Austroads

Research Report
AP-R534-16

Congestion and Reliability Review

Full Report

Congestion and Reliability Review: Full Report

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Abstract

The Congestion and Reliability Review measures the levels of congestion across major cities in Australia and New Zealand and identifies the key causes of congestion.

The report proposes an approach to identifying and assessing congestion interventions and overlays the key areas of focus for road and transport agency capability development to assist agencies in developing a congestion mitigation roadmap.

Keywords

traffic congestion, population growth, urban land use, road network performance, travel time, transport demand, road investment, road user satisfaction

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About Austroads

Austroads is the peak organisation of Australasian road transport and traffic agencies.

Austroads' purpose is to support our member organisations to deliver an improved Australasian road transport network. To succeed in this task, we undertake leading-edge road and transport research which underpins our input to policy development and published guidance on the design, construction and management of the road network and its associated infrastructure.

Austroads provides a collective approach that delivers value for money, encourages shared knowledge and drives consistency for road users.

Austroads is governed by a Board consisting of senior executive representatives from each of its eleven member organisations:

- Roads and Maritime Services New South Wales
- Roads Corporation Victoria
- Queensland Department of Transport and Main Roads
- Main Roads Western Australia
- Department of Planning, Transport and Infrastructure South Australia
- Department of State Growth Tasmania
- Department of Infrastructure, Planning and Logistics Northern Territory
- Transport Canberra and City Services Directorate, Australian Capital Territory
- Australian Government Department of Infrastructure and Regional Development
- Australian Local Government Association
- New Zealand Transport Agency.

Acknowledgements

We would like to acknowledge the assistance of Google in providing access to their Maps and Traffic datasets. This unique and rich data has allowed this report to measure and compare congestion across Australian, New Zealand, and international cities. Google's data, coupled with Deloitte's analysis, has enabled this evidence-based assessment to be undertaken at an unprecedented scale, using data that is aligned to road users' personal experience.

We would also like to thank Craig Moran and Bryan Wiley for their exceptional leadership and unwavering commitment throughout the Review and the substantial contributions from the cross-juridictional CRR Working Group, Professor David Hensher, Founding Director of the Institute of Transport and Logistics Studies in The University of Sydney Business School and Nick Patchett, Partner of Pillar Strategy UK. Finally, we would like to acknowledge the work of the Deloitte team led by Ian Clarke and including Jamye Harrison, Ric Simes, Roshan Mendis, Eamon McGinn, Konrad Gebels, Michelle Mountford, Kiril Alampieski, Sara Ma, Lucy Gregory, Irina Dima, John Vargas, Julian Grimm, Jason Qu, Shivana Thiru-Moorthy, Roger Dong, Johnny Han, Simon Dixon and Warwick Goodall.

Foreword

Traffic congestion is a major problem for urban Australia and New Zealand. While some of this reflects Australia's unprecedented economic success and growing population, congestion has also increased where infrastructure provision has lagged growth, and where land use, public transport and road developments have not been integrated into city plans.

Congestion is, of course, not a new problem. To resolve the traffic problems of ancient Rome, Julius Caesar outlawed the use of private vehicles on the city streets during the first 10 hours of the day. This early demand management intervention appears to have been successful, with Roman populace adjusting their travel patterns.

Though our leaders today rarely enjoy the same freedom of action as the Roman dictator, technology is driving a new revolution in transport management, and will become increasingly embedded in our lives over the next 20 years. For example, consumers today can use a smart phone to select the best route for their journey, access congestion and road closure data in near real time, allowing them to plan ahead, select the best route and navigate around incidents. In future, autonomous vehicles will access this information directly, and execute a journey with no human intervention.

Austroads commissioned this Congestion and Reliability Review to leverage the data provided by Google to allow road agencies to understand road network performance and the causes of congestion, using a consistent methodology across Australia and New Zealand. In addition, the available interventions to road agencies have proliferated and new capabilities will be required in future to continue the evolution from the traditional role of road builder to a manager of the future road network and regulator of the embedded technology.

The Review has unashamedly taken a customer-centric view of congestion with measures that are most relevant to their lives and journeys. This includes a time scheduling budget that includes the actual travel time and the additional buffer that must be allowed due to the uncertainty on how long a trip will actually take. We have also noted that consumers are as interested in public transport alternatives as driving on new roads, are using cars less, and only our population growth is delaying the 'peak car' effect observed in parts of Europe.

Zero congestion is not a realistic goal for a modern city in Australia and New Zealand. The technology that will become embedded in vehicles, roads and the road network will, however, help optimise the use of limited road corridors to both reduce the burden of congestion and make journeys safer. This report provides a baseline for how our road networks perform today, and practical frameworks to help road agencies to improve that performance in future.

Austroads congratulates the whole extended team on this work, and we particularly thank Google for providing their data as a pro-bono contribution to helping Australasia tackle congestion.

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Chapter 1 – Background

1.1 Australia and New Zealand (ANZ) Road and Transport Demand

- Australian and New Zealand growth in **vehicle-kilometres travelled continues to rise** at 1% per annum, at a lower rate than **population growth** (+1.3% p.a.) due to a **reduction in vehicle km per capita,** which peaked in 2004
- There are **three main vehicle-based road user types**: **Personal Vehicles** (75% of road users), **Light Commercial Vehicles** (15%) and **Freight** (3%), with different growth and demand dynamics

1.2 ANZ Road and Transport Supply

- In Australia, the urban road network supply (+1.2% p.a.) is increasing at a faster rate than demand, but in New Zealand, road supply (+0.2% p.a.) is not keeping pace with demand
- Expenditure on Australian roads has been 25% more than funding since 2005
- Expenditure on New Zealand roads has been marginally higher than funding since 2012

1.3 Definitions of Congestion

- Congestion can be measured in different ways, since 'absolute travel time' and 'travel time reliability' are both important to customers:
  - **Average Speed**. How fast does traffic in the city travel?
  - **Travel Time Delay**. How much is traffic delayed from free-flow conditions?
  - **Peak Reliability**. What is the statistical variability of peak travel times?
  - **Peak Scheduling**. How much time does a consumer need to budget to be 90% on time during peak periods, relative to free-flow?

1.4 Impact of Congestion

- Congestion cost is **correlated with population size**, but is systematically better in some cities
- The **Australian congestion cost** was estimated to be **A$16.3bn in 2015** and is forecasted to **grow by 5.5% per year** between 2016 and 2030; **Auckland's congestion cost** is estimated at over **NZ$1.25bn**

Chapter 2 – Customer Perspectives

2.1 Road User Satisfaction

- Road agencies are increasingly **shifting their focus to serving road users as customers**; in general they are most concerned with the reliability of a journey:
  - Commuters need to be at work on time
  - Commercial road users need to schedule delivery windows
  - Freight road users place high value on the arrival speed of goods to ensure efficient production
- **Congestion impacts the 'liveability' of ANZ cities** through loss of personal time, late arrival for employment and education, inability to forecast travel time, reduced health levels and a higher chance of collision

2.2 Acceptable Congestion

- The 'acceptable' level of congestion is a subjective concept related to both urban planning and customer expectations, with four defining factors:
  - **Commute time.** How many minutes per day are required to travel to work on average in a city?
  - **Stability of Commute Time.** Is commute time better or worse than it was last year?
  - **Scheduling.** How variable is the travel time, and what extra time should be scheduled for delays? Can travel time be reduced by travelling earlier or later?
  - **Productivity.** How much traffic flows through a given road compared to its theoretical capacity?
  - **Economic.** Can investment to reduce congestion be justified?

Chapter 3 – Congestion Performance

To ensure that comparison is not made between distinctly different ANZ cities, the cities have been 'grouped' primarily based on population size. The groups of cities are as follows:

- Group 1: Sydney and Melbourne
- Group 2: Perth, Brisbane, Adelaide and Auckland
- Group 3: Darwin, Wellington, Hobart and Canberra

The congestion performance analysis is based on up to 600km of state-managed roads in each city (as detailed in Appendix A.4), hence comparisons are better drawn among cities within the same group based on population size. It uses Google data collected from 9 September 2015 to 26 November 2015.

3.1 ANZ Weekday Congestion Performance

- ANZ cities have significant differences in congestion performance
  - **Sydney and Melbourne** have similar congestion metrics across the analysis, highlighting their similarity as Group 1 cities and as comparators for each other. Melbourne performs better in Travel Time Delay (23% compared to 31%), likely a consequence of its historically planned road network. In the afternoon peak Sydney's road users need to budget 50% additional travel time in order to arrive on time 90% of the time
  - **Adelaide** has slow Average Speeds (28km/hr), in part due to the proportion of its road network that has free-flow speeds of less than 50km/hr (85%); however it has comparatively good Afternoon Peak Reliability (3%), given its city size
  - **Perth, Brisbane and Wellington** have high Average Speeds (at least 50km/hr) , average Travel Time Delay (10-14%) and good Morning and Afternoon Peak Reliability (6-9%); all three have similar congestion measure outputs, despite their geographical differences
  - **Auckland** has low Reliability (10-12%) and road users need to budget 45% additional travel time in order to arrive on time 9 times out of 10 in the afternoon, a likely consequence of the geographical impediments to road characteristics and land use
  - **Darwin and Hobart** have good Reliability (1-6%) and low Travel Time Delay (4-8%), a likely consequence of their small city size and comparatively low demand
  - **Canberra** has the fastest Average Speed of ANZ cities (61 km/hr); its morning peak has poorer Reliability (7%) and Travel Time Delay (15%) than its afternoon peak (4% and 14%)
- **Peak periods vary in time and length for each city**, but are generally from 6am to 10am and 3pm to 7pm – Auckland, Perth and Sydney have the largest ranges

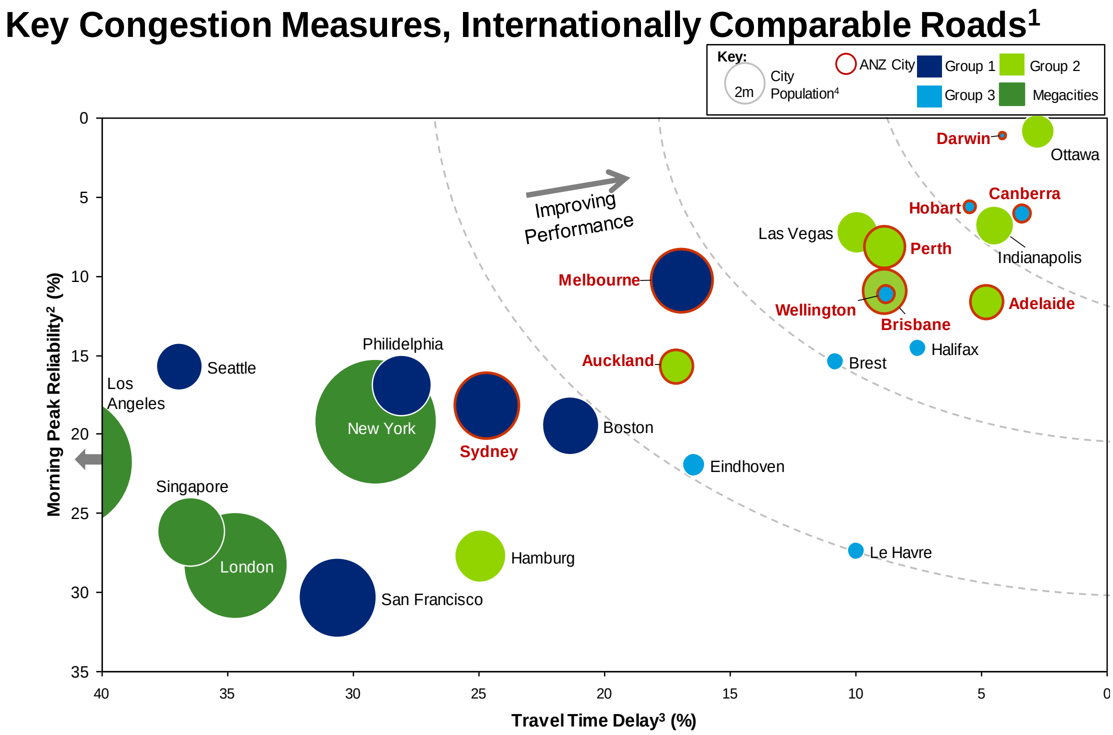
3.2 ANZ Weekend Congestion Performance

- Weekend Travel Time Delay accounts for between 15% and 25% of the total weekly Travel Time Delay
- On weekends, Average Speeds are slowest at approximately 12 midday
- On weekends, Travel Time Delay peaks at approximately 12 midday, with the highest delays observed in cities with larger populations

3.3 Congestion Performance in ANZ Cities and International Comparators

- **ANZ cities perform in line with international comparators** on the three key measures of Average Speed, Travel Time Delay and Reliability (see Exhibit A)
- Cities with **larger populations** (Megacities and Group 1) **have lower Reliability and Travel Time Delay performance**, however Group 2 and 3 cities have comparable performance
- **Group 1: Sydney and Melbourne** have lower Travel Time Delay, similar Average Speeds and similar Reliability as the comparators of Boston, Philadelphia and Seattle
- **Group 2: Auckland** has significantly higher levels of congestion than its international and local comparators in Group 2; **Brisbane and Perth** have similar delays to Las Vegas, but with lower Reliability; **Adelaide** has low Travel Time Delay compared to most Group 2 cities
- **Group 3:** All have relatively low congestion and high Reliability; **Wellington** performs worst and **Canberra, Hobart and Darwin** are similar to each other and to Ottawa

Exhibit A: ANZ cities perform in line with international comparators on Reliability and Travel Time Delay



Note: 1. Internationally Comparable Roads = Roads with free-flow speeds higher than 80km/hr included
2. AM Peak Reliability. The statistical reliability of travel times = 1.44 Standard deviation of travel time for 6am to 10am / Mean Travel time for 6am to 10ar
3. Travel Time Delay. Traffic delay from free-flow conditions = (Mean travel time for 24hrs / Minimum travel time for 24hrs) -1
4. City Population, as per OECD Data (2014)

Chapter 4 - Causes of Congestion

4.1 Key Causes of Congestion

- Each ANZ city has differing cause of congestion; the majority of ANZ urban congestion (~88-98%) is a consequence of recurrent causes
- The identified non-recurrent causes of congestion are incidents, events and weather; these cause between 2% and 12% of congestion in ANZ cities, although better data collection of these drivers would allow more accurate ongoing analysis
- The specific dynamics of congestion may vary significantly, for example:
  - Bad weather on the M3 in Brisbane led to a 63% Travel Time Delay
  - Weekday travel time on Parramatta Road in Sydney is 175% longer than weekends

Chapter 5 – Congestion Interventions

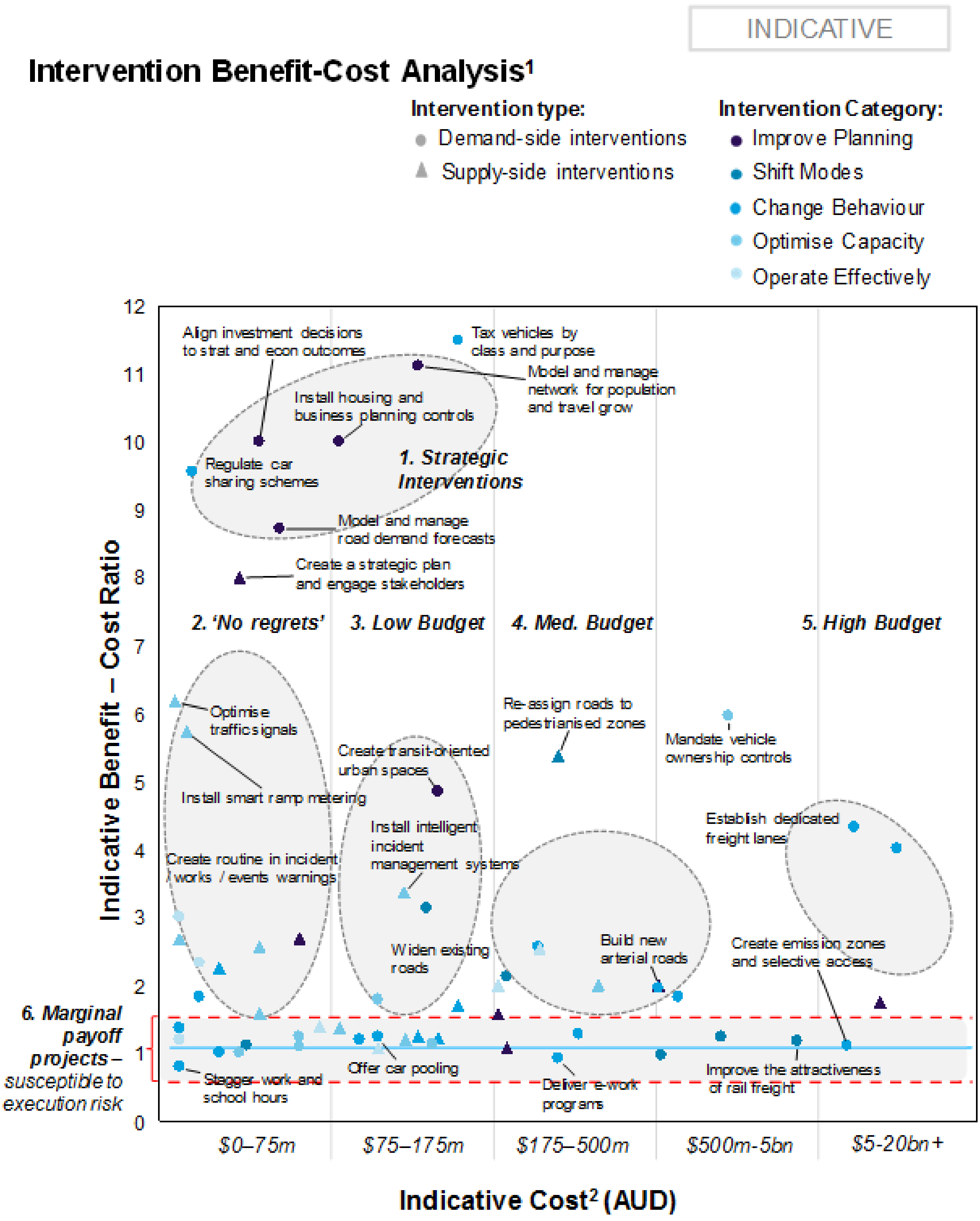
5.1 Interventions Framework Overview

- The congestion intervention framework is a systematic approach to identifying relevant congestion interventions, by segmenting the interventions based on road supply or demand levers and their implementation timeframe
- A Benefit-Cost Ratio (BCR) comparison of interventions provides their indicative relative cost and effectiveness in reducing congestion, which indicates that road and transport agencies should invest in strategic interventions (specifically demand-side), as well as relatively low cost, high BCR interventions (see Exhibit B)
- Interventions with marginal payoffs (1±0.5) require case-by-case assessment, as there would generally be alternative supply or demand measures with superior BCRs

5.2 Intervention Application

- The application of the interventions to specific congestion problems requires different filters:
  - **Location:** Type of road and land use
  - **Cause:** Recurrent / non-recurrent, delay / reliability or time of day
  - **City Type:** Budget, population density and growth potential
- This will leave a set of complementary interventions that should be implemented as a program
- Given **most congestion is recurrent**, appropriate interventions can be prioritised for each ANZ city:
  - **Group 1 cities** are currently investing in building road capacity, so future efforts can focus on their developed road network **demand management**, including interventions relating to 'shifting modes', 'changing behaviour' and 'operating effectively'
  - **Group 2 cities** can use 'planning' interventions to determine appropriate investments, considering their populations are likely to grow to that of larger Group 1 cities. This will ensure they **invest in providing new capacity and appropriate infrastructure in advance of growth**.
  - **Group 3 cities** can operate their road network effectively if high-cost supply-side investments are not determined feasible. They should focus on 'strategic', 'no regrets' and 'low budget' investments and **use planning interventions to determine future budget for appropriate investments**, considering their populations are likely to grow to that of larger Group 2 cities
- When considering the **non-recurrent causes** of congestion, **unplanned incidents** were the most prominent for most cities, therefore 'Operate Effectively' investment should **focus on creating routine in incidents**, rather than enhancing interventions that target events.
- In general, **demand-side interventions** may be most useful in the **short-run** to slow down the rise in the use of vehicles, and therefore recurrent congestion

Exhibit B: Interventions can be grouped by benefit-cost ratio and estimated cost



Notes: 1. Indicative benefit-cost ratio details included in Appendix C,
2. Costs are the average of samples identified, range is included in Appendix C

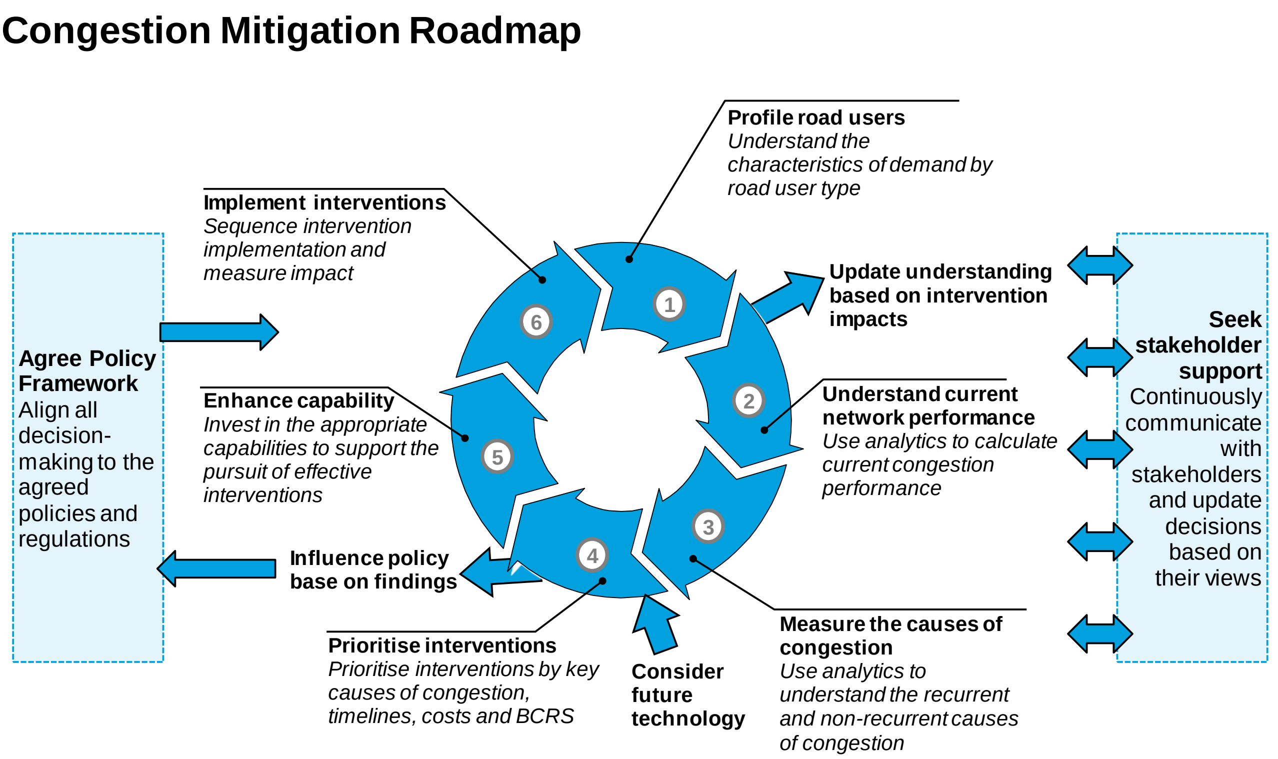
Source: International and national analysis of interventions with information from transport agencies, reports and further research

Chapter 8 – Congestion Mitigation Roadmap

8.1 Roadmap for the Future

- Mitigating congestion is an iterative, ongoing process, with multiple stages that can be applied at a city, corridor or road level (see Exhibit C):
  - **Profile Road Users.** Understand the characteristics of demand by road user type
  - **Understand Current Network Performance**. Use analytics to determine current congestion performance
  - **Measure the Causes of Congestion.** Use analytics to understand the recurrent and non-recurrent causes of congestion
  - **Prioritise Interventions** by key causes of congestion, timelines, costs and BCRs
  - **Enhance Capability**. Invest in the appropriate capabilities to support the pursuit of effective interventions
  - **Implement Interventions**. Sequence interventions and measure outcomes
- **Throughout the process:**
  - Engage with **stakeholders** to gain support
  - Align with and influence the **Policy Framework**

Exhibit C: Mitigating congestion is an iterative process, with support from stakeholders required throughout



Source: Deloitte Experience

Chapter 6 - Capability Requirements

6.1 Capability Maturity Framework

- The Capability Maturity Framework identifies the **capabilities required to mitigate congestion** and identifies priority areas of improvement for ANZ road agencies based on their current state and goals. The framework includes:

  A. **Strategy and Program**: Land Use & Planning, Transport Strategy & Planning, Program

  B. **Delivery Framework**: Performance & Operating Model, Technology & Information

  C. **Project Delivery**: Development Lifecycle

  D. **Business As Usual (BAU) Operations**: Applications & Services

6.2 Relevant Capabilities for Interventions

- Relative to the challenges of congestion, road agencies need to prioritise building capabilities to:
  - **Improve Planning**: Improve long term land use and network design
  - **Change Behaviour:** Focus on customer demand, by providing substitutes and changing incentives
  - **Operate Effectively:** Leverage technology to proactively manage operations

Chapter 7 – Congestion Technology Development

7.1 Enhanced Intelligent Transport Systems Infrastructure

- Austroads' **Intelligent Transport Systems** (ITS) Strategic Roadmap establishes a **shared vision** of ITS activities to achieve the **effective development and deployment of ITS** in Australia and New Zealand Road Agencies

7.2 Regulatory Framework

- Establishing an appropriate **regulatory framework** will provide a **platform for transport innovation**, particularly around demand management and intelligent vehicles

7.3 Congestion Relief Innovations

- Road agencies need to plan for the impact of **technological innovation** that may provide significant **new options for managing congestion** in four key areas
  - **New Mobility Services;** incl. car sharing, ride sharing, bike sharing and P2P car rental
  - **New Kinds Of Vehicles;** incl. connected vehicles and autonomous vehicles
  - **Dynamic Demand Management;** incl. smart parking
  - **New Data Services;** incl. multi-modal trip planning and crowd-sourced traffic data

7.4 Blue Sky…2025 onwards

- In the long run, congestion management will be subject to 3 drivers, which will all drive major changes in ANZ urban transport networks:
  - The **value of time** and life will increase relative to goods and services, therefore the cost of congestion and value of safety will increase
  - The **supply of urban land** will remain fixed and its value will increase
  - **Data generation, processing, transmission and storage costs** will continue to fall in price, weight and size

1. Background

"In 2012, Australian passenger vehicles travelled 167,456 million kilometres, the equivalent of driving approximately 41 million times the distance from the most eastern point of Australia, Cape Byron in New South Wales, to the most western point, Steep Point in Western Australia."

Australian Bureau of Statistics, (2015)

Chapter Summary

1.1 Australia and New Zealand (ANZ) Road and Transport Demand

- Australian and New Zealand growth **in vehicle-kilometres travelled continues to rise** at 1% per annum, at a lower rate than **population growth** (+1.3% p.a.) due to a **reduction in vehicle km per capita**, which peaked in 2004
- There are **three main vehicle-based road user types: Personal Vehicles** (75% of road users), **Light Commercial Vehicles** (15%) and **Freight** (3%), with different growth and demand dynamics

1.2 ANZ Road and Transport Supply

- In **Australia,** the urban **road network supply** (+1.2% pa) **is increasing at a faster rate than demand**, but in **New Zealand, road supply** (+0.2%) **is not keeping pace with demand**
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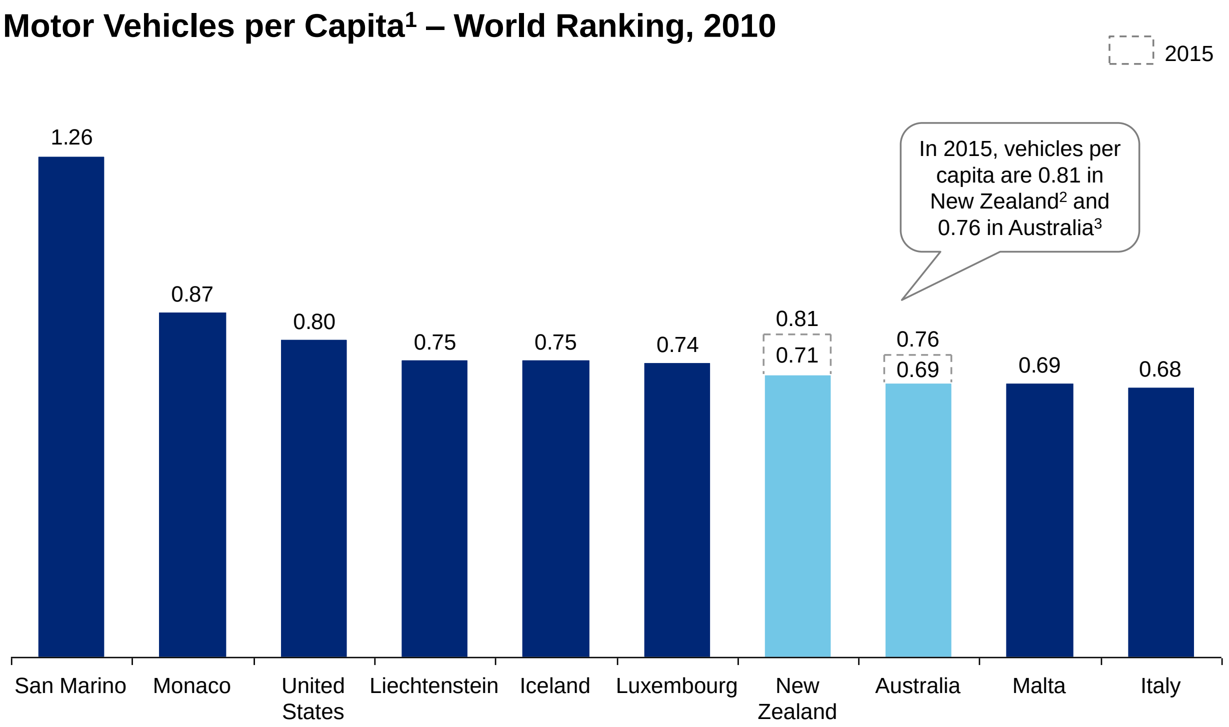
- Congestion cost is **correlated with population size**, but is systematically better in some cities.
- The **Australian congestion cost** was estimated to be **A$16.3bn in 2015** and is forecast to **grow by 5.5% per year** between 2016 and 2030; **Auckland's congestion cost** is estimated at over

Australia and New Zealand (ANZ) cities are relatively young, by international comparison. They are characterised by growing populations and high personal vehicle dependency, which contribute to the growing demand for road transportation, the associated congestion that follows and the challenges of implementing effective interventions. In turn, the increase in the supply of roads has not kept pace with population growth and is not economically viable as a solution on its own. An understanding of travel trends and the use of alternative forms of transport is required in order to determine the appropriate demand and supply side levers available for mitigating congestion.

1.1 ANZ Road and Transport Demand

New Zealand and Australia are highly vehicle-dependent. The 2010 World Development Indicators placed them 7th and 8th internationally[1] for vehicle ownership (see Exhibit 1.1) and ownership is now as high as 0.81[2] and 0.76[3] per capita respectively in 2015.

Exhibit 1.1: New Zealand and Australia are highly vehicle dependent, ranked 7th and 8th in the world for motor vehicles per capita



Source: 1. World Bank (2010), Motor Vehicles (per 1,000 people); 2. New Zealand Ministry of Transport, (2015); 3. Australia Bureau of Statistics, (2015)

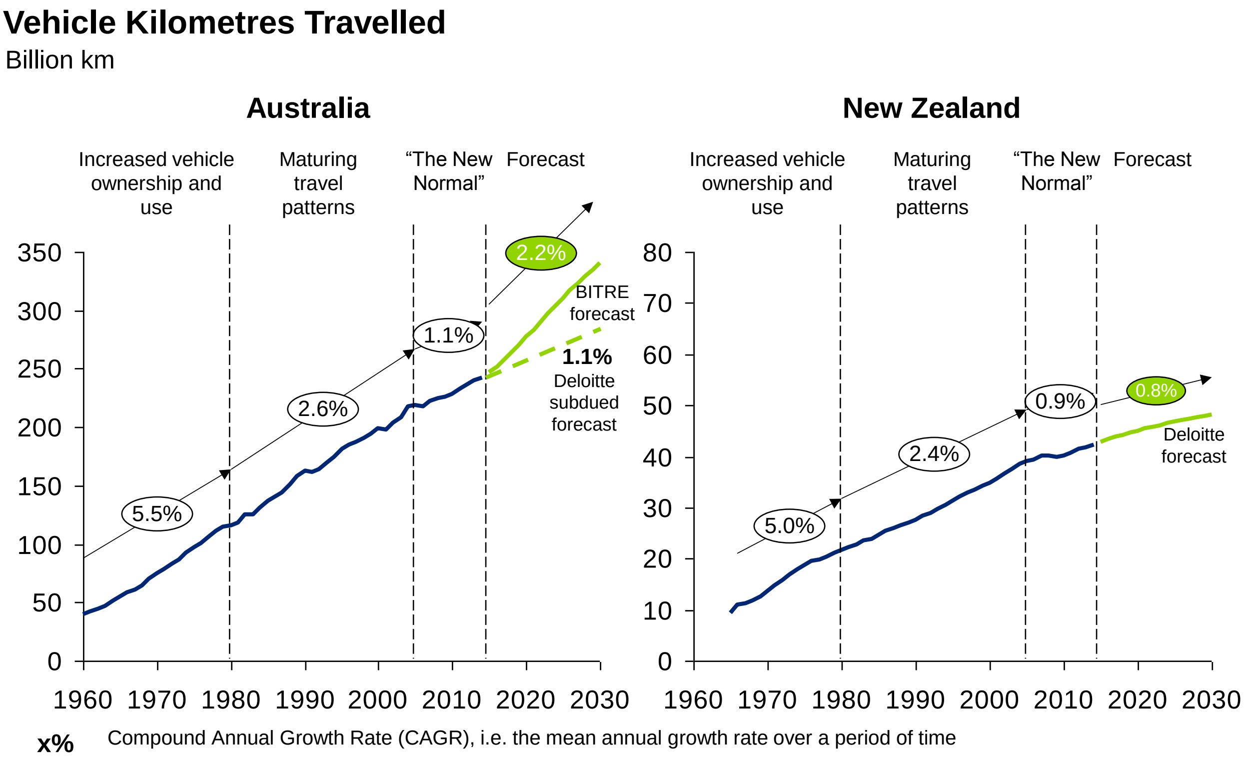
The total demand for road transportation is consistently increasing: vehicle-kilometres travelled have risen a total of 17% in New Zealand[4] and 22% in Australia[5] over the past 15 years. The pace of growth slowed (see Exhibit 1.2) during the late 20th century as travel patterns matured, urban areas became more densely populated and infrastructure developed to support public transport use.

Since 2007, the slowdown to around 1% growth per annum in Australia is generally attributed to the Global Financial Crisis (GFC), with an assumption of a return to travel growth of 2% to 2030. A review of the timing and drivers of travel patterns shows that the slowdown occurred before the GFC and may indicate a phase where travel growth is lower than population growth. This may be due to increased inner city living, where public transport provision is high and car ownership is not essential, but requires further research to understand whether the change is permanent. BITRE's forecasts suggest that by 2030, kilometres travelled could be a further 40% higher than current levels in Australia[6] and a steady increase will result in kilometres travelled of a further 14% in New Zealand. These estimates seem high considering the pace of growth appears to be halving every 25 years.

1 World Bank, (2010), Motor Vehicles (per 1,000 people)
2 New Zealand Ministry of Transport, (2015), Transport volume: Fleet information, Vehicle ownership per capita 2014 TV035
3 Australia Bureau of Statistics, (January 2015), Motor Vehicle Census 9309.0

4 New Zealand Ministry of Transport, (2015), Transport volume: Vehicle travel, Road vehicle kilometres travelled *VKT) TV001
5 BITRE, (2015), Metropolitan Transport Task Estimates - Australia
6 BITRE, (2015), Metropolitan Transport Task Estimates – Australia

Exhibit 1.2: Increases in total vehicle travel have slowed over the last 30 years



Note: 'Vehicles' includes cars, LCVs, rigid trucks, articulated trucks, buses and motorbikes
Source: BITRE 2015 Estimates; New Zealand Ministry of Transport

1.1.1 Demand Drivers

Amongst the economic, social and technological drivers of motor vehicle demand, three main inputs govern the increase in vehicle kilometres travelled: **population growth**, **vehicles owned per capita** and **kilometres travelled per vehicle**. Since 2004, vehicle-kilometres travelled has increased on average 1.0% per year across Australia[7] and New Zealand[8]. ANZ populations have risen 1.3% per year[9,10] in the same timeframe, vehicles owned per capita have increased by 1.0% while kilometres travelled per vehicle has decreased by 1.0%[11,12].

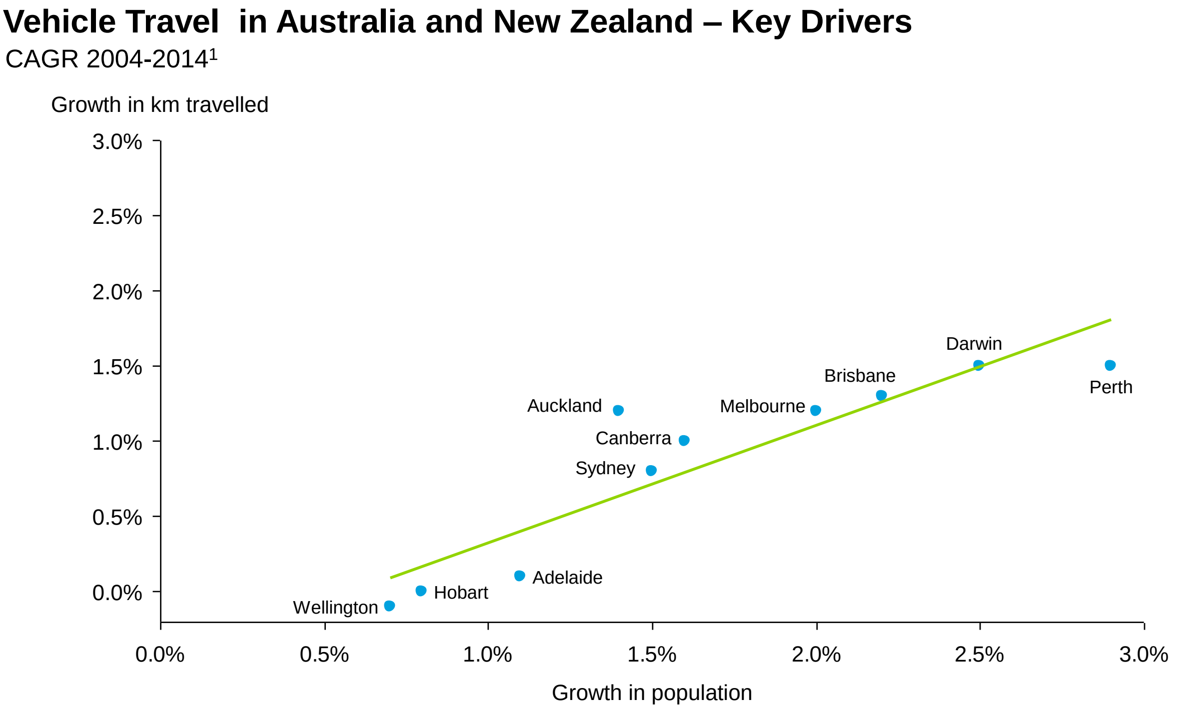
Growth in demand has two impacts:

1. it is more difficult to develop the supply of road infrastructure (and public transport alternatives) in advance of demand
2. the imperative to have good planning of infrastructure is increased

Population growth. As shown in the comparative growth rates above, population growth has therefore been the key driver of increased road demand. In fact, the largest increases in demand for road travel are seen in urban areas with high population growth rates (see Exhibit 1.3). Here, Perth and Darwin's growth rates of over 2.5% have resulted in growth in total vehicle-kilometres travelled of almost 1.5% per year.

7 BITRE, (2015), Metropolitan Transport Task Estimates - Australia
8 New Zealand Ministry of Transport, (2015), Transport volume: Vehicle travel, Road vehicle kilometres travelled *VKT) TV001
9 Australian Bureau of Statistics, (2015), Australian Demographic Statistics 3101.0
10 Statistics New Zealand, (2015), National Population Estimates
11 New Zealand Ministry of Transport, (2015), Transport volume: Fleet information, Vehicle ownership per capita 2014 TV035
12 Australia Bureau of Statistics, (January 2015), Motor Vehicle Census 9309.0

Exhibit 1.3: The growth in kilometres travelled on roads in ANZ cities is largely driven by population growth



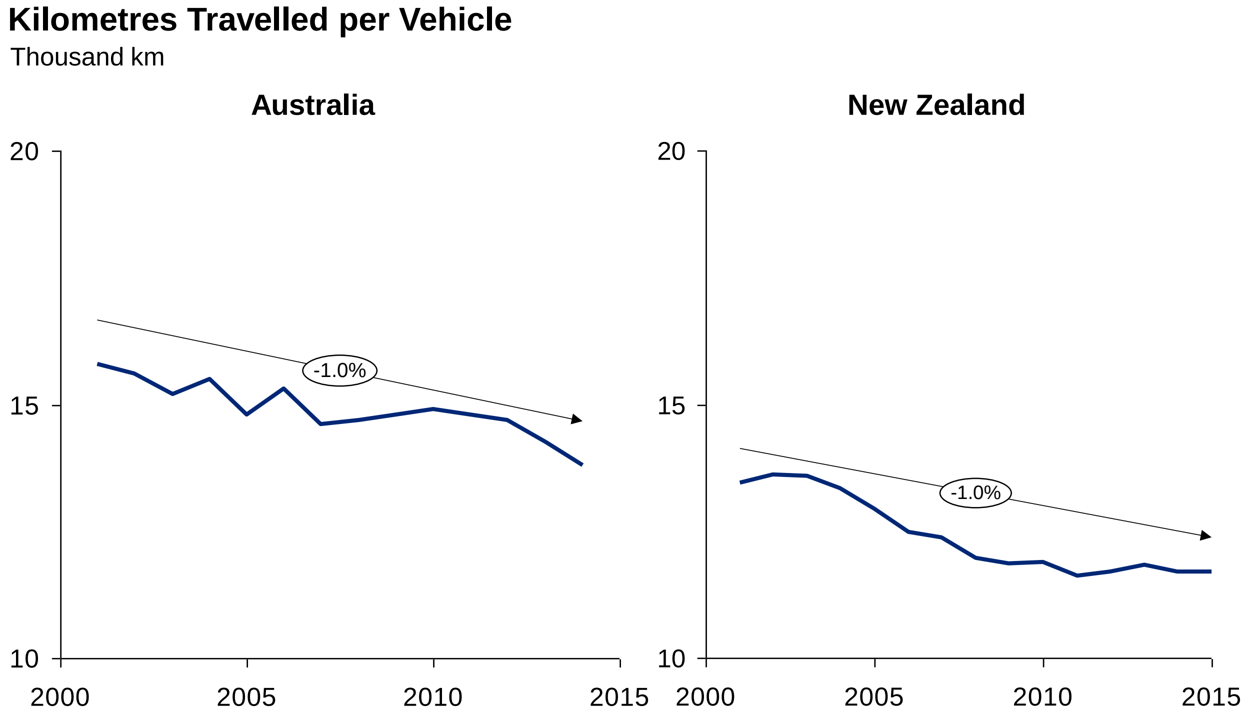
Notes: 1. Kilometres travelled for NZ CAGR for 2005-2014
Source: BITRE 2015 Estimates, NZ Transport Agency 2015

Vehicles owned per capita. At 0.81 for NZ and 0.76 for Australia in 2015, per capita vehicle ownership (including all vehicle types) is also influencing road demand growth, increasing 1% per year since 2004. It is important to emphasise that these figures are for 'all vehicles', whereas 'passenger vehicle' ownership per capita is lower, at 0.56 and 0.59 respectively. Of the jurisdictions, the Northern Territory has passenger vehicle ownership of less than 0.4 per capita13, while New South Wales' car ownership sits at under 0.55 per capita14. In fact, all individual types of motor vehicles are increasing in absolute number: in Australia, the highest increases were seen in campervans (5.3% increase from 2010-11), articulated trucks (5.2% increase) and light rigid trucks (3.8% increase)15. In the future 'shared economy', vehicles owned per capita could fall as technology enables ride-sharing, whilst kilometres travelled could rise (see Chapter 7).

