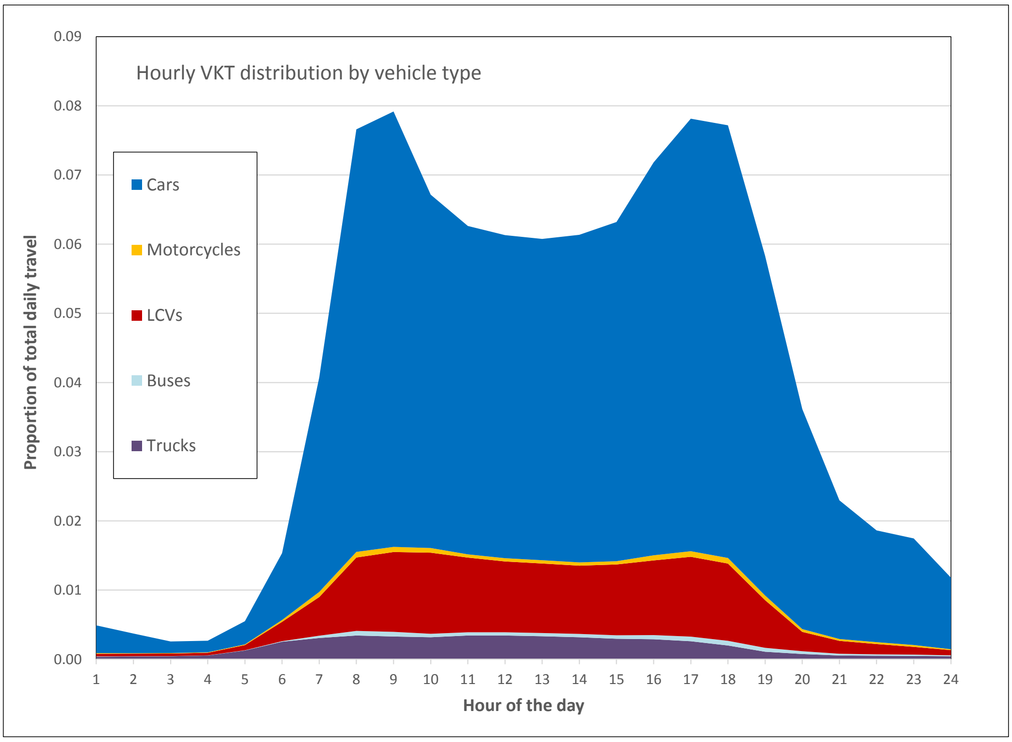
Figure 10: Representative hourly distribution of delay intensity, across an average weekday



Note: Weekend traffic distributions tend to show less severe concentrations during peak periods than such average weekday patterns.

Sources: BTRE (2007) and BITRE estimates.

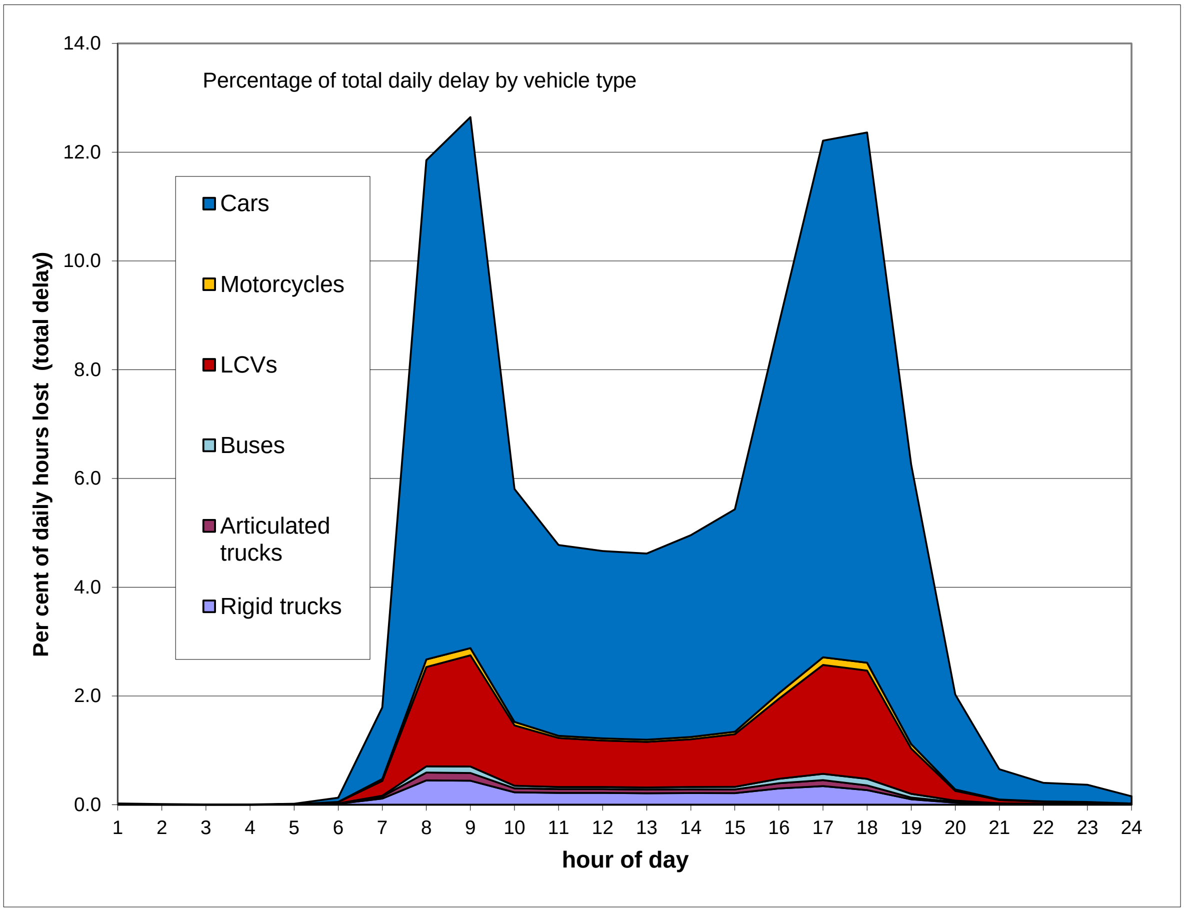
Figure 11: Representative daily profile of urban vehicle use, across an average weekday



Notes: Proportion of daily total by current hourly volumes. Weekend traffic distributions tend to show less severe concentrations during peak periods than such average weekday patterns.

Sources: BTRE (2007) and BITRE estimates.

Figure 12: Representative profile of total urban traffic delay, across an average weekday



Notes: Proportion of daily total by current hourly amounts. Weekend traffic distributions tend to show less severe concentrations during peak periods than such average weekday patterns.

Sources: BTRE (2007) and BITRE estimates.

Congestion costs

Congestion can impose significant costs on society, with interruptions to traffic flow lengthening average journey times, making trip travel times more variable and making vehicle engine operation less efficient. The (generalised) social cost estimates presented in this Information Sheet include allowances for:

- extra travel time (above that for a vehicle travelling under less congested conditions);
- extra travel time variability (where congestion can result in trip times becoming more uncertain—leading to travellers having to allow for an even greater amount of travel time than the average journey time, in order to avoid being late at their destination);
- increased vehicle operating costs (primarily higher rates of fuel consumption from more stop-start driving conditions); and
- poorer air quality (with vehicles under congested conditions emitting higher rates of noxious pollutants than under more freely flowing conditions, leading to even higher health costs).

Keep in mind that the values for extra travel time (due to traffic delay) in Figures 10 and 12 are calculated relative to estimated 'free' speeds (i.e. average traffic speeds encountered under totally uncongested conditions) rather than to travel at posted road speed limits. Some literature values around road performance (and a variety of congestion indicators often used by road authorities) are based on delay values relative to 'nominal' speeds (using average posted speed limits) rather than comparisons to estimated free speeds. This practice has the advantage of such nominal speeds being quite precisely defined, and typically much easier to estimate than free speed values. However, comparisons to posted/nominal speeds are not as useful for congestion cost estimation since constant travel at the speed limit is often not realistic for many actual road links, even in times of zero congestion. Free-flow speeds for many roads are typically dependent on the particular road design, especially concerning the density of traffic lights and other intersection controls (along with a range of other signalised or unsignalised impedances). Therefore, average vehicle speeds (particularly for inner-city streets) will generally be considerably below posted/nominal speeds even during fully uncongested traffic conditions.

The calculation of generalised congestion costs requires the conversion of such estimates of hours lost due to traffic delays into dollar terms—that is, by choosing a suitable 'unit value of time'. The unit time cost rates used in the BITRE congestion cost estimation process (described in the following) were derived from standard Austroads values for road user costs—see the *Guide to Project Evaluation Part 4: Project Evaluation Data* (Austroads 2012) which contains estimates of road user unit costs in 2010 Australian dollars[12]; which are compatible, after CPI adjustment, with travel time cost values given in Transport and Infrastructure Council 2015, *National Guidelines for Transport System Management in Australia, Road Parameter Values [PV2]*.

Such standard unit values for travel time costs are derived using differing proportions (depending on the type of travel) of Average Weekly Earnings for full-time workers in Australia; with Austroads (2012) estimating 2010 values of time for private travel at $13.17 per person-hour[13] and for business car travel at $42.15 per person-hour. The BITRE valuations also use 2010 unit values of $23.32 per person-hour for commercial vehicle travel; with freight vehicles getting a further cost rate in terms of dollars per vehicle-hour (e.g. with a 6-axle articulated truck having an additional time travel value, in 2010 dollars, of $37.25 per vehicle-hour, light commercial vehicles an extra $1.35 per vehicle-hour, and rigid trucks averaging freight time values of around $8 per vehicle-hour).

Congestion impacts on increased vehicle operating costs (VOC) have been roughly estimated using various vehicle response relationships (e.g. fuel consumption to speed) developed for Working Paper 71 (BTRE 2007), supplemented with updated unit resource cost parameters within the VOC sections of Austroads 2012.

The BITRE analyses also include estimates of health damage costs for urban air pollution being increased by congestion, requiring the use of unit costs for motor vehicle emissions (e.g. in terms of dollars per tonne emitted). The values of emissions costs used in this study are also based on unit cost rates given in the *Guide to Project Evaluation Part 4: Project Evaluation Data* (Austroads 2012); supplemented by a range of related literature, such as estimates of the health impacts of Australian air pollution by Paul Watkiss (*Fuel Taxation Inquiry: The Air Pollution Costs of Transport in Australia*, Watkiss 2002). Such values for the costs of environmental damage due to air pollution vary greatly between the different emission species, ranging from unit rates of the order of $3–5 per tonne for carbon monoxide up to costs of over $300 thousand dollars per tonne for particulate matter (for inner-city areas of the larger capitals).

Given estimated volumes of network delay (calculated from the speed differences between congested traffic streams and freely flowing vehicles) and the unit road user costs (such as the *value of time*), aggregate congestion costs can then be derived. Three different 'cost of time delay' calculations are most commonly found in the literature, specifically:

1. Total Cost of Congestion Estimate—*total delay* values use the comparison of elapsed time at actual travel speeds with trip time at estimated free-flow speeds.
2. External Cost of Congestion Estimate—still based on actual travel speeds versus free-flow speeds, but estimates that portion of total costs that road users impose on others (through not having to personally meet the total costs caused by their travel decisions).
3. Deadweight Loss Cost of Congestion—the increase in net social benefit if appropriate traffic management or pricing schemes were introduced and optimal traffic levels were obtained.

Basically, a fundamental problem with a currently congested traffic flow is that it tends to include a quantity of travel for which the total costs imposed on society (by the extra delay felt by all motorists in that traffic stream) exceed the benefits of that element of travel (from the extra utility derived by those excess

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[12] Note that due to wage rate growth and inflation, the specified dollar values for unit costs given in BTRE (2007) Working Paper 71, derived using *Economic Evaluation of Road Investment Proposals—Unit Values for Road User Costs at June 2002* (Austroads 2004), are somewhat below the updated unit cost values used herein.

[13] Income growth over time is also allowed for in the unit value parameter settings—e.g. the 2010 value of time for private travel, at $13.17 per person-hour, is projected to increase to $16.74 per person-hour (also in real 2010 dollar terms) by 2030; and is set to about $9 per person-hour for 1990 cost calculations (still in 2010 Australian dollars).

travellers). The net loss on this amount of excess travel (after converting hours lost to delays into dollar terms) is given by the deadweight loss (DWL) of the current congestion level[14].

Avoiding this loss would produce a net social benefit—leading to the common descriptions of such DWL values as a measure of the 'cost of doing nothing about congestion', or the 'avoidable cost of traffic congestion'. Though somewhat more involved to estimate, the DWL cost definition is generally preferable to the other two definitions—especially for policy assessment—and is employed by this study (as for Working Paper 71) when referring to the 'social costs of congestion'.