Kilometres travelled per vehicle. While population and vehicles per capita have been rising, kilometres travelled per vehicle has been decreasing since the turn of the century, despite some positive fluctuations between years (see Exhibit 1.4)

13 Australia Bureau of Statistics, (January 2015), Motor Vehicle Census 9309.0
14 Australia Bureau of Statistics, (January 2015), Motor Vehicle Census 9309.0
15 Australia Bureau of Statistics, (January 2015), Motor Vehicle Census 9309.0

Exhibit 1.4: Kilometres travelled per vehicle has decreased on average 1% per annum in both Australia and New Zealand since 2000



x% Compound Annual Growth Rate (CAGR), i.e. the mean annual growth rate over a period of time

Source: Australian Bureau of Statistics; New Zealand Ministry of Transport, Deloitte Analysis

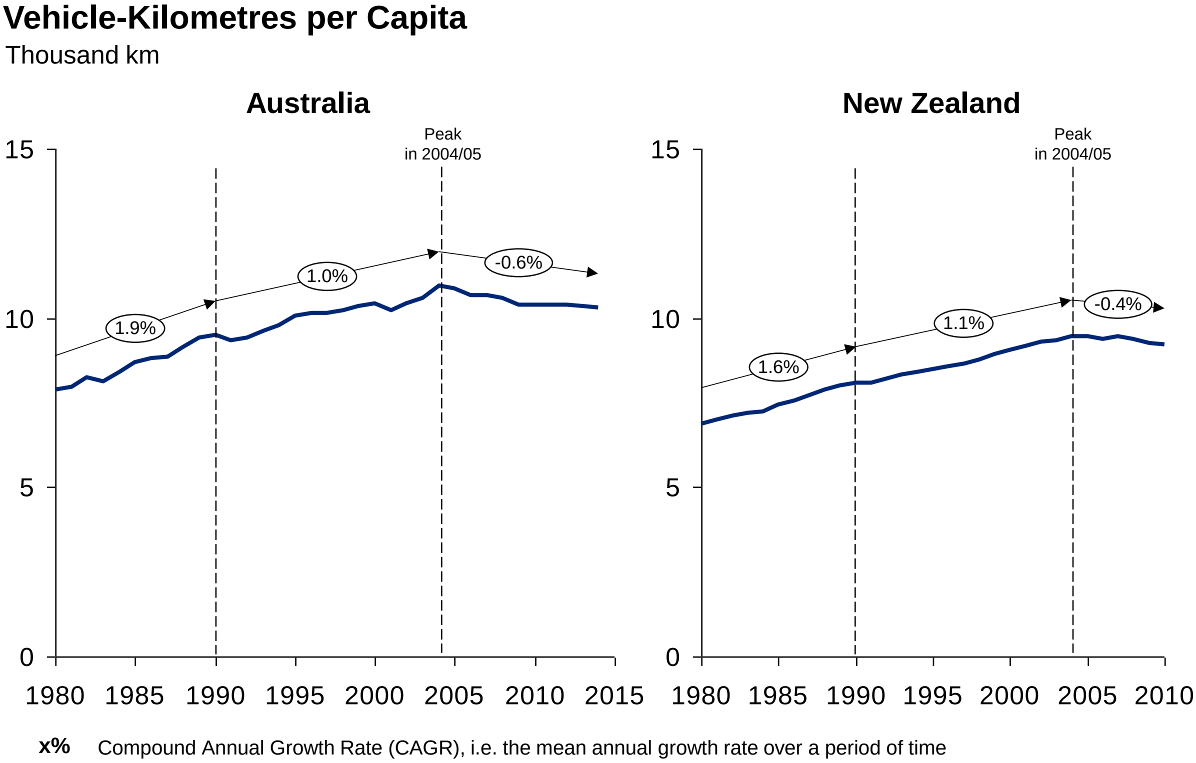
One explanation for this is the decline in driver licensing. In New Zealand, the percentage of those aged 16 to 24 with licences fell from 83% in 2005 to 75% by 2015[16,17]. In Australia, decreases were particularly prevalent across New South Wales and Victoria. In Victoria, license rates for people under 25 fell from 77% in 2001 to 66% in 2015[18]. All Australian states and territories have gradually introduced more restrictions on learner permits and driving licenses; millennials are now required to log up to 120 hours of supervised driving before applying for a provisional license. As well as this, the change in the lifestyles of young ANZ citizens has meant that they are more likely to attend tertiary studies, work part-time, live with their parents and delay marriage than previous generations. They have less need for a car, and also have less money to pay for one. In future, this trend will continue as technology-facilitated ride-sharing becomes increasingly popular. Other drivers of the decrease in vehicle-km travelled per capita include the growth in alternative means of transport as well as the increase in the use of technology to communicate over long distances. Similarly, ageing populations also influence vehicle utilisation – while vehicles may still be owned by those aged 70 and over, they will be far less used than those owned by younger generations.

Vehicle-Kilometres per Capita and 'Peak Car'

Given the above drivers, ANZ vehicle utilisation per capita has been decreasing since 2004. Australia has experienced a decline of 0.6% per annum to an average of 10,330km per capita per year by 2014[19]. Similarly for New Zealand, vehicle utilisation declined 0.4% per annum from 2004 to 9,200km in 2010[20] (see Exhibit 1.5). This can be explained by the concept of 'peak car', a hypothesis that motor vehicle distance travelled per capita has peaked and will now continuously fall into the future. Peak car has been observed in countries around the world including France, Germany, Japan, Sweden and the United Kingdom.

16 New Zealand Ministry of Transport, (2005), Driver Licence and Vehicle Fleet Statistics
17 New Zealand Transport Agency, (2015), Motor Vehicle Registration Statistics
18 Australian Bureau of Statistics, (2015), Vehicle and Driver Statistics
19 BITRE, (2012), Road Traffic Growth in Australia
20 New Zealand Ministry of Transport, (2010), Transport Statistics

Exhibit 1.5: Vehicle kilometres per capita peaked for both Australia and New Zealand in 2004 and has seen steady declines since



Source: BITRE 2015 Estimates; New Zealand Ministry of Transport

1.2 ANZ Road and Transport Supply

Transport and road agencies in ANZ have met rising populations and road demand by building road and alternative infrastructure, but this has the highest impact where it is planned alongside land use decisions in integrated urban plans. The relatively low urban density of some ANZ cities compared to global comparators has resulted in fringe urban areas that are often poorly connected to Central Business Districts (CBDs). For example, London has about three times the spatial area of the Australian Capital Territory but has over 24 times the population[21]. Providing the infrastructure to enable commuters to access the CBD is far more cost effective where density is high. As a continental nation, Australia spends more of its GDP on transport infrastructure than any other developed nation. In 2014 this proportion was 1.4%, compared to New Zealand's 0.5%, the UK's 0.5% and Sweden's 0.6%[22].

In particular, Australia faces the challenge of a sparse population spread over a vast continent. The geography and the resulting political demographics mean that some cities have faced a lower level of investment in infrastructure than would be mandated by both their congestion levels and the economic returns to that investment.

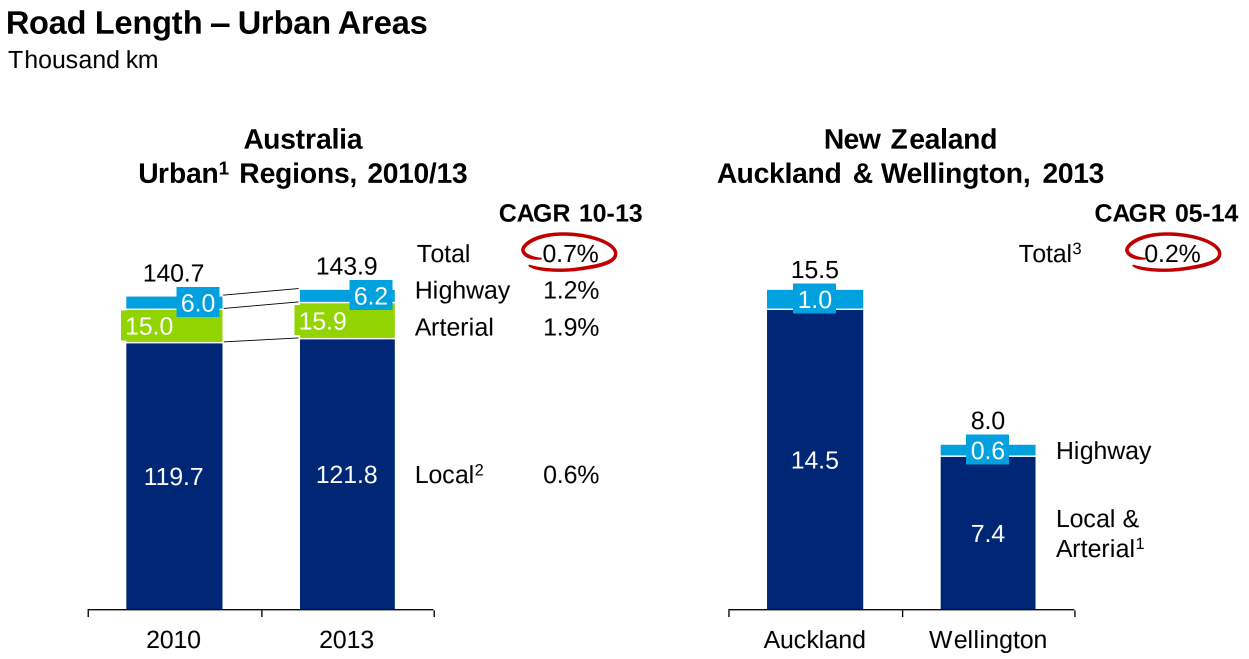
21 Monash University, (2008), Sustainable Transport and Canberra
22 World Bank, (2013/14), International Transport Forum

1.2.1 Road Supply

Road supply is a factor of the length of roads and the associated capacity of that length, determined by the number of lanes and how the road is operated. In Australia, the urban road network is increasing in length at 0.7% annually (2010-2013); slower than population growth (1.6%), but keeping pace with vehicle-km growth (1.1%), as shown in Exhibit 1.6. Eighty five percent of the urban road network is classified as 'local', 11% as 'arterial' and 4% as 'highway'[23]. Arterial roads have the highest rate of growth at 1.9%. Consideration can be given to whether the right 'mix' of roads is being invested in.

In New Zealand, however, road supply is not keeping pace with demand, as road length is growing at a considerably slower rate than both population and vehicle-kilometres travelled (0.2% compared to 1% and 0.9% between 2005 and 2014)[24]. In Wellington, 93% of roads are classified as 'local' and 'arterial', and 7% are classified as 'highways'. In Auckland, 94% are 'local and arterial' and 6% are 'highways'.

Exhibit 1.6: The network of urban roads has increased at a faster rate in Australia than in New Zealand



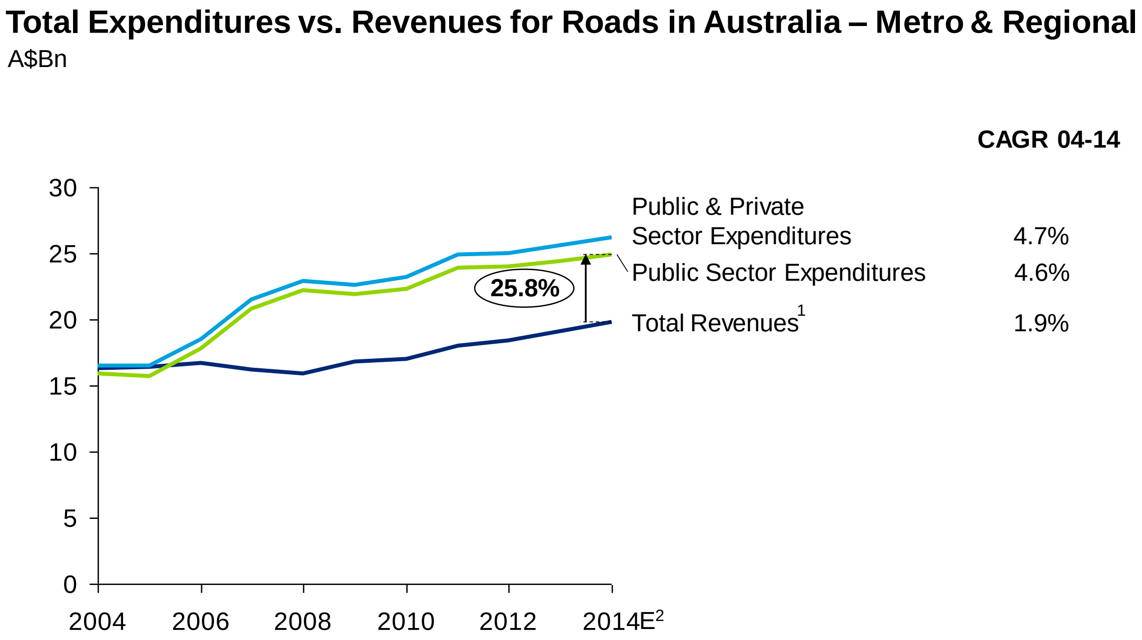
Notes: 1. Urban roads are defined as all roads within city boundaries. New differentiation for road types by ABS in 2014 with limited data available from 2010; 2. Busways are included in local roads; 3. Growth in road length for all national roads
Source: BITRE Australian Infrastructure Statistics Yearbook 2014; NZ Transport Agency

1.2.2 Road Infrastructure Investment Trends

In both Australia and New Zealand, expenditure on roads is greater than funding for roads. Exhibit 1.7 shows that in Australia, total public road expenditure was 26% higher than road funding in 2014[25]. Almost 80% of nationwide expenditure was on 'new construction' in 2012 and as such the network length of urban roads increased at an average rate of 1.2% between 2010 and 2013.

23 BITRE, (2013), Australian Infrastructure Statistics Yearbook
24 New Zealand Transport Agency (2014), Building our roads statistics
25 BITRE, (2014), Australian Infrastructure Statistics Yearbook

Exhibit 1.7: Australian total road expenditure is 26% higher than funding



Notes: 1.Revenues petroleum products excise and Federal Interstate Registration Scheme (FIRS) for the Australian Government as well as vehicle registration fees, driver's licence fees and stamp duty for State and Territory governments;
2. Numbers for 2013 and 2014 are estimates based on the trendline between 2008 and 2012..

Source: BITRE Australian Infrastructure Statistics Yearbook 2014

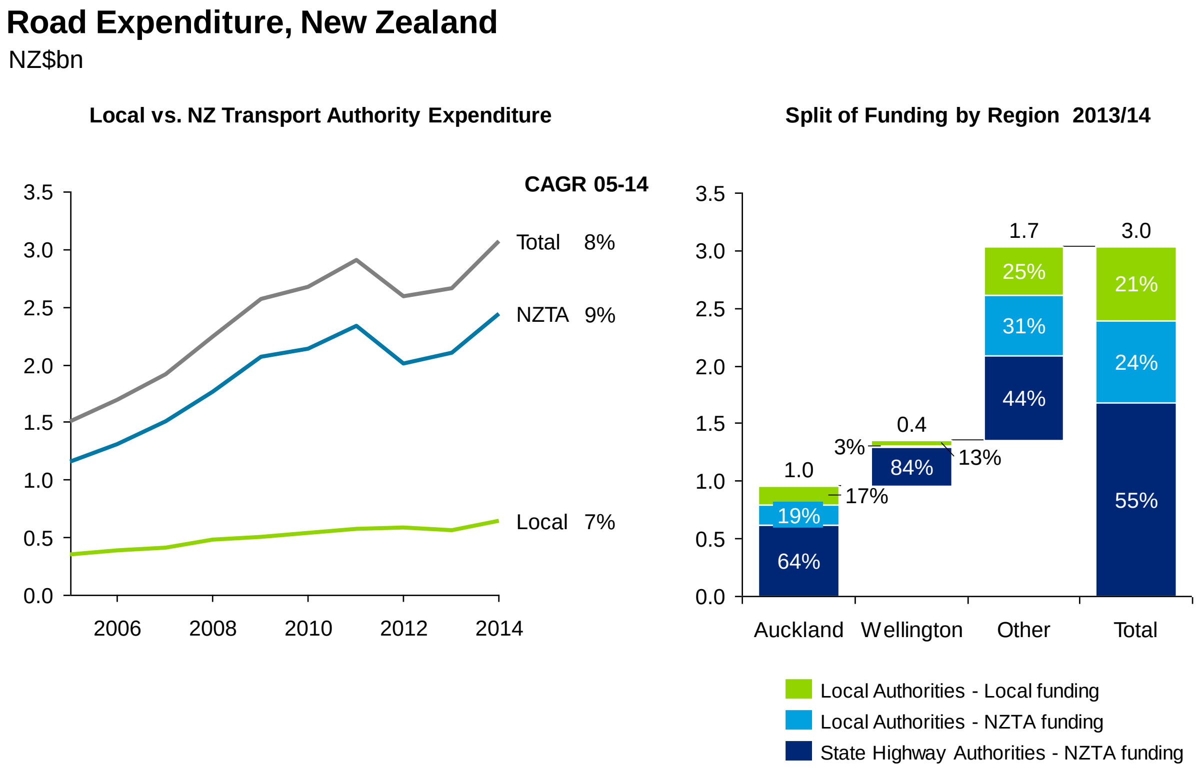
In Australia, responsibility for funding of roads is shared by the three tiers of government (Federal, State and Local), as well as the private sector, with an ad hoc structure of road funding. Many cross-subsidies exist, such as the use of fuel excise to fund other initiatives as well as roads. Expenditure exceeding road-related revenue in Australia is a recent phenomenon; until 2005, road-related revenue and expenditure were more evenly matched. Perhaps we have reached a fundamental inflection point where 'peak car' implies 'peak tax revenue'. For example, if cars become electric, then fuel duty will not raise revenue for the kilometres driven in the same way as it does for current fuels.

To fund additional road investment, Infrastructure Australia's 2014 report[26] suggests that alternative sources of capital should be actively encouraged, so that less is asked of taxpayers. It also suggests that private investment and advances in modern technology, such as the testing of Google Automated cars in Adelaide, could unlock extra productivity in the road network and improve travel times, therefore improving the benefit-cost ratio of road projects. There has also been discussion on the provision and service levels required in order to directly charge heavy freight vehicles. It is clear a 'value proposition' must be given to road 'customers' in this case; for example that the additional funding will be spent on road improvements directly related to freight transit links.

Similarly in New Zealand, total expenditure ($9.2bn) from national funding sources has been above revenue ($9.0bn), in total, for the last three years[27]. For 2012/3 to 2014/15, 55% percent of expenditure was on state highways, 22% on local roads, 10% on road policing and 10% on public transport. Total road expenditure is funded both by the NZ Transport Agency which administers the National Land Transport Fund, and by Local Authorities contributing their local share[28] (see Exhibit 1.8)

26 Infrastructure Australia, (2014), Infrastructure Finance Reform Issues Paper
27 New Zealand Ministry of Transport, (2014), Future Funding Summary Report
28 New Zealand Ministry of Transport, (2013/14), Transport Data

Exhibit 1.8: Road expenditure in New Zealand has increased 8% per year since 2004



Source: NZ Transport Authority, 2014 (includes road maintenance, operation, renewals, new and improved infrastructure)

New Zealand's Ministry of Transport's report 'Future Funding', published November 2014, states that the currently used revenue system is sustainable for around 15 years with expected revenue matching expected expenditure. This revenue is comprised from fuel excise duty, road user charges, motor vehicle registration and licensing and the sale of State highway properties.

Demand on many key urban road and rail corridors is projected to exceed current capacity in the next ten years. Passenger transport movement (both road and public transport) is projected to increase by 58% across Australia's six largest capital cities by 2031[29] and infrastructure will need to be dramatically expanded to meet this growth in demand.

1.2.3 Alternative Transport Supply and Expenditure

The demand for road space by personal and commercial vehicles is influenced by the supply and relative attractiveness of alternative forms of transport. For personal consumers, the alternative consists of modes of public transport, i.e. trains, buses, ferries, and light rail, as well as taxis. For road freight, alternatives are largely via rail freight or shipping freight. For many light commercial vehicles, there is no realistic alternative to the traditional utes and white vans.

For Australian urban mass transit systems the percentage of public transport costs recovered through user payments is around 25-30%[30], well below the level recovered in a number of transport systems internationally, such as 70% in San Francisco, 80% in Washington and 125% in Singapore. Spending on public transport is a combination of federal infrastructure investment, plus State budget spending. Here, Australia and New Zealand's publicly owned transport utilities could be operated more productively by capturing non-fare income from land holdings, particularly stations. The leader here is Hong Kong, whose mass transit system is essentially a network of shopping malls connected by train lines, as discussed in Chapter 6.

29 Infrastructure Australia, (2015), Australian Infrastructure Audit
30 Australian Department of Infrastructure and Regional Development, (2011), Trends: Infrastructure and Transport to 2030

Passenger transport funding in New Zealand has increased consistently from NZ$224m in 2011 to NZ$304m in 2014[31]. In 2013/14, farebox recovery was 46%, with the remaining 54% funded from the National Land Transport Fund (53%) and Local Authorities (47%).

The University of Sydney's Institute of Transport and Logistics six-monthly Transport Opinion Survey (Q3 2015) found that Australian respondents are almost equally divided in opinion between new investment going into public transport (51%) versus roads (49%), partly driven by perceptions that governments struggle in delivering public transport improvements. UMR Research's 2012 New Zealand Annual Review: Mood of the Nation survey found that New Zealanders are more likely to support government funding of public transport (48%) than roads and motorways (37%), with 15% stating 'neither, both or unsure'[32]. Support for public transport investment has grown over the last 20 years from 25% in 1993, when 43% chose roads and motorways and 32% stated 'neither, both or unsure'.

Buses. Buses are a major component of the public transport network in both Australia and New Zealand. Due to the restrictions on rail investment without a critical mass of residents, bus networks are an affordable way of transporting people around and between major cities.

In Australia, 95,149 buses were registered in the 2015 Motor Vehicle Census[33]. Buses are operated by both State government operators and smaller private contracted operators. Most of the bus vehicles across Australia are single-decker rigid buses. Due to the dependency on the bus network by many commuters, many cities have dedicated bus lanes that are sometimes shared by taxis, cyclists and motorcycles.

Buses are the most common form of public transport in New Zealand, making up the majority of trips in every city that has public transport. Buses are operated by local public transportation companies and private operators. There were 9,644 buses registered in New Zealand in 2014[34].

Rail. In Australia, trends in spending by the public sector on railways have fluctuated over the last decade, with a peak of $2.1bn spent in 2011-12, compared to the most recent recorded amount for 2013-14 of $1.0bn. Private sector investment has been higher, both in work done for the private sector ($4.3bn in 2013/14) and work done for the public sector ($2.3bn in 2013/14)[35]. Rail expenditure varies greatly in the six states with rail access: with average spending from 2008/9 to 2012/13 from $338m in Victoria to $34m in Tasmania[36]. Of the Australian cities with rail, Melbourne has the largest route-kilometre supply, with 232 route-kilometres of passenger-only lines and 156 route-kilometres of shared passenger/freight lines.

Passenger rail transport in New Zealand is limited with inter-city rail services focussed primarily on freight; of 4,128km of track, 2,328km is freight only[37]. Only Auckland and Wellington have urban rail systems, with four and five suburban lines respectively, serving travel within each city.

The University of Sydney's Institute of Transport and Logistics Survey (Q3 2015) asked user's opinions on investment in 30 km of rail corridor versus 300km of bus lanes – with 60% of respondents choosing rail. Responses varied by State, but all had rail investment as the majority, from 56% of Queenslanders and South Australians, to 67% of Victorians. This may be due to the perceived reliability of rail over buses transportation or the current lack of rail infrastructure.

Freight Alternatives. For freight, a shift of freight transportation from road to rail reaps more than just congestion-related benefits. Deloitte Access Economics estimates that a modest increase in rail's modal share of the freight task would result in the current $92m in benefits derived from the Australian North-South corridor growing to $227m by 2030[38]. Perhaps consideration should be given to the wider Australian potential for freight transportation: for example, at present the only route between Melbourne and Brisbane is through Sydney.

31 New Zealand Transport Ag, (2014), Transport Data (Figures do not include farebox recover)
32 UMR Research, (2013), Annual Review: Moodle of the Nation
33 Australian Bureau of Statistics, (2015), Motor Vehicle Census 9309.0
34 New Zealand Ministry of Transport, (2015), Transport volume: Fleet information TV035
35 ABS, (2015), Infrastructure Expenditure Statistics
36 BITRE, (2014), Infrastructure Spending Estimates
37 KiwiRail, (2014), Annual Report
38 Deloitte Access Economics / The Australasian Railway Association, (2011), The True Value of Rail

In the 2015 Budget, the New Zealand Government announced investment in KiwiRail of NZ$210m for 2015/16 and $190m for 2016/17, following investment of NZ$1,042m over the previous five years[39].

1.2.4 Interactions of Supply and Demand

Road agencies are aware that demand can be induced by increasing the supply of road space. Building new roads is not always the solution to decreasing congestion. Braess's Paradox[40] details how more roads can lead to more congestion – if new road supply leads to a faster route and all vehicles take the new fastest route, all of the traffic is slowed. In fact, the Reverse Braess Paradox explains that closing a road can actually lead to less congestion, as found in New York with the closure of 42nd Street in 1990 and in Seoul where there was higher traffic speed after a motorway was removed as part of the Cheonggyecheon project.

There are two examples of major infrastructure projects in New South Wales with uncertain benefits. From 1986-1991 there were, on average, 180,000 cars crossing the Sydney Harbour Bridge per day. Since the Harbour Tunnel opened in addition, there has been an average of 250,000 crossing the harbour in this location per day, an absolute increase of 39% when the population only increased by 7% in absolute terms[41]. It is unclear whether this additional mobility has added social, environmental or economic benefits to the people of Sydney. It is important for road agencies to understand the context of a city's strategic plan to consider the best mix of new roads and transportation provision.

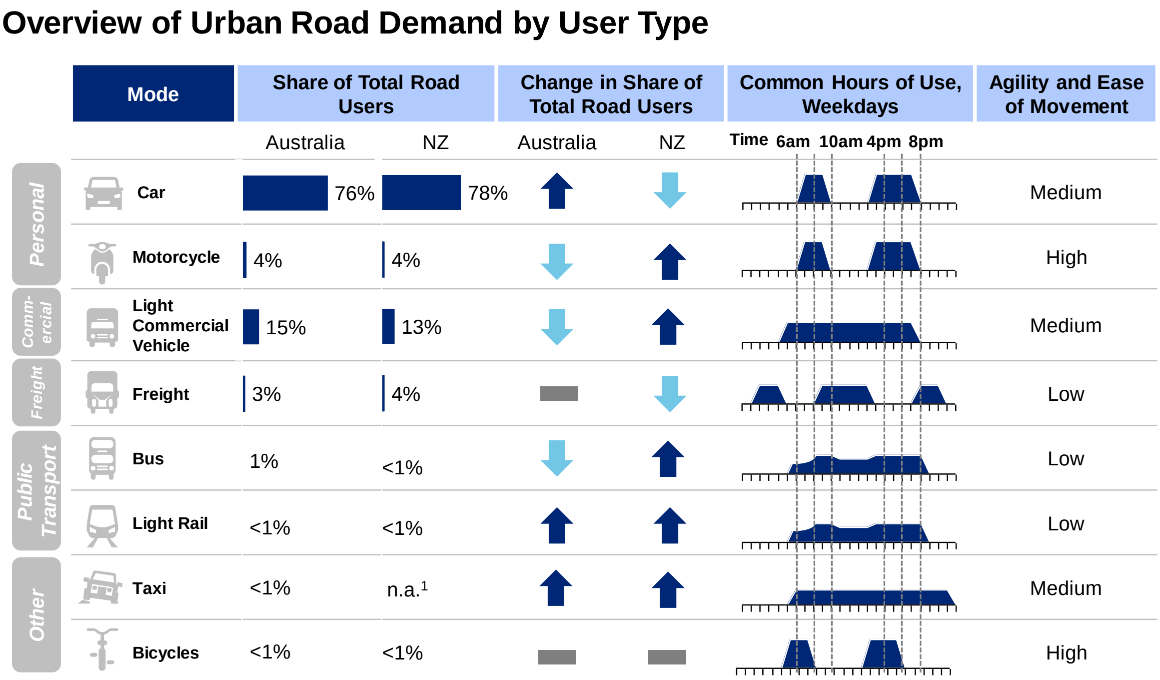
In August 2002, following the completion of a new section of dual carriageway between Yelgun and Chinderah, the NSW Roads and Traffic Authority gave approval for large B-Doubles to use the entire length of the Pacific Highway. This decision led to a 38% increase in the number of heavy trucks using the Pacific Highway each day, many of which shifted from rail to road. By 2006, when 168km of dual carriageway had been built, 75% of Sydney-Brisbane intercity freight was travelling by road[42].These examples show that important second and third order impacts are often overlooked in road infrastructure development and there is little post-project review of benefit realisation.

1.2.5 Customer Demand

In addition to the personal commuter vehicles normally associated with peak-time congestion, ANZ roads play host to a plethora of road customers, with different vehicle-types (see Exhibit 1.9), who also contribute to congestion in both peak and off-peak times. This also includes public transport such as buses and light rail. The characteristics of demand, such as time of day of travel, vary by vehicle-type and associated road-user.

39 KiwiRail, (2015), KiwiRail welcomes funding package press release
40 Braess, D., Nagurney, A., and Wakolbinger, T., (1968), On a paradox of traffic planning
41 The Festival of Urbanism Sydney, Bliemer and Beck, (2015), Lecture entitled 'Myth: Roads are the solution to congestion'
42 Laird, P., (2012), Shifting freight to rail could make the Pacific Highway safer

Exhibit 1.9: The characteristics of urban road demand vary by road user type



Note: 1. NZ 'car' represents 'light passenger vehicles', NZ taxis accounted for in 'car' category;
Sources: ABS Motor Vehicle Census, 2006 to 2011; New Zealand Ministry of Transport: 2011 to 2014 Annual Vehicle Fleet Data; Australian State and Territory Household Travel Surveys, 2013-present

For the purposes of this report, three motor vehicle customer types are considered:

- **A - Personal.** Driving personal vehicles for commuting, dropping children to school, shopping and other personal reasons
- **B - Commercial.** Light commercial vehicles that are owned by a company or a sole trader and are generally driven for business purposes. These vehicles are white vans, utes and taxis, but only require Class A vehicle registration in most states. It must be noted that some freight may be transported in commercial vehicles as 'last mile journeys'
- **C - Freight.** Heavy commercial vehicles owned by trading companies or owner drivers. These vehicles are primarily used to transport goods and require Class B vehicle registration in most states

A. Personal Demand

Personal consumer demand for road space governs demand for cars, motorbikes, taxis and buses. Demand is largely a factor of the provision and attractiveness of alternatives, for example the ability to walk, travel by rail and cycle. In turn, the use of buses as an alternative to personal cars increases the throughput of people at a given level of congestion, reducing the aggregate number of vehicles on the road. Between 2004 and 2014, the use of public transport for journeys to work has increased from 8% to 10% of mode share in Australia[43] and 14% to 17% in New Zealand[44]. Absolute yearly passenger-kilometres on public transport is highest in Sydney at c.1,700km per year (2012/13), with Melbourne experiencing the fastest growth since 2000, from 1,200 to 1,400km per year in 2013 (1% per annum).

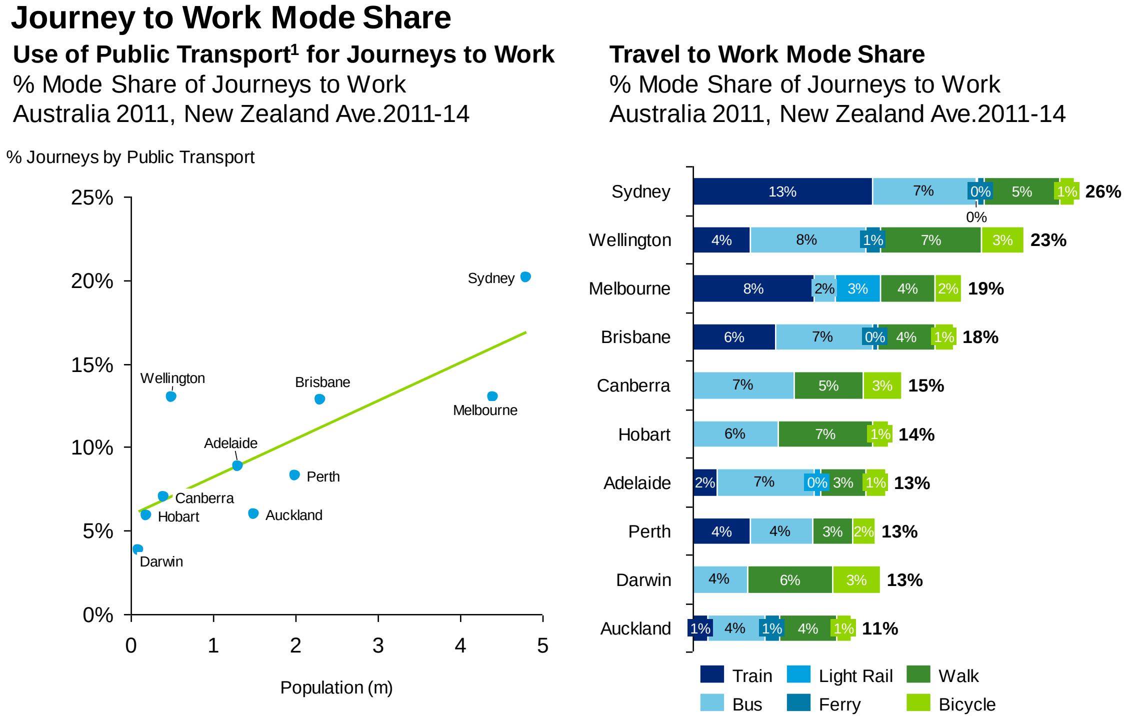
43 Australian Bureau of Statistics, (2011), Journey to Work Census data
44 Statistics New Zealand, (2014), Household Travel Survey, Travel to Work (3-year moving average)

Customer journey choices affect congestion due to the level and mode of demand. There are a number of factors affecting customer journey and mode choices, including but not limited to:

- attributes of the journey:
  - number of passengers
  - the trip purpose (work/commute/leisure/education/serving the passenger)
  - time of day
  - length of stay at destination
  - climate
  - topography of route
- attributes of the traveller:
  - scope for time and cost flexibility
  - demographic factors (including age, household structure (incl. children), labour force status and income)
  - ownership/availability of a vehicle and a drivers' licence
  - environmental consciousness
  - health and fitness levels
- characteristics of the transport facility:
  - access and frequency of public transport options
  - parking availability and cost at destination
  - convenience (how close transport can take you to destination and/or whether mode changes are required)
  - relative safety of available modes
  - relative cost of available modes

As well as these personal characteristics, ANZ cities exhibit a correlation between total population and public transport patronage (see Exhibit 1.10). Those cities with the highest populations also have the highest shares of public transport patronage at peak times, with Sydney's public transport patronage of 20% at one end of the scale compared to Darwin's patronage of 4% at the other. This is a result of the interplay of planning, congestion and land use which drives urban density, tying in with the fact that 9% of Darwin's residents walk or cycle to work, compared to 6% of Sydney and Melbourne's. Relatively high-performing cities in terms of public transport, cycling and walking shares of journey to work are Sydney (26% total), Wellington (23%) and Melbourne (19%). Cities such as Auckland (89% use personal vehicles), Darwin, Perth and Adelaide (87%), have much greater use of cars for commuting.

Exhibit 1.10: Cities with larger populations tend to have a greater percentage of journeys to work on public transport



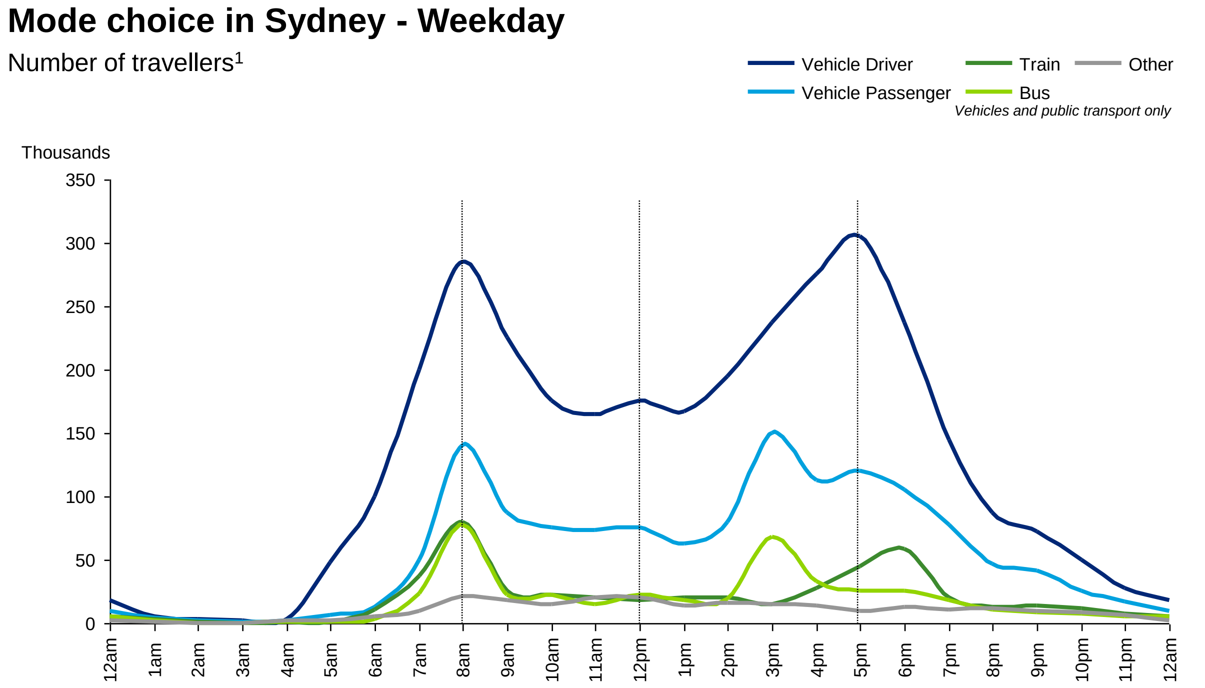
Notes: 1. Public transport = Train, Bus, Ferry, Light Rail
Source: Australia Census Data, 2011; NZ Transport Agency Data, 2011-2014 , 2015

In fact, the alignment between population size and public transport use is possibly a result of congestion levels. Research into customer mode choice has found that demand for alternative modes is highest during periods of greatest congestion. Corpuz[45] analysed the Transport Data Centre's (TDC) Household Travel Survey (HTS) data to assess the factors affecting mode choice in Sydney. An understanding of factors allows for more informed decision making about public transport investment and focussed intervention. It was found that public transport improves its attractiveness relative to the car during the peak commuting periods (and in particular, the more congested AM period). During peak commuting times, speed, cost and service frequency benefits of public transport support a mode shift away from cars. This is partly reflected in the more recent public transport mode shares from 2014 shown in Exhibit 1.11, but is far more evident for London travel patterns in Exhibit 1.12.

Corpuz's data for Sydney also suggests that public transport is most viable when car parking is restricted or expensive, where a car is not available and where driving would be more expensive. Other factors such as travel time, convenience, accessibility and environmental considerations are secondary to these factors. Similarly, a 2012 study in Europe found the main factor affecting modal choice was the availability of parking spaces, and that factors vary by age and sex (males and people aged between 35 and 44 were most likely to prefer driving over public transport)[46]. This may reflect the contrast of Australian modal choice with that of Londoners, who have a greater propensity to use public transport with the knowledge that paying the congestion charge and finding car park spaces in the city is both expensive and time consuming.

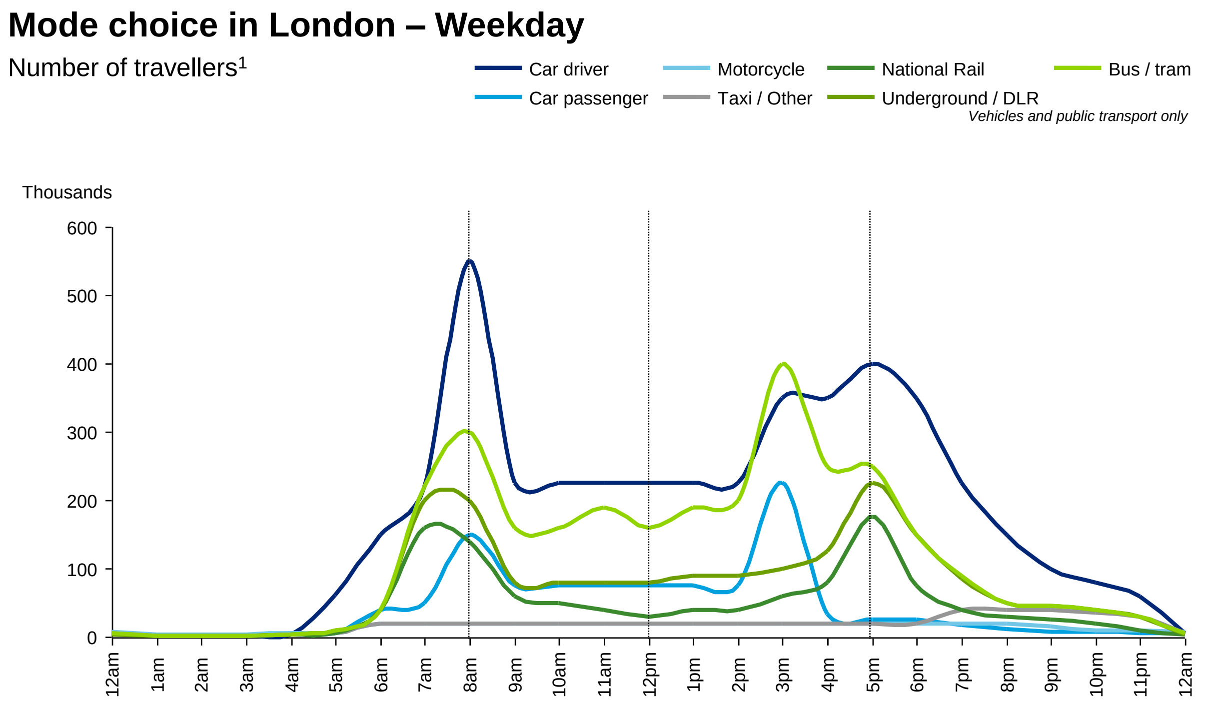
45 Corpuz, G., (2007), Public Transport or Private Vehicle: Factors That Impact on Road Choice
46 Tyrinopoulos, Y. and Antoniou, C., (2012), Factors affecting model choice in urbanmobility

Exhibit 1.11: Public transport[2] patronage relative to cars in Sydney is typically highest during peak periods[3]



Notes: 1. Motorised travel only; 2. Public Transport = National Rail, Underground/DLR, Bus / tram; 3. Peak from 6.30am to 9.30am
Source: Transport for NSW, 2012/13 Household Travel Survey Summary Data

Exhibit 1.12: Relative public transport[2] attractiveness is high throughout the day in London, reflecting the developed state of the network



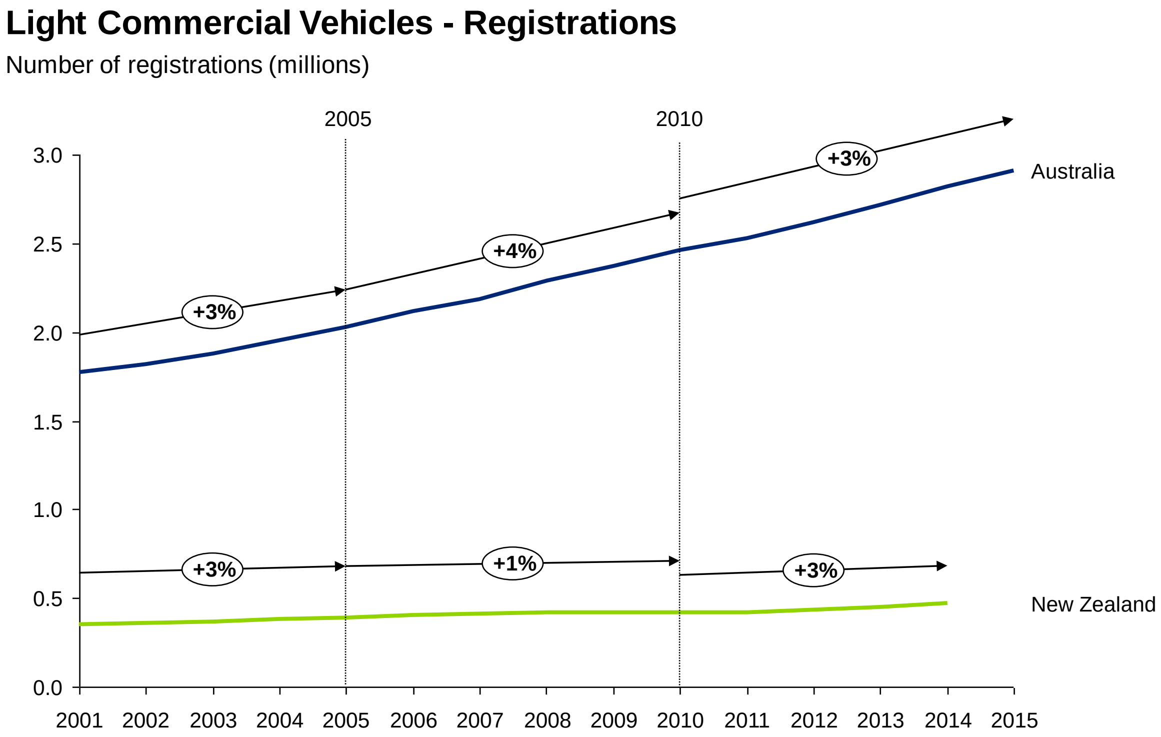
Notes: 1. Trips by main mode by hour of departure, weekdays only; 2. Public Transport = National Rail, Underground/DLR, Bus / tram
Source: Transport for London Travel in London Report 7, 2014

Providing the infrastructure to support continued growth in demand for public transport and ensuring that the provision of public transport is reliable help alleviate the most congested periods of the day on city roads. Otherwise, as cities grow, inconvenient or absent public transport will force car ownership and use, imposing the costs of congestion, through excess time and other costs, on the whole population.