The *avoidable* social cost of congestion, derived from the deadweight loss associated with current traffic volumes, is a direct measure of what can, in principle, actually be achieved by tackling the congestion problem. It is typically of greater policy relevance than *total* delay costs, since there is at least a theoretical possibility of obtaining the net benefits described by DWL valuations, while it will not typically be feasible to reduce total delay costs to zero for real-world traffic streams.

DWL valuations give an estimate of how much total social costs (for time lost and other wasted resources) could be avoided if travel volumes were reduced to the economically most efficient level of traffic for the road network. This economically *optimal traffic level* is defined as the travel volume (and distribution) that would result if, for a given travel demand, the generalised cost that motorists based their trip decisions on was equal to the *marginal* travel cost rather than on their private, individual travel costs (i.e. on the current *average* generalised travel cost). This would be the case if, through an appropriate transport demand management or pricing instrument, each motorist choosing to enter already congested traffic had to take account of not only their personal travel time costs, but also the cost of all the extra delay that their entry into the traffic stream is likely to impose on others.

Essentially, there is no way to avoid all of total delay costs since real-word traffic volumes cannot travel at free flow speeds at all times—whereas the portion of total costs that could *theoretically* be saved, if some traffic management strategy was capable of changing traffic conditions to the economically optimal level, can be estimated by the deadweight loss associated with that change in traffic level. Note that a DWL value will still tend to be an upper bound for the actual social benefits achieved by any particular congestion reduction strategy since it would take a perfectly variable management scheme, that targeted congestion by exact location and time of day (depending on the changing traffic levels on each of the network's road links), to obtain the economic optimum. It also does not allow for any of the wide range of costs that would be associated with actually implementing such traffic management measures—where their introduction would typically incur both set-up and ongoing administration/operating costs.

Various adjustable parameters are used in the modelling, including a cost multiplier for the variability of travel time[15], percentages of very short trips (for which it is assumed that delay lengths will not be noticeable), and an allowance for a proportion of trips to be less time-sensitive than average. The model also allows for increasing delay costs in peak traffic periods to generate some peak spreading over the years (as projected future travel increases).

For the DWL valuation, the current model specification derives typical proportions (averaged over all traffic) of approximately 50–60 per cent of total costs (typically varying by road type and time of day). This part of the cost estimation process is quite imprecise, and is reliant on several rough input assumptions (e.g. around demand curve elasticities), and could introduce an additional element of uncertainty into the final estimates. See Figure 13 for an indication of how this estimated DWL (*avoidable* cost) proportion varies throughout the typical weekday for current average traffic levels (and its rough size comparison with the higher *external* and *total* delay cost levels). Also see Figure 16 for time trend estimates, providing an illustration of how total delay costs and the proportion due to the deadweight losses (avoidable segment) has varied over the years.

Figure 14 demonstrates, for metropolitan areas, how typical weekend delay costs differ from average weekday profiles—both for total delay cost levels (relative to free flow) and for the avoidable cost portion (relative to optimal traffic flows).

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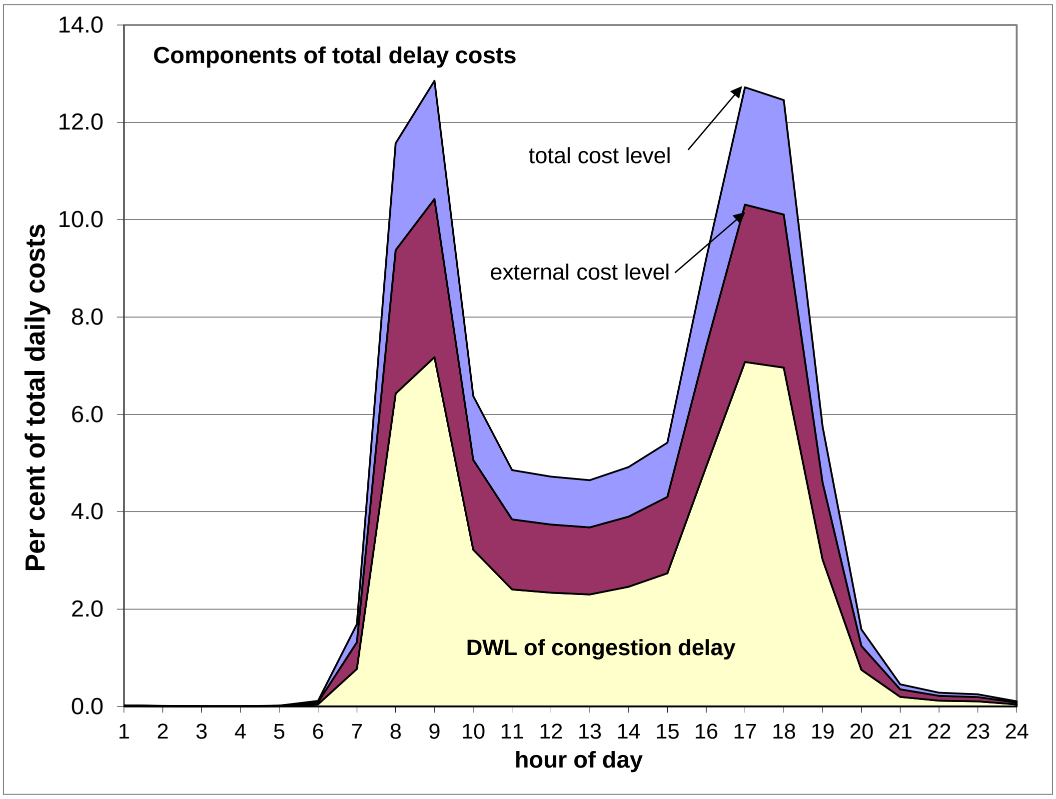
[14] See pages 99–106 of Working Paper 71 (BTRE 2007): for an overview of the basic economic theory behind the DWL valuation with respect to traffic flows (and congestion costs); a presentation of how the estimation of DWLs can be defined in terms of areas between the marginal travel cost curve, the average cost curve and the travel demand curve (referring to a standard supply-demand diagram in WP71 Figure 2.37); and some estimation of the typical proportion of total delay costs that the DWL component accounts for.

[15] See pages 93–95 of Working Paper 71 (BTRE 2007) for details of the costing methodology for trip variability due to increasing traffic levels.

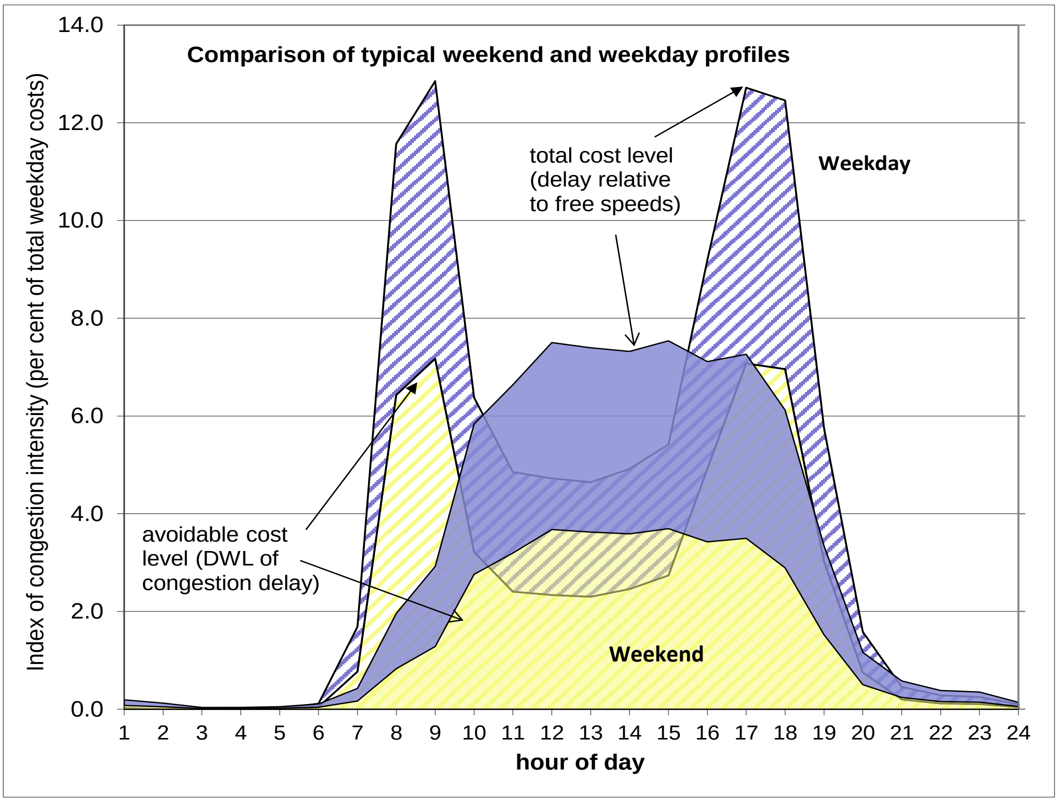
Figure 13: Estimated proportion of total congestion costs due to deadweight losses



Note: Representative distribution for current metropolitan hourly traffic volumes, across an average weekday.

Sources: BTRE (2007) and BITRE estimates.

Figure 14: Difference in hourly profiles of average weekday and average weekend costs



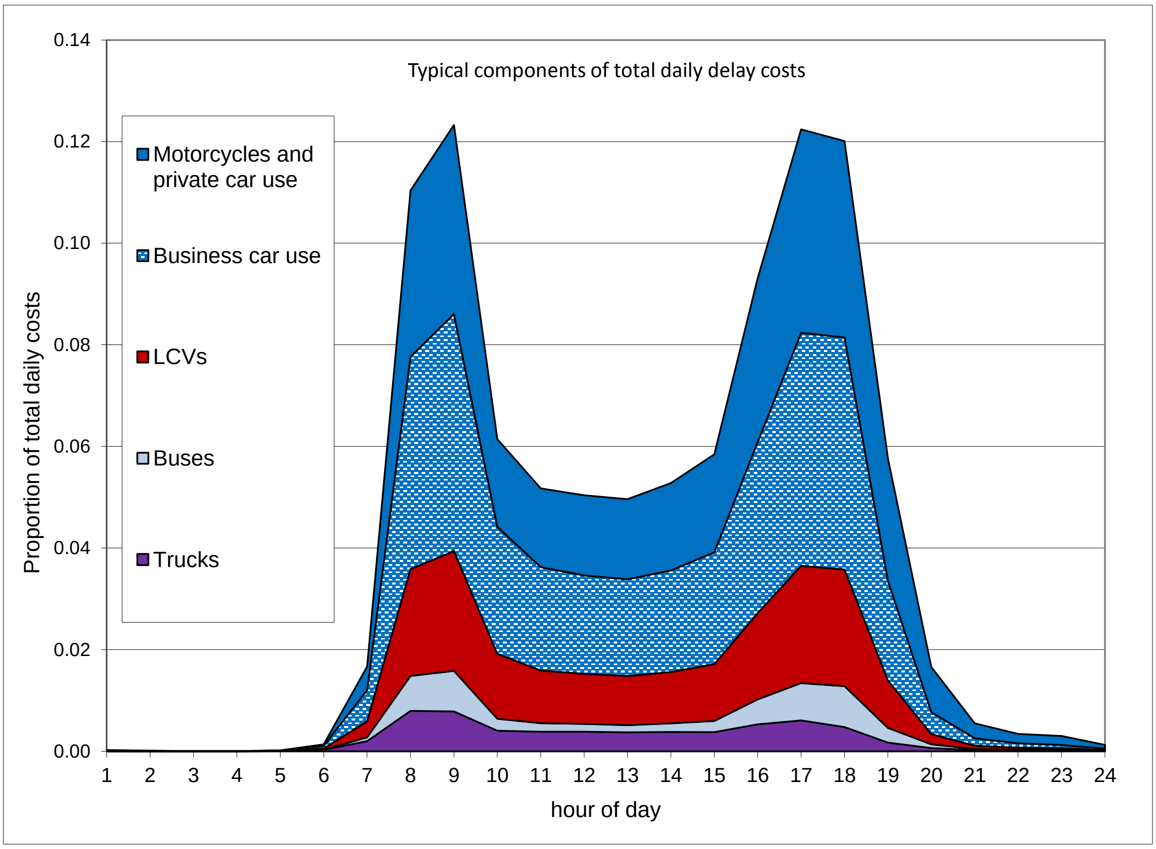
Note: Proportion of weekday total delay costs by current hourly amounts (with average weekend traffic distributions showing less intense cost levels during am and pm 'peak' periods than average weekday patterns).

Sources: BTRE (2007) and BITRE estimates.