B. Commercial Demand

Light commercial vehicles are an increasing proportion of road users as cities grow, as there is no practical public transport alternative (see Exhibit 1.13). They are often operated by small businesses, which would be unable to transport the materials and tools required to provide their services on public transport. In turn, the rise of e-commerce has increased the number of light vans, used for deliveries. Construction traffic can also have a major impact on congestion, as light vehicles and trucks centre on one area. Often, these vehicles may also be used for non-commercial purposes, as a family's main form of transport.

Exhibit 1.13: The number of light commercial vehicles registered for use on ANZ roads has continuously increased since 2001



Source: Australian Bureau of Statistics (2015); New Zealand Ministry of Transport (2015)

Light commercial vehicles are the second most registered type of vehicle on Australian roads, with 2.9m registered in 2015, accounting for 15% of all vehicles. They have increased in number by 18% since 2010, with a 3% increase from 2014 to 2015[47]. In 2014, light commercial vehicles travelled an average of 4,900 tonne-kilometres[48].

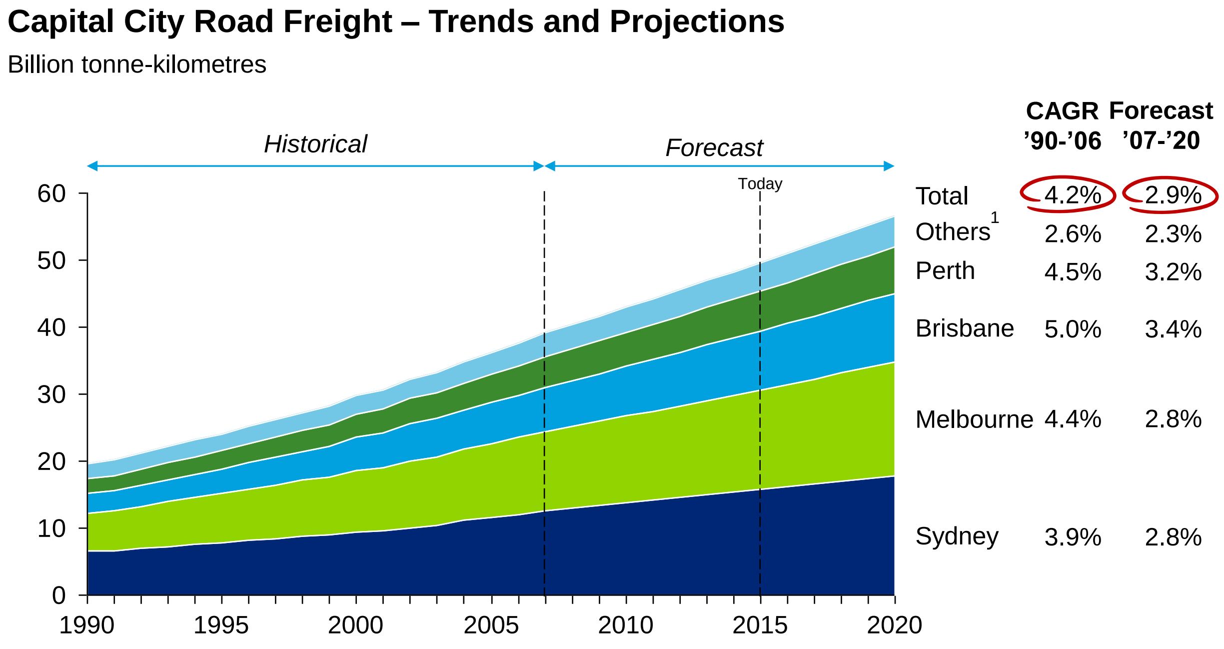
There are 580,000 registered light commercial vehicles (goods van/truck/utility) registered in New Zealand (2015), making them the third most popular 'vehicle' type after 'passenger car/van' and 'trailer/caravan'[49]. They increased in number by 3% p.a. between 2010 to 2014.

47 Australian Bureau of Statistics, (2015), Motor Vehicle Census 9309.0, 2015
48 Tonne-kilometres: A unit of measure of freight transport which represents the transport of one tonne of goods (including packaging and tare weights of intermodal transport units) by a given transport mode, over a distance of one kilometre
49 New Zealand Transport Agency, (2015), New Zealand motor vehicle register statistics

C. Freight Demand

For freight transportation, modal choice is strongly influenced by the characteristics of goods—including mass, density, type, perishability and fragility of freight cargo. In Australia, bulk freight is dominated by rail and shipping, whereas non-bulk freight is dominated by road transportation[50].

Exhibit 1.14: Road freight traffic has increased in every capital city, however is expected to slow to 2020



Notes: 1. Others include Adelaide, Canberra, Hobart and Darwin
Source: BITRE Working Paper No. 71 'Estimating Urban Traffic and Congestion' (2007)

Within every Australian capital city, freight vehicle-kilometres travelled has increased since the turn of the century (see Exhibit 1.14), yet remains a consistent 4% of total vehicle-kilometres travelled on Australian roads from 2000 to 2014[51]. The total road freight task for all eight capitals was estimated at 33 billion tonne-kilometres in 2014. Rail freight transportation has been growing at a faster rate than road freight, at 6.3% year-on-year from 1996 to 2010 compared to 3.8% for road. Rail represented 46% of total freight transportation in 2010 compared to 33% in 1996. Road transport has stayed static at c.33% and shipping has fallen from 32% to 21%[52]. Non-bulk freight (mainly consumer goods and business inputs) has shifted: in 1971 just over half of Australia's non-bulk freight was moved via road. By 2014 that percentage reached 83% and as high as 97% on some routes[53].

For New Zealand, road is the dominant mode of freight transport in terms of both tonnes and tonne-kilometres, accounting for 91% of tonnes moved and 70% of tonne-kilometres (18.5bn tonne-kilometres in 2012)[54]. This represents a year-on-year increase of just 0.7% in tonnes transported by road from 2006/7 to 2012, and a year-on-year decrease in tonne-kilometres of 0.3%. Rail has increased in prevalence from 15% to 16% of tonne-kilometres travelled over the same time period, and coastal shipping has decreased from 15% to 14%.

50 Australia Govt. Department of Infrastructure, Transport, Regional Development and Local Government, (2009), Road and rail freight: competitors or complements?
51 BITRE, (2007), Working Paper No. 71 'Estimating Urban Traffic and Congestion'
52 BITRE, (2007), Working Paper No. 71 'Estimating Urban Traffic and Congestion'
53 The Monthly, (2014), The Monthly Essays: Roads to Nowhere
54 Transport NZ, (2012), National Freight Demand Study 2014

Freight demand is forecast to continue to grow in both Australia and New Zealand, but at a slower rate. BITRE estimated that from 2007 to 2020, tonne-kilometres in Australia will increase by 2.9% per annum[55]. Infrastructure Australia cites that container movements through Australia's ports are projected to grow by 165% from 2014 to 2031, while non-containerised trade is projected to grow by 138% over the same period. As a result, the road and rail freight task is projected to increase from 458bn tonne-km in 2011 to 852bn tonne-km in 2031[56]. For New Zealand, the total freight task is expected to grow by 26% from 2012 to 2022[57], with the majority of freight flow continuing to be located in the Auckland and Canterbury regions. The New Zealand Ministry of Transport predicts mode will stay largely similar at 71% of tonnes-kilometres via road in 2042, 16% via rail and 14% via coastal shipping[58].

This freight demand generally shares the same road infrastructure as cars, but is increasing significantly faster in volume. This change in mix should be reflected in transport planning, as it will result in higher congestion costs than would be expected just from population growth.

External impacts of freight road use must also be considered, as they in turn contribute to congestion. In Australia and New Zealand, trucks are 2.5% and 3.6% of vehicles on the road respectively, but are involved in 20% and 18% of all road fatalities[59,60].

1.3 Definitions of Congestion

A large body of existing research details definitions of congestion from both engineering and economic perspectives. This report leverages traffic data provided by Google, which allows travel time along different road segments to be recorded. These combine to develop near real time information on travel times for corridors and across cities. Therefore, modified congestion definitions have been developed, that can fully leverage insights from the Google data collected. These definitions can, in turn, be meaningfully translated into information that is relevant for road users, practitioners and policy makers alike.

1.3.1 Existing Congestion Definitions

Definitions of congestion centre on both 'absolute travel time' and 'travel time reliability'. Within the context of this discussion and evaluation of travel time reliability, a common decomposition of travel time is Fosgerau et al (2008)[61]:

$$Travel\ time = freeflow\ time + systematic\ delay + unexplained\ delay$$

From the traveller's point of view, 'unexplained delay' is everything that cannot be foreseen; such as additional travel time caused by random demand fluctuations or capacity reductions due to incidents. Such unexplained delay causes fluctuations in reliability; therefore reliability is here only seen as a non-recurrent issue.

Congestion. The NPI definition of urban congestion (Austroads, 2015)[62] implements the above basic idea in a practical manner, and will be used to analyse congestion in the ANZ cities in this report.

$$Congestion = actual\ travel\ time - nominal\ travel\ time$$

where 'nominal travel time' establishes the 'base' and here represents the minimum travel times (i.e. free-flow) recorded in the data analysis.

55 BITRE, (2009), Working Paper No.71: Estimating Urban Traffic and Congestion
56 Infrastructure Australia, (2015), Australian Infrastructure Audit
57 New Zealand Ministry of Transport, (2014), National Freight Demand Study
58 New Zealand Ministry of Transport, (2014), National Freight Demand Study
59 The Monthly, (2014), The Monthly Essays: Roads to Nowhere
60 NZ Ministry of Transport, (2014), Motor Vehicle Crashes in New Zealand
61 Fosgerau, M., Hjorth, K., Brems, C., and Fukuda, D., (2008), Travel Time variability definition and valuation
62 Austroads website, (2015), Variability of travel time (urban) indicator, Procedure SP-NPI-7.4

This calculation, measured in minutes per kilometre, allows for an aggregation of delay per kilometre on a representative sample of urban roads and enables monitoring of the impact of the arterial road system on the level of service to road users.

Reliability. A more technical definition used in transport modelling, ‘unexplained delay’, is represented by a random variable with a probability distribution, such that travel time varies randomly[63]. Travel time reliability in this content is most frequently defined as the random variation in travel time, i.e. the variation in unexplained delay (de Jong and Bliemer, 2015[64]; Carrion and Levinson, 2012[65]). In principle, a transport system with severe congestion may have stable day-to-day travel times; so travellers can anticipate and adapt to any systematic variation based on their past experience, so as to anticipate their arrival time.

This definition leads to the use of ‘mean-dispersion’ models that make use of mean and variance in travel times to come up with a measure: most often the reliability ratio. This ratio focusses on relative dollar valuations of trip reliability compared to trip time. For the purposes of this report, we will use the coefficient of variation:

$$Reliability = \frac{standard\ deviation\ of\ travel\ time}{average\ travel\ time}$$

This measure helps to compare ANZ cities with international benchmarks, through one comparative indicator.

Engineering definitions of trip variability (here, reliability) are commonly based upon 85th percentile travel times (i.e. approximately 1.44 standard deviations from the mean).

Scheduling. A third measurement, that of ‘scheduling’ allows the consequences of reliability to be expressed as the expectation of the number of minutes on arrival (or departure) earlier or later than one’s preferred arrival (departure) time (de Jong and Bliemer 2015)[66]. It should be noted that these are average values, and that there are many considerations to account for in estimating the value of reliability through a scheduling model. As such, for the purposes of our report, we use the 90th percentile to measure reliability, as cited by Hamer et al (2005)[67].

$$Scheduling = \frac{90th\ percentile\ of\ travel\ time}{average\ travel\ time}$$

1.3.2 Congestion Definitions Used

For the purposes of this report, and in order to consider the point of view of the customer, six definitions of congestion are used. All measures will allow ANZ cities to be compared both with each other and with international benchmark cities. For analysis relating to international comparators, to ensure comparability, roads of over 80km/hr free-flow speed are used.

These six measures balance ‘relevant’ metrics that road users can relate to, with the relatively small sample of Google data collected. Due to the sample size of two months’ data, it is best to compare on a ‘weekday’ basis, rather than by individual days of the week. The Google data used has the following characteristics, to which the congestion definitions have been aligned:

- The road network within each jurisdiction was divided into segments, each approximately 1 kilometre in length. This resulted in 17,457 individual road segments within Australia and New Zealand cities
- Travel time data was recorded at intervals:
  - “Peak hour”, Monday to Friday: every 15 minutes
  - All other times: every 30 minutes

63 Fosgerau, M., Hjorth, K., Brems, C., and Fukuda, D., (2008), Travel Time variability definition and valuation
64 de Jong and Bliemer, (2015), On including travel time reliability of road traffic in appraisal
65 Carrion and Levinson, (2012), Value of travel time reliability: A review of current evidence
66 de Jong and Bliemer, (2015), On including travel time reliability of road traffic in appraisal
67 Hamer et al, (2005)

- The schedule was executed 24 hours a day for 60 days during September and October 2015
- Road segments were also monitored in 16 international cities with the equivalent collection frequency to Australian and New Zealand jurisdictions. Each city was scheduled to execute for a two week period during September and October
- The six definitions are as follows (three of which are illustrated in Exhibit 1.15):

Congestion Measure	Formula	Interpretation
1. Average Speed *How fast does traffic in the city travel?*	$\frac{Distance}{Travel\ Time}$	Average speed of traffic
2. Travel Time Delay *How much is traffic delayed from free-flow conditions?*	$\frac{Mean\ Travel\ Time\ for\ 24hrs}{Minimum\ Travel\ Time\ for\ 24hrs} - 1$	The average travel time is x% more than the travel time in free-flow traffic
3. Morning Peak Reliability *What is the statistical reliability of travel times in the morning peak period?*	$\frac{1.44\ Standard\ Deviations\ of\ Travel\ Time\ for\ 6am\ to\ 10am}{Mean\ Travel\ Time\ for\ 6am\ to\ 10am} - 1$	If you drive between 6am and 10am every weekday, your range of travel times would be x% more or less than your average travel time, with a greater range indicating a more unreliable journey
4. Afternoon Peak Reliability *What is the statistical reliability of travel times in the afternoon peak period?*	$\frac{1.44\ Standard\ Deviations\ of\ Travel\ Time\ for\ 3pm\ to\ 7pm}{Mean\ Travel\ Time\ for\ 3pm\ to\ 7pm} - 1$	If you drive between 3pm and 7pm every weekday, your range of travel times would be x% more or less than your average travel time, with a greater range indicating a more unreliable journey
5. Morning Peak Scheduling *How much time does a consumer need to budget during the morning peak period, relative to free-flow?*	$\frac{90th\ Percentile\ of\ Travel\ Time\ for\ 6am\ to\ 10am}{Minimum\ Travel\ Time\ for\ 24hrs} - 1$	If you drive between 6am and 10am every weekday, you would need to increase your travel time by x% more than your minimum travel time to ensure you arrive on time, 9 times out of 10
6. Afternoon Peak Scheduling *How much time does a consumer need to budget during the afternoon peak period, relative to free-flow?*	$\frac{90th\ Percentile\ of\ Travel\ Time\ for\ 3pm\ to\ 7pm}{Minimum\ Travel\ Time\ for\ 24hrs} - 1$	If you drive between 3pm and 7pm every weekday, you would need to increase your travel time by x% more than your minimum travel time to ensure you arrive on time, 9 times out of 10

To calculate these metrics, data from Google is used. The data provides the time taken for movements between origins and destinations, sourced from mobile phones using the Android operating system. Per this approach, 100 million data samples from 17,457 road segments, of approximately 1km in length, were requested at 15 minute intervals at peak periods (5am to 10am, 3pm to 8pm) and 30 minute intervals at non-peak periods (all other times), over 60 days from September to October 2015.

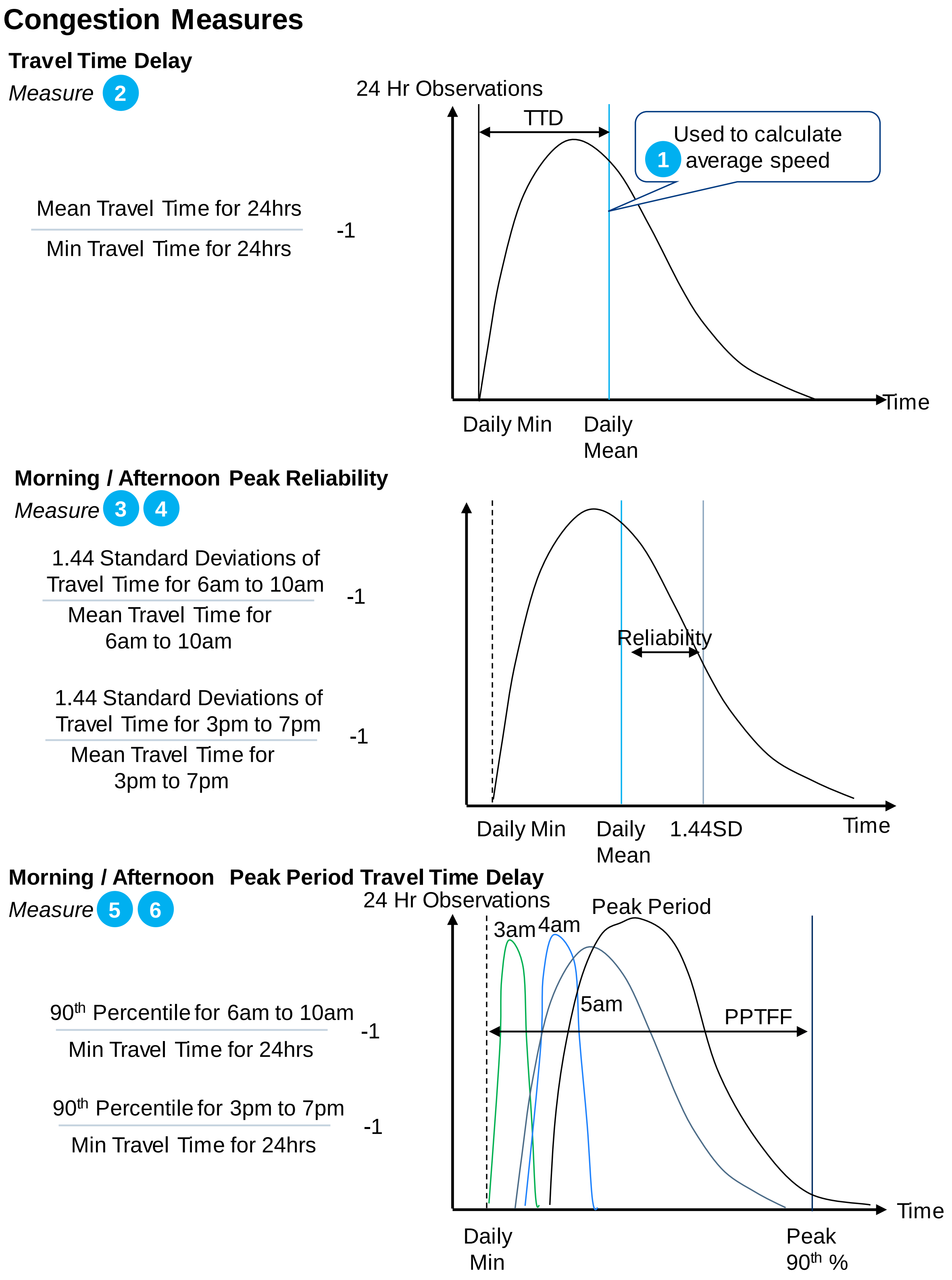
1.3.3 Comparison with NPI definitions

It is acknowledged that the metrics above differ from the National Performance Indicators (NPI). These metrics have been developed for the purposes of this analysis and reflect the aims of this report (such as taking a 'customer'-led view) as well as the nature of the Google data (as explained in Section 1.3.2).

Most of the metrics used are equivalent but slightly different to the NPIs and have been adapted for the purposes of this report. A scheduling measure has been added to overlay a consumer perspective of congestion.

Congestion Measure	NPI Formula	Comparison
Congestion (urban) indicator	Actual Travel Time – Nominal Travel Time	Equivalent to Travel Time Delay metric used in this report. The metric in this analysis is calculated for the whole day rather than 3 estimates for AM, PM and off-peak.
Actual travel speed (urban) indicator	$\frac{60km/hr}{Actual\ Travel\ Time\ (ATT)}$ where ATT = $\frac{\sum_{j=1}^{X}(Tj-Vj)}{\sum_{j=1}^{X}Lj-Vj}$ and j = link number, route in Key Roads Performance Report x = number of linked to be aggregated T = mean travel time of link j (mins) V = representative volume of link L = length of link	In this analysis, speed is measured on a representative sample of arterial and main links. This analysis does not account for volume on each link as this data is not available. The metrics are similar and equivalent.

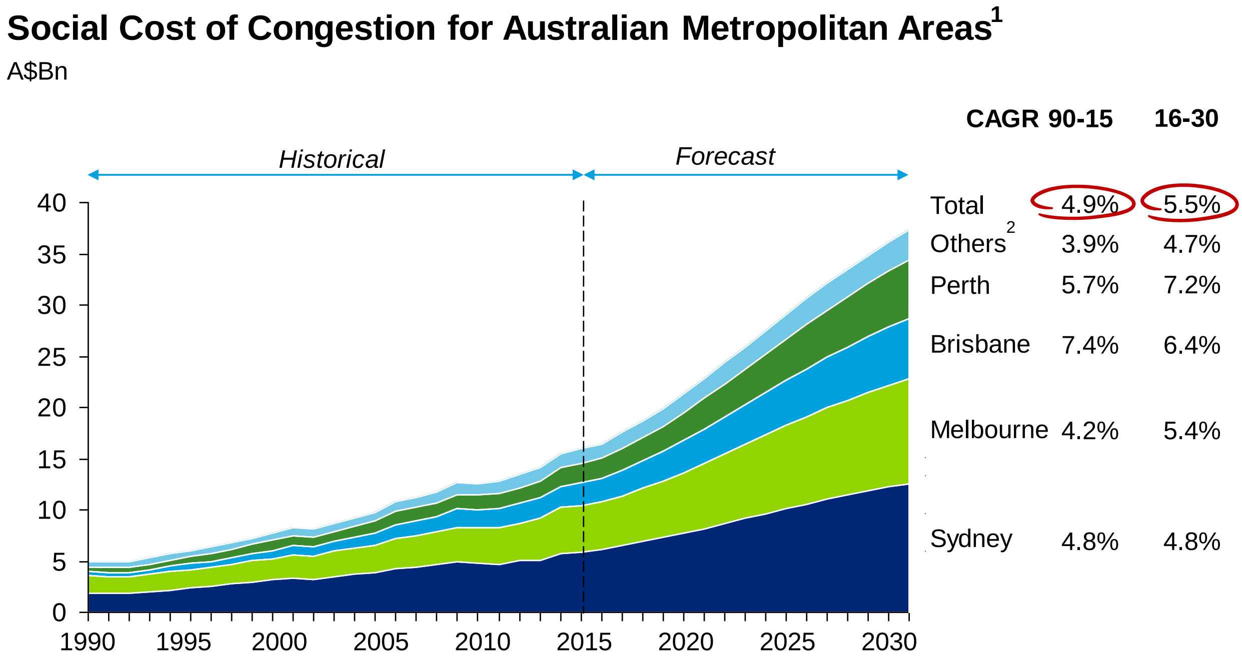
Exhibit 1.15: Key measures of congestion align with how a consumer would consider planning their trip



1.4 Impact of Congestion

As a non-productive activity, congestion has a broad impact on the overall economy, lifestyle and well-being of Australians and New Zealanders. Congestion leads to opportunity costs for all stakeholders. Congested roads can be seen as an example of ‘the tragedy of the commons’, where there is little financial incentive for drivers not to over-use ‘free’ roads, up to the point where traffic collapses into a jam, when demand becomes limited only by the opportunity cost of travellers.

Exhibit 1.16: The overall social cost of congestion is expected to increase by 5.5% per year between 2016 and 2030



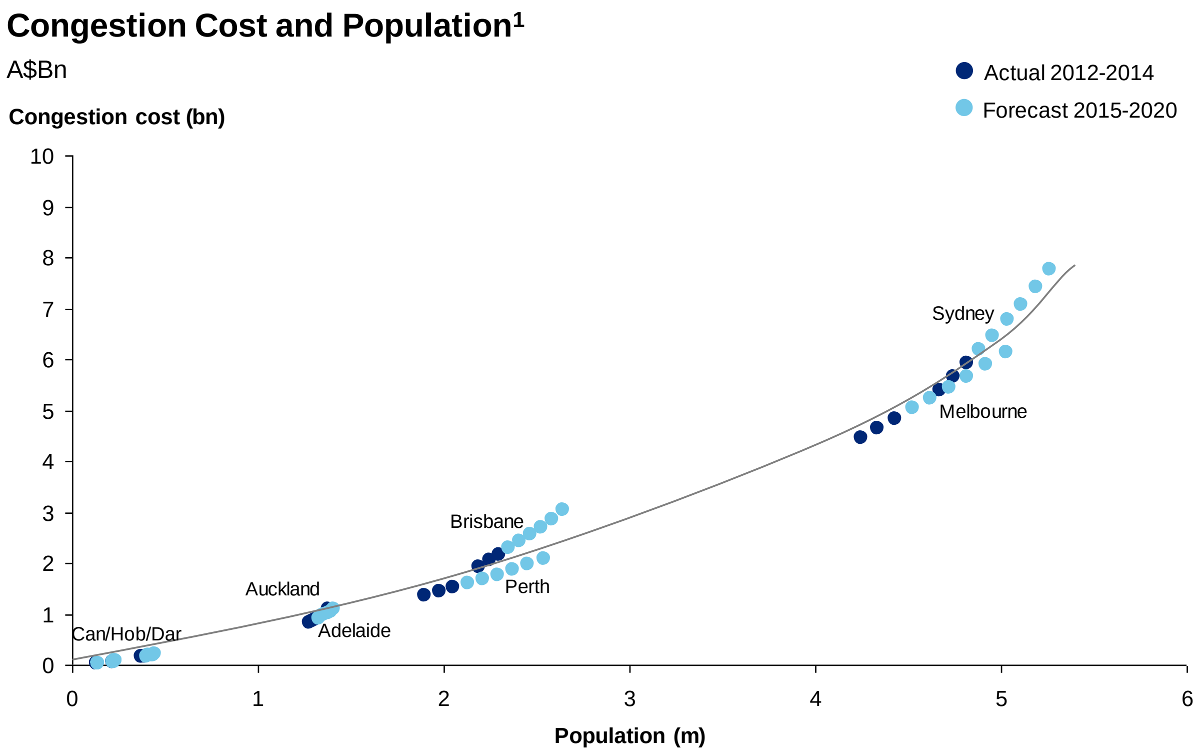
Notes: 1. Avoidable social costs are based on the deadweight losses associated with urban congestion levels (compared with the economically optimal traffic levels). Costs include congestion-related delays, trip variability, increased vehicle operating expenses and increased air pollution damages; 2. Others include Adelaide, Canberra, Hobart and Darwin.

Source: BITRE Report No. 74 ‘Upper baseline projections of avoidable social costs of congestion, by city to 2030’ (2015)

Exhibit 1.16 shows that in Australia, the cost of congestion was estimated by Infrastructure Australia to be $16.3 billion in 2015 and is projected to grow to approximately $20.4 billion by 2020 (measured in delay cost by lane kilometre)[68]. Similarly, the 2006 COAG report, ‘Review of Urban Congestion Trends, Impacts and Solutions’[69] attributed cost across four main categories of impact, totalling $20bn by 2020. The Infrastructure Partnerships Australia analysis[70] (2013) detailed that the cost of congestion in Sydney was over $1,000 per head, Melbourne just under $1,000 per head and Brisbane approximately $800 per head. While no current estimates exist for New Zealand, Auckland’s congestion alone (compared with free-flow conditions) was estimated at over $1.25bn by 2013.[71] Congestion is correlated with population size, but is systematically lower in some cities (see Exhibit 1.17).

68 BITRE, (2015), Report No.74 – Upper baseline projections of avoidable social costs of congestion, by city to 2030
69 COAG, (2006), Review of Urban Congestion Trends, Impact and Solutions
70 Infrastructure Partnerships Australia/Deloitte, (2013), Per capita costs of congestion, analysis of Australian Bureau of Statistics 3220.0 and BITRE Working Paper 71
71 Wallis, I., (2013), The costs of congestion reappraised

Exhibit 1.17: There is a positive correlation between congestion cost and population



Note: No New Zealand data on congestion cost; Auckland has one measurement for 2013, NZ$1.25bn= A$1.1bn using 2013 rate
Source: BITRE Australian Infrastructure Statistics Yearbook 2014, New Zealand Transport Agency 2013

Calculations of the cost of congestion tend to underestimate 'total' cost for three reasons:

1. Unavoidable costs - Calculations generally consider only the estimated avoidable costs, i.e. the calculations do not measure the differential of current delay versus free-flow conditions but consider the deadweight loss of current traffic volumes
2. Non-economic costs – Calculations of current congestion levels are compared with the economically optimal level of congestion, therefore non-economic costs, such as the personal loss of health impacts, are not included
3. Scheduling – Calculations of 'reliability', i.e. the value placed on reliable versus unreliable journeys are not included

The impacts of congestion fall into four main categories: economic, social, environmental and health.

Economic impact: The first, and most costly, is economic-related. This form of impact is a result of non-productive waiting time in traffic, which leads to decreases in overall productivity and results in opportunity cost and negative impact on economic growth. The value of such impact was estimated by the BITRE to be worth $8.9bn in Australia by 2020[72], defined as the business time costs of congestion (trip delay plus reliability).

Analysis by Sweet from 88 of the most congested metro areas in the United States between 1993 and 2008[73], suggested that high levels of congestion are initially associated with faster economic growth. However above a certain threshold, congestion starts to become a drag on growth. Specifically, congestion seems to slow job growth when it becomes worse than about 35 to 37 hours of delay per commuter per year[74].

72 COAG, (2006), Review of Urban Congestion Trends, Impacts and Solutions
73 Sweet, M., (2012), Does traffic congestion slow the economy?
74 Sweet, M., (2012), Does traffic congestion slow the economy?

The costs of congestion also affect businesses. Gibbons et al (2010) found that businesses with better transport access have higher total factor productivity relative to places that are less accessible[75]. If congestion increases average travel time, this is equivalent to reduced transport accessibility and so a reduction in firm productivity.

There is also a wider economic benefit derived from demand management measures and additional public transport introduction through uplifts in land values.

Social impact: The social impact, i.e. the socialised cost shared by all people, is a result of the combined cost of delays for all vehicle passengers involved in congestion. This, for example, can be the cost of blocked traffic interfering with access for emergency vehicles, or additional vehicle operating costs (valued at $2.4bn by 2020, BITRE).

Spillover effects exist in a wide variety of settings given that congestion can change the character of a city. In documented research, this is highlighted as the risk of 'community severance'. Examples of such risks can be physical barriers on cyclists, motorists and pedestrians, psychological barriers with road safety and traffic noise and social impacts on neighbourhood communities[76]. Australian private travel time cost (trip delay and travel time reliability) is estimated to be worth $7.5bn by 2020.

However, it is important to understand social urban congestion impacts in the wider context of urban dynamics. Often, congestion is the outcome of successful economic development, employment, housing and cultural policies that make people want to live and work relatively close to each other. This in turn attracts firms to benefit from gains in productivity. There are many indications that urban road users are prepared to live with crowded roads so long as they derive other benefits from living and working in their cities.

Environmental impact: An often mentioned, but comparatively low value cost is that of environmental impact (BITRE), where air pollution and carbon dioxide emissions rise given worse traffic flow. Such environmental costs will have negative, uncertain long-term consequences on the environment. Despite this, BITRE estimated this to be the smallest of the four impacts by 2020, costing $1.5bn to the Australian economy. In reality, it is difficult to value the environmental impact on society, such as from noise and other forms of pollution. Beevers and Carslaw (2004)[77] found that when the London Congestion Charging Scheme was implemented, mono-nitrogen oxides levels reduced by 12% but increased on the inner ring road by 1.5% - a trade-off.

Transport accounted for approximately 14 percent of greenhouse gas emissions in Australia in 2005 with a 90 percent share of road transport. On top of that, it is the second-fastest growing category of emissions[78]. The use of fossil fuels with a significant concentration of greenhouse gases has led to accelerating levels of climate change. While the repercussions of air pollution lead to local costs across a region, greenhouse gas emissions have a global impact and, thus, require an Australian-wide response[79].

75 Gibbons, S., Lyytikainen, T., Overman, H., Sanchis-Guarner, R., (2010), Productivity and employment impacts of agglomeration: evidence from transport improvements
76 Australian Treasury, (2015), Australia's future tax system, Final report: Detailed analysis, Chapter E: Enhancing social and market outcomes, E3. Road Transport Taxes, E3-3 Road pricing should reflect social costs
77 Beevers and Carslaw, (2004), The impact of congestion charging on vehicle emissions in London
78 Garnaut Review, (2015), Australia's emissions in a global context
79 Australian Treasury, (2015), Australia's future tax system, Final report: Detailed analysis

Health impact: For Australia, BITRE (2005) estimated the health costs associated with air pollution from vehicles to be worth $3.3 billion each year[80]. Increased air pollution as a result of extended vehicle operation and emissions will continue to increase this cost. The causative link between traffic-related air pollution and health was evidenced in the US where a study of 83 US cities found that traffic-related pollution caused 4,000 premature deaths in 2000 at a cost of US$31billion[81]. Air pollutants including carbon monoxide, nitrogen oxides, sulphur dioxides and fine particle matter (PM10-PM2.5) can impact the health of individuals through impairment of the cardiopulmonary function. A study conducted by the American Heart Association Journal in 2010 found that short exposures to PM2.5 for a few hours per week could cause the development of cardiovascular illnesses. Extended exposure for a few years was found to greatly increase cardiovascular mortality shortening the life expectancy of high exposure groups from months to a few years[82]. Congestion can also impact on stress levels, associated with the associated social and economic impacts.

80 Bureau of Transport and Regional Economics (2005), Health Impacts of transport emissions in Australia: Economic costs
81 Harvard Centre for Risk Analysis (2010), The Public Health Costs of Traffic Congestion
82 Climate and Health Alliance, (2013), Inquiry into the impacts on health of air quality in Australia

2. Customer Perspectives on Congestion

"Reliability is becoming more and more an issue because of changing lifestyles of people towards so-called just-in-time living with fully booked diaries… Information can play an important role since better knowledge appears to lead to more conscious decisions."

Bovy, P. and Tacken, M., (1995), 'Behavioural Reactions to Traffic Congestion'

Chapter Summary

2.1 Road User Satisfaction

- Road agencies are increasingly shifting their focus to serving road users as customers; in general they are most concerned with the **reliability of a journey**:
  - Commuters need to be at work on time
  - Commercial road users need to schedule delivery windows
  - Freight road users place high value on the arrival speed of goods to ensure efficient production
- **Congestion impacts the 'liveability' of ANZ cities** through loss of personal time, late arrival for employment and education, inability to forecast travel time, reduced health levels and a higher chance of collision

2.2 Acceptable Congestion

- The 'acceptable' level of congestion is a subjective concept related to both urban planning and customer expectations, with four defining factors:
  - **Commute time.** How many minutes per day are required to travel to work on average in a city?
  - **Stability of Commute Time.** Is commute time better or worse than it was last year?
  - **Scheduling.** How variable is the travel time, and what extra time should be scheduled for delays? Can travel time be reduced by travelling earlier or later?
  - **Productivity.** How much traffic flows through a given road compared to its theoretical capacity?
  - **Economic.** Can investment to reduce congestion be justified?

This chapter considers congestion from the perspective of the road user[83] as a customer of a service, as opposed to the perspectives of road agencies or the government. Historically, the main focus of road agencies has been to build and maintain road infrastructure. Occasionally, road users may lobby for or against building new roads, however the aftermath of the construction and impact on road user satisfaction has not been systematically tracked or measured. As road users are increasingly perceived as customers of a service, road agencies have shifted their focus to improving road user experience and customer satisfaction.

83 'Road user' refers to: personal vehicle drivers, commercial vehicle drivers, freight vehicle drivers

2.1 Road user satisfaction

Congestion is only one of several factors that impact on road user satisfaction. Customer surveys indicate that road users value well-maintained roads, good networks, synchronised and steady traffic, reliability of travel time, convenience and road safety. High quality in these areas is a result of intermodal and network planning. The University of Sydney's Institute of Transport and Logistics Transport Opinion Survey (Q3 2015)[84] found that road users have a low level of confidence about transport in Australia in the short term, with only 7% stating that they believe it will have improved in a year's time (perhaps due to the understood need for long-term change).

2.1.1 Customer Satisfaction

To understand the impact of congestion on liveability, it is important to determine the different customer 'types', and seek their individual opinions on how road experiences could be improved.

- Segment A - Personal
- Segment B - Commercial
- Segment C - Freight

A. 'Personal' Road User Satisfaction

As shown in Exhibit 2.1, several jurisdictions have studied customer preferences and behaviour, all finding that customers desire 'reliable' journey times and often make their own adjustments to ensure reliability. 'Personal' customers see a strong role for road and transport agencies in improving reliability through driver education, installing timely signposting to assist with merging lanes, providing real time information, and increasing accessibility of public transport services (e.g. providing parking around train stations). Users recognise, however, that longer travel times are to be expected during peak periods and during bad weather, and allow buffer time to ensure they arrive on time.

84 University of Sydney, Institute of Transport and Logistics Studies (ITLS), (Q3 2015), Transport Opinion Survey (TOPS)

Exhibit 2.1: Customer surveys indicate that many customers make their own adjustments to obtain reliability

Overview of Research Papers – Key Quotes

Expectations of a 'reliable' journey

Customers expect to be able to reasonably foresee their journey times

"A reliable journey gets you to your destination on time and without too much stress"

"A reliable journey gets you there safely, on time and in a reasonable time"

"A reliable journey is one where I can confidently predict the time it will take if I leave at a given time"

"A reliable journey allows me to predict my departure and arrival times"

"A reliable journey falls within the estimated time of travel to enable one to be punctual"

"A reliable journey is predictable and as expected"

"A reliable journey arrives safely, roughly on time, within the usual variations"

"A reliable journey is consistent in terms of the time it takes"

Customer-type considerations

Road agencies are increasingly consider the different users of the road

"The pedestrian crossings are way too fast. I am fit and struggling to get across in time – other people with impairments or young children must struggle"

"We get a lot of explosive and gas trucks that shouldn't be on our roads – these materials should travel by train"

"The lights often change before you can get a toddler and a pram across the road in time"

"Road trains do not slow down at any of the signs that have reduced speed, this is dangerous for cars"

Future expectations of road agencies

Customers expect road agencies to respond to reliability problems

"Up to date and accurate travel information"

"Consult with the community about traffic facilities and traffic conditions"

"Educate drivers – e.g. merging; Wise Old Owl campaign (MCC)"

"Remove short 'third lanes'"

"More considered application of transit lanes, for example not 24/7"

"No trucks in peak periods"

"Improved and timely signposting to assist drivers to get into correct lane / position more readily"

"Improved parking and safety at CityRail stations to encourage train travel"

Solutions to improving reliability

Customers make their own adjustments to improve the reliability of their journeys

"I leave later"

"I take public transport"

"I don't travel – I work from home"

"I don't leave home on the hour or half-hour"

"I make use of live traffic information, for example via my TomTom"

"I car pool to enable me to use transit lanes"

"I try to spot patterns and leverage them"

"I ask around – 'water cooler talk'"

Source: Multiple Research papers including RTA, 'Community Attitudes to Traffic Management', 2003; Instinct and Reason, 'The Customer Story', 2011; Main Roads Western Australia 'Community Perceptions Survey 2015'

Understanding the factors underpinning road user satisfaction is important for road agencies to make informed decisions and ensure they are achieving the appropriate outcomes as defined by their consumers. Recent findings from individual jurisdiction surveys also help to inform transportation policy and decision-making, by seeking customer perspectives.

Victoria: A 2015 study into 'Enabling integrated transport choices and making journeys pleasant and predictable'[85] summarised the five key expectation statements of customers:

- "I have the ability to plan my journey"
- "The traffic will flow"
- "I will be kept informed of delays and options available to me"
- "The road system will be safe"
- "I can easily provide feedback about my journey"

Meeting and exceeding customer expectations will always be the nature of a customer-facing business organisation strategy. Public services are no different in their customers' expectations; Victoria's study has helped in defining what customers see as the critical aspects of satisfaction.

New South Wales: Transport for NSW's 2013 'Driving Customer Value Proposition' research[86] found that private vehicle drivers in NSW place value on attributes relating to safety, information, enforcement, access/convenience and time. 'Good roads and networks' had the largest 'share' of importance (37%), followed by 'safety and enforcement' (22%), 'synchronised and steady traffic' (21%) and 'predictability and convenience' (20%). Further, there were no key differences identified between private and heavy vehicle drivers' perceptions on these factors.

Further, qualitative research commissioned by the NSW Roads and Traffic Authority (RTA) in 2011[87] sought to understand the key issues identified by customers, including perspectives on congestion and reliability. Customers were asked for their view on appropriate interventions. Responses included improvements in public transport (and hence more people using public transport), better management of traffic lights, application of a congestion tax, and staggering work times. Customers thought the RTA could improve by providing timely, proactive, clear and concise information, as well as encouraging sharing of the road.