Total daily traffic levels during the weekend tend to be substantially lower than average (generally around 80 per cent of average weekday levels), and typically do not exhibit the same concentration around the standard morning and evening peak hours. The result is avoidable congestion costs for a typical weekend day totalling around 60 per cent of those for a typical weekday (Figure 14), and with a far more uniform pattern of congestion intensity throughout the day.

Figure 15 displays the estimated contribution to total delay costs from the different vehicle types (and the hourly variation of these components, for typical metropolitan traffic volumes over an average 2015 weekday), with passenger car delay costs accounting for about 70 per cent of the daily fleet aggregate.

Figure 15: Representative profile of total vehicle delay costs, across an average weekday



Notes: Proportion of daily total by current hourly amounts. Weekend traffic distributions tend to show less severe concentrations during peak periods than such average weekday patterns.

Sources: BITRE (2007) and BITRE estimates.

Estimates of avoidable congestion costs

For this updated study (based on the methodology of previous Working Paper 71), BITRE derives aggregate congestion cost estimates for the 2015 financial year of approximately $16.5 billion (on the basis of potentially avoidable social costs, calculated from the deadweight losses associated with current congestion levels across the Australian capitals). This national metropolitan total (given in terms of 2010 Australian dollars[16]) is comprised of approximately $6 billion in private time costs (losses from trip delay and travel time variability), $8 billion in business time costs (trip delay plus variability), $1.5 billion in extra vehicle operating costs, and $1 billion in extra air pollution damage costs.

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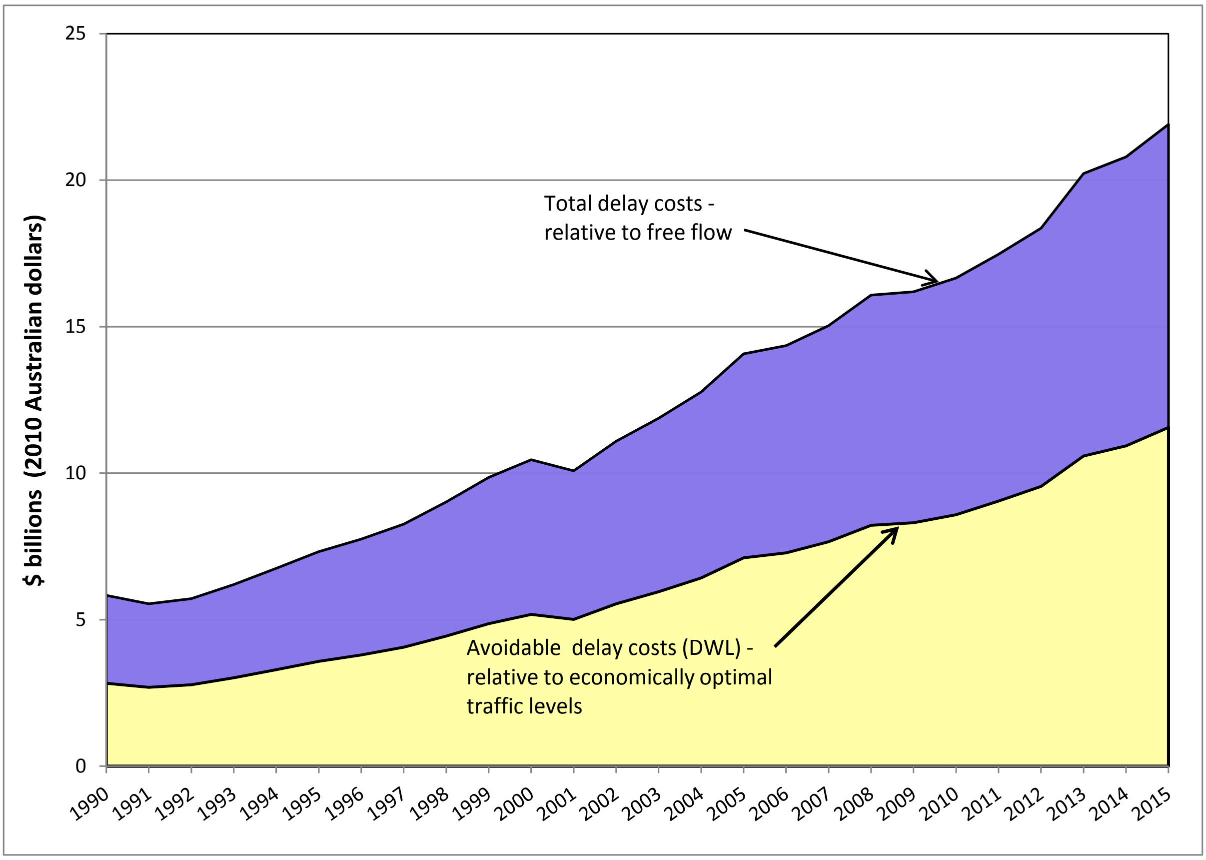
[16] BITRE estimates of real congestion costs are given in terms of 2010 Australian dollars throughout this Information Sheet, since the most complete coverage of road user unit costs available at the time of the analysis (Austroads 2012) provided unit values in A$2010.

Figure 16: Trends in total and avoidable congestion cost levels for trip delays, 1990–2015



Notes: Avoidable cost values are deadweight losses (for years ending June 30) associated with total metropolitan traffic delay across all Australian capital cities. Total delay costs relate to travel time losses, across all annual capital city traffic, compared with travel at free flow speeds.

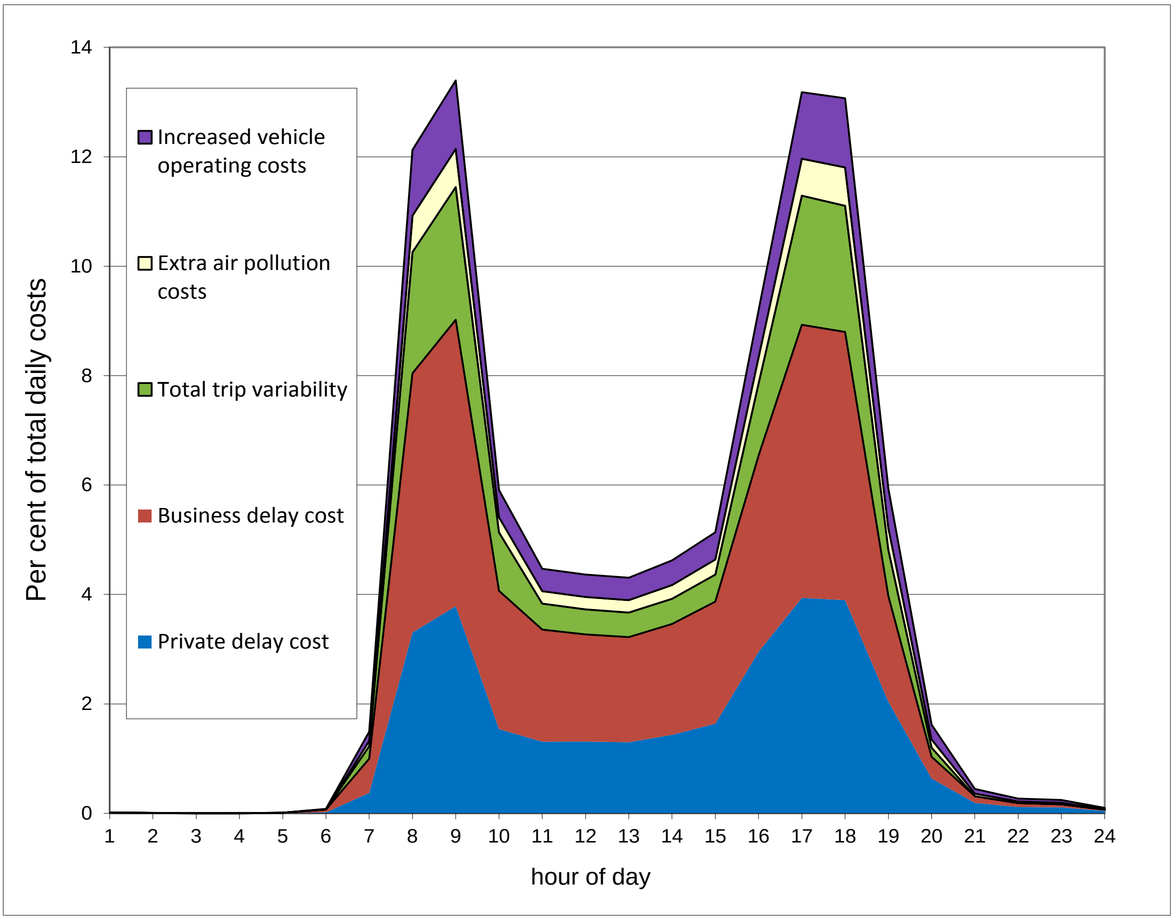
Sources: BTRE (2007) and BITRE estimates.

Figure 16 displays the estimated trend in avoidable costs due to trip delay (i.e. the deadweight loss of actual congestion levels—relative to economically optimal traffic levels) over the last decade and a half, plotted showing such levels' rough proportion of total delay costs (i.e. travel time costs relative to free flow speeds). The 2015 estimate for avoidable trip delay (metropolitan aggregate of about $11.6 billion) accounts for approximately 53 per cent of total delay costs for that year.

The national 2015 total for avoidable costs (of about $16.5 billion, across all cost components) is spread over the capital cities, with Sydney currently the highest (at about $6.1 billion), followed by Melbourne (with about $4.6 billion), Brisbane ($2.3 billion), Perth ($2 billion), Adelaide ($1.1 billion), Canberra ($0.2 billion), Hobart ($86 million) and Darwin ($30 million). This is significant historical growth from estimated 1990 levels (see Table 4)—with city specific levels having risen from approximately $1.9 billion for Sydney, $1.7 billion for Melbourne, $0.4 billion for Brisbane, $0.5 billion for Perth, $0.45 billion for Adelaide, $54 million for Canberra, $39 million for Hobart and $8 million for Darwin; for a national 1990 total of about $5 billion (all values again in 2010 Australian dollars).

The average daily composition of the current estimates for avoidable social costs (DWL of metropolitan road congestion) is demonstrated in Figure 17, along with the typical hourly variation of the cost components' relative sizes.

Figure 17: Representative profile for major components of avoidable congestion costs



Notes: Proportion of daily total by hourly amounts. Deadweight losses associated with current average weekday congestion levels across the Australian capital cities.

Sources: BTRE (2007) and BITRE estimates.

Though the congestion cost values derived by this study are considerable, it should be emphasised the dollar estimates obtained are not directly comparable to standard aggregate measures of economic performance—such as Gross Domestic Product (GDP). Some elements involved in these costings would have GDP implications (e.g. the timeliness and reliability of freight and service deliveries will impact on business productivity levels). However, a major proportion of the derived social cost values refer to elements that play little part in the evaluation of GDP, such as the opportunity cost of time lost to delays during private travel. Essentially, the DWL valuation gives an (order-of-magnitude) estimate of the price society places on the disadvantages of congestion-related delays (and associated transport inefficiencies), relative to urban travel under less-dense traffic conditions (specifically, at economically optimal road traffic levels).

The (DWL-derived) aggregate cost values given in this study do not evaluate how the flow-on effects of any congestion changes will impact on general economic activity. While personal travel costs influence the availability and cost of labour, the largest component of the estimated avoidable congestion costs (i.e. travel time) is not directly measured in GDP. Though congestion improvements could have national productivity benefits (e.g. through reductions in labour or housing costs), the difficult issue of precisely quantifying all the possible impacts on GDP, resulting from some particular congestion management program, is beyond the scope of this study.

Some indication of the possible relativity between such different activity measures is provided by a Canadian study that calculated DWL-based costs of congestion for Toronto (Metrolinx 2008)—using similar travel cost components/inclusions to the BITRE methodology—and also made some assessments of the impacts of excess congestion on regional labour demand and economic activity. With the higher operating costs caused by congestion depressing business activity, and excess commuting time estimated to reduce overall job numbers, the Metrolinx study derived aggregate dollar values for the probable reduction in regional GDP (i.e. to a level below would exist in the absence of excess congestion) of a similar magnitude to their estimates of deadweight losses due to traffic delay (with their mean "reduction of regional economic output" estimate, at about $2.7 billion for 2006, approximately 80 per cent the size of their mean "annual excess cost of congestion" estimate, at about $3.3 billion for 2006)[17]. If these Canadian results are also applicable to Australian conditions, then perhaps the DWL values for avoidable congestion costs derived by this BITRE study correspond to a roughly similar magnitude in GDP decreases due to congestion effects.

Projecting avoidable congestion costs

The BITRE base case projections of urban travel, and consequent increases in average traffic delays, result in modelled BAU values for the avoidable social costs of metropolitan congestion roughly doubling from 2015 levels, of $16.5 billion, by 2030; rising to around the order of $30 billion—with the various baseline modelling scenarios having aggregate 2030 results ranging from $27.7 to $37.3 billion, depending upon the chosen input assumptions and model parameters.