Western Australia: A 2015 'Community Perceptions Survey' by Main Roads Western Australia[88] considered performance measures across a number of areas including congestion, road safety, road maintenance, cycleways and pedestrian facilities. Traffic congestion, particularly in peak times, was found to be the highest priority for Western Australian customers, especially in Perth. Indeed, without prompting, 22% of Perth customers mentioned road congestion as the main area to focus on improving.

Queensland: The 2015 'Transport User Choice Report' by the Queensland Department of Transport and Main Roads (TMR) investigated the key considerations for Gold Coast residents when choosing an appropriate mode of transport[89]. Time considerations ('quickest option available') were the most important for all journey types (79% 'care' about this journey aspect). Directness of route (69%), freedom of movement (68%) and reliability (65%) were also key considerations. When asked the characteristics of private vehicles, 82% said that they were the quickest option available and 70% stated they go the most direct route – explaining the region's high private vehicle mode share.

New Zealand: The New Zealand Transport Agency (NZTA) conducted research into its State Highways in 2013[90], involving customers across the country. In this survey, customers rated safe systems (related to risk of crashes), road surface maintenance and journey time as the three key areas where the NZTA could improve State Highways.

85 VicRoads, (2015), Enabling integrated transport choices and making journeys pleasant and predictable
86 Transport for New South Wales, (2013), Driving Customer Value Proposition (CVP)
87 Instinct and Reason, NSW RTA, (2011), The Customer Story – Findings from Qualitative Research
88 Main Roads WA, (2015), Annual Community Perceptions Survey – Final Report
89 Queensland Department of Transport and Main Roads, (2015), Transport User Choice Report: Influence of attitudes and perceptions
90 New Zealand Transport Agency, (2013), State Highways Customer Survey

A. ‘Commercial’ Road User Satisfaction

For light commercial road users, one of the primary concerns of commercial drivers is scheduling. As well as affecting the general economic productivity of a city, the ability to accurately plan for trip time has an effect on the bottom-line of commercial operators given that businesses run to timetables.

For light commercial deliveries, users normally operate within delivery windows. For example, Woolworth’s delivery windows are three hours long and Coles charges premium prices for shorter windows[91]. Here, customers are demanding an accurate forecast of arrival time, and will pay more for increased reliability. Missing such windows will have negative impacts on the business, therefore scheduling is key.

In turn, small businesses, such as plumbers and electricians, who are paid per hour, could forego wages if they are late for appointments and could miss subsequent appointments leading to lost business. Given customer attributes, such as price elasticity, are different from consumers in Segment A, it would be appropriate for road agencies to build a much better understanding of Segment B’s characteristics. Ultimately, separate vehicle licensing may be appropriate to recognise and possibly price their distinct contribution to both congestion (by travelling at the same time as commuters) and liveability (by providing services reliably to travellers).

B. ‘Freight’ Road User Satisfaction

For freight, the ability to schedule delivery times is critical to success. The intricacies of customer satisfaction are dependent on the type of freight. Heavy goods freight is often scheduled by ‘windows’ of port delivery times, where trucks are incentivised to queue at ports so as not to be late for their allocated arrival slot. Mining freight, which often travels long distances intra- and interstate, will be more reliant on the quality of roads to ensure smooth journeys, and will therefore be affected by congestion resulting from incidents and roadworks. Perishable consumer freight has a high cost when delivered late, due to the reliance on the freshness of the product. Similarly, with goods manufactured ‘just-in-time’, a high value is placed on the arrival speed of goods to ensure efficient production.

In Australia, drivers must abide by the National Heavy Vehicle fatigue management regulations[92] and in New Zealand drivers must abide by the NZTA Work Time requirements[93]. Congestion, as well as poor quality of roads, can lead to longer travel times and therefore longer ‘work’ times. This will limit the distance that freight can travel in one day. In Australia, ‘standard hours’, i.e. the work and rest hours allowed without additional safety countermeasures, are normally a total of 12 hours work time, plus at least 7 hours continuous rest time in any 24-hour period. For those with Basic Fatigue Management accreditation, work of up to 14 hours in a 24 hour period is allowed. For those accredited with Advanced Fatigue Management (AFM) accreditation, rather than prescribing work and rest hours, AFM offers flexibility over the standard hours in return for the operator demonstrating greater accountability for fatigue risks. In New Zealand, drivers must take a break of at least 30 minutes after five and a half hours of work time and in any cumulative work day, they can work a maximum of 13 hours with a continuous break of at least 10 hours. Congestion can therefore push a driver over the maximum work time and result in delivery delay in the form of poor scheduling performance greater than the congestion alone would have caused.

When travelling through densely populated areas, freight operators also face restrictions on freight movement such as insufficient space for their vehicles and limitations on delivery and pick-up times. Such limitations result in large numbers of vehicles waiting outside urban areas until the appropriate delivery time[94]. This mitigates congestion in peak hours for other road users, but can cause significant queuing delays for freight. For the London 2012 Olympic Games, Transport for London worked closely with the freight industry to determine a better approach to schedule freight and logistics deliveries. In many cases, early morning or late evening deliveries were possible, with only a small amount of knock-on change (e.g. working hours of staff to receive good) necessary to change behaviour. These lessons have been carried forward to change the nature of freight usage of the network following the Olympic Games95.

91 Supermarket websites, (2015)
92 National Heavy Vehicle Regulator website, (2015). Work and rest requirements
93 NZ Transport Agency, (2015), Work-time and logbook requirements
94 US Department of Transportation, Federal Highway Administrations, (2015), Freight Management and Operations
95 Deloitte UK, SME

Growth in freight traffic can be significant contributor of congestion. With growing freight demand, recurring congestion occurs increasingly at freight bottlenecks. These can be considered as locations in which passenger service and freight overlap and cause conflicts given that there is not enough space for pickup and delivery. Overall, passenger cars and trucks compete for limited road space – the same applies for commuter and freight trains[96].

Finally, the economics of freight mean that it is particularly liable to innovation from autonomous vehicle technology, where investment in efficiency is likely to be more prominently considered than for individual consumers and small businesses. This technology is already in use on private mining roads, such as by Rio Tinto in Pilbara (Western Australia), and the freight industry is likely to be an early adopter in isolated locations given the overwhelming economic benefits.

2.1.2 Information and forecasting

Regardless of road user type, accurate and timely information is important to mitigate the effects of congestion: time delay, reliability and scheduling. Customers are more likely to find congestion acceptable if they know that traffic is likely to be slow and are kept informed about delays.

Customers that use the road network now have access to timely information pre-, during and post-journey, via smartphone apps, websites, radio broadcasts and new digital channels. The Victorian 'Enabling integrated transport choices and making journeys pleasant and predictable' study97 (2015) involved a survey of 800 road and public transport users and 100 truck drivers to understand customer behaviorrelating to journey planning and the use of available tools. The study outlined an approach to investigate customer journey expectations and considerations. Before the journey, customers expect to have the ability to plan their journey based on what the traffic is like, whether there are delays and what the best route is to get to the destination on time. During the journey, customers expect that traffic will flow, the road system will be safe and they will be kept informed of delays and options. They will consider how they can get away from traffic depending on suitability of the alternative route. Post-journey, customers expect to be able to provide feedback on their journey if they so wish. They will consider how they can raise concern about traffic and they will want to share their experiences with family and friends. Fulfilling these expectations and answering or enabling the associated considerations are key to customer satisfaction.

The same Victorian study found that road users who planned their journeys experienced a higher degree of journey satisfaction, but around 30% of car drivers and 38% of truck drivers do not plan their trips. Twenty percent were aware of the VicTraffic app, but only 10% actually used it. Twenty percent of respondents preferred an integrated road and public transport app. Further, the survey found that Google Maps was most used to plan journeys, and updates via the radio was the most popular channel for information upon commencing the journey.

2.1.3 Congestion and Liveability

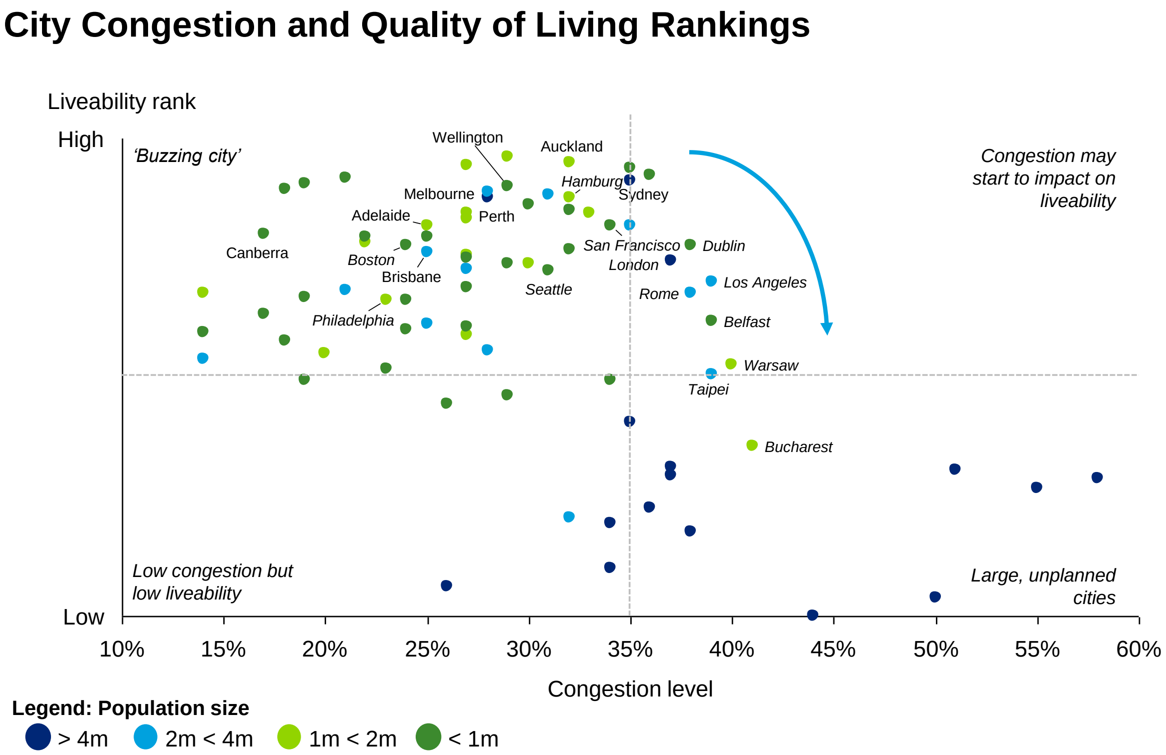
As outlined in Chapter 1, the social impacts of congestion are those directly impacting the customer, the result of insufficient levels of service and decreases in satisfaction. Social impacts of congestion include, but are not limited to:

- Loss of personal time
- Late arrival for employment, meetings, education - resulting in monetary cost
- Inability to forecast travel time accurately
- Reduced health levels given stress
- Higher chance of collision in densely populated roads, with potential for personal consequences (however may lower the severity of collisions because of slower speed)

96 US Department of Transportation, Federal Highway Administrations, (2015), Freight Management and Operations
97 VicRoads, (2015), Enabling integrated transport choices and making journeys pleasant and predictable

All of the above points impact on the 'liveability' of a city as shown in Exhibit 2.2. In fact, comparing road congestion levels with Mercer's Quality of Living rankings[98], there is a correlation between a higher level of congestion and a lower liveability ranking. Australian and New Zealand cities tend to maintain relatively high standards of living (from Auckland ranking 3rd to Brisbane ranking 37th) despite their congestion levels[1] ranging from 17% in Canberra to 35% in Sydney. However, there appears to be a strong decline in quality of living rankings when congestion reaches 40% - a region that Sydney and Melbourne are approaching. This suggests that there is potential for improving the relative attractiveness and liveability of a city by improving its congestion levels.

Exhibit 2.2: Population growth influences both congestion and liveability; congestion must be managed to mitigate the negative results



Source: Mercer Quality of Living Rankings, 2015, based on consumer goods, economic environment, housing, medical and health considerations, natural environment, political and social environment, public services and transport, recreation, schools and education, socio-cultural environment; TomTom congestion data

Those cities with high congestion and low liveability rankings are also those that have high populations. As expected, a by-product of a large population will be an increase of vehicles on the road. As Australian populations expand, it will be necessary for them to mitigate the downward trajectory in liveability associated with highly populated urban area.

2.2 'Acceptable' congestion

While congestion is measured as the time above the nominal travel time (as defined in Chapter 1) and is clearly considered a negative by road users, this does not suggest that zero congestion (free-flow traffic) is an achievable goal in our cities at a reasonable cost. Some comparable cities have come close to achieving zero congestion, but their methods are unlikely to be replicable, or desired, in Australia:

- **Singapore.** Singapore achieves a very tight distribution of travel speed on its extensive highways network, through the world's highest prices for vehicle registration and variable cost per kilometre pricing. This policy is unlikely to be acceptable in Australia.

98 Mercer, (2015), 2015 Quality of Living Rankings

- **Indianapolis.** Indianapolis achieves low levels of congestion on its freeways. This appears to be because it has developed a textbook ‘concentric circles’ configuration, with:
  - A ring road to both bypass the city centre and reduce cross-city journeys
  - Radial freeways to provide quick access to the ring road

This is easier to achieve in ANZ cities than Singapore’s method, but is expensive due to coastal locations, rivers and hills.

Congestion indicates high demand for use of a road, therefore indicating that the road is linking important origins and destinations. This, in turn, can be an indicator of economic success and growth in a region.

The ‘acceptable’ range of congestion (i.e. that which the road user is comfortable with) is likely to be greater than any mathematically ‘optimal’ point. The aim of congestion management should be to target this acceptable range. Indeed, it is likely that during peak hour the road user may accept a higher level of congestion than at other times of day, particularly if there are no mode substitutes.

The acceptable level of congestion will vary by city and road user type (defined by purpose of trip and time of day). For example, people who are using the road for business purposes may have a higher value of travel time savings than those using the road for recreational purposes, resulting in business road users having a lower acceptable level of congestion than recreational road users (on average). For businesses, as discussed earlier, depending on the purpose of trip, ‘scheduling’ is likely to be the most important factor. Acceptable congestion may depend on the ‘charge-out’ rates of the business, for example there may be costs if a plumber arrives more than 15 minutes late, or he may then go on to forego another job.

The theory of acceptable levels of congestion is upheld by the ‘Fundamental Law of Road Congestion’ as measured by Duranton and Turner[99]. The Fundamental Law indicates that, regardless of investment in either road infrastructure or public transport, travel patterns tend to adjust to return a road to a stable level of congestion.

For example, the duplication (and addition of three extra travel lanes) of the Iron Cove Bridge in Sydney had minimal impact on congestion levels, although it did have an effect of increasing the capacity of the bridge by up to 2000 cars per hour on each extra lane constructed[100]. It is important to note that this finding does not mean that the duplication at Iron Cove was a failure that should not have happened. Rather, it did not deliver its planned benefit (reduction in travel time) because consumers found utility by changing their behaviour. In this case, it is likely that relative demand for housing changed along the transport corridor with a migration from closer, smaller houses to large houses further from the city centre. The critical deficiency in transport and urban planning was that this impact was not modelled into the initial investment case nor tracked after the bridge was built, so it is not possible to know what alternatives (if any) would be better next time.

Research indicates that four factors are important in defining an acceptable level of congestion:

A. **Commute Time:** How many minutes per day are required to travel to work on average in a city?

B. **Stability of Commute Time:** Is commute time better or worse than it was last year?

C. **Scheduling:** How variable is the travel time, and what extra time should be scheduled for delays?

D. **Productivity:** How much does traffic flow through a given transport project compared to its designed capacity?

E. **Economic:** Can investment to reduce congestion be justified?

99 Duranton and Turner, (2009), The Fundamental Law of Road Congestion: Evidence from US Cities
100 Sydney Morning Herald, (2011), As construction nears end, focus turns to local impact

The acceptable level of congestion can be defined as follows:

A. **Commute Time:** Less than 80 minutes average commute time per day.

B. **Stability of Commute Time:** Stable or declining average commute time across the urban area.

C. **Scheduling:** Knowledge that 9 times out of 10, travel time will be 'average travel time + X minutes'. 'X' cannot be defined for ANZ cities as a whole, but can be defined for individual cities when considering their performance metrics in Chapter 3.

D. **Productivity:** Roads operating a productive flow, in line with the speed-volume relationship. Austroads NPIs consider this to be 100% when speed is 80% of posted speed for freeways and 65% for arterials, and flow is 2000 pc/h/lane for freeways and 900 pc/h/lane for arterials.

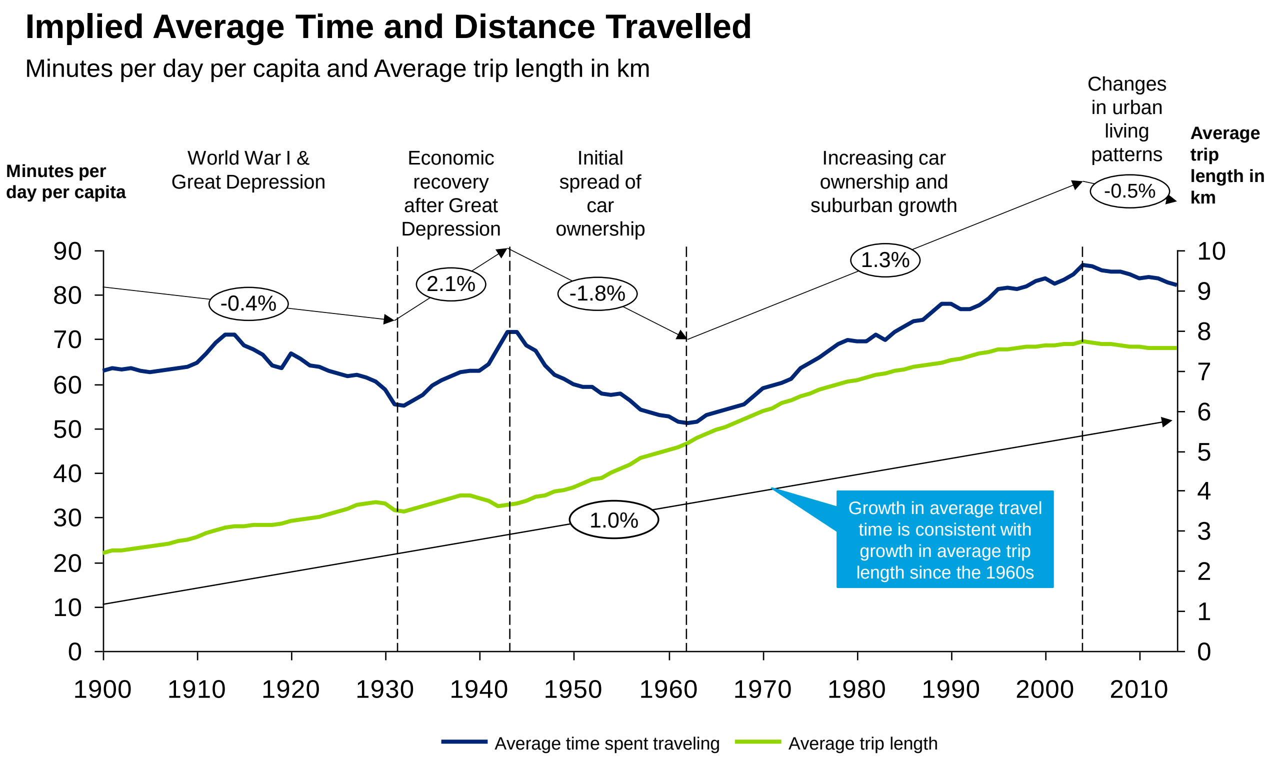
E. **Economic:** Congestion is acceptable where the marginal cost of an additional 'unit' of congestion is lower than the marginal cost of intervention to prevent that 'unit'.

Additional research is required to identify city-specific acceptability.

A. Commute Time

Behavioural drivers of congestion are complex; interactions between both supply and demand side influences impact on journey decision-making. Exhibit 2.3 indicates that Australians have a tolerance band for commuting between 50 to 80 minutes per day, regardless of travel mode (i.e. in 1900-1930, travel was on foot, horse, tram, train and boat).

Exhibit 2.3: Time spent travelling has not changed significantly in Australia since the start of the 20th century



Source: BITRE 2015 Estimates

This journey time is end-to-end, so includes walking, waiting and parking times. End-to-end journey manipulation requires coordination between three tiers of government and multiple state ministries.

Studies on customer priorities align with theoretical work identifying reliability as a key factor in congestion. Despite the perceived desire for lower travel times, Marchetti's Constant posits that although forms of urban planning and transport may change, and although some live in villages and others in cities, people gradually adjust their lives so that average travel time stays approximately constant: such commuting time is approximately one hour. We see this between the cities in our study: consider the difference in size, planning and geography of Sydney and Perth – the average Perth commute is 27 minutes and the average Sydney commute is 35 minutes. Further, the average time spent commuting to work in England has remained constant from 1965 to 2014.

From a road operator perspective, there are relatively few supply-side interventions that can directly influence travel time:

- Building a freeway network that connects and bypasses important places (e.g. CBD, airports, ports) so that traffic can make trips in mainly free-flow conditions
- Creating arterial corridors between freeways and other important places such as hospitals, schools, stations, shopping centres and high density residential centres

The optimal road system therefore requires a long-term integrated transport plan to supply appropriate infrastructure at a given point in time in the development of a city. There are significantly more demand side interventions that influence congestion, most of which are outside the traditional remit of road agencies. This is precisely the reason integrated city-wide agencies, such as Transport for London and Transport for New South Wales, are required to balance investment in supply and demand side interventions end-to-end.

B. Stability of Commute Time

From a customer perspective, the acceptable level of commute time is driven by broader choices around lifestyle, for example:

a) Should I buy a large house for $Xm, with a 60 minute commute by car?

b) Should I buy a large apartment for $Xm, with a 60 minute trip by public transport?

c) Should I buy a small apartment for $Xm, with a 30 minute walk to work?

d) Should I take a lower paying job in the suburbs or in another city with a better housing and commute lifestyle balance?

Once these long-term decisions are made, adverse changes in transport mix are likely to drive the view that congestion is not acceptable. When road users decide to live in a specific area, they are doing so with the presumption that commute time will either remain static or improve if they stay in that area, and a worsening of commute time will not be seen as acceptable. For example, it will not be deemed acceptable if additional development in higher density housing causes commute times to increase without sufficient increase in public transport. However commuters may accept increased commute times if they decide to move further from the city, as a decision based on the trade-off of trip distance, duration and lifestyle.

Decision-making choices c) and d) are more robust, so are the likely (and observed) choices where transport investment lags growth or land-use planning isn't aligned with transport planning.

C. Reliability

Reliability approach. Reliability (as defined by the statistical approach of standard deviation divided by the mean) is a critical measure of the variability of travel. A standard deviation consolidated close to the median is of higher value to all road user types, compared to a highly dispersed range. Often, reliability is a key metric used by road agencies to measure congestion.

Scheduling model approach. The effect of reliability is particularly felt when unreliable travel causes disturbances to road users' plans. This effect is captured in 'scheduling models' of road user behaviour. Indeed, poor reliability means that road users may add 'buffer' travel time onto a trip which effectively extends the duration of a trip and is therefore in some ways equivalent to longer travel times. The 'scheduling' approach to congestion explores this, by looking at the relationship between the 90th percentile of recorded travel times and the free-flow. Customers put value on knowing that 'nine times out of ten the trip will take 60 minutes'. The level of acceptability in this case will be based on the personal value that the customer attaches to the different aspects of congestion.

The scheduling consequences of reliability are expressed as the expectation of the number of minutes one arrives (or departs) earlier or later than one's preferred arrival (departure) time (de Jong and Bliemer 2015)[101]. In an Australian study Hensher, Li and Rose (2010)[102] found a significant difference in the valuation of early arrival compared to late arrival, with a mean estimate for early arrival of $24.10 per hour, and mean estimate for late arrival of $38.86 per hour. This suggests that there is indeed a cost of reliability whether one arrives early or late, but that the cost of being late is greater.

It should be noted that these are average values, and that there are many considerations to account for in estimating the value of reliability through a scheduling model. For example, travel time distribution may not be constant during the day, and there may not always be disutility associated with arriving early or late. It is possible that for certain non-work trips or work trips with flexible arrival schedules, there may be a low cost to being early or late. As such, planning and real time information also significantly impacts the satisfaction of road users.

As discussed with economic theory, investments in reducing congestion should only be made if they result in net economic benefits for society, and so should take into account the fact that there is an acceptable level of congestion. Investments should be made in line with best practice as set by Austroads.

D. Productivity

A 'productivity' view of congestion looks at how much traffic flows through a given transport route compared to its designed capacity. Speed stays relatively constant with increases in volume until a given point, where the minimum feasible headway (or close to it) is reached. If there are available substitutes (such as public transport) for the route travelled, the speed-volume relationship will not reverse past the point of 'acceptable', or 'mathematically optimal' volume. The data shown in Exhibit 2.4 shows the point at which the volume of cars passing a point diminishes as speed slows to an amount attributable to congestion.

As per Austroads National Performance Indicator methodology, productivity is considered 100% when speed is 80% of posted speed for freeways and 65% for arterials, and flow is 2000 pc/h/lane for freeways and 900 pc/h/lane for arterials.

E. Economic Cost

An economic perspective considers the acceptable level of congestion based on the economic costs to reduce it. Congestion is at an acceptable point where the:

Marginal Cost of an additional 'unit' of Congestion = Marginal Cost of Intervention to Prevent an additional 'unit' of Congestion

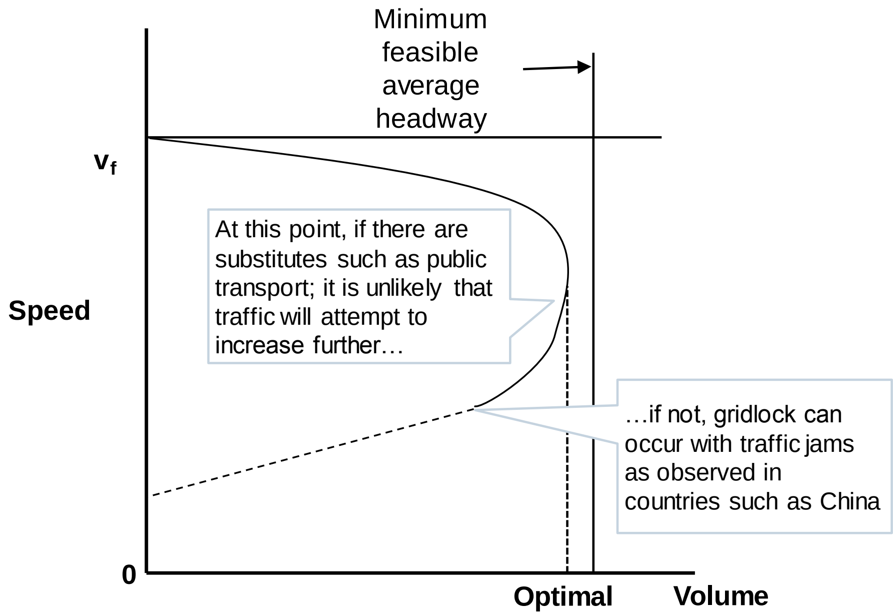
Where the marginal cost of congestion is greater than the marginal cost of intervention, congestion is above the 'acceptable' level. Therefore, congestion is acceptable where the marginal cost of congestion is lower than the marginal cost of intervention. Given this, if the Benefit-Cost Ratio of a given intervention is greater than 1, then the intervention should be invested in.

101 de Jong, G., C., and Bliemer, M. C. J., (2015), On including travel time reliability of road traffic in appraisal, Transport Research Par A: Policy and Practice 73, 80-95

102 Hensher, D., Li, Z., and Rose J. M., (2010), Willingness to pay for travel time reliability in passenger transport: A review and some new empirical evidence, Transportation Research Part E, 46, 384-403

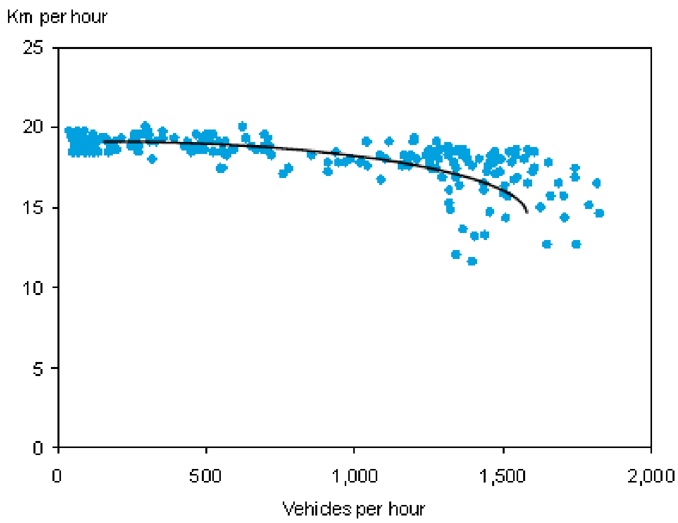
Exhibit 2.4: The optimal volume of traffic is the point past which additional volume causes speed to decrease

Speed-Volume Relationship - Theory



Actual Speed-Volume Relationship

Adelaide, Segment of South Road, September



Note: Speed = Average speed of cars; Volume = Number of cars passing a given point; Density = Number of cars per km^2

It is clear that improving road user satisfaction relies on a combination of defining the ‘acceptable’ level of congestion, understanding what that level congestion means to the customer, consulting the customer on the influences of acceptability and incentivising the use of alternative modes of transport. As both road and transport agencies continue to develop their understanding of customer needs, a combined approach to serving journeys in Australian and New Zealand cities will make for the most satisfied customers.

3. Congestion Performance

"Performance: If you know you're any good at all, you'll know you can be better."

L. Buckingham, Fleetwood Mac

Chapter Summary

3.1 ANZ Weekday Congestion Performance

- **Sydney and Melbourne** have similar congestion metrics across the analysis, highlighting their similarity as Group 1 cities and as comparators for each other. Melbourne performs better in Travel Time Delay (23% compared to 31%), likely a consequence of its historically planned road network. In the afternoon peak Sydney's road users need to budget 50% additional travel time in order to arrive on time 90% of the time
- **Adelaide** has a slow Average Speed (28km/hr), in part due to the proportion of its road network that has free-flow speeds of less than 50km/hr (85%); however it has comparatively good Afternoon Peak Reliability (3%), given its city size
- **Perth, Brisbane and Wellington** have high Average Speeds (at least 50km/hr) , average Travel Time Delay (10-14%) and good Morning and Afternoon Peak Reliability (6-9%); all three have similar congestion measure outputs, despite their geographical differences
- **Auckland** has low Reliability (10-12%) and road users need to budget 45% additional travel time in order to arrive on time 9 times out of 10 in the afternoon, a likely consequence of the geographical impediments to road characteristics and land use
- **Darwin and Hobart** have good Reliability (1-6%) and low Travel Time Delay (4-8%), a likely consequence of their small city size and comparatively low demand
- **Canberra** has the fastest Average Speed of ANZ cities (61 km/hr); its morning peak has poorer Reliability (7%) and Travel Time Delay (15%) than its afternoon peak (4% and 14% respectively)

3.2 ANZ Weekend Congestion Performance

- **Weekend Travel Time Delay** accounts for between **15% and 25% of the total** weekly Travel Time Delay
- On weekends, Average Speeds are **slowest** at approximately **12 midday**
- On weekends, **Travel Time Delay peaks** at approximately **12 midday**, with the highest delays observed in cities with larger populations

3.3 Congestion Performance in ANZ Cities and International Comparators

- **ANZ cities perform in line with international comparators** on the three key measures of Average Speed, Travel Time Delay and Reliability
- Cities with **larger populations** (Megacities and Group 1) **have lower Reliability and Travel Time Delay performance**, however Group 2 and 3 cities have comparable performance
- **Group 1: Sydney and Melbourne** have lower Travel Time Delay, similar Average Speeds and similar Reliability as the comparators of Boston, Philadelphia and Seattle
- **Group 2: Auckland** has significantly higher levels of congestion than its international and local comparators in Group 2; **Brisbane and Perth** have similar delays to Las Vegas, but with lower Reliability; **Adelaide** has low Travel Time Delay compared to most Group 2 cities
- **Group 3:** All have relatively low congestion and high Reliability; **Wellington** performs worst and **Canberra, Hobart and Darwin** are similar to each other and to Ottawa

The nature of a city's road network (including road type and land use), the quality and effectiveness of alternatives to driving (including public transport), the geographical features (including topography) and the population characteristics (including absolute size and density) all play a part in determining congestion performance.

All ANZ cities experience congestion, but at varying levels and with differing characteristics. In order to gain an appropriate understanding of congestion performance, ANZ congestion is measured based on the six definitions of congestion discussed in Chapter 1, Section 1.3. These measures are specific to this analysis, and are the most appropriate for capturing insights from the significant Google dataset used in this work. This dataset provides greater practical and real-time insights than traditional data sources used to date, and as such, the measures used in this report are similar but distinct from the Austroads NPIs[103].

The analysis in this chapter is based on a selection of major roads in each city. Three key inputs determined this selection (as detailed in Appendix A.4), including:

- Information provided by jurisdictions in response to the data request
- Google Maps' traffic layer
- Shape files of cities

The ANZ cities and international comparators referred to in this chapter are approximated by their individual road selection; that is, the analysis has been conducted on a relevant subset of roads rather than the entire road network for each cities.

The congestion performance analysis is based on Google maps data collected from 9 September 2015 to 26 November 2015[104]. Observations over this period are assumed to be a representative sample, including weekdays, weekends, school holidays, public holidays and special events (sporting finals). However, it is acknowledged that there are likely to be differences in data collected over this period compared with data collected for a whole year, with incidents and roadworks not necessarily reflective of the longer period. Regardless of the period of data collection, there are likely to be anomalies.

To ensure that comparison is not made between distinctly different ANZ cities, the cities have been 'grouped' primarily based on population size. Population density (higher density where population large) and public transport mode share (higher share where population large) are also correlated with these groups, however GDP per capita was largely irrelevant. The groups of cities are as follows:

- Group 1: Sydney and Melbourne
- Group 2: Perth, Brisbane, Adelaide and Auckland
- Group 3: Canberra, Hobart, Wellington and Darwin

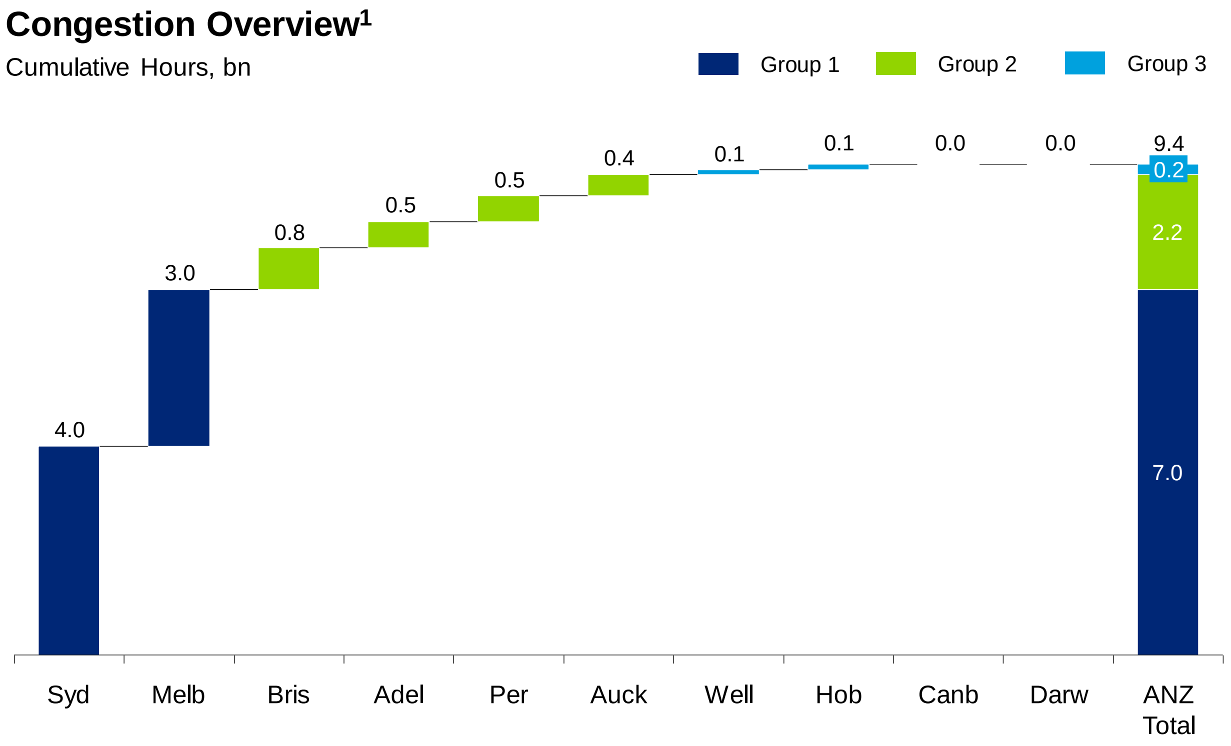
Across the ANZ sample of roads, total Travel Time Delay is 9.4 billion hours per annum[105], with Group 1 cities accounting for 75%, Group 2 accounting for 23% and Group 3 accounting for 2% of the total hours (see Exhibit 3.1).

103 TMR notes that results from the department's strategic transport modelling and traffic count program do not align with the Report's analysis as presented here, nor are they reflective of current network performance data which is used to prioritise future investment

104 Data for ANZ cities were collected in September and October, with data for international comparator cities collected in November. Appendix A.5 provides the specific date ranges for data collection for each city.

105 September and October hours have been aggregated to represent annual hours. Total person hours are estimated by estimating excess travel time per kilometre (through estimates of excess travel time for each city and total length of road network) multiplied by the total vehicle kilometres travelled in capital cities (based on ABS and Ministry of Transport data).

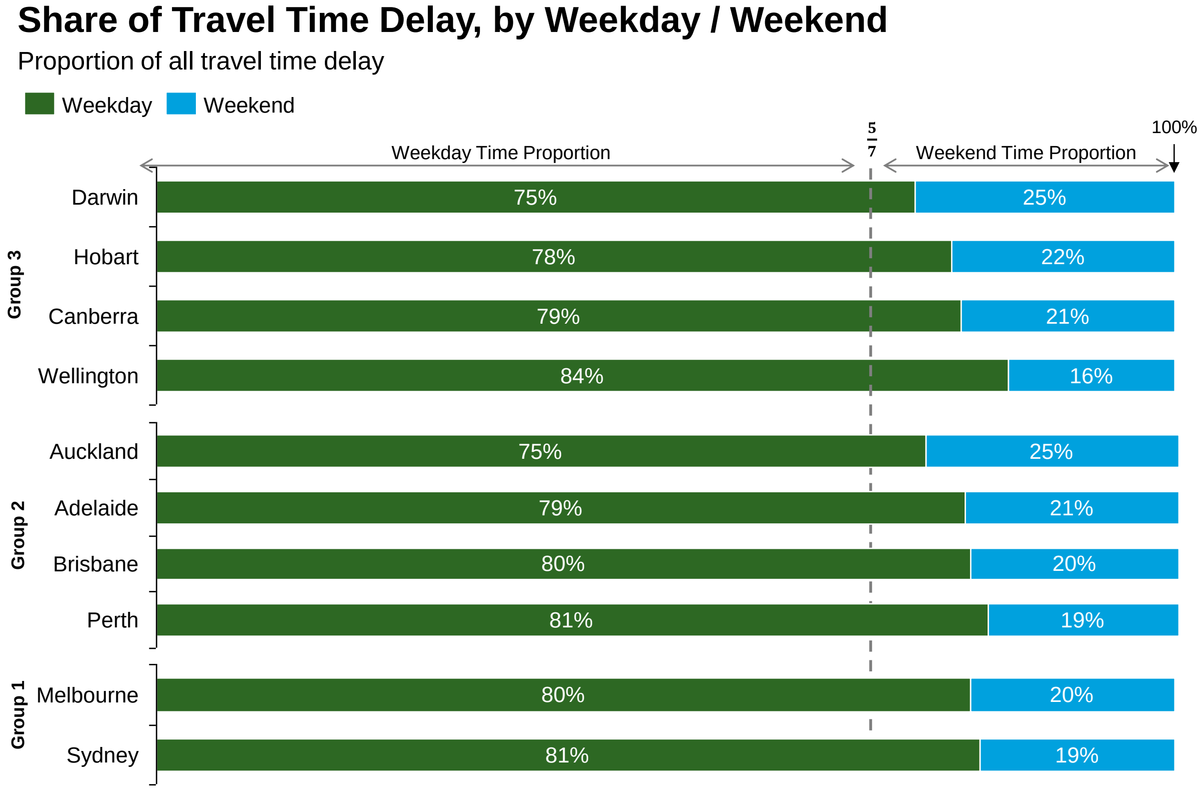
Exhibit 3.1: The ANZ sample of roads has a cumulative travel time delay congestion of 9.4 billion hours



Note: 1. Cumulative sum of excess road time, peak period scheduling and travel time delay
Source: Google maps data (2015-09-09 to 2015-10-29)

In this chapter, congestion performance is analysed separately for weekends and weekdays. Weekdays account for five of the seven days of the week (71%), yet their share of Travel Time Delay is more than this for all ANZ cities (~75 to 85%), as illustrated in Exhibit 3.2. In Group 3, Darwin has the highest proportion of Travel Time Delay at the weekend (25%) and Wellington has the lowest (16%).

Exhibit 3.2: Weekdays account for ~75-85% of Travel Time Delay, more than the proportion of time they represent



3.1 ANZ Weekday Congestion Performance

For each ANZ city, the six measures of congestion are detailed in Exhibit 3.3. Each measure is investigated in detail in Sections 3.1.1 to 3.1.5. Group 1 cities (i.e. the largest cities by population) have comparatively low level of congestion performance and Group 3 cities (i.e. the smallest cities by population) have comparatively high level of congestion performance.

In general, Afternoon Peak Reliability (3pm to 7pm) is better than Morning Peak Reliability (6am to 10am), however Morning Peak Travel Time Delay is better than Afternoon Peak Travel Time Delay. This suggests that the afternoon peak period is spread over a longer time period.

Exhibit 3.3: Sydney, Auckland and Wellington are the worst performing cities in their respective groups

Key Congestion Measures – By City, Weekdays

Group 1 | Group 2 | Group 3

City	Average Speed (Km / Hr)	Travel Time Delay (%)	Reliability (%) Morning Peak (6am to 10am)	Reliability (%) Afternoon Peak (3pm to 7pm)	Scheduling (%) Morning Peak (6am to 10am)	Scheduling (%) Afternoon Peak (3pm to 7pm)
	How fast does traffic in the city travel?	*How much is traffic delayed from free-flow conditions?*	*What is the statistical reliability of travel times in the morning peak period?*	*What is the statistical reliability of travel times in the afternoon peak period?*	*How much time does a consumer need to budget during the morning peak period, relative to free-flow?*	*How much time does a consumer need to budget during the afternoon peak period, relative to free-flow?*
Sydney	29	31%	14%	9%	49%	50%
Melbourne	34	23%	11%	8%	34%	41%
Brisbane	52	12%	8%	6%	23%	23%
Perth	58	14%	7%	6%	22%	25%
Auckland	42	22%	12%	10%	37%	45%
Adelaide	28	11%	7%	3%	16%	17%
Canberra	61	9%	7%	4%	15%	14%
Hobart	42	8%	6%	4%	12%	15%
Wellington	55	10%	9%	9%	21%	20%
Darwin	36	4%	1%	2%	5%	6%

Note: As analysis was based on 600km of the most congested roads, comparisons are better drawn among cities within the same group based on population size.

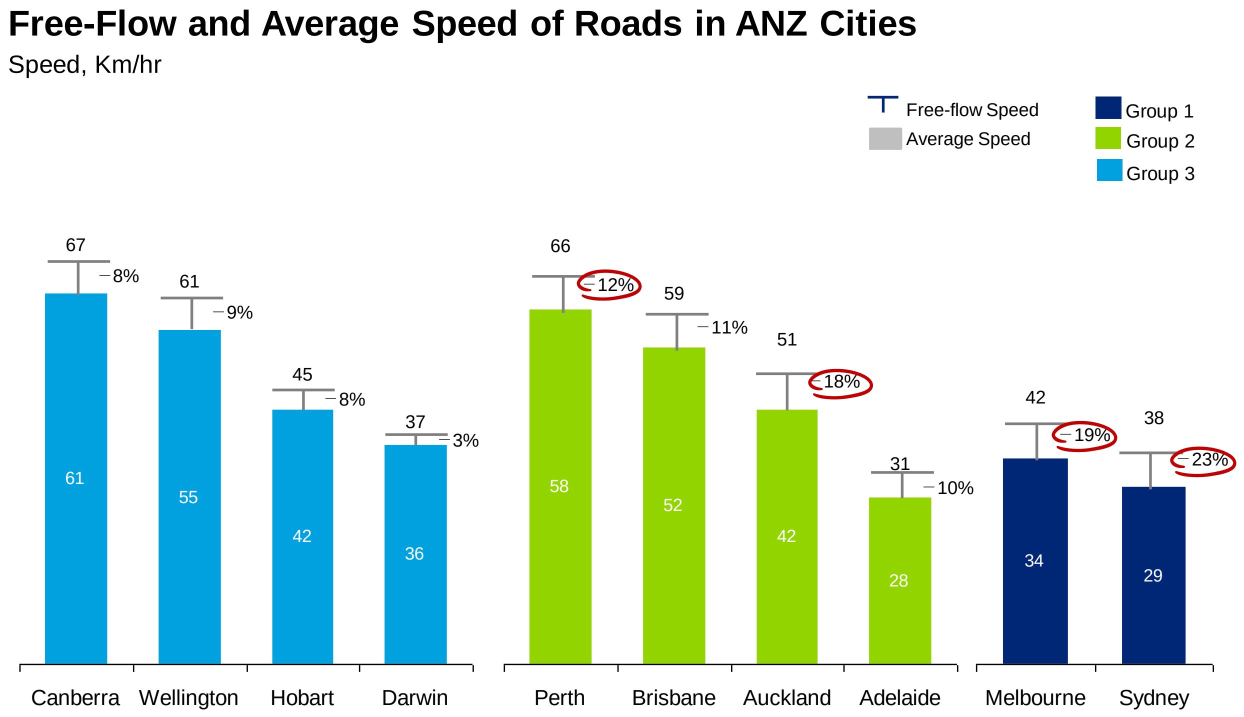
The key findings of comparative ANZ congestion performance measurement include:

- **Sydney and Melbourne** have similar congestion metrics across the analysis, highlighting their similarity as Group 1 cities and as comparators for each other. Melbourne performs better in Reliability (23% compared to 31%), likely a reflection of its historically planned road network. In the afternoon peak, Sydney's road users need to budget 50% additional travel time in order to arrive on time 9 times out of 10
- **Adelaide** has slow Average Speeds (28km/hr), in part due to the nature of the slow speed limits on its road network; however it has comparatively high Afternoon Peak Reliability (3%), given its city size
- **Perth, Brisbane and Wellington** have high Average Speeds (at least 50km/hr), average Travel Time Delay (10-14%) and good Morning and Afternoon Peak Reliability (6-9%); all three have similar congestion measure outputs, despite the differences in their size, topography and historical development
- **Auckland** has low Reliability (10-12%) and road users need to budget 45% additional travel time in order to arrive on time 9 times out of 10 in the afternoon, a likely consequence of the geographical impediments to road characteristics and land use
- **Darwin and Hobart** have high Afternoon Peak Reliability (1-4%) and low Travel Time Delay (4-8%), a likely consequence of their small city size and comparatively low road network demand
- **Canberra** has the fastest Average Speed of ANZ cities (61 km/hr); its morning peak has poorer Reliability (7%) and Travel Time Delay (15%) than its afternoon peak (4% and 14%)

3.1.1 Average Speed

Exhibit 3.4 shows the Average Speed of roads in each of the cities. Canberra has the fastest average travel speeds in Group 3 (61km/h), largely reflecting a number of high-speed rural roads and major motorways with high speed limits and low congestion, as well as low density. Perth and Brisbane have the highest average travel speeds for Group 2 (58km/h, 55km/hr and 52km/hr, respectively) which reflects the makeup of their road networks.

Exhibit 3.4: Sydney, Auckland and Wellington are the worst performing cities in their respective groups



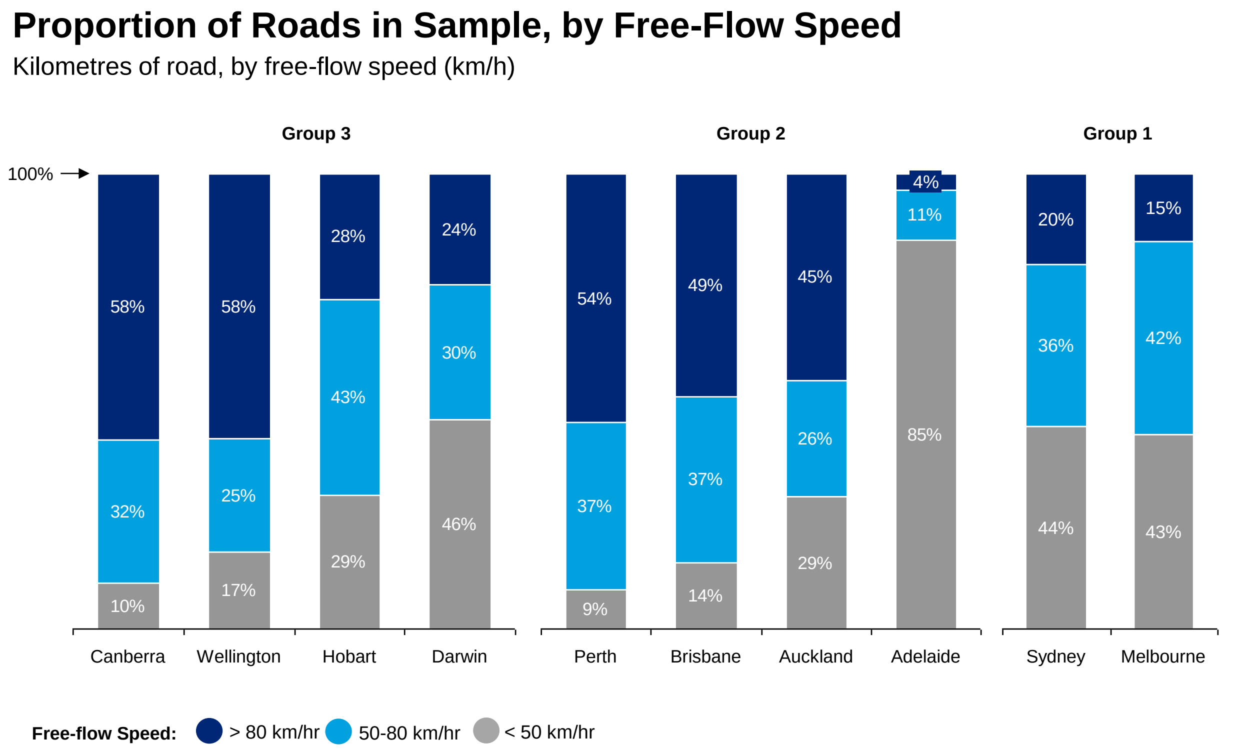
Adelaide has the slowest Average Speed of 28km/h[106], largely influenced by the very slow Average Speeds on King William St and North Terrace, and the types of roads in this urban area compared with other cities, as discussed in the next section. Sydney and Melbourne also have very low Average Speeds (33km/h and 34km/h, respectively), reflecting the size of their populations and number of vehicles on the roads.

Speed of Roads in Sample

Average speeds should be treated with caution as there are a number of factors which can influence Average Speeds. For instance, where road selection in a given city included a greater number of motorways, or roads with higher speed limits, Average Speeds tend to be higher (see Exhibit 3.5). Indeed, in Adelaide, only 4% of the observed kilometres of road are motorways (defined as roads with free flow speeds in excess of 80km/h), while 45% of the road sample in Auckland, and 58% of the sample in Canberra are motorways. Cities with more commercial streets or people-centred spaces in their road sample are likely to have lower Average Speeds.

106 It is acknowledged that separate analysis conducted by South Australia using Bluetooth data found average speeds in Adelaide in excess of 40km/h. For consistency, Google data was used across all jurisdictions, rather than using a separate data source for analysis of Adelaide. The differences between the data sources may be attributable to Google estimates (which are based on Google Maps and may not be based on live speeds but received and historical data), the time period of analysis, road selection and considerations such as road and time weighting over a 24 hour period.

Exhibit 3.5: Adelaide has the highest proportion of roads with free-flow speeds slower than 50km/hr



Note: As analysis was based on 600km of the most congested roads, comparisons are better drawn among cities within the same group based on population size

Source: Road distribution, as per those selected by Austroads jurisdictions

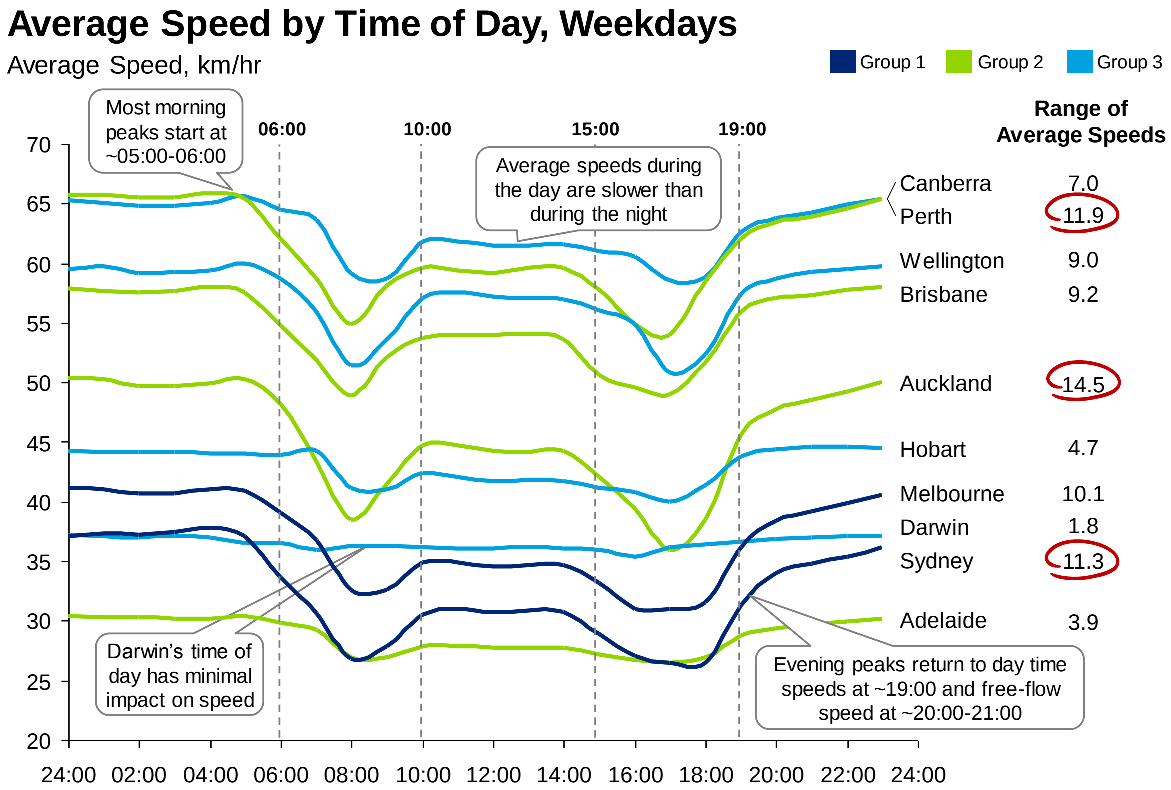
Further, different road intersection controls may also affect the flow of traffic and hence Average Speed. For example, Canberra's road network is characterised by a number of roundabouts whereas other cities may be more dependent on traffic signals, which respond less efficiently to actual traffic patterns.

It should be noted that the 'grouping' of cities is not a clear predictor of Average Speed; while Group 1 cities are together at the slower end of the scale, Group 2 and Group 3 cities are interspersed.

Weekday Peak Periods

Regardless of the overall Average Speed, there are clear peak periods of lower comparative Average Speed in the morning and afternoon for all cities apart from Darwin (see Exhibit 3.6). Most cities have morning peak periods starting between 5am and 6am, with Sydney, Melbourne, Perth, Brisbane, Auckland and Wellington exhibiting the largest spreads of morning peak, from around 5am until 10am. For Hobart, Average Speeds improve at 10am, but gradually worsen again until 5pm, with no clear afternoon peak period. Other cities tend to exhibit afternoon peaks between 3pm, returning to daytime speed at around 7pm and free-flow speed between 8 and 9pm.

Exhibit 3.6: Peak periods differ in time and length for each city; Auckland, Perth and Sydney have the largest ranges of average speed



Fastest and Slowest Roads

Exhibit 3.7 shows the fastest and slowest roads in the ten ANZ cities. It should be noted that only a selection of roads in the major cities themselves have been considered, that is, there may be roads outside the sample that are either faster or slower than those identified above. Of course, the Average Speed of individual roads will depend on a number of factors including location, road type and land use. In general, however, high speed roads that lead to the city centre, or connect important areas of the CBD, are required to cope with population growth without adversely impacting productivity.

Exhibit 3.7: ANZ's slowest roads are traffic thoroughfares, which are often used for purposes other than their intended design

ANZ Slowest Roads[1]
Km / hr

Rank	Road	City	Avg Speed
1	King William St	Adelaide	13.5
2	Harris St	Sydney	14.5
3	Punt Rd	Melbourne	16.1
4	North Terrace	Adelaide	16.2
5	Cleveland St	Sydney	17.1
6	South Dowling St	Sydney	17.2
7	Stacey St	Sydney	18.3
8	Military Rd	Sydney	18.7
9	Lane Cove Rd	Sydney	18.9
10	Church St	Sydney	19.5

ANZ Fastest Roads[1]
Km / hr

Rank	Road	City	Avg Speed
1	Northern Gateway Toll Rd	Auckland	98.8
2	Federal Highway	Canberra	98.1
3	Hume Highway	Sydney	97.9
4	Upper Harbour Mtwy	Auckland	94.5
5	Northern Expressway	Adelaide	93.8
6	Eastlink	Melbourne	93.5
7	Warrego Highway	Brisbane	91.4
8	Logan Mtwy	Brisbane	91.2
9	Western Freeway	Melbourne	90.9
10	Cunningham Highway	Brisbane	89.8

Legend: Motorway Traffic Thoroughfare Commercial Street

Note: 1. For roads longer than 5km, in a view to remove the effect of local roads which may have lower speed limits (and therefore appear to be slow but otherwise have freely flowing traffic), as well as limiting the effect of very short roads which are not representative of a city's overall network and congestion.
Source: Google maps data (2015-09-09 to 2015-10-29)

The analysis suggests that King William Street in Adelaide is the slowest road in the ANZ cities, with an Average Speed of just 13.5 km/h. This main road, through the centre of the Adelaide CBD and adjacent to Rundle Mall, is shared by cars and trams and also heavily used by pedestrians. North Terrace, which intersects, with King William Street, is the fourth slowest road. That said, seven of the ten slowest roads in the ANZ cities are in Sydney, in the CBD and surrounding suburbs, mostly with adjacent commercial land uses.

Another consideration is the demand for each of these roads. Higher populations in Sydney and Melbourne lead to high demand for roads. This can result in slower Average Speeds in these cities, unless demand management policies are implemented.

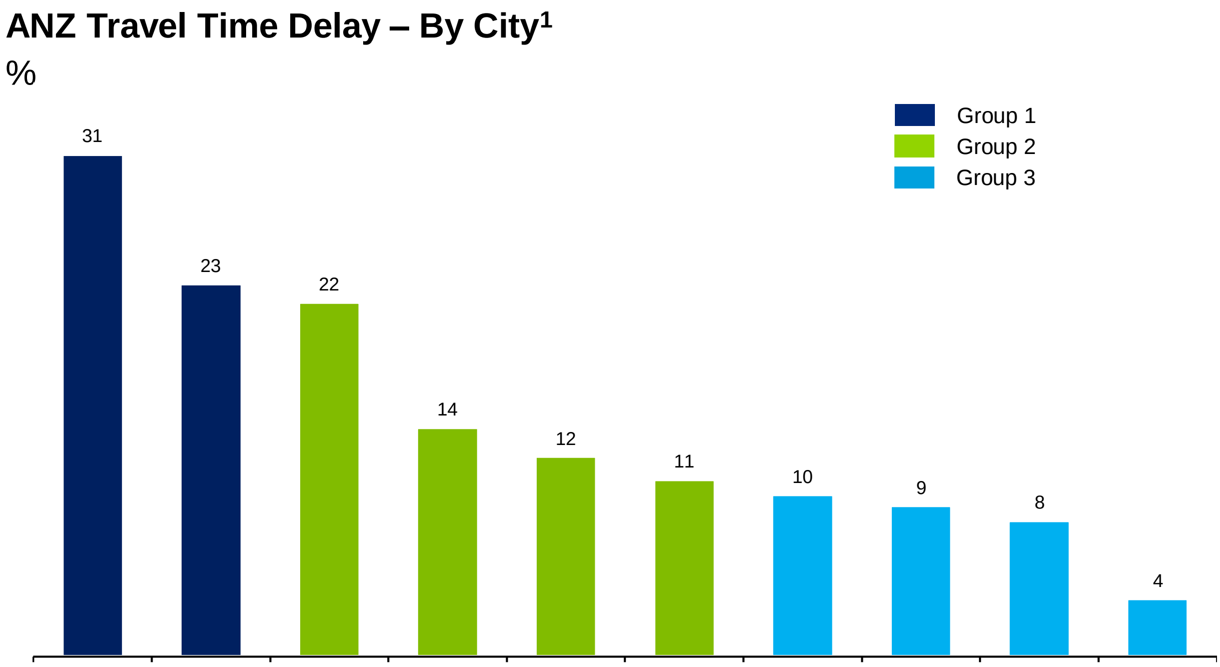
Unsurprisingly, it is clear that the fastest roads in the analysis are motorways, freeways and expressways with higher speed limits. The Northern Gateway Toll Road in Auckland is the fastest road identified in the analysis, with an Average Speed of around 99km/h. Brisbane is well-represented in this list, with three of its major roads and highways accounted for in the top ten list.

It is also important to note that the 'type' and use of a road has an impact on its Average Speed. Some roads, originally designed as traffic thoroughfares, have become congested over time as they adopt the features of a commercial street. For example, Cleveland Street, through Surry Hills in Sydney, was designed as a traffic thoroughfare, but commercial developments over time have led to cars being parked along the road at certain times of day and pedestrian activity associated with this business, ultimately reducing the estimated Average Speed to around 17km/hr.

3.1.2 Travel Time Delay

Exhibit 3.8 shows that Sydney has the highest Travel Time Delay of Group 1 cities (measured as mean travel time relative to minimum travel time) at 31% higher than the minimum travel time recorded over the study period. Auckland has a Travel Time Delay of 22%, significantly higher than the other Group 2 cities. Travel times are more consistently close to the minimum travel time in the Group 3 cities, with mean travel times less than 10% the free flow travel time in Wellington, Canberra, Hobart and Darwin.

Exhibit 3.8: Sydney, Auckland and Wellington exhibit the highest travel time delay within their respective groups

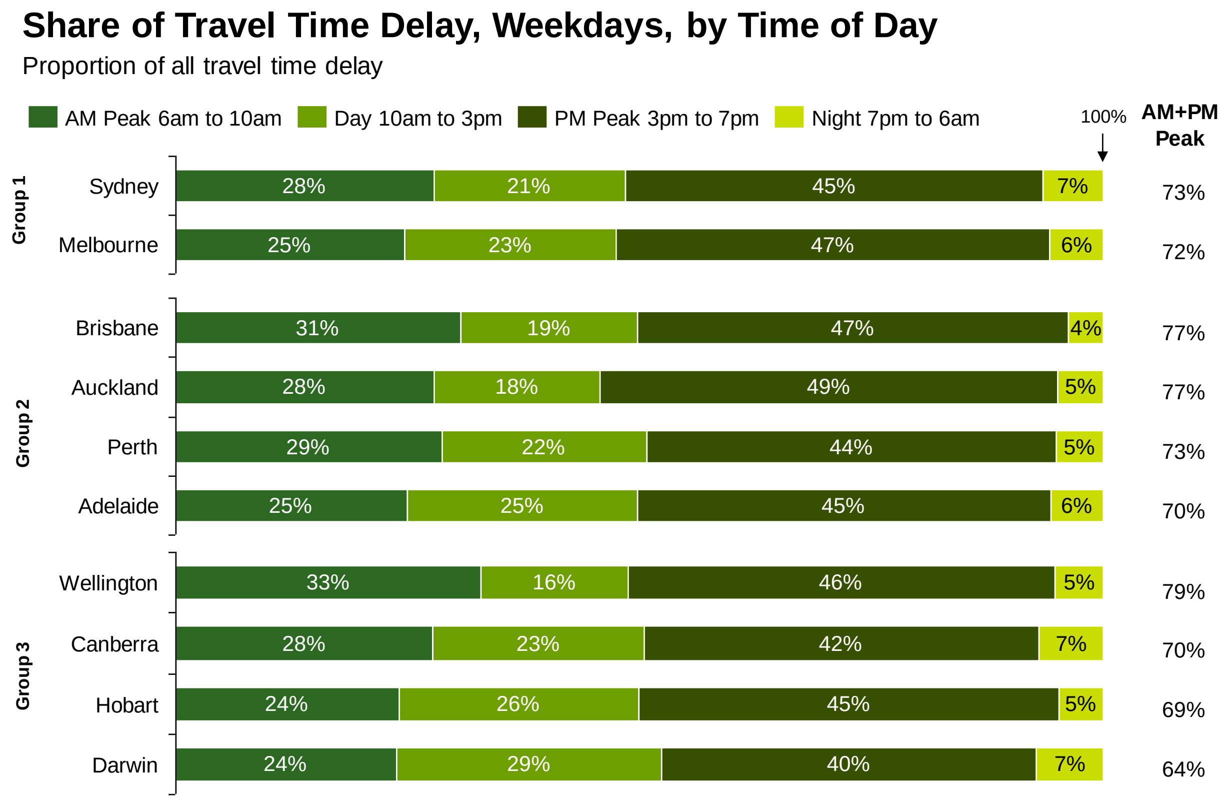


Note: 1. Delay defined as (mean travel time for 24 hours/minimum travel time for 24 hours) -1
Source: Google maps data (2015-09-09 to 2015-10-29)

Time Delay by Time of Day

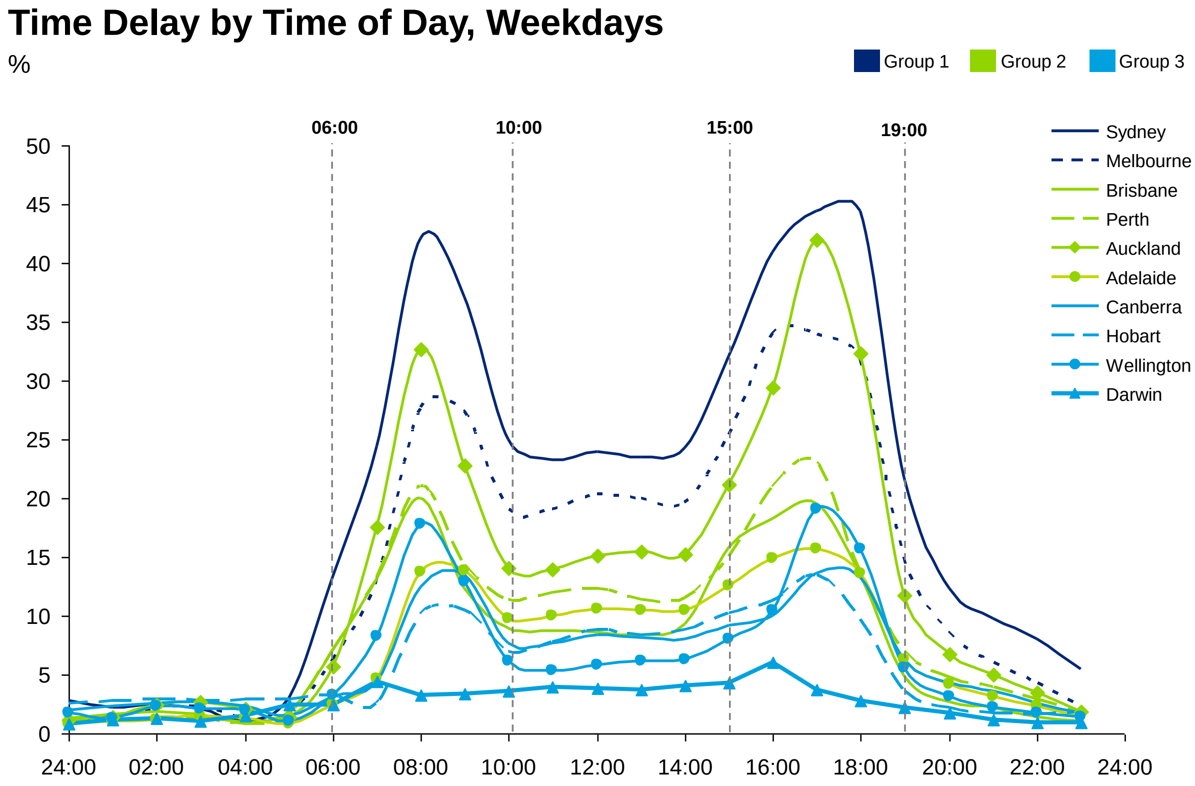
When comparing Travel Time Delay across the day, road users will state that most weekday delay occurs during peak periods, when they are commuting to and from work. This is qualified in Exhibit 3.9. Wellington has the highest proportion of Travel Time Delay during peak periods (79%) and Darwin the least (64%) in Group 3. In general, Travel Time Delay is worse in the afternoon peak than the morning peak. Despite accounting for almost half of the hours of the day, the hours of 7pm to 6am represent 4% to 7% of total Travel Time Delay for each city.

Exhibit 3.9: Most weekday Travel Time Delay occurs during the morning and afternoon peak times (~65-80%)



The most delayed times of day are similar to the periods where Average Speed is lowest (see Exhibit 3.10). Travel Time Delay exhibits a morning peak at approximately 8am and an afternoon peak at approximately 5pm. The afternoon peak has a larger spread than the morning peak. Darwin shows little relationship between time of day and Travel Time Delay.

Exhibit 3.10: Travel Time Delay at ~8am in the morning peak period and ~5pm in the afternoon peak period



Least Delayed and Most Delayed Roads

Exhibit 3.11 presents the most delayed roads in ANZ cities. Burke Road, a major north-south thoroughfare in Melbourne, is the most delayed road in the ANZ cities with an average travel time about 80% longer than the minimum travel time recorded. Seven of the most delayed roads are in Sydney.

At the other end of the spectrum, the ten least delayed roads in ANZ cities have a mean travel time less than 2% greater than the minimum, suggesting that on average, the travel time is essentially the same as the time taken in free-flow traffic. Brisbane accounts for 4 out of the top 10 least delayed roads.

Exhibit 3.11: Group 1 cities have ANZ's most delayed roads, while Brisbane has the most entries into ANZ's least delayed roads

ANZ Most Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Burke Rd	Melbourne	79.8
2	Centenary Drive	Sydney	77.4
3	Punt Rd	Melbourne	71.1
4	M5 East Freeway	Sydney	69.2
5	Toorak Rd	Melbourne	67.2
6	Lane Cove Rd	Sydney	64.9
7	Epping Rd	Sydney	63.7
8	Homebush Bay Drive	Sydney	63.0
9	Eastern Distributor Mtwy	Sydney	60.2
10	Cahill Expressway	Sydney	59.4

ANZ Least Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Richmond Rd	Hobart	0.0
2	State Highway 53	Wellington	0.1
3	Acton Rd	Hobart	0.3
4	Kaipara Coast Highway	Auckland	0.6
5	Northbrook Parkway	Brisbane	0.7
6	Cox Peninsula Rd	Darwin	0.8
7	Mount Glorious Rd	Brisbane	1.0
8	Ipswich-Rosewood Rd	Brisbane	1.2
9	Kings Highway	Canberra	1.2
10	Forest Hill-Fernvale Rd	Brisbane	1.2

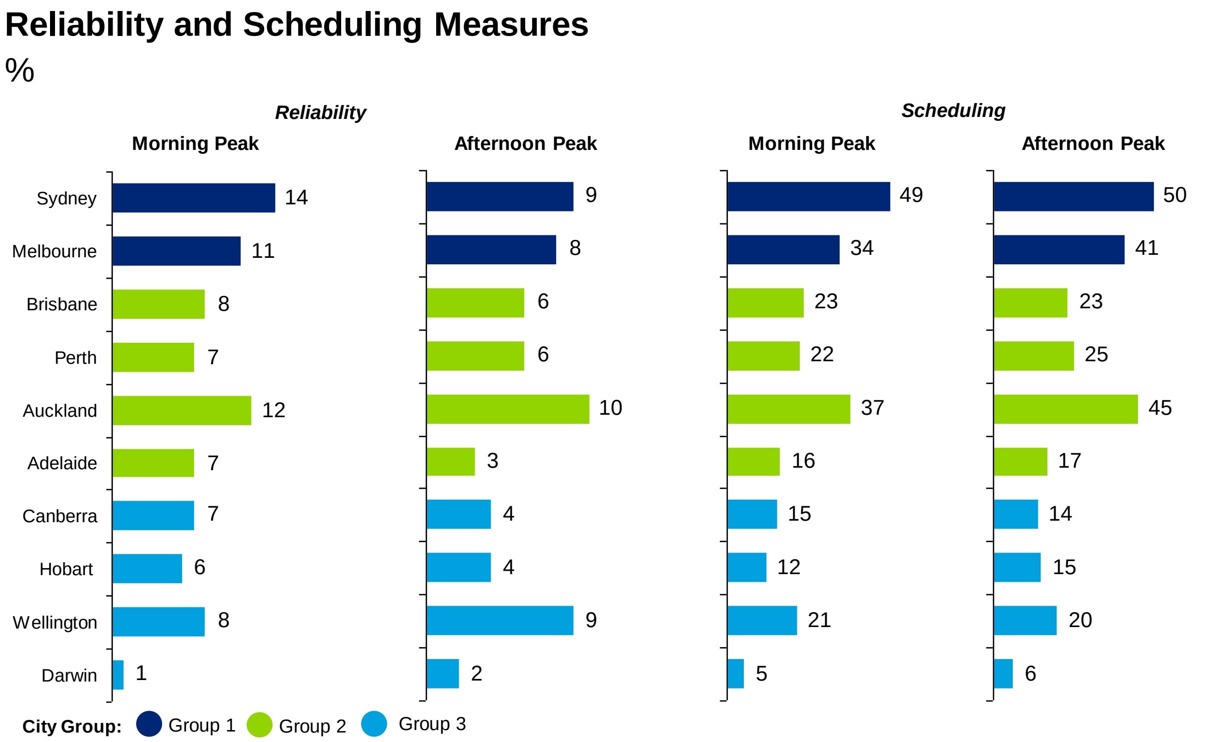
Legend: Motorway Traffic Thoroughfare Commercial Street

Note: 1. Delay defined as (mean travel time for 24 hours/minimum travel time for 24 hours) -1
Source: Google maps data (2015-09-09 to 2015-10-29)

3.1.3 Reliability

Reliability is 1.44 x standard deviation of travel time relative to the average travel time, measured over the morning and afternoon peaks. A greater standard deviation suggests a greater range of travel times, and hence unreliability. Exhibit 3.12 shows that Sydney, Auckland and Wellington have the most unreliable roads in their respective groups, in the morning peak period, while Auckland and Wellington exhibit the lowest level of reliability of their groups, over the afternoon peak period.

Exhibit 3.12: Sydney, Auckland and Melbourne exhibit the greatest unreliability within their groups



Source: Google maps data (2015-09-09 to 2015-10-29)

Notes: 1. Morning Peak = Weekdays 6am to 10am; Afternoon Peak = Weekdays 3pm to 7pm
2. As analysis was based on 600km of the most congested roads, comparisons are better drawn among cities within the same group based on population size.

3.1.4 Morning and Afternoon Peak Scheduling

Morning Peak Scheduling shows that commuters in Sydney, Auckland and Wellington must allow the greatest buffer time in their respective groups during the morning peak relative to free flow traffic, to ensure they arrive at their destination on time. Travel in the morning peak in Darwin, on the other hand, is around 5% longer than minimum recorded travel times.

A similar pattern is evident in the afternoon peak, though for most cities, slightly longer buffer times are required in the afternoon to ensure arriving at the destination on time (see Exhibit 3.12).

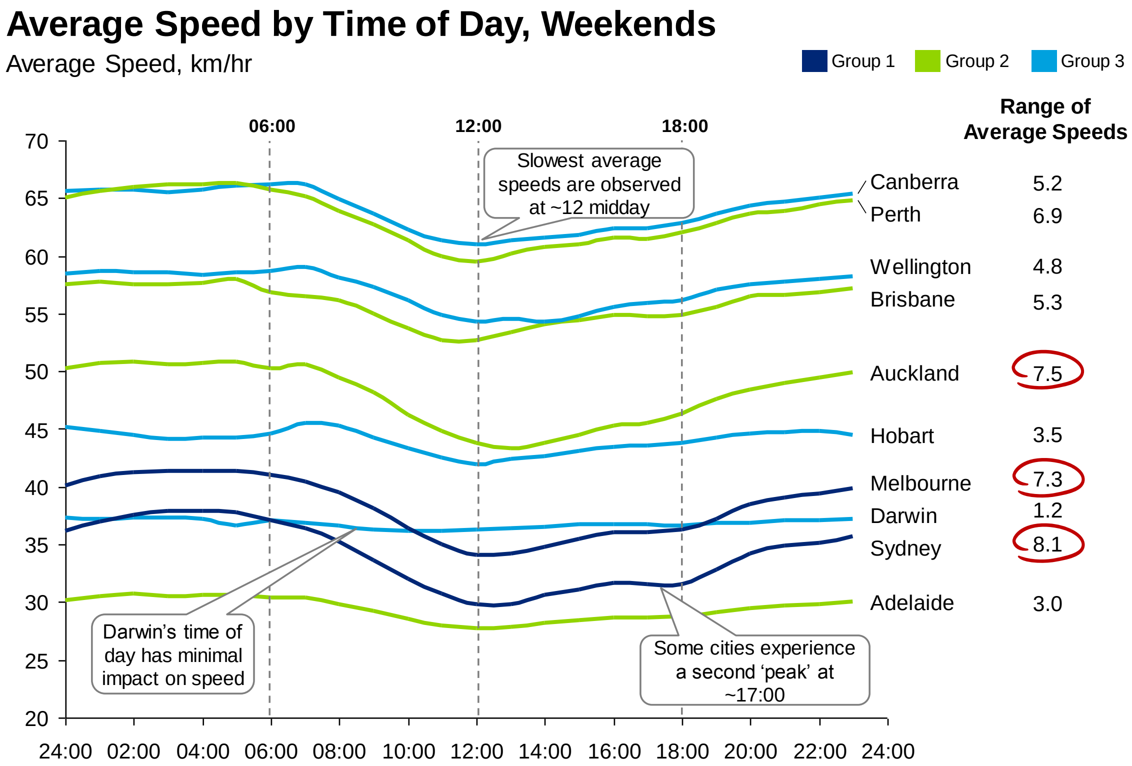
3.2 ANZ Weekend Congestion Performance

Despite congestion being associated with weekday peak periods, as commuters travel to and from work, congestion is prevalent at weekends too. Similarly, depending on the time of day, Travel Time Delay also varies at weekends.

3.2.1 Average Speed

For weekends, Average Speeds are lowest in the middle of the day, at around noon (see Exhibit 3.13). Average speeds start to slow at approximately 6am to 7am and do not return to near free-flow speeds until approximately 8pm. Larger cities experience a second 'slowing' of speeds at approximately 5pm.

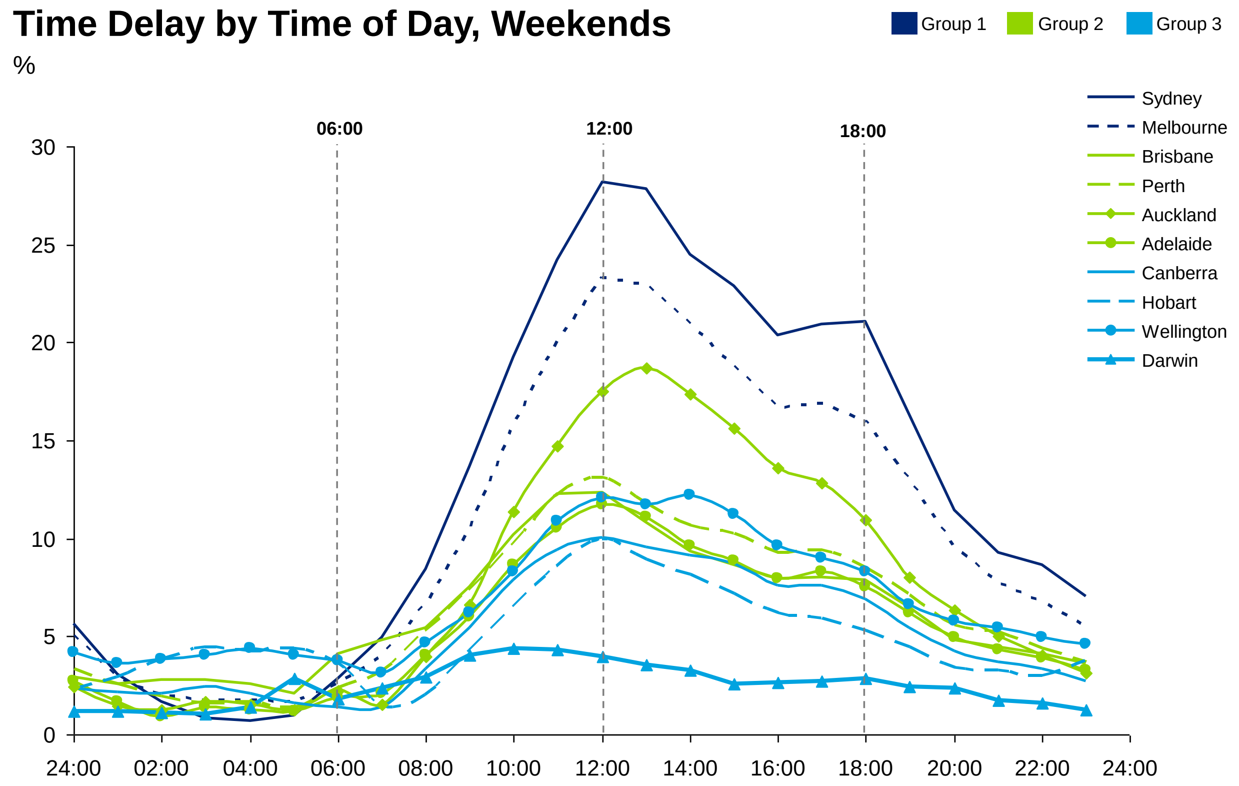
Exhibit 3.13: During weekends, speeds reach their lowest point at midday with Sydney, Auckland and Melbourne experiencing the largest drops



3.2.2 Travel Time Delay

Similarly, weekend Travel Time Delay peaks at approximately 12pm and is largest in Sydney for Group 1 and Auckland for Group 2 (see Exhibit 3.14). Weekend Travel Time Delay is better at weekends than weekdays for all cities. Larger cities tend to have higher weekend Travel Time Delay.

Exhibit 3.14: Travel Time Delay peaks at ~12 midday at weekends; with the highest delays observed in cities with larger populations



3.3 Congestion Performance of ANZ Cities and International Comparators

To understand the congestion performance of ANZ cities relative to international benchmarks, global comparators have been used to assess Average Speed, Travel Time Delay, Morning Peak Reliability and Afternoon Peak Reliability. Exhibit 3.15 shows the comparators for each city group.

The comparator cities were selected from 230 comparators based on their similarity to the ANZ city groups in terms of population, population density, GDP per capita and public transport mode share. The topography was qualitatively considered and cities with grid network structures and/or orbital roads were found to align with planned ANZ cities such as Melbourne and Adelaide. A technical description of the clustering analysis methodology is provided in Appendix A.3. Four 'megacities' were also selected to aid understanding of possible future trajectories for the largest ANZ cities.

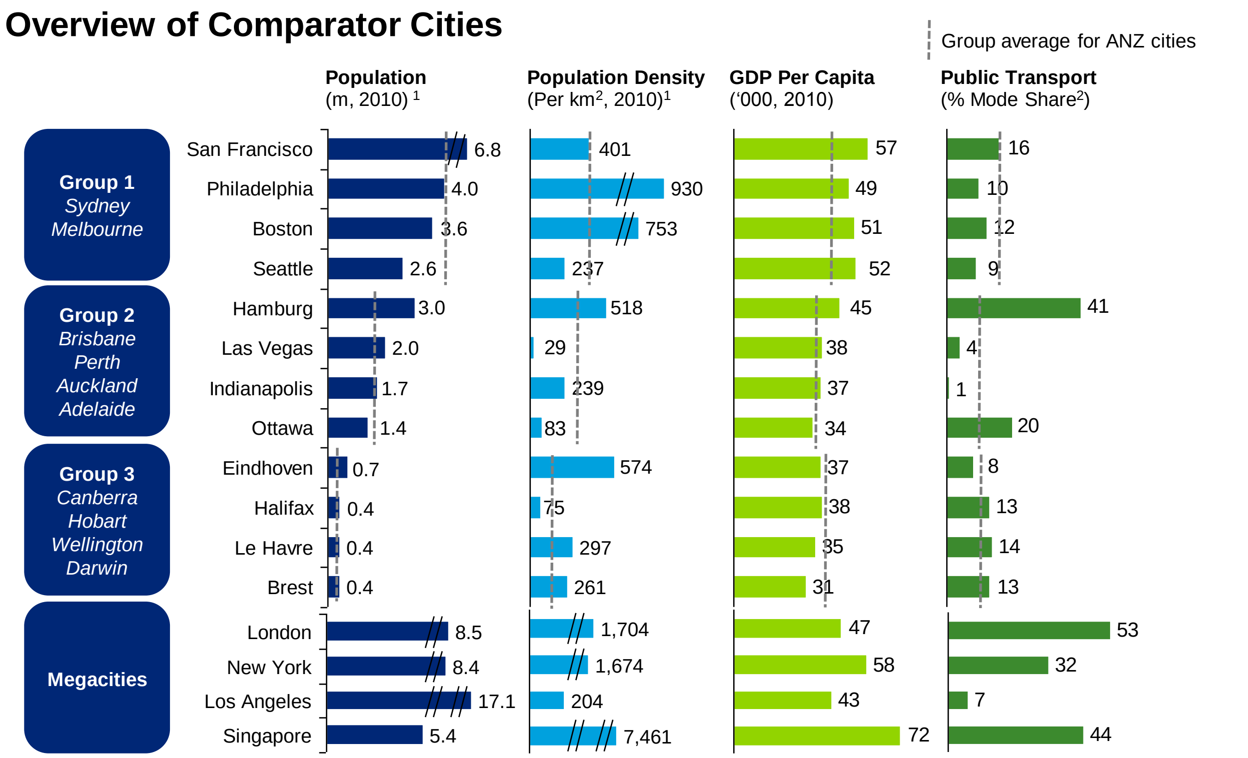
This analysis showed that, in general, the best comparators for ANZ cities are:

- The city in the past
- ANZ cities of similar size
- Similar sized United States cities
- European port towns for smaller cities

The specific comparator cities are:

- Group 1 – Seattle, Philadelphia, Boston, San Francisco
- Group 2 – Indianapolis, Ottawa, Hamburg and Las Vegas
- Group 3 – Halifax, Eindhoven, Le Havre, Brest
- Megacities – London, New York, Los Angeles, Singapore

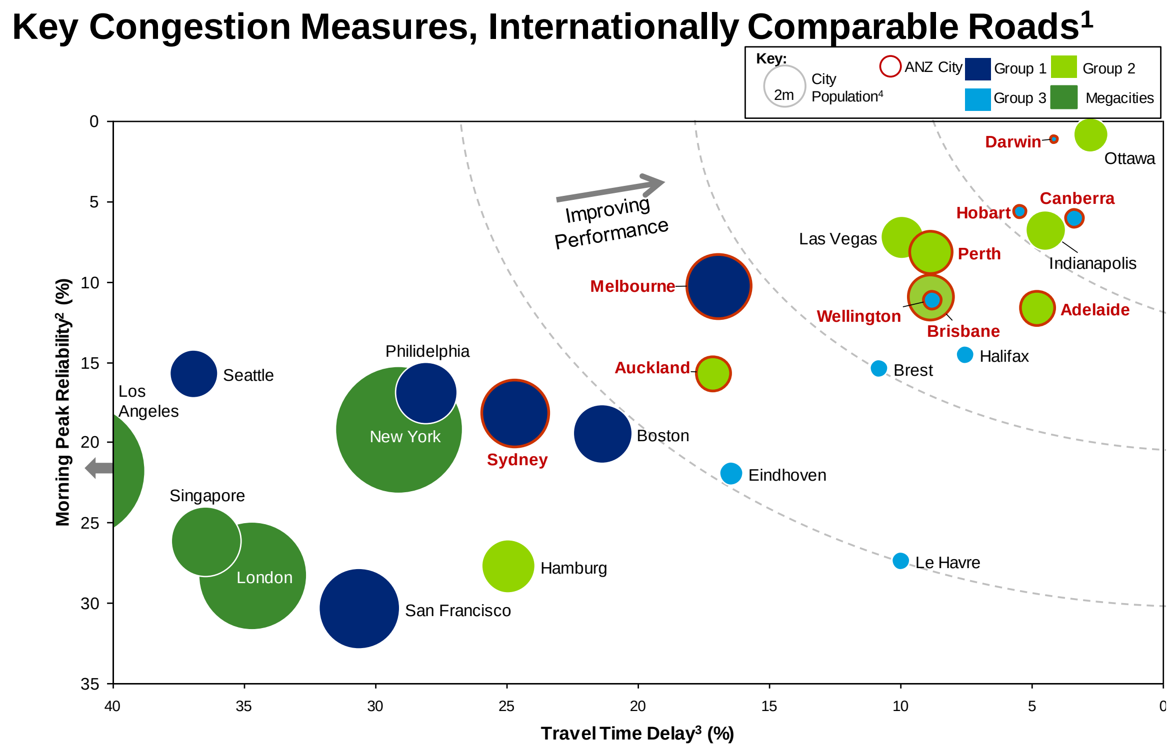
Exhibit 3.15: ANZ comparator cities have been identifies based on a criteria set with a qualitative overlay for topography



Notes: 1. Population and population density data for Le Havre and Brest are based on French arrondissements; 2. Only considers travel to work
Source: OECD Data, US Census, CAN Census, Eurostat Database

Roads analysed for the purpose of international comparison focus on major roads and highways, to ensure consistency and comparability. The analysis in this section considers roads with free-flow speeds of over 80km/hr (and below 130km/hr), for both ANZ cities and international cities. These roads have higher speed limits than the overall network and therefore higher Average Speeds and differing associated congestion measures than those detailed in Section 3.1. For example, Sydney's Afternoon Peak Reliability outperforms Melbourne's for roads with free-flow speeds of over 80km/hr, in contrast to all roads where Melbourne outperforms Sydney on this measure.