The plausible range for aggregate BAU congestion cost increases is plotted in Figure 18; with time-series estimates, for each capital city, given in Table 4a (for the upper baseline scenario) and Table 4b (for the lower baseline scenario). In summary, the city-specific projections have avoidable cost estimates for Sydney rising from current (2015) levels of about $6.1 billion to between $9.5 billion (lower baseline estimate) and $12.6 billion (upper baseline estimate) by 2030; Melbourne values rising from around $4.6 billion (2015) to between $7.6 and $10.2 billion (2030); Brisbane rising from $2.3 to $4.1–$5.9 billion (2015–2030); Perth rising from $2 to $4.4–$5.7 billion; Adelaide rising from $1.1 to $1.7–$2.3 billion; Canberra rising from $0.2 to about $0.3–$0.4 billion; Hobart rising from $0.09 to $0.12–$0.16 billion; and Darwin rising from approximately $0.03 to $0.05–$0.07 billion.

Numerically, the aggregate base case values (national cost estimates out to 2020, averaged across BAU scenarios) happen to be very similar to those previously published in BTRE (2007) Working Paper 71. This is not totally unexpected, given that the same overall methodology (with only a few alterations to model inclusions during the update process) has been used for both studies—though how very close the results appear at first is actually partially coincidental. This is due to the Working paper 71 results being given in terms of older Australian dollars, and inflation effects (as well as underlying trends such as income growth changing road user unit costs) have to be allowed for. A more consistent comparison is given in Figure 19, where the BAU results from Working Paper 71 have been scaled, to agree with the updated costings on the earlier study's base year (2005). This re-based trend, though still roughly similar to the current study's results, makes it apparent how the earlier Bureau study (BTRE 2007) somewhat over-estimated expected congestion costs after 2008 (largely due to unforeseen effects—principally travel demand reductions flowing from the economic slowdown after the Global Financial Crisis).

Figures 20 and 21 provide plots of the upper baseline projections of avoidable congestion costs (based on estimated DWL trends), respectively by city and by primary cost components.

The proportion of the estimated cost totals due to *extra air pollution* declines during the projection period (see Figure 21), primarily due to the modelled emissions performance of the Australian vehicle fleet improving over time, and counteracting the underlying BAU increases in projected VKT (and average congestion intensity). This effect is less apparent for the *extra vehicle operating cost* component—since even though the average energy efficiency of the vehicle fleet is also forecast to improve over the projection period (e.g. see BITRE 2010, 2014d), consequent reductions in average vehicle running costs are offset to some extent by higher future fuel prices in the base case scenarios.

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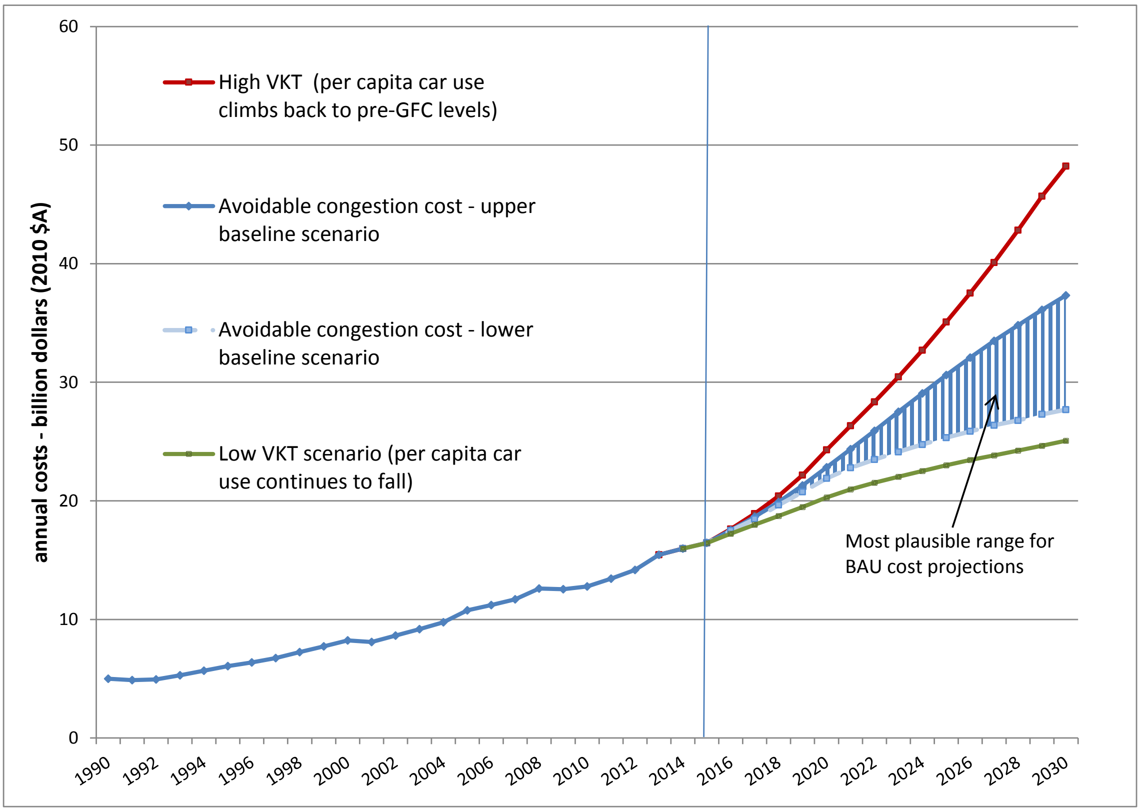
[17] Accounting for uncertainty in the valuation, Metrolinx 2008 had the annual 'estimated cost of congestion' for Greater Toronto falling within a 90 per cent confidence interval ranging from $2.9 to $3.8 billion (2006 Canadian dollars); and the estimated 'decreased GDP due to congestion' within a 90 per cent confidence interval ranging from $2.1 to $3.6 billion.

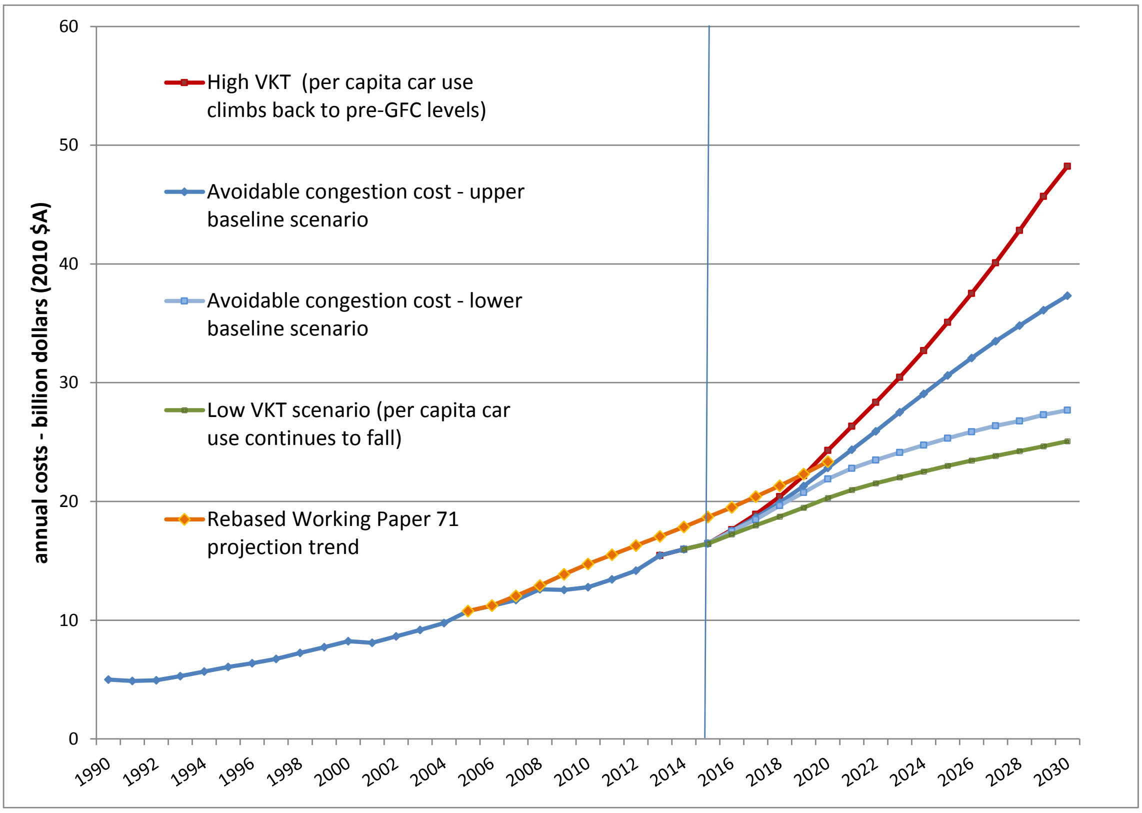
Figure 18: Trends in avoidable social costs of congestion, base case scenario results



Note: Deadweight losses (years ending June 30) associated with total metropolitan traffic levels across all Australian capital cities.

Sources: BTRE (2007) and BITRE estimates.

Figure 19: Comparison with base case scenario results from Working Paper 71



Note: Deadweight losses (years ending June 30) associated with total metropolitan traffic levels across all Australian capital cities.

Sources: BTRE (2007) and BITRE estimates.

Table 4a: Upper baseline projections of avoidable social costs of congestion, by city to 2030

Year ending 30 June	Sydney	Melbourne	Brisbane	Adelaide	Perth	Hobart	Darwin	Canberra	Metropolitan total
				($ billion, real 2010 Australian dollars)					
1990	1.91	1.66	0.38	0.45	0.50	0.039	0.008	0.054	5.00
1991	1.85	1.63	0.38	0.44	0.49	0.038	0.008	0.055	4.88
1992	1.85	1.65	0.41	0.43	0.49	0.039	0.008	0.057	4.94
1993	2.00	1.75	0.44	0.45	0.54	0.043	0.009	0.062	5.29
1994	2.14	1.84	0.50	0.46	0.61	0.046	0.009	0.066	5.67
1995	2.35	1.85	0.55	0.46	0.72	0.049	0.010	0.071	6.06
1996	2.50	1.90	0.59	0.46	0.79	0.051	0.012	0.074	6.37
1997	2.83	1.90	0.60	0.47	0.81	0.052	0.013	0.076	6.74
1998	2.97	2.06	0.68	0.49	0.90	0.051	0.014	0.079	7.24
1999	3.19	2.04	0.79	0.53	1.03	0.051	0.014	0.082	7.73
2000	3.38	2.16	0.96	0.58	1.00	0.053	0.015	0.088	8.23
2001	3.25	2.21	0.92	0.58	0.97	0.052	0.015	0.088	8.09
2002	3.53	2.42	0.97	0.60	0.94	0.055	0.016	0.091	8.63
2003	3.69	2.52	1.15	0.65	0.99	0.060	0.016	0.099	9.18
2004	3.86	2.67	1.24	0.70	1.11	0.067	0.018	0.110	9.77
2005	4.24	2.98	1.36	0.71	1.28	0.068	0.019	0.115	10.77
2006	4.41	3.03	1.47	0.77	1.33	0.071	0.020	0.119	11.21
2007	4.64	3.20	1.54	0.80	1.31	0.075	0.022	0.124	11.70
2008	4.87	3.44	1.79	0.86	1.41	0.079	0.024	0.131	12.61
2009	4.81	3.48	1.67	0.85	1.50	0.077	0.025	0.139	12.55
2010	4.70	3.53	1.87	0.90	1.54	0.076	0.025	0.144	12.78
2011	5.05	3.68	1.90	0.99	1.54	0.078	0.026	0.168	13.44
2012	5.06	4.10	1.99	1.02	1.71	0.082	0.027	0.181	14.17
2013	5.76	4.45	2.12	1.07	1.76	0.082	0.028	0.189	15.45
2014	5.88	4.55	2.20	1.09	1.93	0.084	0.030	0.194	15.97
2015	6.12	4.62	2.29	1.11	1.99	0.086	0.030	0.192	16.45
2016	6.54	4.85	2.48	1.19	2.15	0.092	0.033	0.203	17.52
2017	6.89	5.18	2.67	1.25	2.31	0.097	0.035	0.217	18.65
2018	7.28	5.54	2.87	1.33	2.50	0.102	0.037	0.232	19.90
2019	7.71	5.94	3.10	1.41	2.73	0.108	0.039	0.248	21.29
2020	8.18	6.38	3.35	1.50	2.98	0.114	0.042	0.266	22.82
2021	8.65	6.84	3.60	1.58	3.23	0.119	0.045	0.284	24.34
2022	9.14	7.28	3.85	1.67	3.50	0.125	0.048	0.302	25.91
2023	9.64	7.71	4.12	1.75	3.78	0.130	0.051	0.318	27.50
2024	10.12	8.12	4.39	1.84	4.07	0.135	0.053	0.334	29.07
2025	10.60	8.51	4.66	1.92	4.37	0.140	0.056	0.350	30.60
2026	11.08	8.88	4.92	1.99	4.64	0.145	0.059	0.365	32.09
2027	11.52	9.21	5.17	2.06	4.92	0.149	0.062	0.379	33.49
2028	11.90	9.55	5.43	2.13	5.19	0.152	0.065	0.393	34.81
2029	12.25	9.88	5.69	2.19	5.46	0.156	0.067	0.406	36.10
2030	12.60	10.19	5.94	2.25	5.69	0.159	0.070	0.419	37.32

Notes: Values are based on deadweight losses for excess traffic congestion. Avoidable social costs refer here to the estimated aggregate costs of delay, trip variability, vehicle operating expenses and motor vehicle emissions—associated with traffic congestion—being above the economic optimum level for the relevant network. Projection values relate to the ‘upper baseline’ scenario.