Exhibit 3.16: ANZ cities perform in line with international comparators on Reliability and Travel Time Delay



Note: 1. Internationally Comparable Roads = Roads with free-flow speeds higher than 80km/hr included
2. AM Peak Reliability. The statistical reliability of travel times = 1.44 Standard deviation of travel time for 6am to 10am / Mean Travel time for 6am to 10ar
3. Travel Time Delay. Traffic delay from free-flow conditions = (Mean travel time for 24hrs / Minimum travel time for 24hrs) -1
4. City Population, as per OECD Data (2014)

Exhibit 3.16 presents the performance of ANZ cities against their international comparators:

- ANZ cities perform in line with international comparators on the three key measures of Morning Peak Reliability, Afternoon Peak Reliability and Travel Time Delay
- In general, the worse the Reliability on roads with free-flow speeds of at least 80km/hr, the worse the Travel Time Delay
- Cities with larger populations (Megacities and Group 1) have lower Reliability and Travel Time Delay performance, however Group 2 and 3 cities have comparable performance to international cities of similar population sizes
- Darwin, Canberra and Hobart perform comparatively well against all cities, as well as their international comparators, in both Reliability and Travel Time Delay

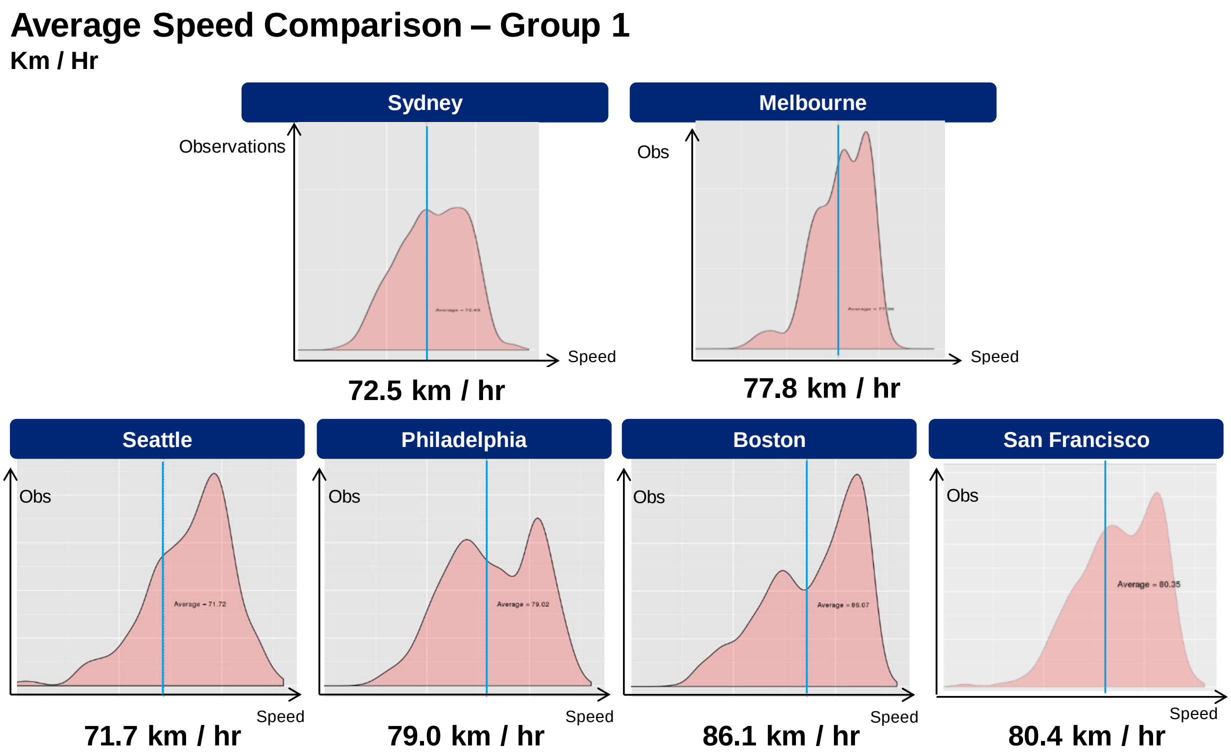
3.3.1 Group 1 (Sydney, Melbourne) vs. International Comparators

Average Speed

The following group-level analysis incorporates histograms showing the distribution of city Average Speeds. The use of only a network-wide Average Speed fails to capture the distribution of Average Speeds across road segments in the network. Thus, two cities with the same Average Speed can be vastly different. More information can be found in Appendix A.6.

Exhibit 3.17 shows Average Speed comparisons for the Group 1 cities[107]. The charts show that Average Speeds of motorways in Sydney and Melbourne are below the Average Speeds of the comparator cities of Philadelphia, Boston and San Francisco, but higher than the Average Speed of Seattle. Sydney and Melbourne have relatively similar Average Speeds, reinforcing the econometric analysis which suggested that they were also strong comparator cities for each other.

Exhibit 3.17: Sydney and Melbourne have similar average speed to international Group 1 comparators



Source: Google maps data 2015-09-09 to 2015-11-26

Australia's cities can learn from Boston's road design, transport design and land use. Boston's road network design allows vehicles to bypass the city with ease, despite its coastal location. There are a series of 'half' concentric circles that run around the perimeter of the city, as well as roads with fast speed limits that run through the centre. Underground and elevated rail lines facilitate travel, by ensuring that they do not interact with vehicles in the city centre. This also reduces the need for buses to use roads.

There were substantial benefits from "The Big Dig" project[108] in 1991-2007 which

- Replaced an elevated 6-lane highway with an 8-10 lane underground tunnel – through the city; and
- Extended the I-90 Massachusetts Turnpike to Logan Airport which substantially increased the capacity of the I-93 Central Artery and I-90

This decongested the core city and created additional land for redevelopment and economic use. It demonstrated that:

- A major project to divert traffic into higher capacity tunnels can substantially improve the city, free up land used by roads and reduce congestion

107 These charts plot speeds against observations and are not to the same scale. They are intended to be illustrative of the distribution of speeds, with peaks reflecting different road types and speed limits, and are not intended to be compared through scale. Blue lines represent average (not median) speeds.

108 Massachusetts Department of Transportation, Highway Division Website, (2015), The Central Artery/Tunnel Project – The Big Dig

- There is a need to keep pace with continuing demand for road space – the Big Dig was not a final solution to congestion

Boston also has a series of industrial centres spread around the city, ensuring that jobs are located near to residents' homes, both reducing the need for vehicle travel and moving road demand away from the city centre. All of these features not only improve the speed of travel in the city, but also help to improve the reliability of roads by reducing the demands placed upon them.

Travel Time Delay

Sydney's motorways have similar Travel Time Delays to Boston and Philadelphia, while Travel Time Delay on Melbourne's motorways is below all the comparator cities, as show in Exhibit 3.18. The Travel Time Delays for Group 1 comparator cities are all lower than 32%, meaning that the average travel time in these cities is less than 32% more than the minimum travel time. While Boston, Philadelphia and Seattle exhibit Travel Time Delay around their CBDs, Melbourne and in particular, Sydney exhibit more wide-spread Travel Time Delay.

Seattle's population density is lower than other Group 1 cities, implying there is potentially more land available for further economic growth, employment and travel demand. The city is characterised by a few expressways over bridges, which connecting islands and feed directly into the city grid system. Substantial North, South and East capacity from the CBD is created by these expressways. Washington State Department of Transport (WS DoT) has used tolling as a key enabler for reducing congestion and also financing new roads in and around Seattle. Recent WS DoT road projects include:

- SR 520 Bridge
- Tacoma Narrows Bridge
- SR 167 HOT lanes
- I-405 Express Toll Lanes

In the future, the SR 99 Alaskan Way Tunnel will be added.

In Philadelphia there are two critical bottlenecks which drive the congestion level:

- I-95 South (AM) and North Bound (PM) as the main route to New York and Washington DC
- The Pennsylvania Turnpike I-76 East (PM) and West Bound (AM)

Coupled with low PT usage, (only 10% mode share) and high population density means Philadelphia is regularly within the most congested US cities.

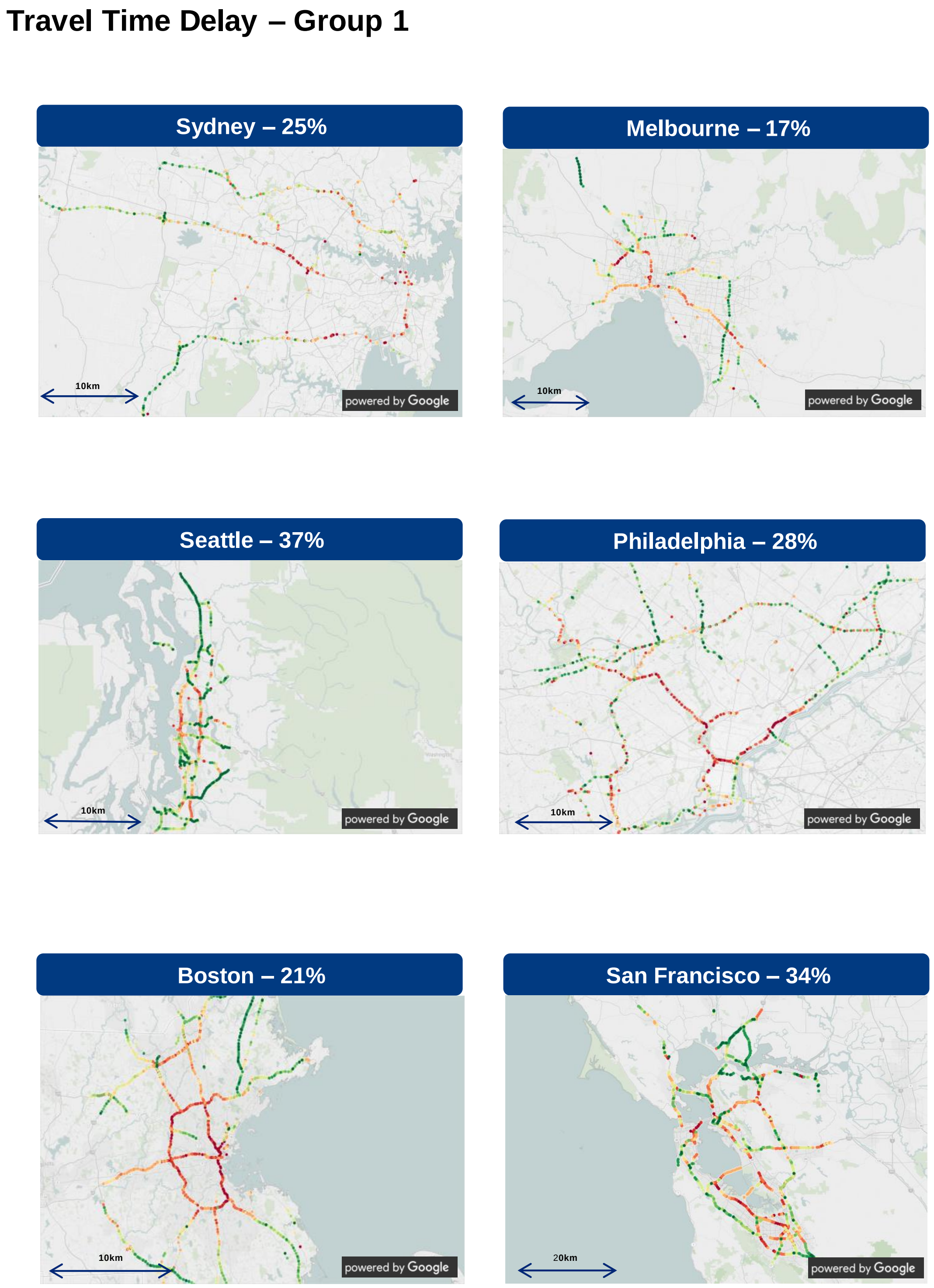
Reliability

In terms of Reliability, Sydney and Melbourne motorways sampled are broadly comparable with the motorways sampled in the comparator cities of Seattle, Philadelphia and Boston, as shown in Exhibit 3.19 and 3.20. All cities perform better in the morning peak than in the afternoon peak, however Melbourne performs particularly well in the morning peak. Where the standard deviation of travel time is compared with the mean travel time in the morning peak, the Group 1 ANZ and comparator cities have variability in travel times of around 10-30%.

Sydney unreliability is spread throughout its major arterials while unreliability is more isolated for Melbourne. Boston exhibits unreliability on its ring roads, with good reliability on most other roads, while Seattle and Philadelphia exhibit some reliability on specific road sections.

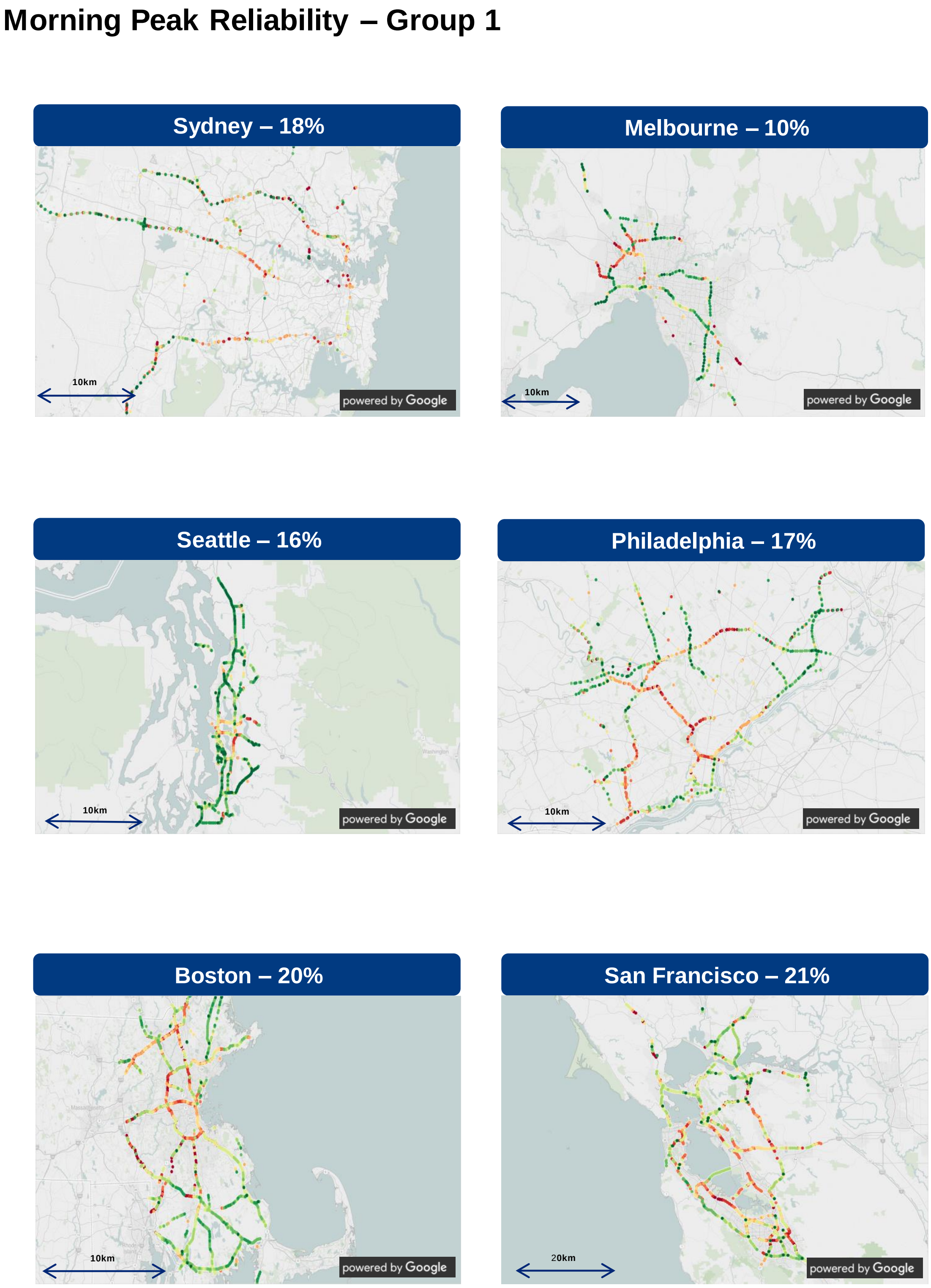
San Francisco's city positioning, on the coast, with San Francisco Bay, makes road and land use planning difficult, as vehicles must travel across expanses of water in order to reach the city centre. This is likely to lessen reliability, as all vehicles are converging on a small number of routes into the city centre during peak periods. Despite its position further inland, Philadelphia has reliability comparable to the ANZ Group 1 cities. There are a number of roads that enable vehicles to bypass the city, for example Route 95 from New York to Baltimore, so there is likely a mismatch of supply and demand or non-recurrent congestion that is resulting in lesser reliability than other international comparators.

Exhibit 3.18: Sydney has similar and Melbourne has lower travel time delay compared to international Group 1 comparators



Source: Google maps data 2015-09-09 to 2015-11-26

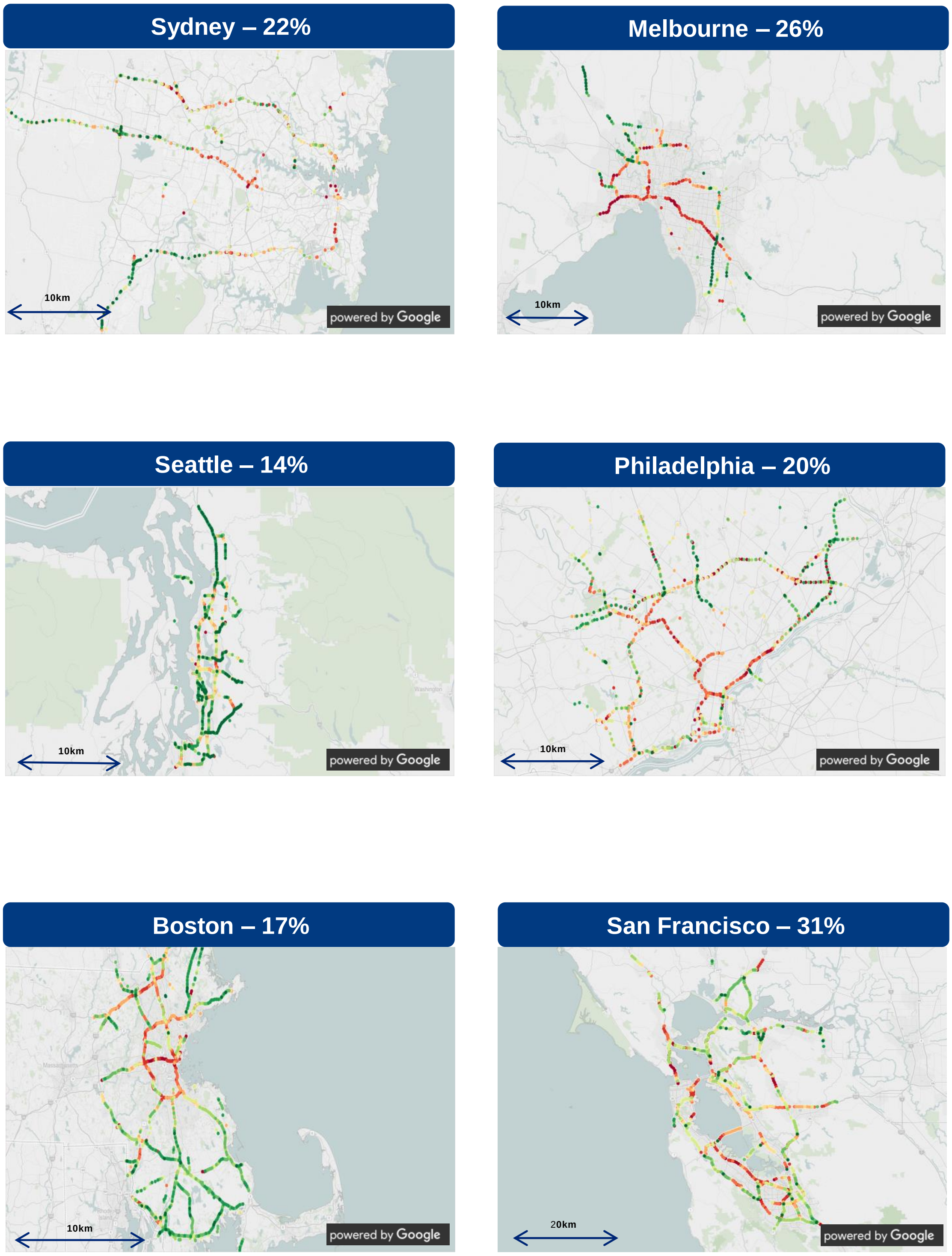
Exhibit 3.19: Sydney and Melbourne exhibit better reliability relative to international Group 1 comparators in the morning



Source: Google maps data 2015-09-09 to 2015-11-26

Exhibit 3.20: Sydney and Melbourne exhibit lower reliability relative to international Group 1 comparators in the afternoon

Afternoon Peak Reliability – Group 1



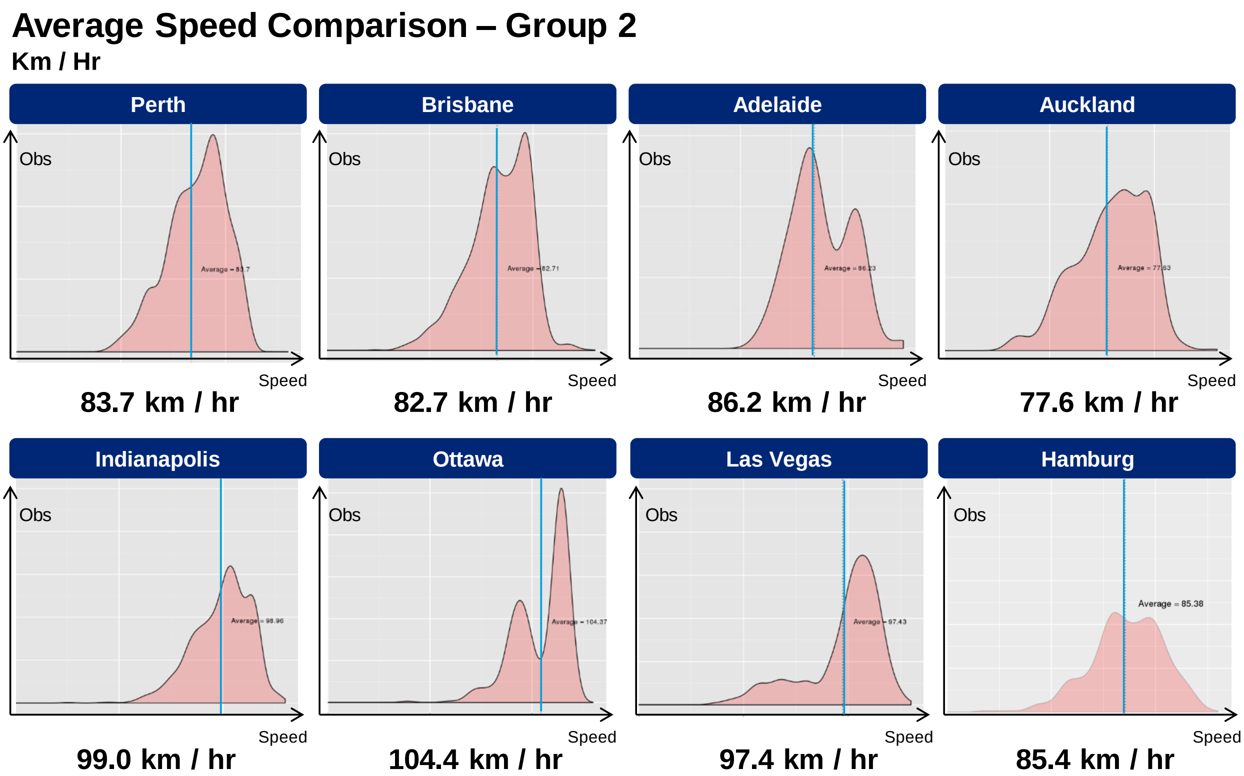
Source: Google maps data 2015-09-09 to 2015-11-26

3.3.2 Group 2 (Perth, Brisbane, Adelaide, Auckland) vs. International Comparators

Average Speed

Exhibit 3.21 shows the comparison of Average Speeds for the Group 2 ANZ cities against the comparator cities. The motorways in the Group 2 ANZ cities have lower Average Speeds than Las Vegas, Indianapolis and Ottawa, even when similar types of roads are being compared.

Exhibit 3.21: ANZ cities have a lower average speed than international Group 2 comparators



Source: Google maps data 2015-09-09 to 2015-11-26

Travel Time Delay

From Exhibit 3.22, it can be seen that Brisbane and Perth have similar Travel Time Delay metrics to Las Vegas and Adelaide has a similar Travel Time Delay metric to Indianapolis. Indianapolis's ring road has little Travel Time Delay, a result of the design of the transport network of the city. Auckland has similar Travel Time Delay to Hamburg. Ottawa performs particularly well, with very low levels of Travel Time Delay on its motorways.

Indianapolis's ring road and high-speed freeways that run both into and through the city centre and grid-shaped city road network enable road demand to be effectively and efficiently served by the road network. These features enable traffic to flow around and through the city, with optimised traffic lights at intersections to optimise capacity on local roads. Such a road network is only possible on cities located on flat plains, and therefore it is actually Group 3 cities such as Canberra, who may one day become as large as the Group 2 cities, who may be able to best learn from Indianapolis's road and land use planning.

Reliability

In the morning peak, motorways in the Group 2 ANZ cities are more unreliable than the comparator cities of Indianapolis, Ottawa, and Las Vegas, as shown in Exhibit 3.23. Where the standard deviation of peak travel time is compared with the mean peak travel time, it can be seen that the ANZ Group 2 cities have greater variability in travel times relative to international counterparts, with Perth performing the best of the ANZ cities.

In the afternoon peak, as shown in Exhibit 3.24, there is slightly greater variability in travel times in the ANZ cities and most of the Group 2 international comparators. There is a slight decrease in unreliability Indianapolis in the afternoon.

Perth exhibits unreliability throughout its major roads, whereas Brisbane exhibits more scattered unreliability at key bottlenecks. Auckland's Southern Motorway exhibits some unreliability, but other parts of the city's road network exhibit good reliability. Adelaide's slow Average Speed determines that journeys are 'reliably around 28km/hr', which is a positive in setting road user expectations. As with travel time delay, Indianapolis's ring road helps to maintain good reliability and Las Vegas's grid road network is more unreliable than the main arterial roads.

Of the Group 2 cities, Auckland performs worst across most measures. There are some specific reasons which help explain why this is the case.

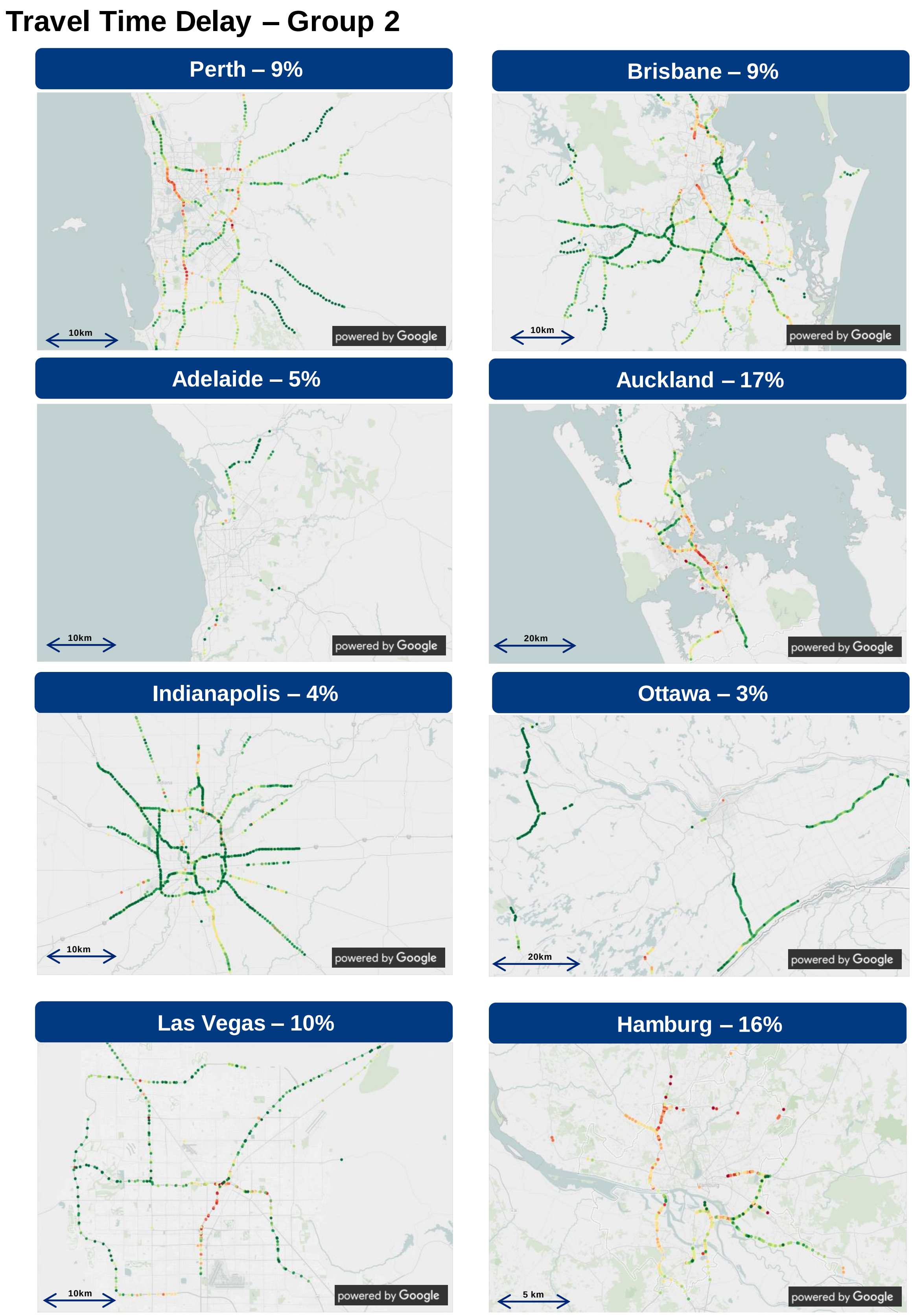
- Auckland's geography, particularly its harbours and waterways, impose constraints on the transport system, meaning the main transport links are confined to narrow corridors
- There exists a high concentration of commuter trips into the city centre for work, rather than to suburban or regional locations
- Compared with other cities there is a lower level of public transport provision for commuters
- There exists highly available and low cost parking in Auckland which encourages commuters to drive

These points are considered in the 2006 New Zealand Ministry of Transport report on 'Tackling Congestion in Auckland – Auckland Road Pricing Evaluation Study'[109].

In contrast to Auckland, Las Vegas has very low population density and therefore lots of space to expand road capacity. The only significant bottleneck is the I-15 Northbound which is congested with commuter traffic in the afternoon.

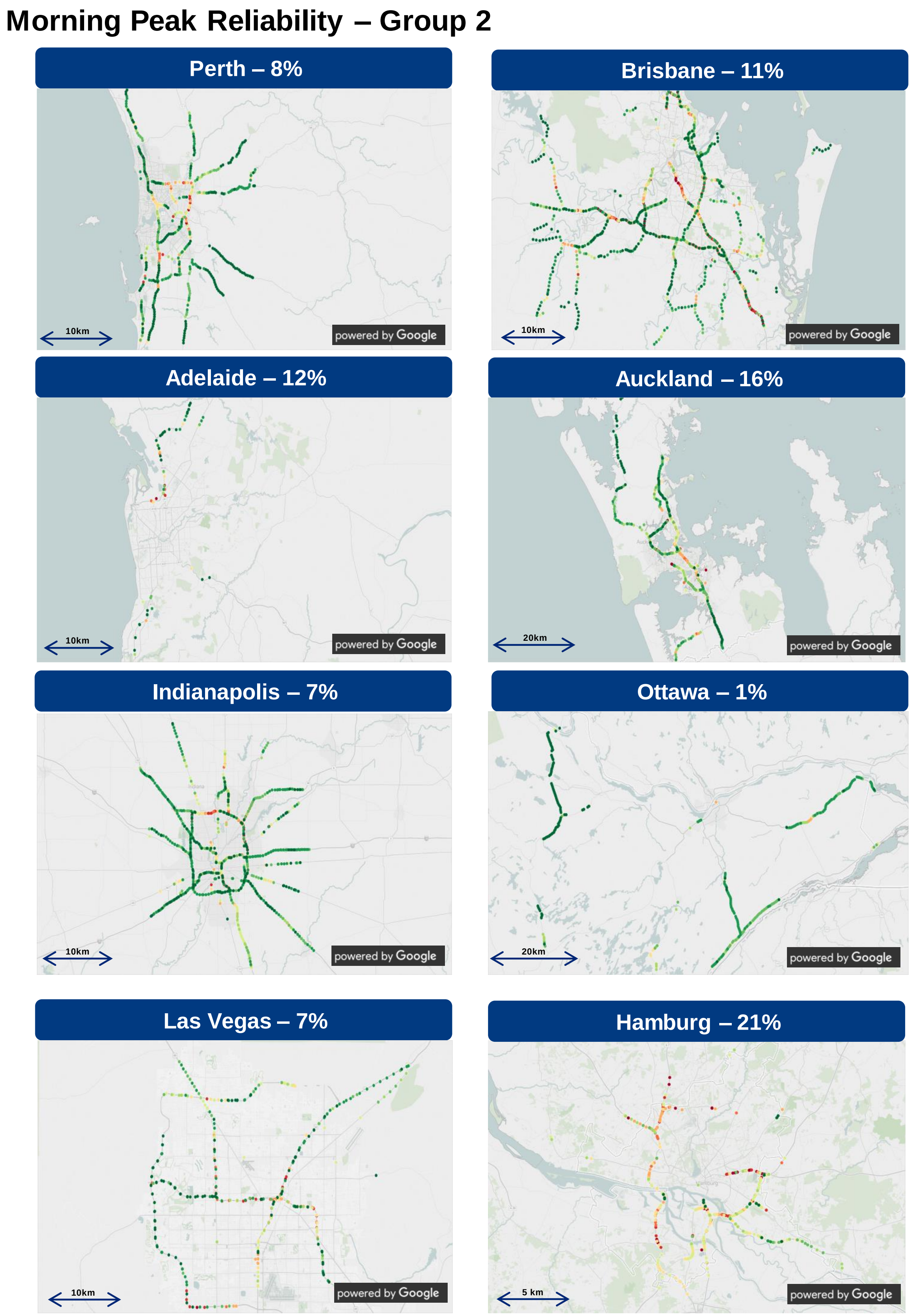
109 New Zealand Ministry of Transport, (2006), Tackling Congestion in Auckland – Auckland Road Pricing Evaluation Study

Exhibit 3.22: ANZ cities exhibit higher travel time delays relative to international Group 2 comparators



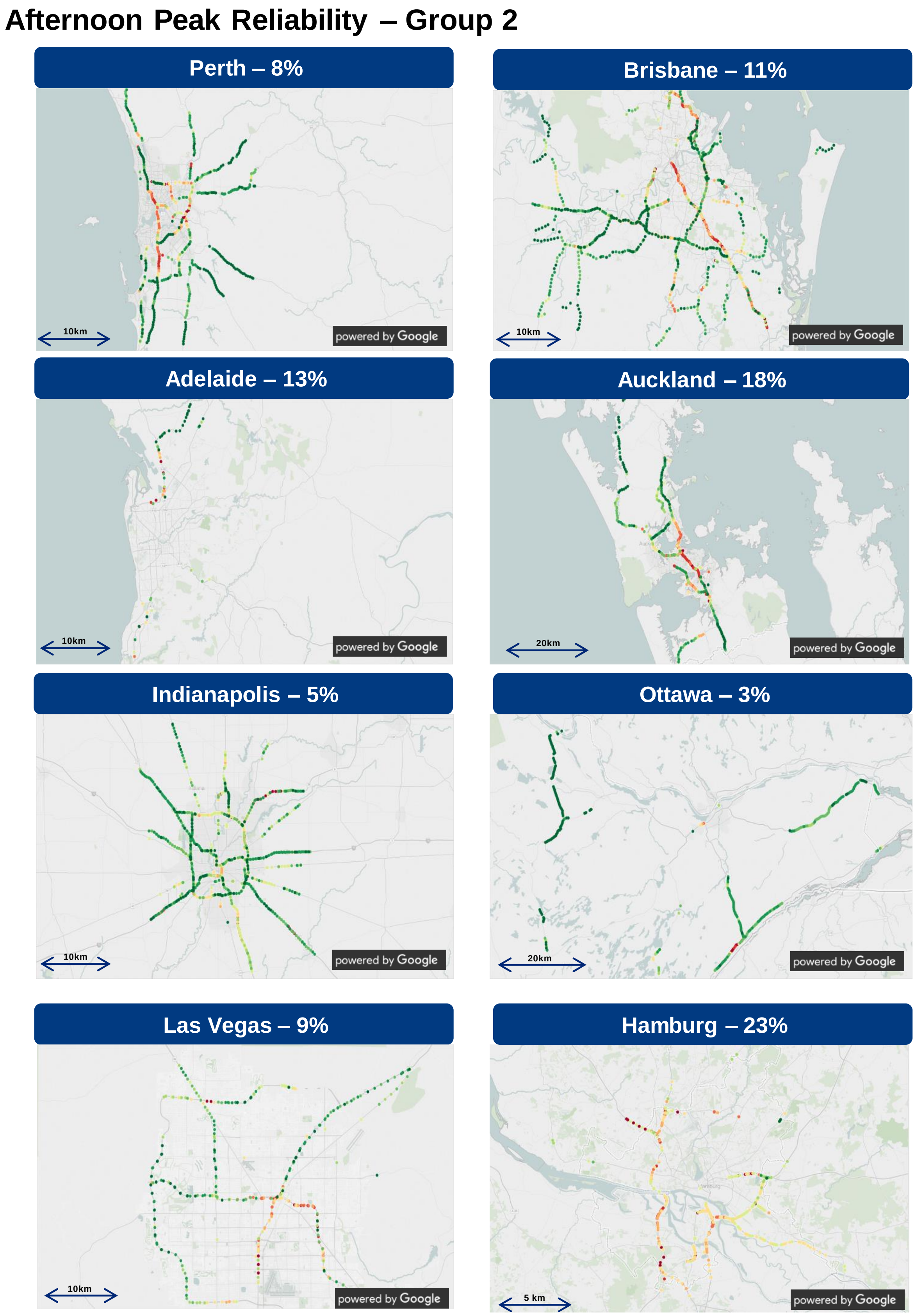
Source: Google maps data 2015-09-09 to 2015-11-26

Exhibit 3.23: ANZ cities exhibit worse reliability relative to international Group 2 comparators in the morning



Source: Google maps data 2015-09-09 to 2015-11-26

Exhibit 3.24: ANZ cities exhibit worse reliability relative to international Group 2 comparators in the afternoon



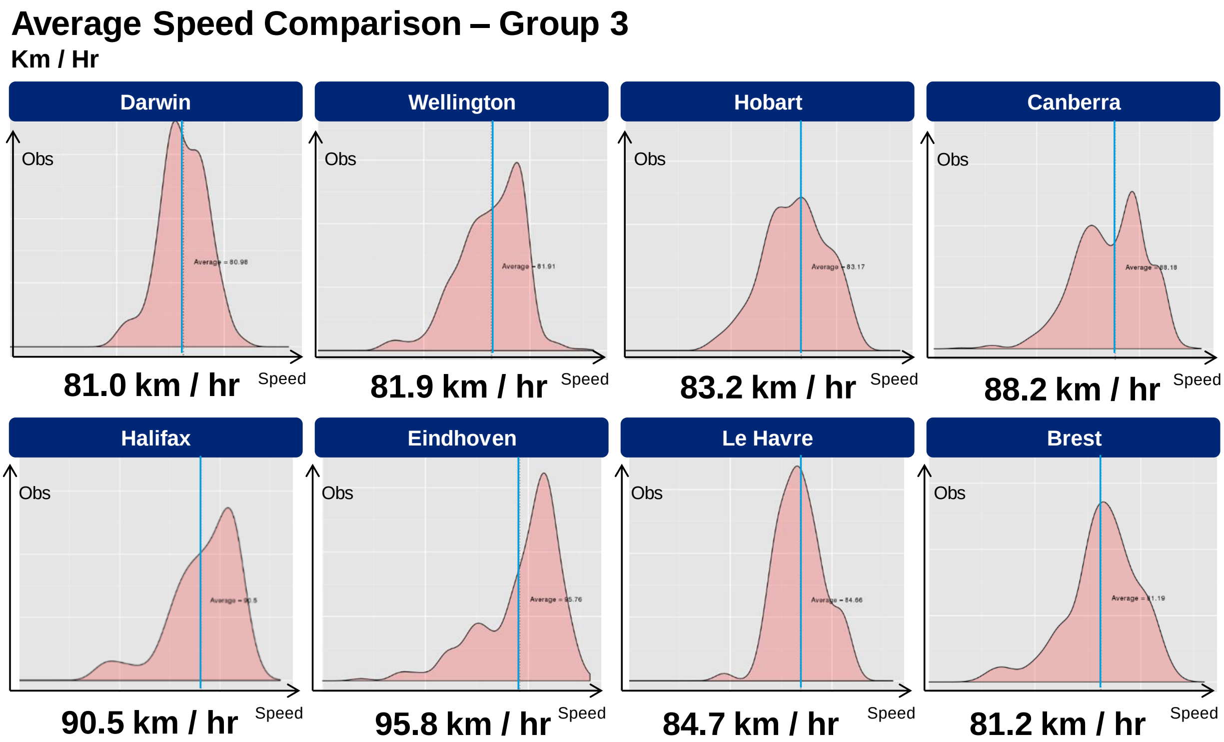
Source: Google maps data 2015-09-09 to 2015-11-26

3.3.3 Group 3 (Darwin, Wellington, Hobart, Canberra) vs. International Comparators

Average Speed

When comparing the motorways of Group 3 cities and their international comparators (as shown in Exhibit 3.25), Darwin has a lower Average Speed than all the international comparator cities, Wellington and Hobart perform better than Brest and Canberra has a higher Average Speed than Le Havre and Brest. Both Halifax and Eindhoven have higher Average Speeds than the Group 3 ANZ cities. This suggests that the smallest ANZ cities are on par, or may even perform better than, some international counterparts in terms of Average Speed of travel.