Sources: BTRE (2007), BITRE (2014a) and BITRE estimates.

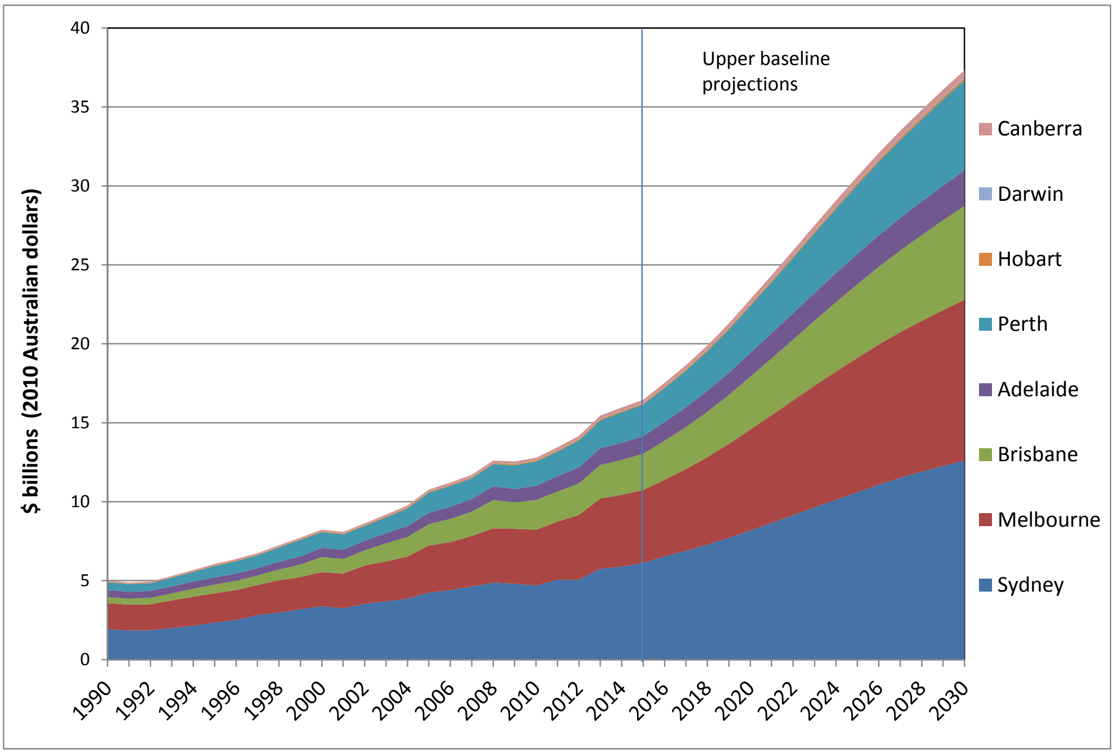
Table 4b: Lower baseline projections of avoidable social costs of congestion, by city to 2030

Year ending 30 June	Sydney	Melbourne	Brisbane	Adelaide	Perth	Hobart	Darwin	Canberra	Metropolitan total
				($ billion, real 2010 Australian dollars)					
1990	1.91	1.66	0.38	0.45	0.50	0.039	0.008	0.054	5.00
1991	1.85	1.63	0.38	0.44	0.49	0.038	0.008	0.055	4.88
1992	1.85	1.65	0.41	0.43	0.49	0.039	0.008	0.057	4.94
1993	2.00	1.75	0.44	0.45	0.54	0.043	0.009	0.062	5.29
1994	2.14	1.84	0.50	0.46	0.61	0.046	0.009	0.066	5.67
1995	2.35	1.85	0.55	0.46	0.72	0.049	0.010	0.071	6.06
1996	2.50	1.90	0.59	0.46	0.79	0.051	0.012	0.074	6.37
1997	2.83	1.90	0.60	0.47	0.81	0.052	0.013	0.076	6.74
1998	2.97	2.06	0.68	0.49	0.90	0.051	0.014	0.079	7.24
1999	3.19	2.04	0.79	0.53	1.03	0.051	0.014	0.082	7.73
2000	3.38	2.16	0.96	0.58	1.00	0.053	0.015	0.088	8.23
2001	3.25	2.21	0.92	0.58	0.97	0.052	0.015	0.088	8.09
2002	3.53	2.42	0.97	0.60	0.94	0.055	0.016	0.091	8.63
2003	3.69	2.52	1.15	0.65	0.99	0.060	0.016	0.099	9.18
2004	3.86	2.67	1.24	0.70	1.11	0.067	0.018	0.110	9.77
2005	4.24	2.98	1.36	0.71	1.28	0.068	0.019	0.115	10.77
2006	4.41	3.03	1.47	0.77	1.33	0.071	0.020	0.119	11.21
2007	4.64	3.20	1.54	0.80	1.31	0.075	0.022	0.124	11.70
2008	4.87	3.44	1.79	0.86	1.41	0.079	0.024	0.131	12.61
2009	4.81	3.48	1.67	0.85	1.50	0.077	0.025	0.139	12.55
2010	4.70	3.53	1.87	0.90	1.54	0.076	0.025	0.144	12.78
2011	5.05	3.68	1.90	0.99	1.54	0.078	0.026	0.168	13.44
2012	5.06	4.10	1.99	1.02	1.71	0.082	0.027	0.181	14.17
2013	5.76	4.45	2.12	1.07	1.76	0.082	0.028	0.189	15.45
2014	5.88	4.55	2.20	1.09	1.93	0.084	0.030	0.194	15.97
2015	6.12	4.62	2.29	1.11	1.99	0.086	0.030	0.192	16.45
2016	6.53	4.84	2.47	1.18	2.15	0.092	0.032	0.202	17.50
2017	6.83	5.13	2.63	1.24	2.29	0.096	0.034	0.215	18.47
2018	7.20	5.48	2.81	1.31	2.47	0.101	0.036	0.230	19.64
2019	7.54	5.79	2.99	1.37	2.67	0.105	0.038	0.244	20.75
2020	7.89	6.10	3.16	1.44	2.89	0.109	0.041	0.259	21.89
2021	8.15	6.36	3.29	1.48	3.08	0.112	0.043	0.271	22.79
2022	8.33	6.55	3.39	1.52	3.25	0.114	0.044	0.280	23.48
2023	8.51	6.71	3.50	1.54	3.41	0.116	0.045	0.289	24.13
2024	8.68	6.86	3.60	1.57	3.58	0.117	0.047	0.296	24.74
2025	8.83	7.00	3.69	1.59	3.74	0.118	0.048	0.304	25.33
2026	8.98	7.13	3.78	1.61	3.88	0.119	0.049	0.310	25.86
2027	9.12	7.25	3.87	1.63	4.02	0.120	0.051	0.317	26.38
2028	9.22	7.34	3.94	1.64	4.14	0.120	0.051	0.323	26.78
2029	9.35	7.48	4.04	1.66	4.27	0.121	0.053	0.329	27.30
2030	9.45	7.57	4.12	1.66	4.37	0.121	0.054	0.334	27.69

Notes: Values are based on deadweight losses for excess traffic congestion. Avoidable social costs refer here to the estimated aggregate costs of delay, trip variability, vehicle operating expenses and motor vehicle emissions—associated with traffic congestion—being above the economic optimum level for the relevant network. Projection values relate to the 'lower baseline' scenario.

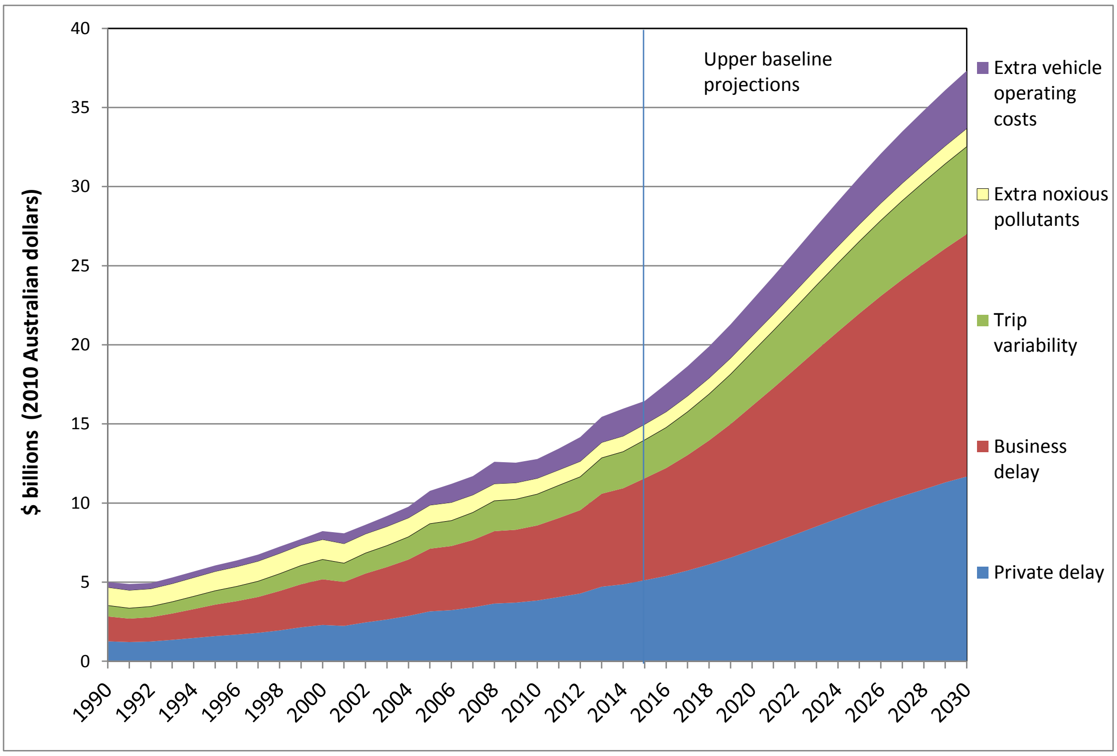
Sources: BTRE (2007), BITRE (2014a) and BITRE estimates.

Figure 20: Upper baseline projections of avoidable social costs of congestion, by city



Sources: BTRE (2007) and BITRE estimates.