Exhibit 3.25: ANZ Group 3 cities have similar average speed to their international comparators



Travel Time Delay

Travel time delay for the Group 2 comparator cities are all below 16%, that is, the average travel time in these cities is less than 16% more than the minimum travel time, suggesting relatively consistent journey times close to the free flow duration, as shown in Exhibit 3.26. There is even less variability in the ANZ Group 2 cities, however, ranging from 9% above the minimum time in Wellington to just 3% above the minimum time in Canberra. In contrast to Indianapolis, Eindhoven's inner ring road exhibits travel time delays. Brest, Halifax and Le Havre's time delays are dissipated over the entire city.

The European comparators are likely to have road networks developed from historical road and land use, prohibiting the design of the city from first principles. This helps to explain why Halifax (USA) performs comparatively well on each congestion measure; it has a similar 'design age' to Wellington. Halifax has two high-speed routes that pass through the city centre; unlike a ring road, they do not avoid the city, but considering Halifax's small size there is no need for a ring road at present. In contrast, Brest and Le Havre have little road capacity operating at 80-130km/hr, with typically older, narrower road networks.

Reliability

In the morning peak, the Group 3 ANZ cities have less variance (and hence greater Reliability) than their international comparator counterparts, as shown in Exhibit 3.27. Darwin performs best of the ANZ Group 3 cities, while Brest and Halifax perform the best of the international comparators in terms of Reliability, but still slightly worse than the ANZ cities.

Exhibit 3.28 shows the comparison during the afternoon peak; there is an improvement in Reliability in Hobart and Canberra during the afternoon peak, but greater variability of travel times in Darwin. Similarly, the distribution of travel times relative to the mean is lower in Halifax in the afternoon, unchanged in Brest, and higher in Eindhoven and Le Havre.

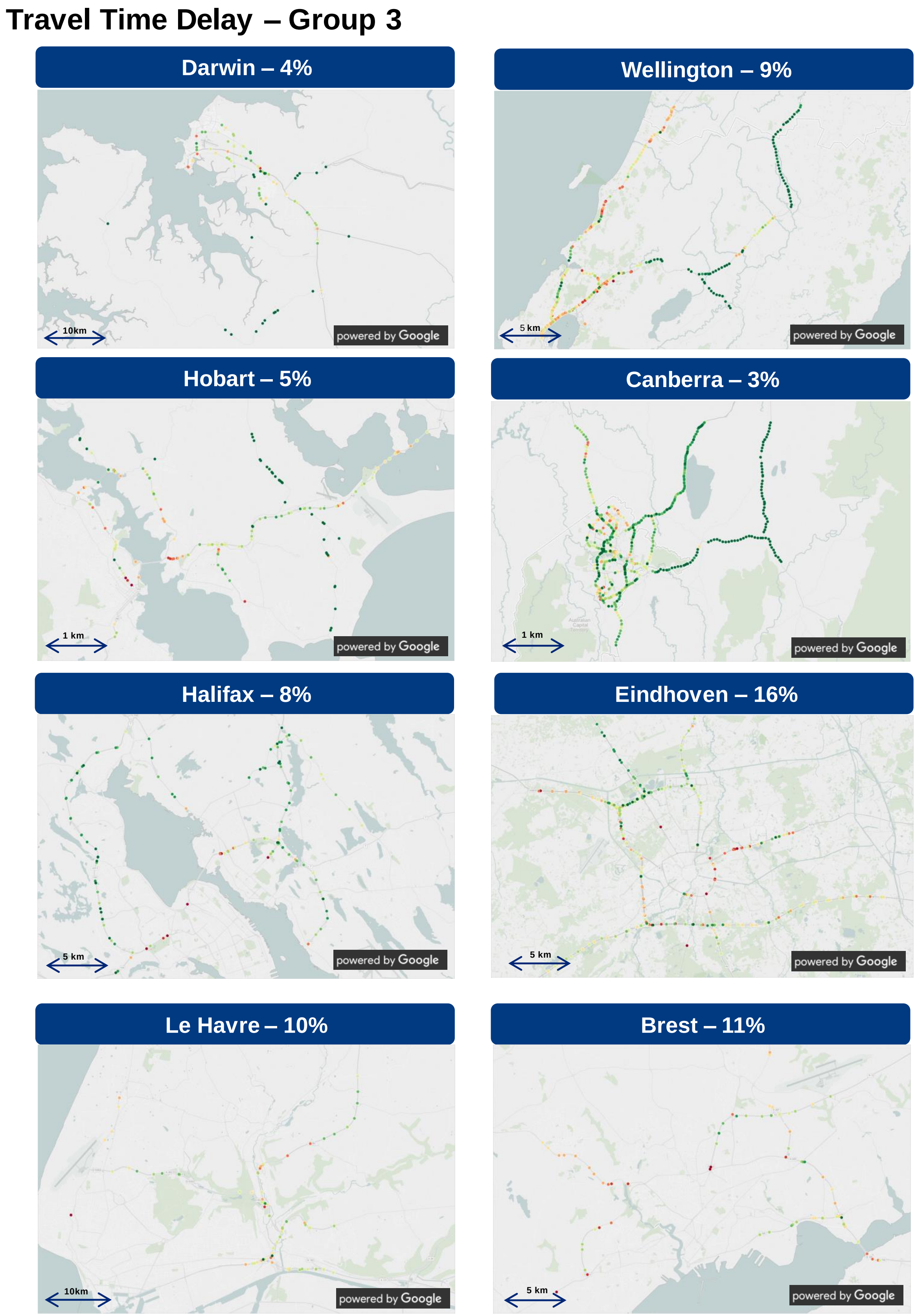
All Group 3 cities should consider how they can plan their road network and land use in advance of having populations the size of the Group 2 cities. This will allow for the appropriate capacity to be built, preventing the levels of congestion seen in the Group 2, and further the Group 1, cities.

Eindhoven is the worst performer of Group 3 across the majority of the congestion measures. There are some distinct reasons that this may be the case[110].

- The high population density in the Netherlands as a whole
  - Congestion costs in the Netherlands were estimated in 2009 as ranging from €5.6bn to €7.2bn per year on the motorway and secondary road network
  - The total number of lost hours due to congestion is 61.6m hours and societal costs in 2009 ranged from €18.0bn to €29.3bn per year – 3.1% to 5.1% of Dutch GDP
- The particularly high population density in Eindhoven and the province of Nord Brabant
- Even though Eindhoven is a relatively new city, it was designed and built on a grid-based residential road network with quite narrow road widths and little provision for expressways – only recently has city planning sought motorway access to new developments
- Cycling has been the mode most encouraged in Eindhoven with less road capacity provided for motor vehicles

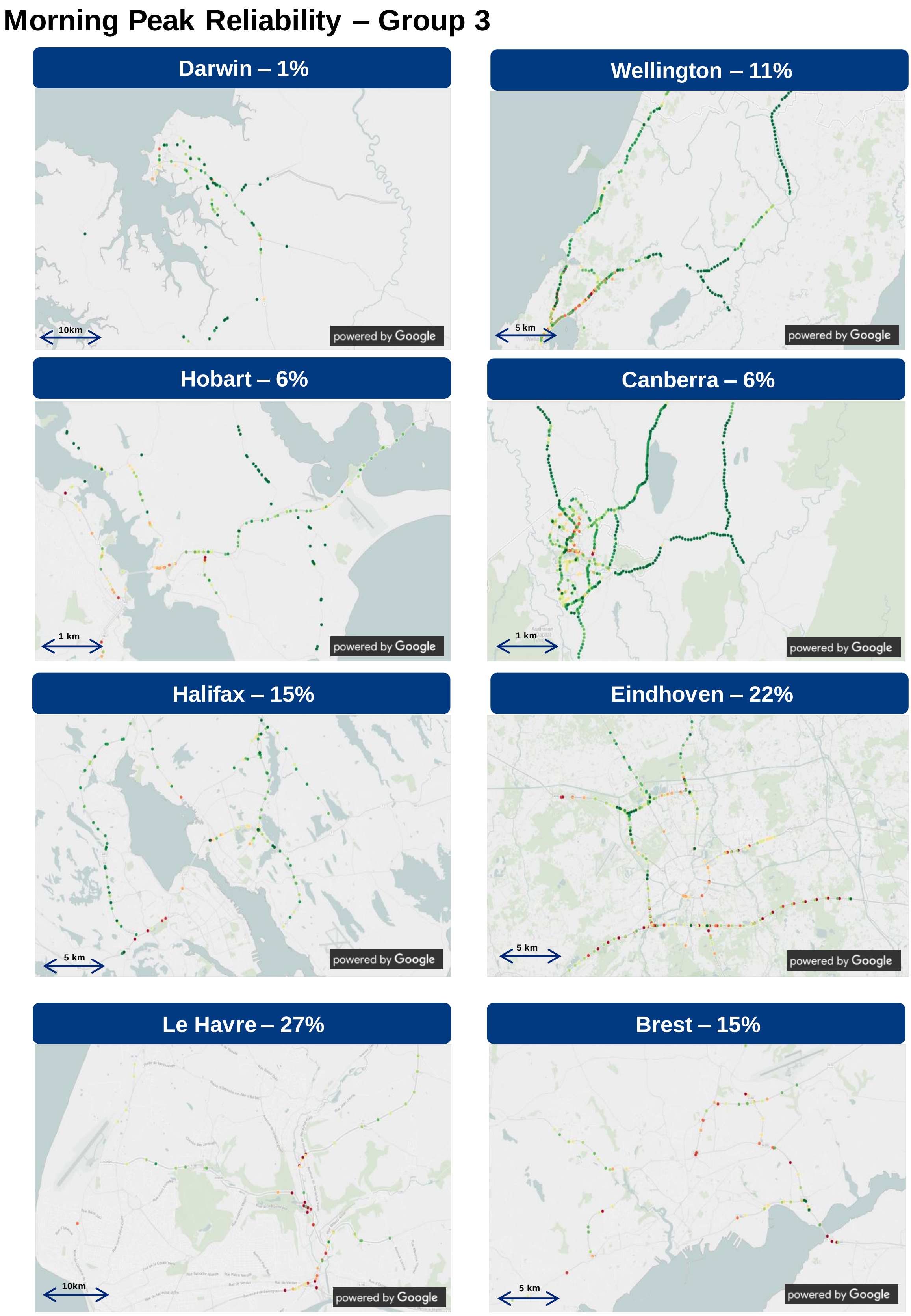
110 Rutten, B.J.C.M., Weijer, C.J.T., Woensel, T., (2013), Distributed Traffic Management Enables Lower Infrastructure Costs and Higher Societal Benefits

Exhibit 3.26: ANZ cities exhibit lower travel time delays relative to international Group 3 comparators



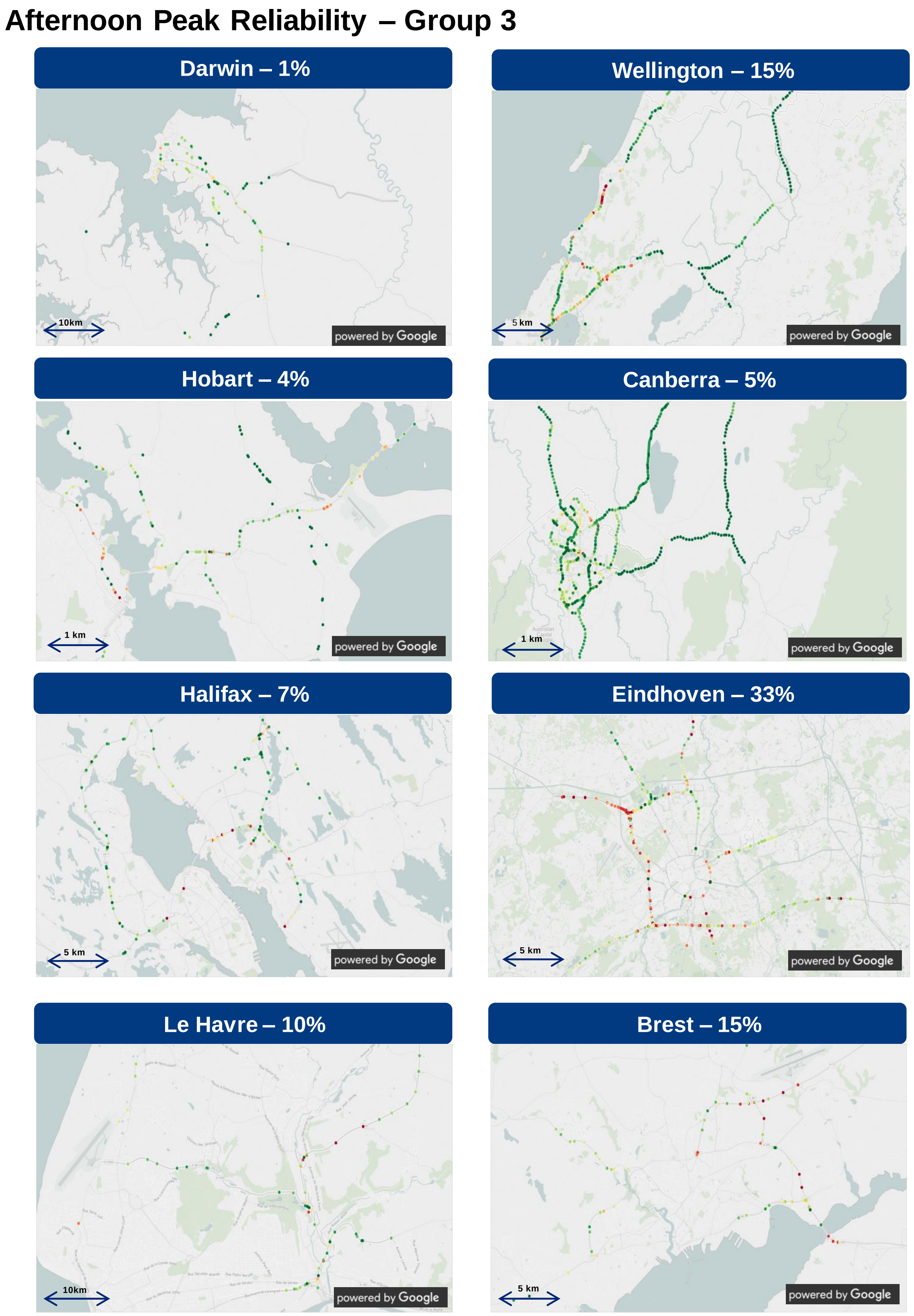
Source: Google maps data 2015-09-09 to 2015-11-26

Exhibit 3.27: ANZ cities exhibit better reliability relative to international Group 3 comparators in the morning



Source: Google maps data 2015-09-09 to 2015-11-26

Exhibit 3.28: ANZ cities exhibit better reliability relative to international Group 3 comparators in the afternoon



Source: Google maps data 2015-09-09 to 2015-11-26

3.3.4 Megacities

Megacities are included as 'international comparators' to enable ANZ Group 1 cities to understand the potential future of their road networks, if their populations continue to grow. Across the measures, For Average Speed and Travel Time Delay Los Angeles performs comparatively poorly; it has experienced large increases in population throughout the 1900s and at present, and its road capacity has difficulties coping with such demand.

Average Speed

Of the megacities considered in this analysis, New York has the highest Average Speed (76.6 km/h). This is comparable to the Average Speed of the Group 1 ANZ cities: faster than the Average Speed recorded for Sydney (72.5km/h), but slower than Melbourne (77.8 km/h).

As shown in Exhibit 3.29, Singapore's observations are grouped at a similar speed limit. Singapore has congestion pricing in place, which has been found to be an effective congestion management tool. Roads in New York and Los Angeles roads exhibit 'humps' of observations that would be expected from different road types, but are dispersed more equally over the entire range of speeds.

Travel Time Delay

Exhibit 3.29 also shows Travel Time Delay in Los Angeles, New York and Singapore. Travel time delay in Los Angeles is significantly worse than the Group 1 ANZ and international comparator cities, which have Travel Time Delays ranging from 17% in Melbourne to 37% in Seattle. Travel time delays in New York, London and Singapore are comparable with Group 1 cities and comparators. New York has an orbital freeway, a likely reason for its high Average Speed.

Reliability

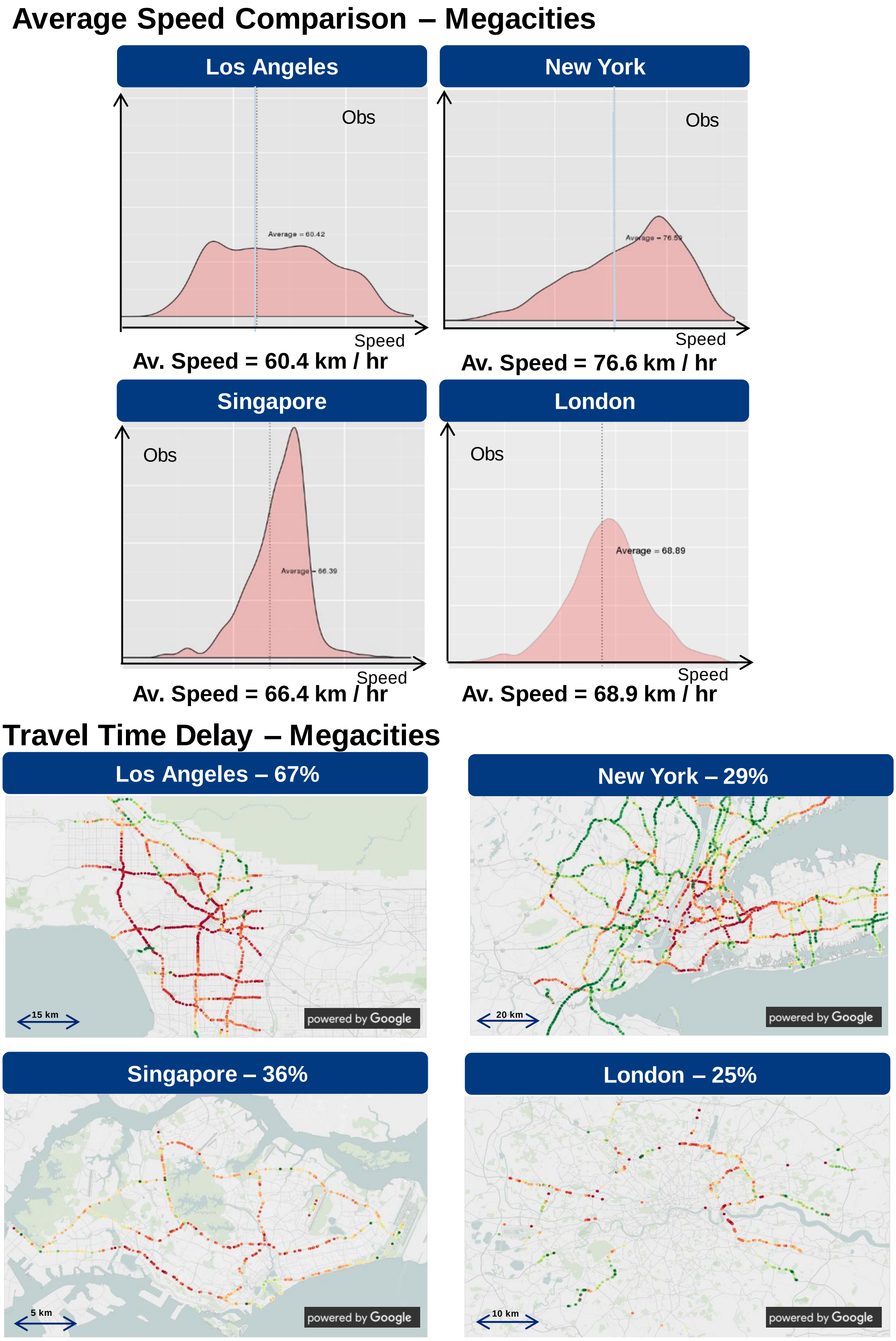
The megacities are slightly less reliable than the Group 1 ANZ and international comparators during the morning peak, but have similar Reliability during the afternoon peak. As shown in Exhibit 3.30, their unreliability tends to be distributed across the entire city centre, rather than on specific arterial roads or local roads.

As with the European Group 2 comparators, London's road network is built on the remnants of historical road and land use. Greater London has very few roads which operate at over 80km/hr at free-flow speed. The inner ring road, the North and South Circular, operates at 30mph and 40mph and so would not satisfy the criteria for inclusion in this section of the report. The Transport for London road network operates at 30mph and 40mph and carries 33% of the traffic, but represents only 5% of the network. London Boroughs are introducing more 20mph zones which means that Average Speeds will continue to reduce. In total, approximately 25% of London's roads could operate at 20mph[111]. In contrast to this, Singapore has a much more extensive urban motorway network, delivering commuters within the city and CBD at speeds of over 180km/hr in some cases.

The London Roads Task Force review in 2013 determined that 'place', the environment and air quality, as well as road space should be considered when planning new developments. Therefore increasingly road space expansion is not part of London's strategy. Instead the intent is to use technology to make road space safe and road space allocation more dynamic, and detect and reduce incident impacts[112]. The construction of the London Cycle Superhighway network during the period of data collection may have impacted the statistics.

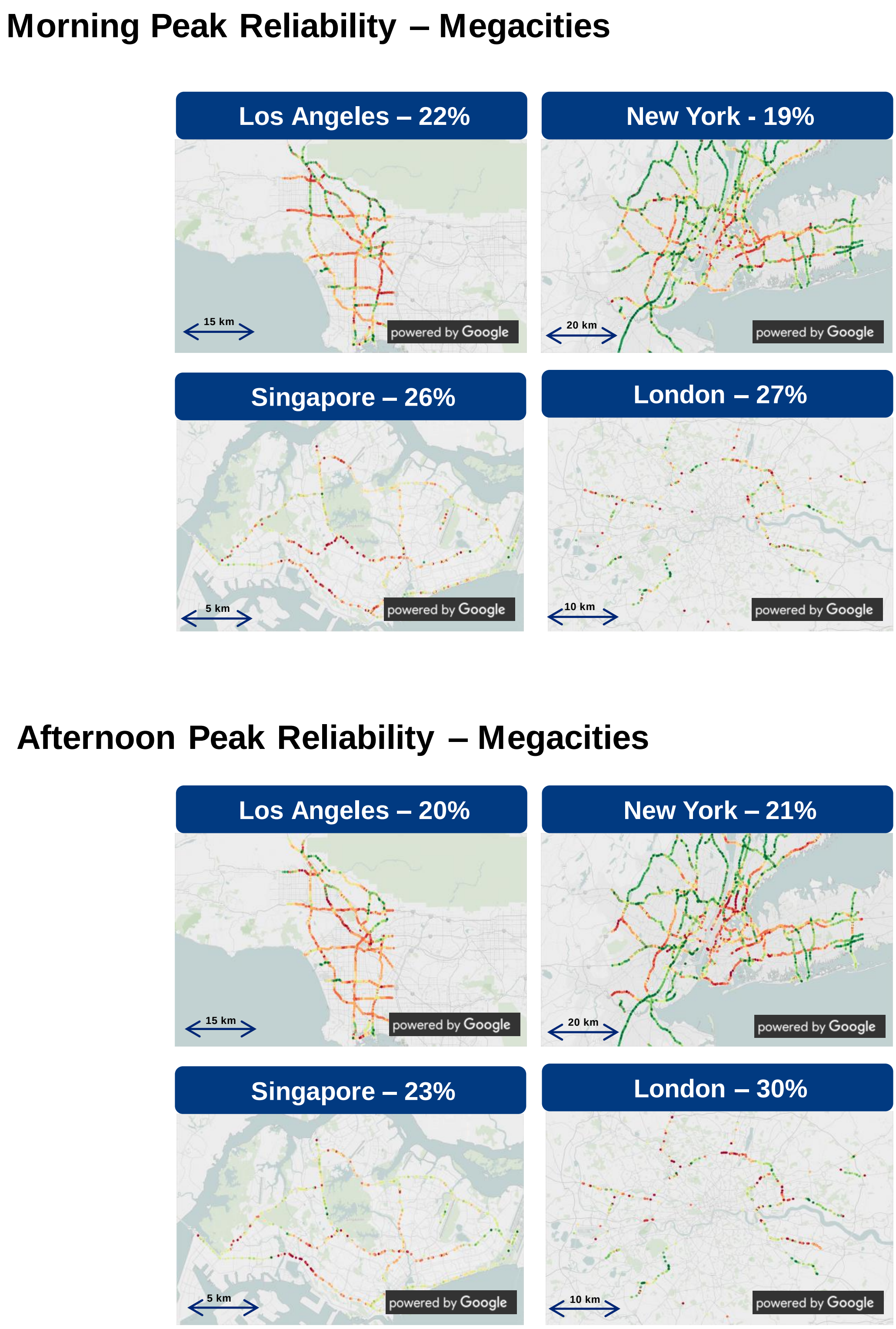
111 Transport for London website, (2015), TfL outlines new sites for potential 20mph speed limits
112 Transport for London, (2015), Surface Intelligence Transport System Consideration

Exhibit 3.29: Los Angeles has the highest Travel Time Delay and Slowest Roads of the Megacities



Source: Google maps data 2015-09-09 to 2015-11-26

Exhibit 3.30: London is the most unreliable of the megacities in both the morning and afternoon peak periods



Source: Google maps data 2015-09-09 to 2015-11-26

4. Congestion Causes

"Heavy rain, flash flooding and traffic queues have caused havoc on the roads into and around Sydney after the new year's break"

The Sydney Morning Herald, 3rd January 2016

Chapter Summary

4.1 Key Causes of Congestion

- Each ANZ city has differing causes of congestion; **the majority of ANZ urban congestion (~88-98%) is a consequence of recurrent causes**
- The identified non-recurrent causes of congestion **are incidents, events and weather;** these cause **between 2% and 12%** of congestion in ANZ cities, although better data collection of these drivers would allow more accurate ongoing analysis
- The **specific dynamics of congestion may vary significantly**, for example:
  - Bad weather on the M3 in Brisbane led to a 63% travel time delay

The analysis presented in Chapter 3 provides a measurement of congestion levels in Australian and New Zealand capital cities. However, in order to develop an approach to reduce levels of congestion, an understanding of the drivers of congestion is required. This chapter provides an overview of the key contributors to variations in travel time for each ANZ city.

4.1 Key Causes of Congestion

The quantitative analysis presented in Chapter 3 considers a number of potential causes of congestion that could impact upon overall travel times. These have been categorised into recurrent and non-recurrent congestion, and are summarised in Exhibit 4.1. This approach leverages existing international work, as well as jurisdictional available data.

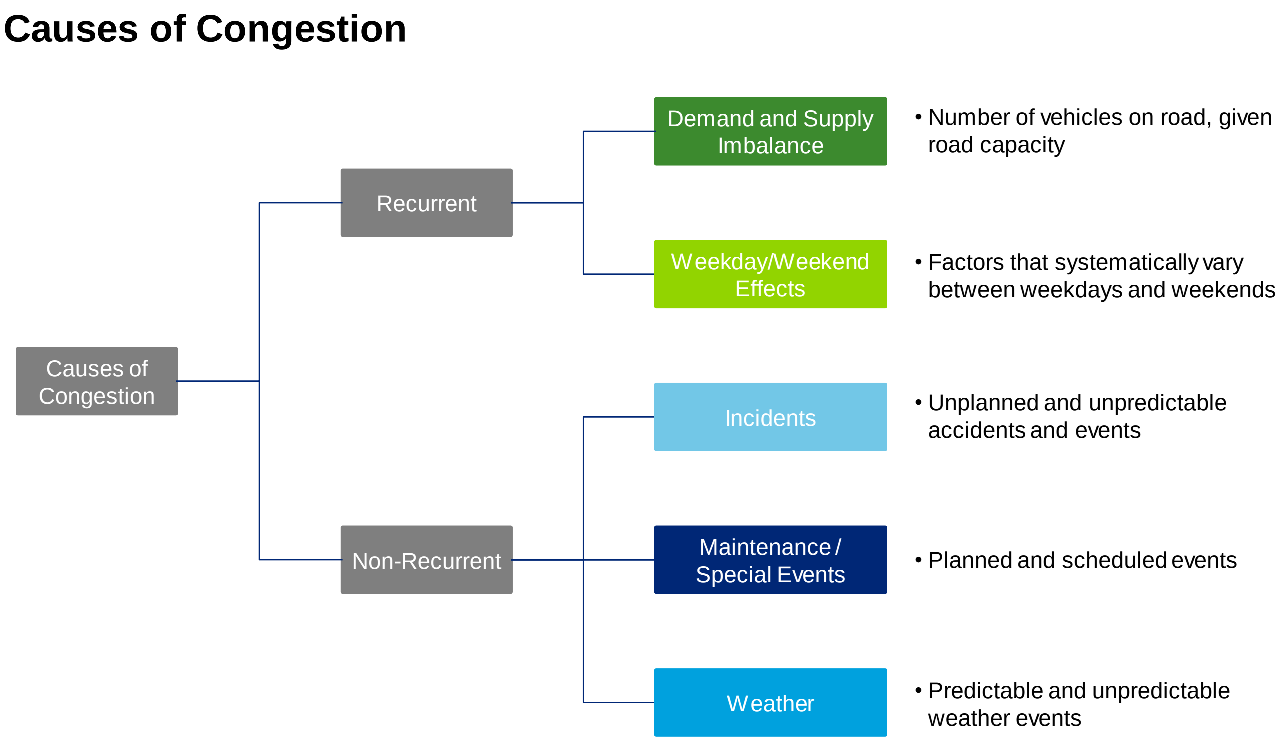
Recurrent causes of congestion include:

- **Demand and Supply Imbalance:** The number and type of vehicles on a road at a given point in time, relative to the road design capacity. For a particular road with a fixed vehicle capacity, increased traffic volumes tend to result in greater congestion and travel times.
- **Weekday Effects:** There are several factors that systematically vary between weekdays and weekends that are not captured by the number of road users. This can include traffic management tools that are used to manage congestion, such as clearways and traffic light signals. It also includes driver behaviour, which can be significantly different between weekdays and weekends.

Non-recurrent causes of congestion include:

- **Traffic Incidents:** Incidents, such as traffic accidents or signal failures, are unplanned and therefore unpredictable.
- **Maintenance and Special Events:** Planned events such as road closures due to roadworks or other scheduled maintenance.
- **Weather:** Rain can impact on the speed of traffic, as drivers manage the risks of low visibility and road traction by reducing their speed (very few ANZ cities experience snowfalls). The secondary effect can increase the likelihood of road accidents which can further compound congestion.

Exhibit 4.1: Key causes of congestion are categorised as Recurrent and Non-Recurrent



Further details on the modelling methodology and variables used to estimate the impact of these congestion causes on travel times are discussed later in this chapter and in Appendix A.7.

It is important to note that under our methodology, only non-recurrent causes where data were available could be analysed, so the analysis may underestimate the impact of non-recurrent causes on travel time and congestion in jurisdictions with limited data availability. Where these data limitations have been encountered, they have been noted in the analysis that follows. It is therefore recommended that further research is conducted with a larger and more complete and consistent dataset across these jurisdictions.

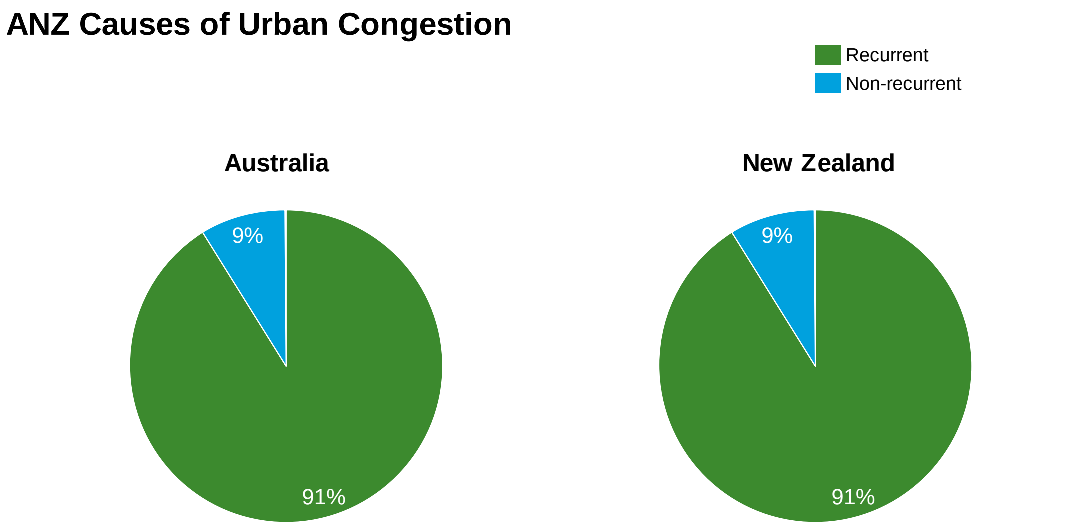
This section summarises the findings for the ten jurisdictions and outlines the key causes of congestion in each city. Congestion is examined by using travel time data from Google for a sample of road segments in each jurisdiction. An aggregate view is presented below, followed by analysis of the causes of congestion individually for each city.

4.1.1 ANZ Congestion Causes

Across the Australian cities, recurrent causes of congestion had the largest impact on explained variations of travel time, explaining an average of 91% of variations for the September and October 2015 data sample (see Exhibit 4.2). Non-recurrent causes had relatively small impacts on explaining variations of travel time. Unplanned incidents and rainfall each explained an average of 4% of travel time variations, while planned events explained 1% of variations.

Across the New Zealand cities, recurrent causes of congestion also had the largest impact on explained variations of travel time, explaining an average of 91% of variations for the September and October 2015 data sample. Again, non-recurrent causes had relatively small impacts on explaining variations of travel time. Unplanned incidents explained an average of 7% of travel time variations, while rainfall and planned events each explained 1% of variations.

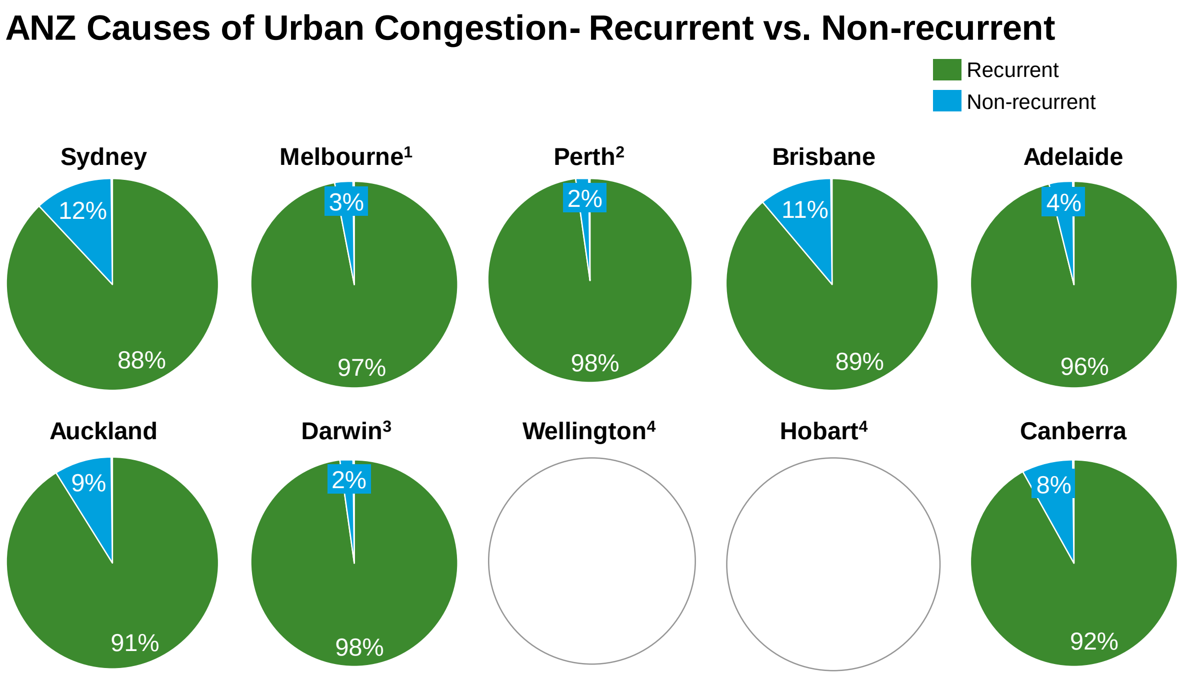
Exhibit 4.2: The majority of ANZ urban congestion is a consequence of recurrent causes of congestion



Note: 1. The cities included in the Australia pie chart include Sydney, Melbourne, Perth, Brisbane, Adelaide, Darwin and Canberra. The cities included in the New Zealand pie chart include Auckland and Wellington. Data limitations may have impacted the modelling results for Melbourne, Perth, Darwin and Wellington – these limitations are described in further detail in the city-specific analysis.
Source: Google data, September and October 2015; Jurisdictional data on volume of road users, maintenance/special events, incidents; Australian Bureau of Meteorology; New Zealand National Institute of Water and Atmospheric Research

At an individual city level, recurrent causes of congestion explained between 87% and 98% of variations for the September and October 2015 data sample (see Exhibit 4.3). Non-recurrent causes explained between 2% and 13% of variations in travel time.

Exhibit 4.3: For individual cities, between 88% and 98% of congestion is a consequence of recurrent causes of congestion

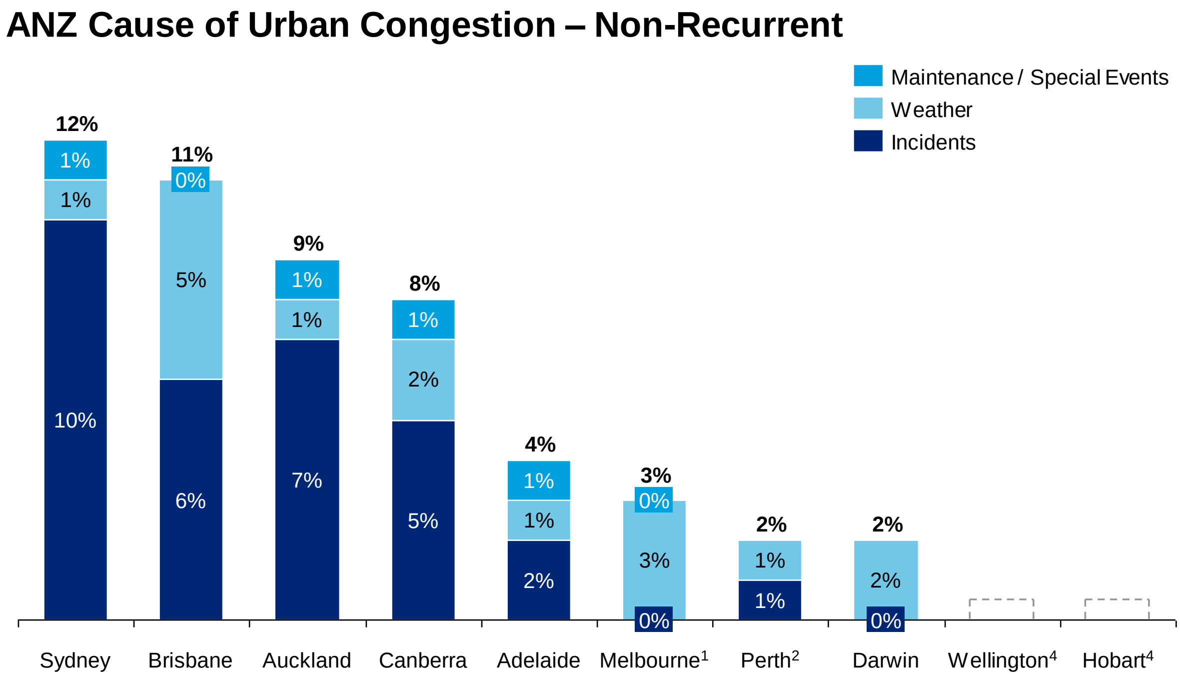


Note: 1. Due to data limitations, there were no maintenance/special events and only a limited number of incidents (0.01% of total observations) recorded around the road segments used in the analysis; 2. Due to data limitations, maintenance/special events could not be mapped to the road segments used in the analysis; 3. Due to data limitations, there were no maintenance/special events or incidents recorded around the road segments used in the analysis; 4. Insufficient traffic counter data to determine causes of congestion
Source: Google data, September and October 2015; Jurisdictional data on volume of road users, maintenance/special events, incidents; Australian Bureau of Meteorology; New Zealand National Institute of Water and Atmospheric Research

There exists no correlation between the size of a city and its causes of congestion. Cities with the largest variation explained by non-recurrent causes are Canberra, Auckland, Brisbane and Sydney, all with varying comparative population sizes and geographical characteristics.

Non-recurrent causes explain between 2% and 12% of congestion. As shown in Exhibit 4.4, incidents are the non-recurrent cause with largest impact (on average), explaining between 1% and 10% of variation where data exists. Weather (1% to 5%) and planned road maintenance and special events (1%) have relatively small impacts.

Exhibit 4.4: Of the non-recurrent causes of congestion, 'incidents' have the greatest impact on congestion



Note: 1. Due to data limitations, there were no maintenance/special events and only a limited number of incidents (0.01% of total observations) recorded around the road segments used in the analysis; 2. Due to data limitations, maintenance/special events could not be mapped to the road segments used in the analysis; 3. Due to data limitations, there were no maintenance/special events or incidents recorded around the road segments used in the analysis; 4. Insufficient traffic counter data to determine causes of congestion

Source: Google data, September and October 2015; Jurisdictional data on volume of road users, maintenance/special events, incidents; Australian Bureau of Meteorology; New Zealand National Institute of Water and Atmospheric Research

4.1.2 Congestion Causes - Group 1

Sydney

In Sydney, recurrent causes have the greatest impact on explained variations in travel time (88%). Of the non-recurrent causes of congestion, unplanned incidents (10%) make a moderate contribution to explaining travel time variation. Planned road maintenance and special events, as well as rainfall, had relatively smaller impacts in explaining variations in travel time.

Unplanned incidents had a disproportionately large effect on travel time in Sydney, affecting 5% of observations but contributing to 10% of explained variations in travel time. In contrast, planned road maintenance and special events affected 24% of observations but contributed to only 1% of explained variations in travel time.

Melbourne

For Melbourne, recurrent causes have the greatest impact on explained variations in travel time (97%). Of the non-recurrent causes of congestion, rainfall had a relatively small impact in explaining variations in travel time (3%), while unplanned incidents made a negligible contribution.

However, these results should be treated with caution because data limitations meant that there was no planned road maintenance and special events and only a limited number of unplanned incidents (0.01% of total observations) recorded around the road segments used in the analysis. As such, the fact that these variables do not appear to contribute to variations in travel time is more likely to reflect a lack of data, not that these factors have no impact on travel time in Melbourne.