Figure 21: Avoidable congestion cost components, upper baseline scenario projections



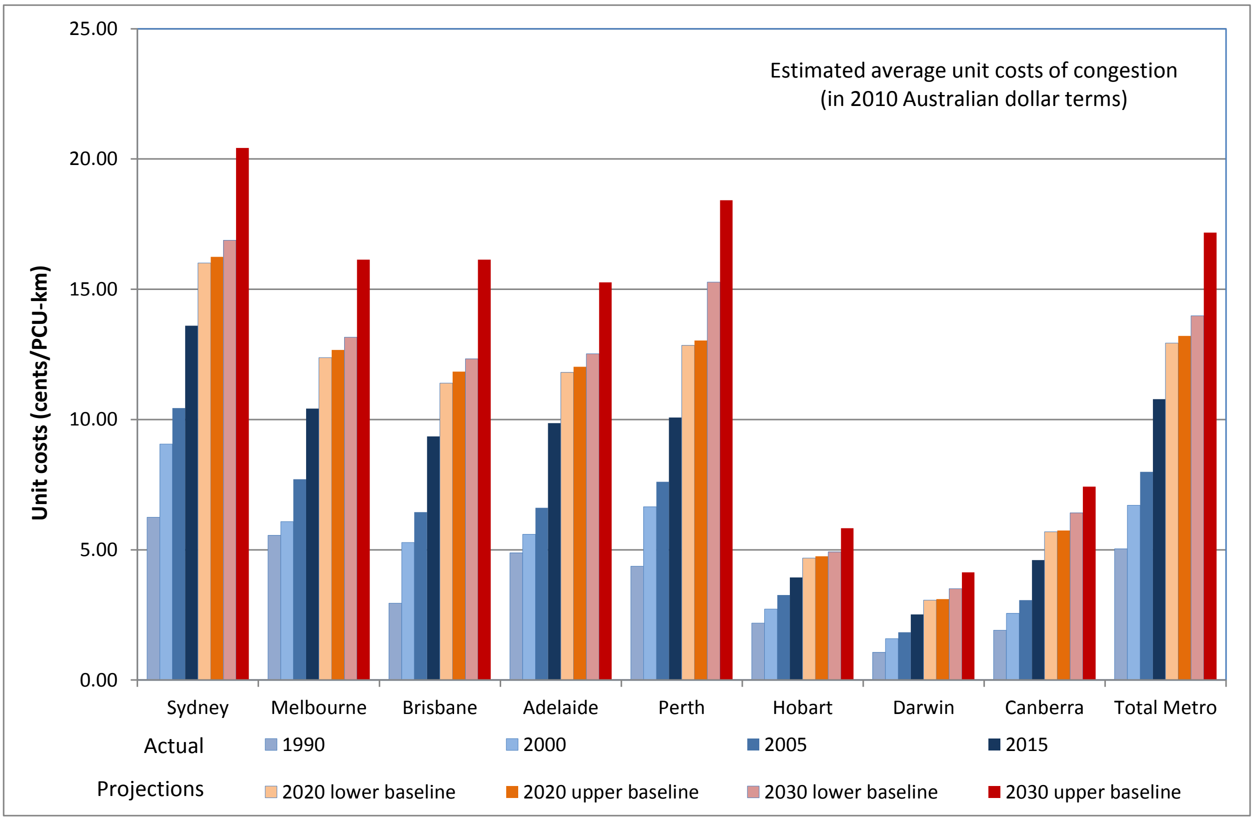
Note: Such (deadweight loss) trend values, for total metropolitan traffic effects, would probably be about 1-2 per cent higher if a further cost component—for extra greenhouse gas emissions due to excess congestion—was added, using standard control costs for CO_2.

Sources: BTRE (2007) and BITRE estimates.

Unit costs of congestion

Under base case trends, the average unit costs of urban traffic congestion are forecast to rise substantially over the projection period—as average delays become longer, congestion more widespread and the proportion of freight and service vehicles increases. Figure 22 displays how the unit congestion cost trends (in average cents per PCU-km) vary between the capital cities, and demonstrates the evolution over time in congestion cost intensity (i.e. in aggregate avoidable congestion costs for metropolitan Australia divided by total traffic in PCU-km terms).

Figure 22: Average unit costs of congestion for Australian metropolitan areas



Notes: Costs here refer to avoidable social costs, and are based on the deadweight losses associated with the relevant congestion levels. That is, these unit social costs refer to the estimated aggregate costs of delay, trip variability, vehicle operating expenses and motor vehicle emissions—associated with traffic congestion above the economic optimum level for the relevant networks—divided by the total travel (in PCU-km performed) on each network. Unit costs in terms of c/km (i.e. using VKT instead of PCU-km as the divisor) are typically around 10 per cent higher than these c/PCU-km values (e.g. the 2030 upper baseline value for the metropolitan average is 19.1 c/km, as opposed to the graphed 17.2 c/PCU-km).

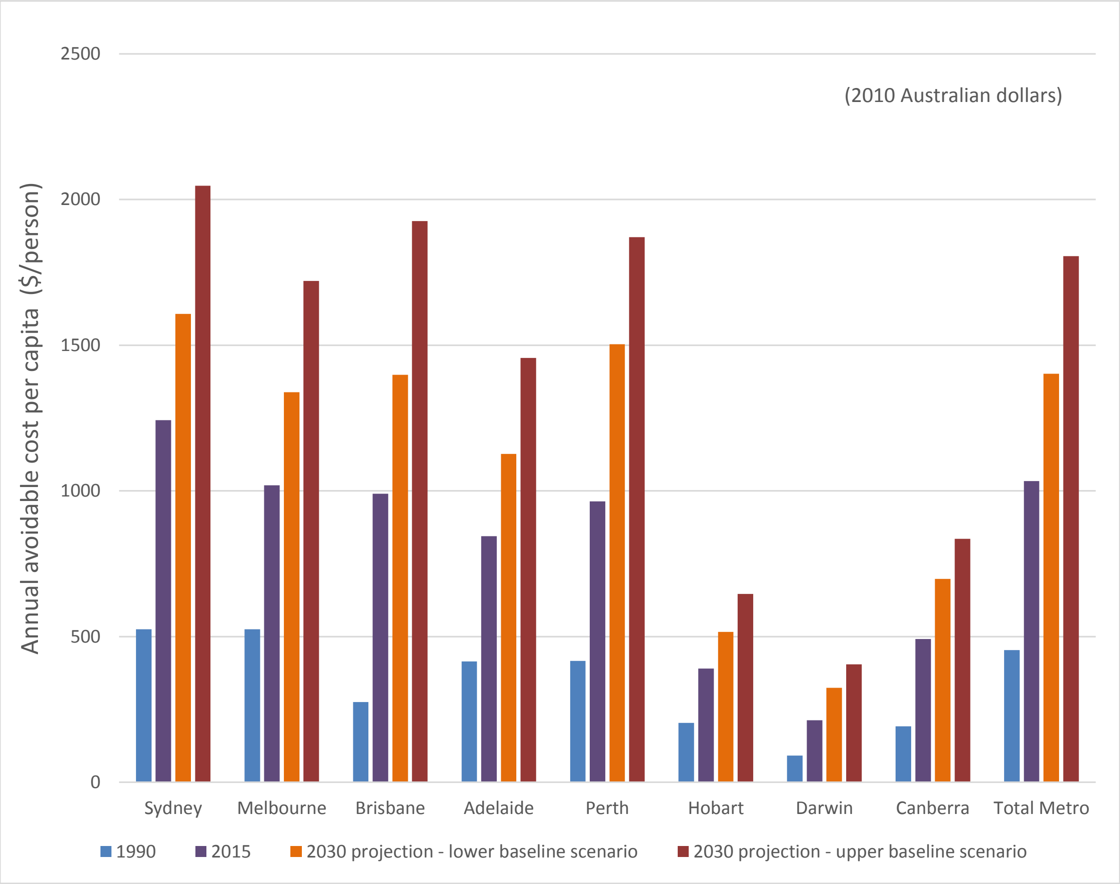
Sources: BTRE (2007), ABS (2013b), BITRE (2014a, 2014b) and BITRE estimates.

Such unit costs have already risen significantly over the last few decades; and for the metropolitan average, the plausible range for BAU congestion (as given in Figure 18) implies further increases—from 30 per cent (lower baseline scenario) to 60 per cent (upper baseline scenario)—are to be expected over the period from 2015 to 2030, if aggregate VKT and road capacity both continue to increase at close to historical average levels.

In particular, Figure 22 illustrates how the projected unit costs grow quite dramatically, especially between 2020 and 2030, for the ‘upper baseline’ VKT increases. This indicates that should metropolitan vehicle use experience growth over the next decade and half towards the higher end of the base case range, then higher than historical rates of increase in *effective* network capacity—through extra infrastructure provision, more efficient use of existing infrastructure or improved travel demand management (including modal shift)—could be required to prevent average congestion intensity from swelling.

Referring to Figure 23, the range in base case congestion estimates (Figure 18) is equivalent to 2015–2030 increases in (metropolitan average) per capita congestion costs of between 36 per cent (lower baseline scenario) and 75 per cent (upper baseline scenario).

Figure 23: Average per capita congestion costs for Australian metropolitan areas



Notes: Costs here refer to avoidable social costs, and are based on the deadweight losses associated with the relevant congestion levels. That is, these per capita social costs refer to the estimated annual costs of delay, trip variability, vehicle operating expenses and motor vehicle emissions—associated with traffic congestion above the economic optimum level for the relevant networks—divided by the resident population (for the years ending 30 June) for each capital city (ABS GCCSA geographies).

Sources: BTRE (2007), ABS (2014, 2013a), BITRE (2014a, 2014b) and BITRE estimates.

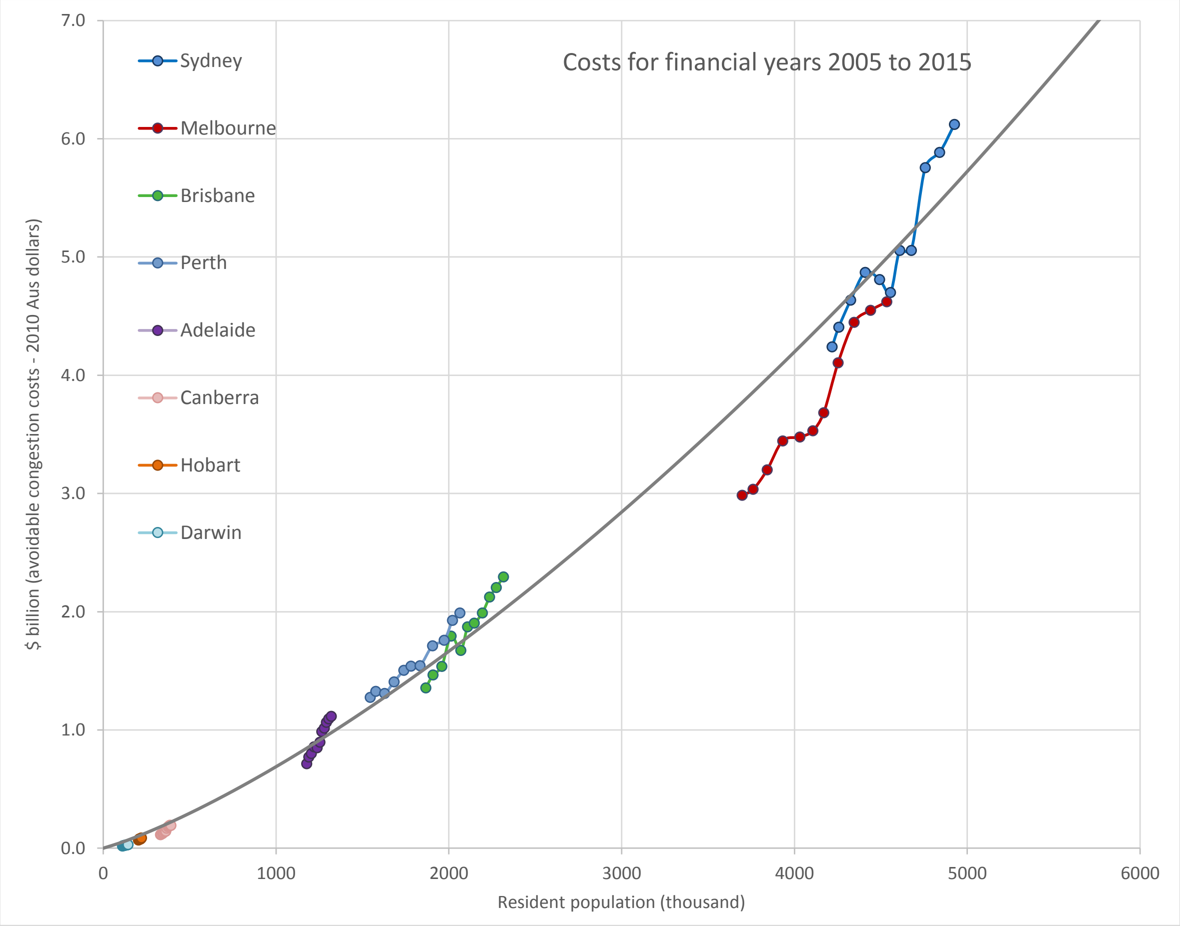
As is apparent from Figure 23, the 5 larger capital cities (Sydney, Melbourne, Brisbane, Perth and Adelaide) have current per capita congestion levels (typically around the order of $1000 per person per annum) well above the smaller capitals (Canberra, Hobart and Darwin—in 2015, all averaging less than $500 per person per annum); with the largest in population, Sydney, also having the largest per capita value. Thus, by plotting each of the cities' annual costs on the same graph, relative to their population levels (see Figure 24a), they basically form an arc of climbing congestion totals—loosely tracing out a trend of intensifying congestion with population that gradually, as you move to higher populations, gets more strongly increasing than linear.

If we then roughly draw a trend-line through this sweep of historical congestion costs (Figure 24a, simply fitting a basic power curve to the cities' aggregate data-points), they string out along that line—with the cities approximately separating into three groups: with the smaller capitals (Canberra, Hobart and Darwin) at the base of this implied 'average' trend-line; the three next larger cities (Brisbane, Perth and Adelaide) forming a rough middle cluster further along the line; and the two largest cities (Sydney, Melbourne) both well up the curve.

Furthermore, Figure 24a has (like Figures 22 and 23) a time evolution element, showing how aggregate costs have increased for each city over the last decade. Note that wherever most cities happen to sit along the 'average' (cost versus population) trend curve, their averaged increase in annual congestion costs over the previous 10 years has typically been faster than the rate of increase on that part of the curve (perhaps due to each city experiencing issues with major network bottlenecks as traffic has grown).

For those portions of the decadal city profiles that overlap, there tends to be rough general agreement in magnitude (i.e. the congestion values exhibited at particular population levels for one city are typically similar to values for another city once the other grows to those population levels).

Figure 24a: Avoidable congestion costs by city population levels, historical trend

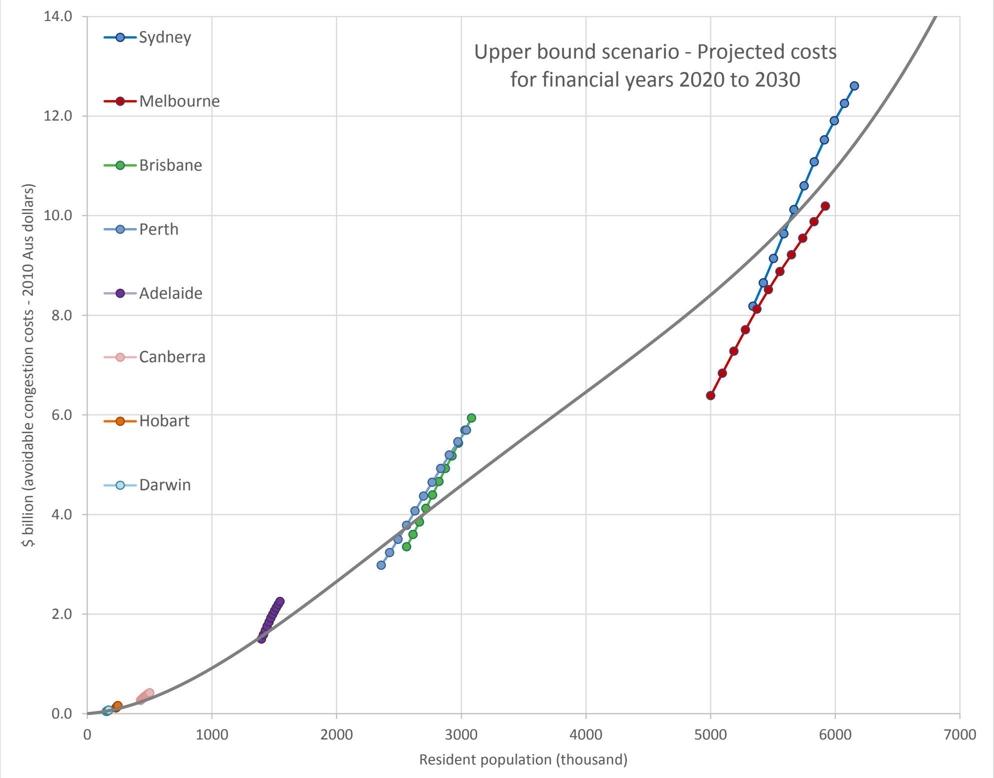


Note: Costs (given in 2010 Australian dollars) refer to annual avoidable social costs, based on the deadweight losses associated with the relevant capital city's levels of excess trip delay, trip variability, vehicle operating expenses and motor vehicle emissions due to congestion—plotted relative to the resident population (ABS GCCSA geographies) for the city (for years ending 30 June, from 2005 to 2015).

Sources: BTRE (2007), ABS (2014), BITRE (2014a) and BITRE estimates.

In an equivalent manner, the resulting city by city patterns for the base case projections are portrayed in Figure 24b (for the upper baseline scenario) and Figure 24c (for the lower baseline scenario)—again for decadal cost growth (2020–2030).

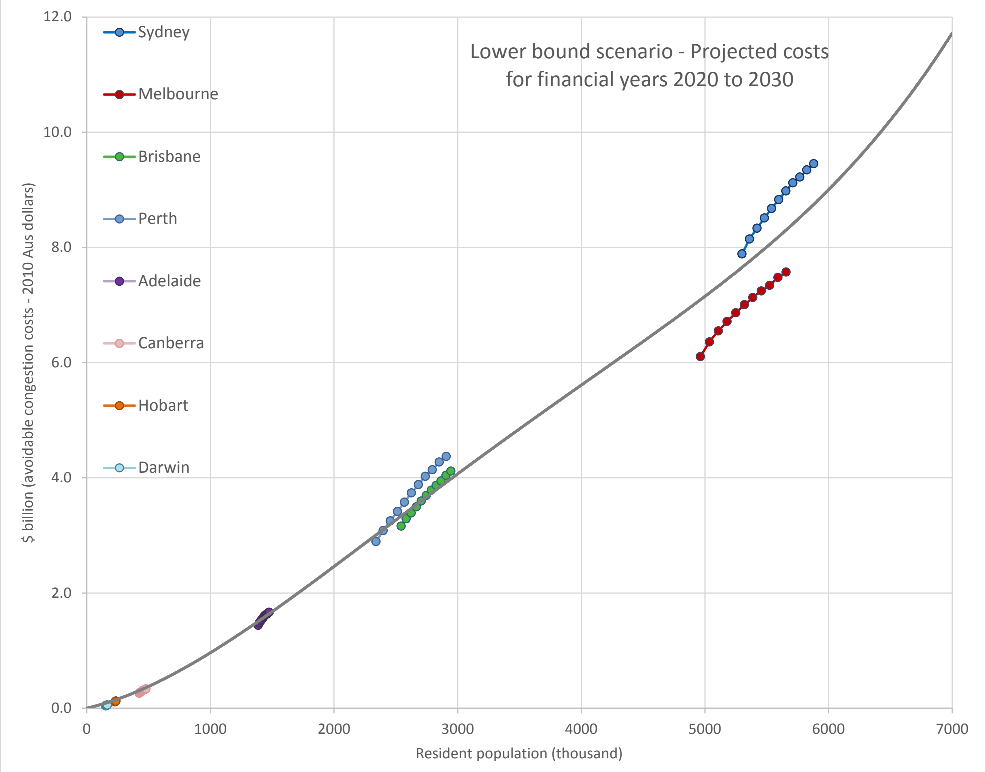
Figure 24b: Base case congestion costs by city population levels, upper baseline scenario



Note: Costs (A$2010) refer to annual avoidable social costs, based on the deadweight losses associated with the relevant capital city's level of excess congestion; plotted relative to projected population, for the upper baseline scenario (years ending 30 June, 2020–2030).

Sources: BTRE (2007), ABS (2013a) and BITRE estimates.

Figure 24c: Base case congestion costs by city population levels, lower baseline scenario



Note: Costs (A$2010) refer to annual avoidable social costs, based on the deadweight losses associated with the relevant capital city's level of excess congestion; plotted relative to projected population, for the lower baseline scenario (years ending 30 June, 2020–2030).

Sources: BTRE (2007), ABS (2013a) and BITRE estimates.

Sensitivity scenarios for projection trends

As mentioned previously, both the complex nature of attempting to mathematically replicate the occurrence of urban congestion and the approximations inherent in the Bureau's aggregate projection methodology (used both in this study and BTRE 2007), lead to significant levels of uncertainty in the cost estimation process. Forecasting of some major input parameters—given an uncertain future, especially over the longer term—will also be inescapably quite imprecise.

As a guide to the level of approximation, and how wide the range might be for possible future social costs of congestion in Australia, this section of the information sheet reports the results of various sensitivity tests. Basically, these tests run a series of alternative future scenarios, altering the input assumptions and/or default parameter settings for the models to see how sensitive the final cost estimates are to possible variations (or uncertainty in such input values).

A certain amount of modelling sensitivity—or uncertainty in the future metropolitan costing levels, primarily concerning the outlook for travel demand patterns—has already been dealt with:

- by the use of a range for the main base case projection results (between the lower baseline scenario and the upper baseline scenario, as given in Figure 18); and
- Figure 18 also presenting the resulting avoidable cost trends for a 'High VKT' scenario—with higher than median population growth, and increasing VKT per capita over the medium term—and a 'Low VKT' scenario—with lower than median population growth, and decreasing VKT per capita over the medium term.

Other important factors in the model specifications that are quite speculative concern the extent of average annual increases in future road network capacity, especially over the longer term. As discussed, effective capacity increases can be promoted by factors such as: infrastructure development (including urban design improvements); enhanced transport systems operation or delivery of services; and travel demand management (including pricing reforms). Figure 25 displays the results on the upper baseline scenario from differing model inputs for future road capacity provision.

Specifically, with underlying VKT increases for all three BITRE scenarios shown in Figure 25 averaging approximately 2.3 per cent per annum between 2015 and 2030:

- the high cost scenario (red trend-line of Figure 25) assumes that annual increases in road-lane supply start decreasing after this year, and fall to zero for all the capitals by about 2020— i.e. the scenario has no further effective capacity increases thereafter (either through improved infrastructure or traffic management measures), leading to strongly rising average volume to capacity ratios (V/C) for future urban roads—essentially estimating the effects of having to accommodate substantially higher traffic levels in the future on the current road network
- the lower than baseline scenario (green trend-line of Figure 25) assumes that, over the projection period, effective network capacity increases at roughly twice the historical average rate, leading to substantially lower values for average V/C in the future than for the upper trend-lines[18].

The higher cost ('High V/C') BITRE scenario can be compared with congestion cost estimates performed for Infrastructure Australia's recent (April 2015), *Australian Infrastructure Audit*—as part of their assessments of a wide range of infrastructure services. The urban congestion projections conducted for the Infrastructure Australia (IA 2015) Audit[19] assumed a 'low transport investment scenario' that, over the period to 2031, only increases the current extent of metropolitan transport infrastructure by network enhancements already under construction or committed to. Both scenarios use the ABS 'Series B' population projections as the basis for future travel demand trends. The basic specifications of both these capacity-constrained projection scenarios are thus quite similar, and the congestion cost results of both the BITRE High V/C and the IA 2015 modelling configurations also happen to be similar.

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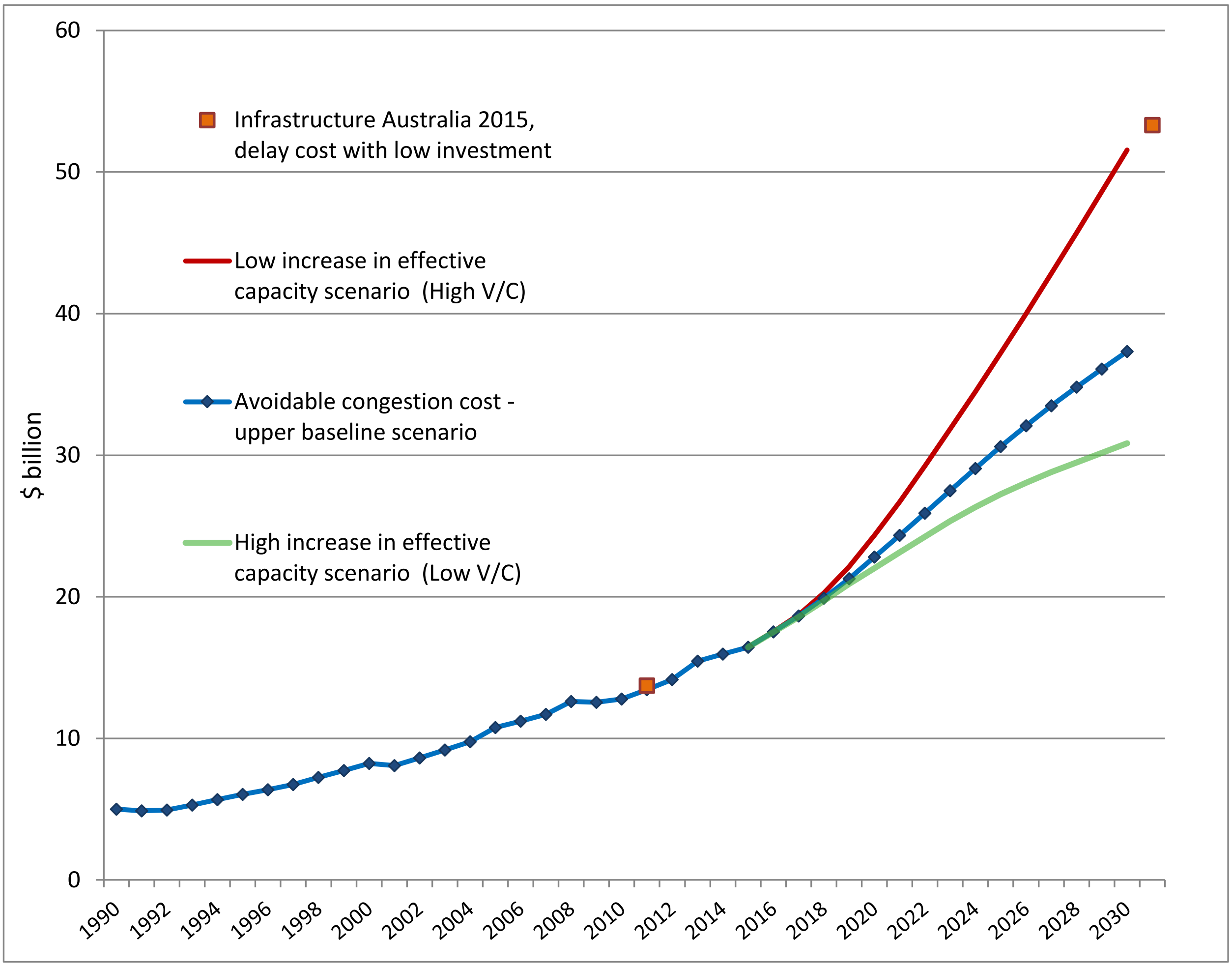
[18] These particular road supply parameter adjustments were done using model runs otherwise based on the 'upper baseline' scenario—whilst performing a similar 'Low V/C' parameter alteration on the lower end of the baseline range (i.e. using the 'lower baseline' VKT trends) results in 2030 congestion values of approximately $22 billion.

[19] Results based on city-by-city traffic modelling by Veitch Lister Consulting (2015), e.g. *Greater Melbourne – Travel modelling report*.

Despite significant differences in methodology[20] between the two traffic simulation approaches, both scenarios estimate that urban road congestion costs for Australia could hypothetically climb to over $50 billion per annum by about 2030, if current metropolitan networks do not receive any further increases to effective capacity[21].

Figure 25: Sensitivity of congestion cost projections to road supply assumptions



Notes: Cost values for BITRE results refer to *avoidable* social costs (in 2010 Australian dollars), and are based on the deadweight losses associated with the relevant congestion levels; including estimated annual costs of traffic delay, trip variability, vehicle operating expenses and motor vehicle emissions—associated with traffic congestion above the economic optimum level. Congestion cost estimates performed for Infrastructure Australia's *Australian Infrastructure Audit* (2015) relate to *total* delay costs (relative to free flow traffic, in 2011 Australian dollars); and do not have exactly the same range of cost category inclusions as the BITRE estimates.

Sources: BTRE (2007), Infrastructure Australia (2015), BITRE estimates.

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[20] One of the main differences concerns comparison speeds—with IA 2015 congestion values being based on total delay costs (i.e. relative to free flow speeds), while BITRE avoidable social costs are relative to economically optimal traffic speeds. The IA 2015 results have the advantage of underlying network assignment modeling (Veitch Lister Consulting 2015) being conducted for each of the major cities, compared with the less-detailed BITRE aggregate estimation method. The BITRE analyses included a wider range of cost categories than the IA values (which are more purely delay-based); and the BITRE calculations deal with the various trip and vehicle types involved in urban travel somewhat differently—but overall, the much higher modelling detail of the IA approach offers intrinsically higher precision for the simulation of congestion effects, especially for location-based impacts (such as dealing with specific city bottlenecks). There are also various other lesser differences between the two modelling exercises and their input parameters, such as concerning the exact values used for unit road user costs.

[21] The *Australian Infrastructure Audit* (IA 2015) results have estimated congestion costs (for total vehicle delay, summed across the 6 largest capital cities) rising from about $13.7 billion in 2011 to $53.3 billion in 2031 (in 2011 Australian dollars)—under a 'low transport investment scenario' that increases road traffic volumes over the projection period while holding the network infrastructure of each city roughly at current levels.

Structural change

As to be expected (and is apparent in the results plotted in Figures 18 and 25), lower-range projections of aggregate congestion costs result from those scenarios assuming lower population growth rates, lower levels of per capita travel or otherwise lowered volume to capacity ratios for future urban roads. Though each of the scenarios described so-far, even for the lower-range input settings, have still predicted some rise in avoidable congestion costs over the projection period. Yet eventual reductions in the aggregate congestion costs could be feasible (especially over the medium to longer term) from potentially 'disruptive' technologies (such as autonomous vehicles) or from structural change either to the management and financing of urban transport systems (such as the application of optimal congestion pricing across capital city road networks) or to standard work and commuting practices (such as offered by greater use of teleworking and vehicle sharing through communications technology).

A wide range of actual congestion levels are possible over the coming years, depending on future social patterns, technology implementation and associated infrastructure development. One example of a potential structural change, that could even be large enough to alter the expected medium-term saturation path (in per capita travel, as plotted in Figure 6), is the likely future availability of self-driving road vehicles—where infrastructure allowing autonomous or semi-autonomous vehicle movement will both increase the motorisation participation rate (with the possibility of vehicle use by persons currently not able to drive) and support easier, more stress-free trips. Though a substantial amount of driverless vehicle technology already exists at the prototype stage (with some on-road testing starting to appear), large-scale deployment of such systems on actual road networks is still likely to be well into the future. The current base case analyses assume that any elements of autonomous vehicle technology that start appearing on Australian roads over the coming decades will only have a relatively slight impact on overall vehicle travel within the 2030 projection timeframe chosen here.

As another sensitivity example, around possible *disruptive* changes to Australian transport systems, Figure 26 presents a somewhat speculative scenario based on assuming a relatively rapid deployment of autonomous vehicles across Australian city networks (otherwise applied to the economic and demographic specifications of the upper baseline scenario).

Based on a fast technology penetration scenario—from a paper detailing some projection analyses by Telstra researchers (Bradlow and Jayachandra 2015) into the potential medium-term impacts of emerging vehicle and communications technology—this hypothetical traffic simulation assumes that fully autonomous vehicles are introduced by about 2020, and that their take-up is so swift (driven primarily by safety and convenience advantages) that by 2030 they account for about 30 per cent of the light vehicle fleet.

The sizeable amount of fleet replacement required by such a rapid movement to autonomous vehicles would have major implications for fleet-wide energy and emission intensities; and could lead to a massive acceleration in the penetration of electric vehicle use (possibly dramatically lowering total CO_2 emissions from light vehicles). Since autonomous vehicles offer significant improvements to average traffic speeds and throughput—through reduced vehicle headways freeing up road capacity, advanced logistics (especially for trips involving multiple passengers with varying origin-destination needs) optimising VKT, and fewer stoppages from traffic incidents—this particular scenario results in 2030 congestion estimates substantially below those of the upper baseline scenario (Figure 26).

Various related scenarios, adding in possible effects for other viable innovations (such as more widespread use of vehicle sharing, tele-working or efficient road pricing[22]), also delivered congestion cost reductions, with some modelled combination scenarios deriving estimates for 2030 avoidable costs of even below present levels. There are so many unknown factors in these sorts of fairly speculative modelling scenarios that the results are especially rough—but at least indicative that various congestion management options (most of which are enhanced as vehicle and communications technology progresses) offer significant potential for future improvements to network efficiencies, relative to currently expected BAU trends.

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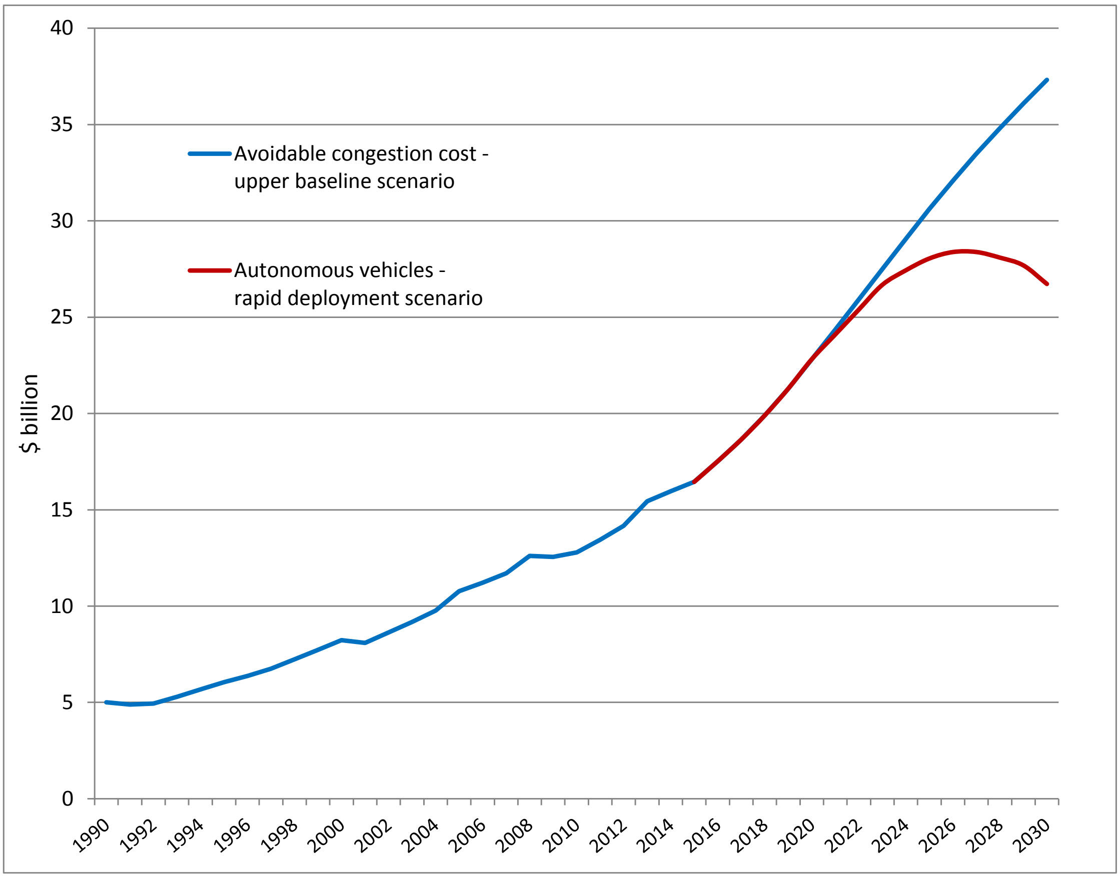
[22] Appropriate road or congestion pricing mechanisms could be even more important (than conventionally regarded) in a possible future where the ease of vehicle travel is substantially enhanced by communication or transport system technology—specifically, to help control potential 'rebound' travel effects. Historically, any significant reductions in generalised travel costs have tended to result in the encouragement of some extra (previously latent) travel. Due to Australian daily travel now apparently nearing per capita saturation levels, it would be expected that the attraction of such extra travel is less considerable than in the past—yet if some technology innovation strongly alters standard travel patterns, such previous structural relationships (as currently implied saturation levels) could change.

Figure 26: Sensitivity scenario for self-driving vehicles



Note: The 'autonomous vehicle' scenario roughly estimates the effects on avoidable congestion costs from assuming that approximately 30 per cent of urban VKT is accounted for by self-driving vehicles by 2030; with model input settings otherwise from the upper baseline scenario.

Sources: BTRE (2007), Bradlow & Jayachandra (2015), BITRE estimates.

The approximate nature of congestion estimates using aggregate modelling methods (as opposed to link-by-link network models), and the wide range of uncertainties concerning projection input parameters, impose limitations on the precision of a study like this (i.e. in terms of capability to simulate current and future urban congestion levels). However, despite a fairly wide range of 2030 endpoints, essentially all of the scenarios tested by the BITRE modelling using broadly business-as-usual or 'base case' input assumptions (for technology, demographic and macro-economic parameters), exhibited considerable increases in congestion costs over the projection period (2015 to 2030). As well, the relative increase in aggregate congestion costs estimated for capacity-constrained scenarios appears to be in general agreement with the results of more detailed network modelling of a similar scenario (Infrastructure Australia 2015).

So, irrespective of caveats around exact dollar valuations[23], the principal conclusions of this study essentially remain those of Working Paper 71:

- in the absence of improved congestion management, rising traffic volumes in Australian cities are likely to lead to escalating congestion impacts, such that the net social costs of congestion over the next 15 years (under scenarios with roughly business-as-usual increases in metropolitan travel) are expected to approximately double;
- the exact extent of actual congestion increases—and consequent implications for mobility and amenity in our cities—will depend on a broad range of social and technical factors, and careful analysis will be required of potential options (including suitable pricing measures and emerging technologies) when attempting to identify the most economically-efficient level and manner of congestion management.

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[23] With the wide range of results obtained by the various sensitivity tests giving some indication of inherent uncertainty levels in the projections.

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