4.1.3 Congestion Causes - Group 2

Perth

For Perth, recurrent causes have the greatest impact on explained variations in travel time (98%). Of the non-recurrent causes of congestion, unplanned incidents and rainfall had relatively small impacts in explaining variations in travel time.

Data limitations meant that the information received on planned maintenance and special events could not be mapped to the road segments used in the analysis. As such, the fact that this variable does not appear to contribute to variations in travel time reflects a lack of data, not that this factor has no impact on travel time in Perth.

Rainfall had a disproportionately small effect on travel time in Perth, affecting 19% of observations but contributing to only 1% of explained variations in travel time.

Adelaide

For Adelaide, recurrent causes have the greatest impact on explained variations in travel time (96%). Of the non-recurrent causes of congestion, planned road maintenance and special events, unplanned traffic incidents and rainfall all had relatively small impacts in explaining variations in travel time.

However, the relatively small impact of unplanned incidents represented a disproportionately large effect on travel time in Adelaide, as unplanned incidents affected only 0.3% of observations but contributed to 2% of explained variations in travel time. In contrast, rainfall affected 19% of observations but contributed to only 1% of explained variations in travel time.

Brisbane

For Brisbane, recurrent causes have the greatest impact on explained variations in travel time (89%). Of the non-recurrent causes of congestion, unplanned traffic incidents (6%) and rainfall (5%) also both made moderate contributions to explaining travel time variations. Planned road maintenance and special events had a relatively smaller impact in explaining variations in travel time.

However, the relatively small impact of unplanned incidents represented a disproportionately large effect on travel time in Brisbane, as unplanned incidents affected only 0.2% of observations but contributed to 6% of explained variations in travel time.

The Queensland Department of Transport and Main Roads (TMR) has also completed an assessment of the causes of congestion on Brisbane's roads.[113] While the TMR analysis examined similar congestion drivers to this study, including weather events, roadworks and traffic incidents, it used an alternative methodology to the approach developed in this study. The differences between the two methodologies include:

- The approach examines travel time in aggregate, whereas the TMR approach separates 'abnormal congestion' and 'normal excessive congestion'
- The approach for this report uses regression analysis to determine how each factor influences travel time, while TMR creates abnormal congestion footprints and examines which factors are correlated with abnormal congestion events, averaging the impact where multiple factors are involved
- The sample includes data from September and October 2015, while TMR's uses data from the 2014 calendar year.

113 Queensland Department of Transport and Main Roads (2015), Causes of Congestion: Draft Executive Summary

Further details on our modelling methodology can be found in Section 4.2 below, while the TMR's approach has been summarised in the 2015 report *Causes of Congestion: Draft Executive Summary*.

Both studies have found that recurrent causes have the greatest impact on congestion, with these causes explaining 89% of variations in travel time under our methodology and contributing to 78% of congestion under the TMR approach.

Auckland

For Auckland, recurrent causes have the greatest impact on explained variations in travel time (91%). Of the non-recurrent causes of congestion, unplanned incidents (7%) also make a moderate contribution to explaining travel time variation. Planned road maintenance and special events, as well as rainfall, had relatively smaller impacts in explaining variations in travel time.

Unplanned incidents had a disproportionately large effect on travel time in Auckland, affecting 3% of observations but contributing to 7% of explained variations in travel time. In contrast, rainfall affected 20% of observations but contributed to only 1% of explained variations in travel time.

4.1.4 Congestion Causes - Group 3

Darwin

For Darwin, recurrent causes have the greatest impact on explained variations in travel time (98%). Of the non-recurrent causes of congestion, rainfall (2%) had a relatively small contribution to explaining travel time variation.

However, these results should be treated with caution because data limitations meant that there was no planned road maintenance and special events or unplanned incidents recorded around the road segments used in the analysis. As such, the fact that these variables do not appear to contribute to variations in travel time reflects a lack of data, not that these factors have no impact on travel time in Darwin.

Rainfall had a disproportionately small effect on travel time in Darwin, affecting 19% of observations but contributing to only 5% of explained variations in travel time.

Canberra

For Canberra, recurrent causes have the greatest impact on explained variations in travel time (92%). Of the non-recurrent causes of congestion, unplanned incidents (5%) also make a moderate contribution to explaining travel time variation. Planned road maintenance and special events, as well as rainfall, had relatively smaller impacts in explaining variations in travel time.

Unplanned incidents had a disproportionately large effect on travel time in Canberra, affecting 0.6% of observations but contributing to 5% of explained variations in travel time. In contrast, rainfall affected 15% of observations but contributed to only 2% of explained variations in travel time.

Hobart and Wellington

Due to data limitations related to an insufficient amount of traffic count data supplied for Hobart and Wellington, there were not enough road segments to conduct a robust analysis on these two cities.

4.2 Congestion Model

4.2.1 Methodology

The pie charts above use an econometric model to analyse the relative impact of different drivers of congestion on travel time across each of the 10 jurisdictions.

To start with, data was gathered on each of the causes of congestion identified above for a collection of road segments across the 10 cities. Google data was collected at a half-hourly interval where available, over a period spanning September and October 2015[114].

This data was then used as an input into regressions to identify the impact of each cause on travel time. Congestion and traffic data are complex and can be challenging to model given the numerous drivers of congestion and their relationships. Our methodology considered a number of features of the data so as to be able to account for them in the econometric model, including:

- The impact that drivers of congestion that occur in previous periods could have on future periods, such as rainfall at a given time continuing to cause congestion an hour later due to wet road surfaces;
- How the relationship between traffic volume and travel time might change as a road reaches capacity; and
- The potentially different effects of traffic management tools (such as clearway zones or traffic light signalling patterns), driver behaviorand other factors on weekdays compared to weekends

More specific technical details on how data was collected on these variables and the estimation methodology on how this data was incorporated into the econometric modelling are provided in Appendix A.7.

After estimating the model, we used the results to calculate the relative contribution of the different congestion drivers to variations in travel time, i.e. to explain the relative impact of the drivers on overall congestion. It should be noted here that the method used for this decomposition only allows us to measure the relative contribution of each congestion driver to the *variation that is explained by the model*. Unexplained variations are not accounted for in the decomposition. Technical details on this process are provided in Appendix A.7.

This modelling was conducted for each road segment. Road segments within each of the 10 cities were aggregated to calculate the overall breakdown of how each congestion driver impacts upon explained variations in travel time across the city. The aggregation process placed higher weights on segments with relatively higher congestion and traffic volumes.

4.2.2 Recurrent Congestion Variables

Causes of recurrent congestion are those which affect the level of congestion on a regular and relatively predictable basis, such as the number of road users and weekday/weekend effects.

Demand and Supply Imbalance

The number of vehicles on the road at any given time is a key cause of congestion. In general, the greater the number of vehicles on roads (i.e. the greater the demand), the greater the congestion is likely to be for a road with a fixed vehicle capacity (i.e. a fixed supply).

114 The two months for which we collected data include several periods which may not be representative of 'regular' travel conditions across some of the jurisdictions. For example, in Queensland, the September to October 2015 period includes two weeks of school holidays (19/9 to 4/10), the Labour Day holiday (5/10) and a student-free day (19/10). As such, four out of the eight Mondays in the sample were not 'regular' Mondays. However, to the extent that these days have impacted upon traffic volume which in turn affects travel times, this is captured by the number of road users variable (demand and supply imbalance). Future research could look to collect data for a longer time period in order to better model the impacts of these 'irregular' days.

This represents a recurrent cause of congestion because the number of road users has predictable peaks and troughs throughout a standard weekday and weekend. A number of reasons can influence these peaks and troughs, including:

- Morning and afternoon peaks associated with commuting to and from work and school;
- Lower levels of traffic in between peaks and in the early morning/late evening; and
- Seasonal periods of high traffic volumes such as the school holidays and long weekend public holidays

These factors are drivers of short-term cyclical variations in the number of vehicles using the road network. In the longer term, there are a number of broader factors that can impact upon the number of road users in a city, such as:

- Population growth and demographic change within the population;
- Trends in vehicle ownership levels and vehicle ownership type; and
- The availability of public transportation options and take-up of these options

Given that the quantitative analysis conducted for this study uses data collected over the two-month period of September and October 2015, these longer-term determinants of the number of road users are unlikely to be reflected in the analytical results. The impact that the volume of vehicles has on congestion in the subsequent analysis is more likely to reflect the shorter-term peaks and troughs in traffic activity discussed above.

Exhibit 4.5 shows the impact that traffic volume can have on congestion and supply and demand imbalances on a particular road in the short term. In this chart, congestion is represented by average vehicle speeds, with slower speeds indicating more congested conditions. There is an inverse relationship between vehicle volume and speed, with the negative impact of volume on speed becoming larger in magnitude as the road approaches its capacity.

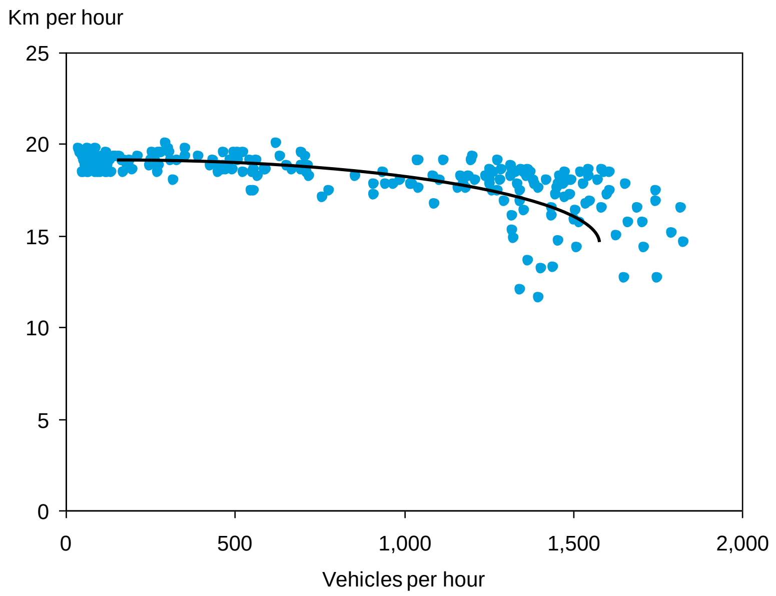
This variable was included in the model using traffic count data sourced from road agencies within each city (refer to Appendix A.7 for more details).

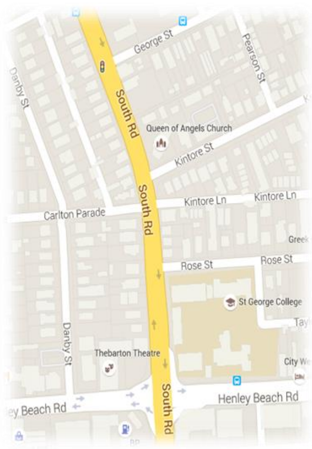
Exhibit 4.5: The number of road users impacts the speed and therefore travel time along a corridor

Volume-Speed Relationship

Adelaide, Segment of South Rd, September

Average Speed, Kilometres per hour / Vehicles per hour





Notes: Polling conducted at 30 minute intervals

Weekday/Weekend Effects

There are a number of factors that could impact upon congestion that are likely to vary between weekdays and weekends that are not captured by the number of road users variable. For example, there are a wide range of traffic management tools that road agencies can use to manage traffic flow on particular roads, and the use of these often changes across weekdays and weekends. These can include:

- Traffic light signalling patterns and cycle lengths, which can lead to shorter or longer wait times at road intersections;
- Clearway zones specifying when vehicles may or may not park on the side of the road; and
- Variable speed limits which change based on road, traffic and weather conditions, potentially being able to restrict vehicle speeds during adverse conditions.

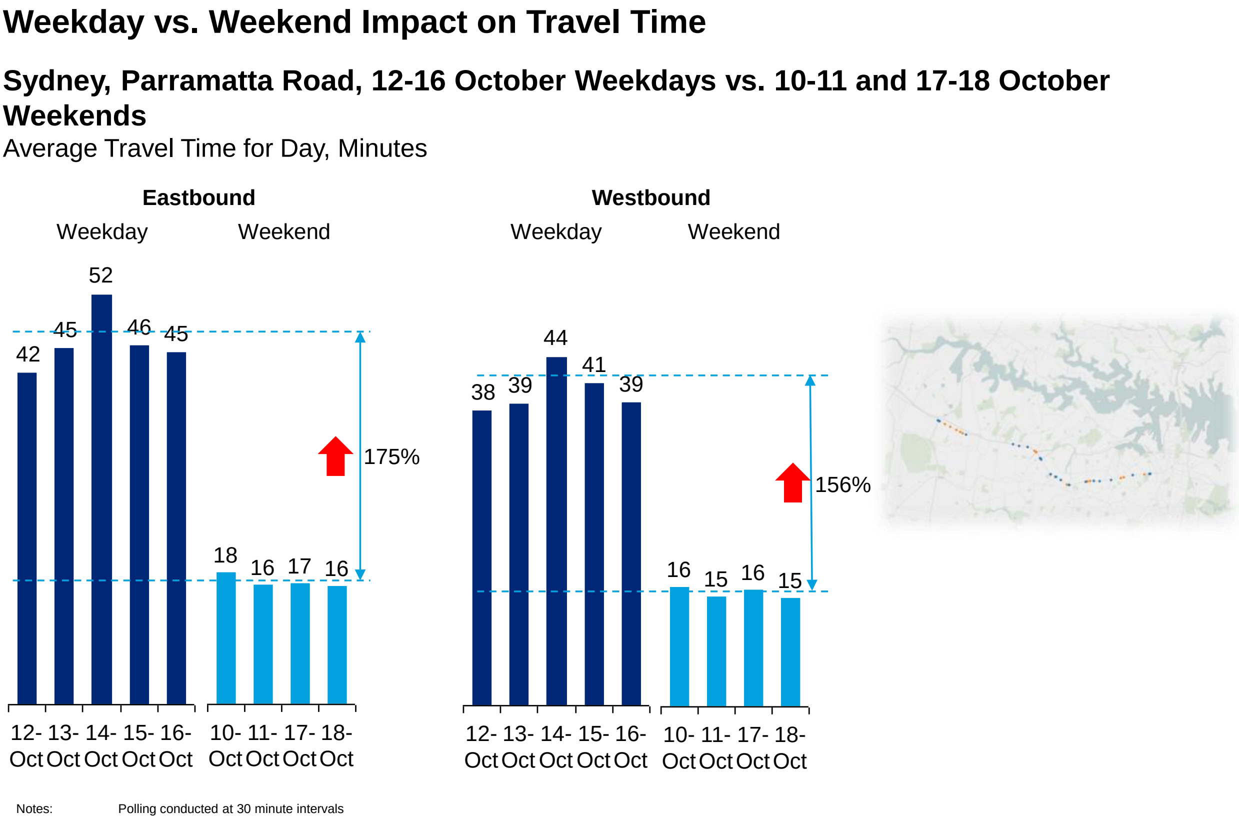
Given the significantly different traffic conditions that arise on weekends compared to weekdays, it is likely that the above traffic management tools will have different impacts across these two types of days. For example, clearway zones are often operational during peak hour periods on weekdays but not during weekends. Similarly, traffic light cycles between green and red lights might be longer on weekdays to accommodate larger volumes of traffic flow. Note that in some cases, the use of these traffic management tools may even vary by the time of day given that a number of road agencies are moving towards more advanced and automated network operation planning and optimisation techniques.

Another factor that can differ across weekdays and weekends is driver behaviour. Different purposes for travel and travelling at different times to different places could potentially lead to systematic variations in average travel times between weekdays and weekends.

Exhibit 4.6 shows a comparison of travel times on Parramatta Road (Sydney) on weekends as compared with weekdays. The differences between traffic conditions on weekdays and weekends are likely to be attributable to both traffic volume and factors contributing to weekday/weekend effects such as traffic management tools and driver behaviour.

In light of these differences, the quantitative analysis conducted for this study includes a fixed effects indicator based on weekdays and weekends (refer to Appendix A.7 for more details).

Exhibit 4.6: Traffic conditions can be significantly different between weekdays and weekends



Other Recurrent Causes

There are a number of other recurrent factors that can cause congestion on a road network.

One such factor is road infrastructure, which can play a significant role in causing congestion. The vehicle capacity of a road depends upon a number of features such as the number of lanes on the road, the number of alternative roads or routes, and physical bottlenecks such as bridges or sharp turns. The road network as a whole – including the quality of roads, complexity of the system, and interaction between road signals – also contributes to overall congestion levels.

City planning and design can also impact upon traffic congestion through the structure of the city. For example, where the central business district is not actually centrally located, congestion may be heightened as commuters must travel greater distances on more complex routes to converge on the city. Secondary city hubs or other centralised industry clusters may assist in alleviating congestion in these instances.

While these are all factors that could potentially have a recurrent impact on traffic congestion, we were unable to collect sufficient data across all of the road segments and time intervals to be used as an input for the quantitative analysis. As such, the effects of these other recurrent causes have not been quantified in this study.

4.2.3 Non-Recurrent Congestion Variables

Non-recurrent causes of congestion are less predictable in terms of their occurrence and impact on the level of congestion and on Reliability. However, they can result in a significant increase in travel times and congestion depending on the severity of the impact. These non-recurrent causes include accidents and other traffic incidents, planned delays such as road maintenance and special events, and weather-related delays.

Traffic Incidents

Incidents, such as traffic accidents or signal failures, are unplanned and therefore unpredictable in nature. Their impact on congestion depends on the severity of the incident and the clearance time required to return to pre-incident traffic flow. As such, despite their relatively random occurrence, traffic incidents are a cause of congestion which cities can actively manage by improving their incident response procedures.

Traffic incidents can range from having a relatively minor impact on congestion, to severe accidents that have a significant negative impact on travel times. For example, Exhibit 4.7 shows that a truck incident on Sydney's M2/M7 motorway in the eastbound lanes at around 12pm on 3 October 2015 caused a large increase in congestion, with travel times more than tripling relative to previous comparable periods.

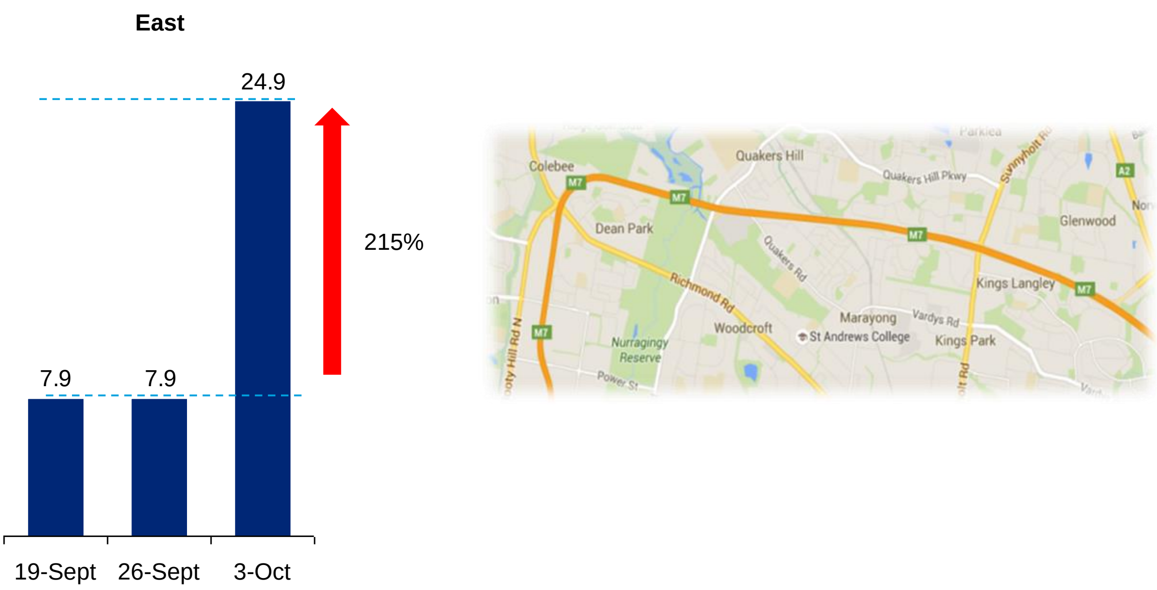
This variable was included in the model using traffic incidents data sourced from road agencies within each city (refer to Appendix A.7 for more details).

Exhibit 4.7: Analysis shows that incidents have a large impact on journey time

Incident Impact on Travel Time

Sydney, M2/M7 East Bound - 3rd October, 12pm

Average Travel Time for Day, Minutes



Maintenance and Special Events

Another category of non-recurrent causes of congestion is planned events. This includes road closures due to roadworks or other scheduled maintenance, which – while irregular – is likely to be planned in advance, often to coincide with non-peak periods for traffic. The extent to which road users are informed of planned maintenance and their knowledge of alternative routes can lessen the impact of this cause of congestion. Nonetheless, road maintenance activity and the associated road closures have the potential to lead to an increase in traffic congestion.

Similarly, special events can increase congestion but can be planned for. These include events where outright road closures are required, such as the ANZAC Day parade and 'fun run'-type events, as well as events that are likely to lead to significant volumes of traffic flowing to and from a concentrated area, such as high profile sporting fixtures like the AFL grand final match. Such events are likely to lead to large but temporary increases in travel times around the affected roads. For example, Exhibit 4.8 shows that road closures in the Sydney CBD area for the Sydney Running Festival on the morning of September 20 caused a large increase in travel times on William St for traffic coming into the city, relative to other comparable periods.

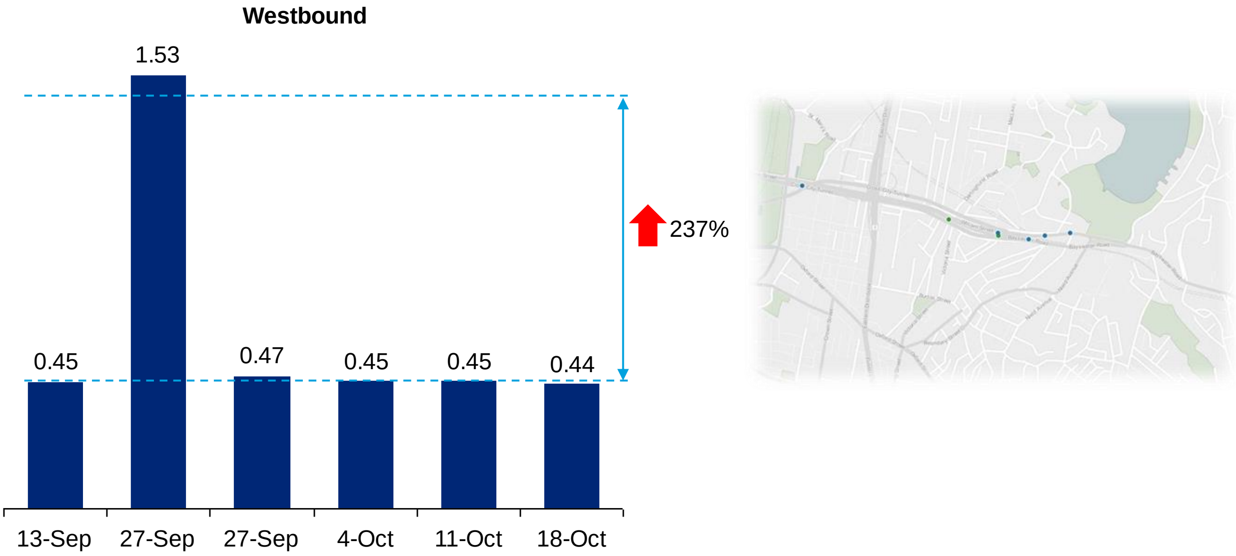
This variable was included in the model using planned events data sourced from road agencies within each city (refer to Appendix A.7 for more details).

Exhibit 4.8: Planned events can also have a significant impact on travel time

Event Impact on Travel Time

Event - Sydney, Segment of William St, West Bound – 20 September, 8am-12pm

Average Travel Time, Minutes



Notes: Polling conducted at 30 minute intervals

Weather – Rainfall

Local weather conditions can also impact upon journey times and travel time reliability, particularly in the case of rain, hail, flooding, snow and fog. In general, traffic is slower when weather conditions are poor, as drivers manage the risks of low visibility and road traction by reducing their speed. Bad weather also increases the likelihood of road accidents which can further compound congestion.

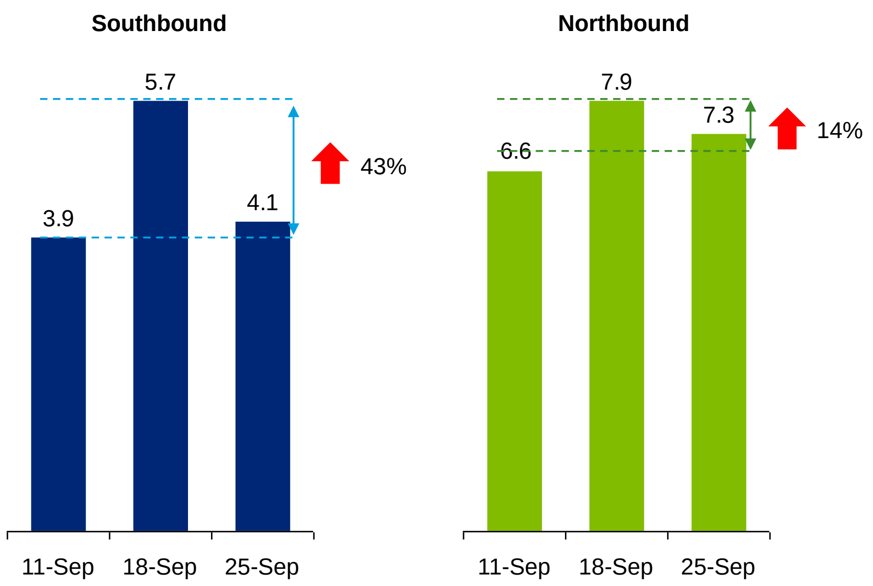
For example, Exhibit 4.9 shows the impact of heavy rainfall on travel times for the M3 motorway in Brisbane. The poor weather conditions observed on 18 September 2015 saw average travel times increase by more than 40% for the northbound road, relative to other comparable periods.

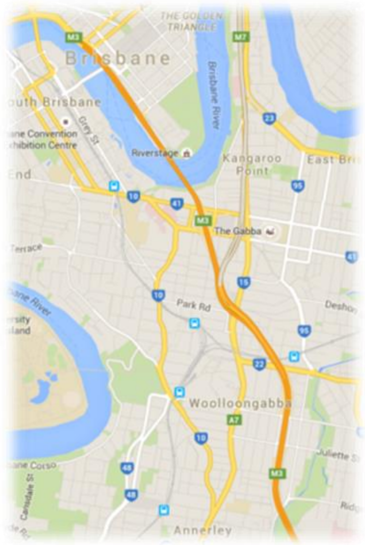
This variable was included in the model using rainfall data sourced from weather agencies within each city (refer to Appendix A.7 for more details).

Exhibit 4.9: Weather may have an impact on travel time, as shown in Brisbane on 18th September

Weather Impact on Travel Time

Brisbane, M3 Woolloongabba to CBD - September 18th
Average Travel Time for Day, Minutes





Notes: Polling conducted at 30 minute intervals

4.2.4 Travel Time Variable

The travel time data used as the dependent variable in our regression analysis was collected using the Google Maps Distance Matrix Application Programming Interface (API).

One of the key benefits associated with using Google as the data source for the travel time data is the ability to gather real-time travel and road performance data. When this data is integrated with other data sources such as rainfall data from weather agencies or traffic count and incident data from road agencies, this can provide us with immediate insights on unusual episodes of congestion and the causes driving these. Such information can assist the relevant authorities in minimising congestion in an operational and strategic context.

In addition, while road agencies may have a detailed view of the performance of and congestion on their own roads, the Google travel time data can provide insights into the performance of roads beyond their own network. It can also assist with benchmarking performance between cities, identifying bottlenecks to their roads and helping customers to find optimal routes.

5. Congestion Interventions

"Eighty percent of the people of Britain want more money spent on public transport - in order that other people will travel on the buses so that there is more room for them to drive their cars."

John Selwyn Gummer

Chapter Summary

5.1 Interventions Framework Overview

- The congestion intervention framework is a systematic approach to identifying relevant congestion interventions, by segmenting the interventions based on road supply or demand levers and their implementation timeframe
- A Benefit-Cost Ratio (BCR) comparison of interventions provides their indicative relative cost and effectiveness in reducing congestion, which indicates that road and transport agencies should invest in strategic interventions (specifically demand-side), as well as relatively low cost, high BCR interventions
- Interventions with marginal payoffs (1±0.5) require case-by-case assessment, as there would generally be alternative supply or demand measures with superior BCRs

5.2 Intervention Application

- The application of the interventions to specific congestion problems requires different filters:
  - **Location:** Type of road and land use
  - **Cause:** Recurrent / non-recurrent, delay / reliability or time of day
  - **City Type:** Budget, population density and growth potential
- This will leave a set of complementary interventions that should be implemented as a program
- Given **most congestion is recurrent**, appropriate interventions can be prioritised for each ANZ city:
  - **Group 1 cities** are currently investing in building road capacity, so future efforts can focus on their developed road network **demand management**, including interventions relating to 'shifting modes', 'changing behaviour' and 'operating effectively'
  - **Group 2 cities** can use 'planning' interventions to determine appropriate investments, considering their populations are likely to grow to that of larger Group 1 cities. This will ensure they **invest in providing new capacity and appropriate infrastructure in advance of growth**.
  - **Group 3 cities** can operate their road network effectively if high-cost supply-side investments are not determined feasible. They should focus on 'strategic', 'no regrets' and 'low budget' investments and **use planning interventions to determine future budget for appropriate investments**, considering their populations are likely to grow to that of larger Group 2 cities
- When considering the **non-recurrent causes** of congestion, **unplanned incidents** were the most prominent for most cities, therefore 'Operate Effectively' investment should **focus on creating routine in incidents**, rather than enhancing interventions that target events.
- In general, **demand-side interventions** may be most useful in the **short-run** to slow down the rise in the use of vehicles, and therefore recurrent congestion

Road agencies play a key role in reducing congestion through the supply of new roads, the operation and maintenance of existing roads and the active management of demand through trip information, tolling and registration. Transport agencies, other public service providers, private businesses and the public can also influence congestion, from individuals' choices on travel mode through to the timing and organisation of major events.

Interventions can reduce congestion by influencing supply of, or demand for, road space. They seek to prevent or reduce the negative effects of the causes of congestion. The timescale of intervention investments ranges from thirty years for land-use planning through to day-to-day decision-making based on real-time information, with minor to significant investment required.

The following chapter provides a framework and filtering process for intervention application, and proposes a set of specific recommended interventions for each ANZ city based on its causes of congestion.

5.1 Intervention Framework Overview

There are a wide range of potential interventions that can be applied to mitigate congestion in ANZ cities. A uniform method for considering each and analysing their relative pros and cons is required to ensure successful selection and application.

5.1.1 Intervention Framework

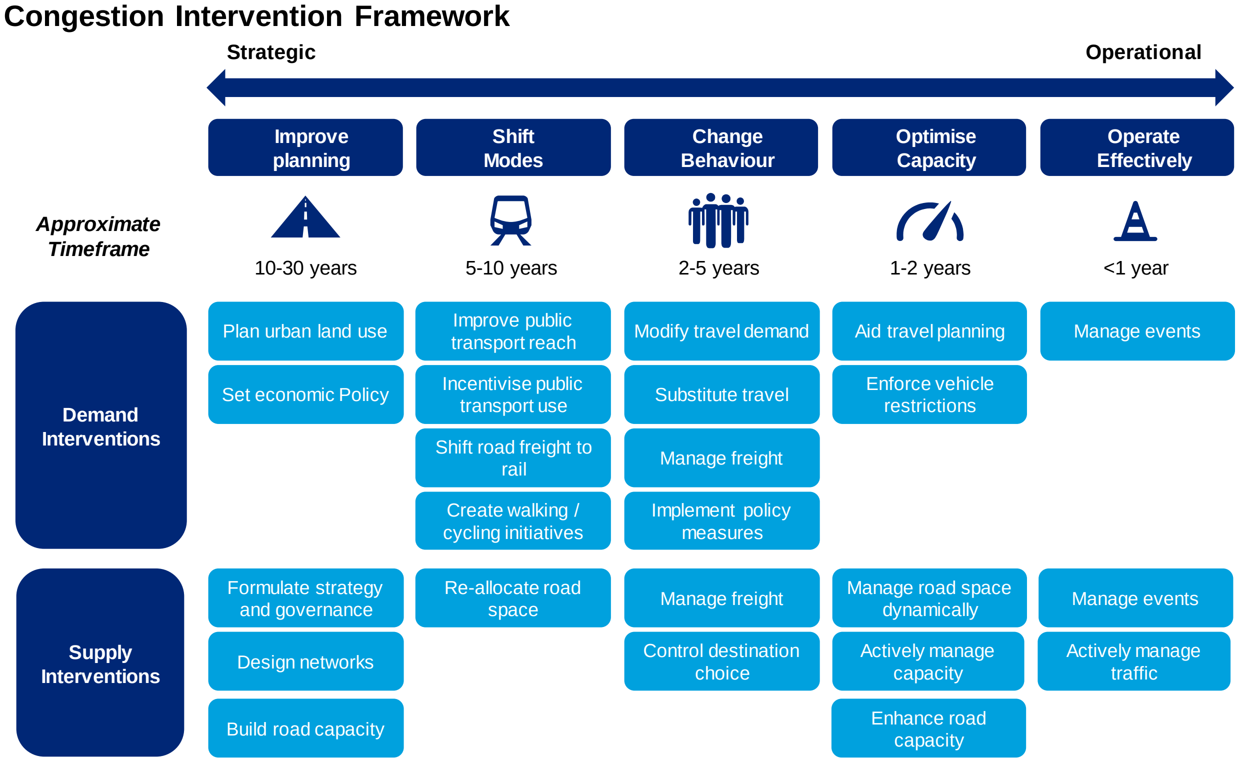
Exhibit 5.1 provides a framework for classifying interventions that are currently used in many developed cities. This framework builds upon the 2006 Council of Australian Government's 'Review of Urban Congestion'[115] report. Within each segment of the framework there are a number of interventions, details of which are provided in Appendix C.

The framework segments interventions by two dimensions:

- **Impact of intervention application.** Approaches to managing congestion can be broadly categorised into two types: demand-side or supply-side interventions. Demand-side interventions alter the demand for road use by modifying the volume and type of road users. Supply-side interventions alter the supply of road capacity. In this framework, increasing public transport options is classified as a demand-side intervention, as this would reduce the demand for road use.
- **Timeframe for intervention results.** Interventions have been segmented based on the approximate timeframe to realise benefits. For example, the results of improving planning today may only be realised in 10 to 30 years' time. At the other end of the spectrum, improvements in incidents and events, such as on-street works, can have immediate consequences for the mitigation of congestion.

115 Council of Australian Governments, (2006), Review of Urban Congestion: Trends, Impacts and Solutions

Exhibit 5.1: The framework groups interventions by approximate timeframe, from long-term strategic change to short-term operational management



There are also a number of emerging technologies, not included in the framework that may allow for congestion to be managed in new ways over the coming decade. These are discussed in Chapter 7.

5.1.2 Benefit-Cost Analysis

As well as their timeframe and impact on supply or demand, interventions have different benefits and costs. Benefit-cost analysis is important to undertake for all individual congestion intervention projects and programs; it provides decision-makers with an understanding of the relative return on investment, particularly when different metrics may be used across different types of intervention. A comprehensive analysis should also consider feasible alternative projects to inform decision makers of the option with the greatest net benefits.

Benefit-cost analysis should minimise the ‘externalities’ of congestion by including environmental and social impacts (both positive and negative) into the decision-making framework.

Costs of interventions include:

- Absolute monetary cost (incl. the initial capital cost and ongoing costs)
- Minimum cost required to implement (associated with the minimum number of units)
- Associated environmental costs (e.g. cost of pollution during implementation)
- Associated human and social costs (e.g. increased time delay during implementation)
- Associated safety cost during implementation

Benefits of interventions include:

- Absolute monetary benefit
- Minutes reduction in travel time
- Percentage reliability improvement
- Associated economic consequences (e.g. better commercial access)
- Wider economic benefits (e.g. industry productivity increases)
- Associated environmental consequences (e.g. reduction in pollution as demand falls)
- Associated human and social consequences (e.g. improvements to livelihoods)
- Associated road safety benefits

Benefit-cost analysis is particularly important for large infrastructure projects because their total capital commitment, benefits and risks are all significant and are typically only marginally above the acceptable benefit-cost threshold of 1[116]. Indeed, there are likely to be a large number of small projects with higher benefit-cost ratios that could be completed instead, for the same cost as a larger project. These are often not completed because agencies have limited resources; they may not be able to fund the fixed costs or provide the number of managers required to undertake multiple smaller projects. Another possible contributory factor is the difficulty in tracking benefits post-implementation and therefore the difficulty of holding multiple individuals, departments or companies accountable for actual project performance.

The benefit-cost analysis included in this report provides an approximate relative comparison of the intervention impacts attributed to congestion travel time and reliability improvements. Where possible, actual monetary values for these measures have been used to represent direct congestion benefits, but in some cases an approximation has been used where external benefits, such as environmental impacts, cannot be accurately separated.

The intervention landscape in Exhibit 5.2 details the relative cost to implement each intervention and the associated benefit-cost ratio. A full list of interventions and their BCR analysis can be found in Appendix C. While each intervention will have range of BCRs depending on project characteristics, the exhibit details the average, or relative, BCR given analysis of a sample of past projects. The analysis demonstrates that, while there are a significant range of costs and benefits for each intervention, interventions can be broadly classified into six categories:

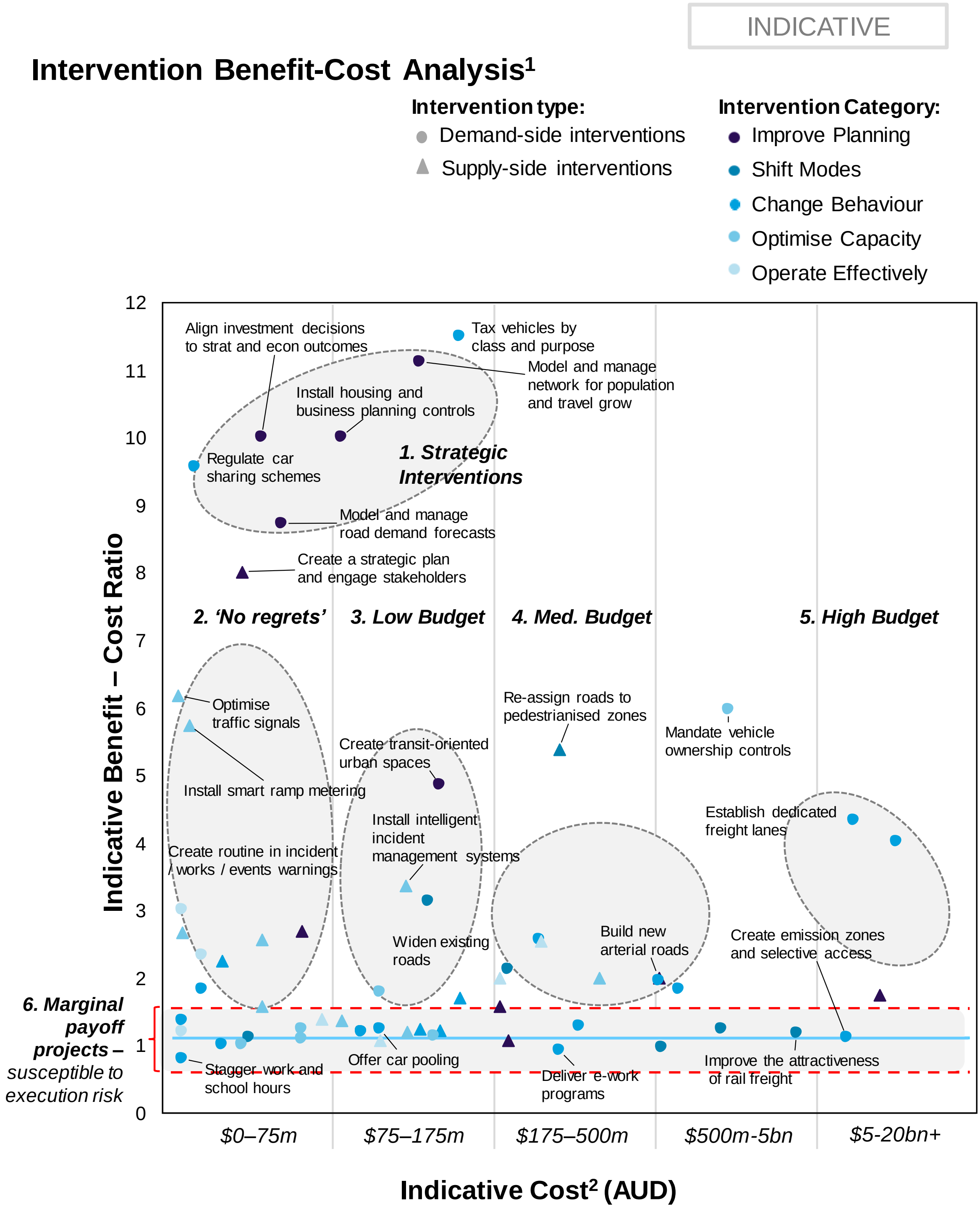
1. **Strategic interventions.** There is a general correlation between longer term projects ('improve planning') and those with high benefit-cost ratios (8:1 and above). Such interventions consider traffic management in the broader context of land use, population growth and integration with economic policy over time periods of more than 20 years. Road agencies need a rich, integrated framework in which to prioritise interventions in respect of them satisfying global goals of system performance. This includes interventions such as 'align investment decisions to strategic and economic outcomes' and 'install housing and business planning controls'. Good strategic interventions act as a multiplier to the effectiveness of all subsequent investments. Such interventions should be actioned with high priority.
2. **'No regrets'.** Many of the lowest cost interventions, such as those relating to optimising capacity and operating effectively, have relatively high benefit-cost ratios. These interventions are termed 'no regrets' due to their minimal levels of investment required to implement. In fact, investing in multiple of these interventions may be more effective than one large, expensive project. Once strategic decisions are made, many of the lowest cost interventions may fall out as 'quick wins'.

3./4./5. **Low budget / Medium budget / High budget.** The remaining interventions are categorised by their cost of implementation. It is unlikely that a small city would be able to implement a 'high budget' project, unless deemed to be strategically significant. Comparatively, a very large city could afford the entire range of projects, therefore the benefit-cost ratios across all can be compared and ideally, a benefit-cost ratio for various combinations of projects would be calculated.

116 Australian Government Productivity Commission, (2015), PC Productivity Update

6. **Marginal payoff projects.** Interventions with benefit-cost ratios of less than 1.5:1 are susceptible to execution risk. Agencies should only consider proceeding with such interventions if they are strategically required to mitigate congestion, by enabling higher BCR interventions to be implemented subsequently. However, many projects with low BCRs are implemented successfully and sustainably, so they should not be discarded.

Exhibit 5.2: Interventions can be grouped by benefit-cost ratio and estimated cost



Notes: 1. Indicative benefit-cost ratio details included in Appendix C,
2. Costs are the average of samples identified, range is included in Appendix C

Source: International and national analysis of interventions with information from transport agencies, reports and further research

5.2 Intervention Application

Within each segment of the framework there are a number of interventions, each of which are applicable to different congestion mitigation circumstances. In order to be relevant and effectively mitigate congestion causes, interventions can be filtered according to their characteristics. These have been classified as cause-specific, location-specific and city-specific. Past guidelines, such as the Australian Transport Council's 2006 'National Guidelines for Transport System Management'[117] use a multi-stage appraisal process, including a qualitative assessment of the 'strategic fit' of each proposal, benefit-cost analysis on a filtered group, and detailed analysis of the impacts and merit of specifically selected initiatives.

5.2.1 Location-Specific Filtering

Certain interventions are only applicable to specific types of road or specific land-use areas due to the nature of the infrastructure, speed limits, vehicle types and congestion issues facing certain roads. In this report, we focus on the motorways, traffic thoroughfares and commercial streets for congestion performance analysis, because they are strategically significant within ANZ cities.

Filter A. Type of road and land-use (Exhibit 5.3)

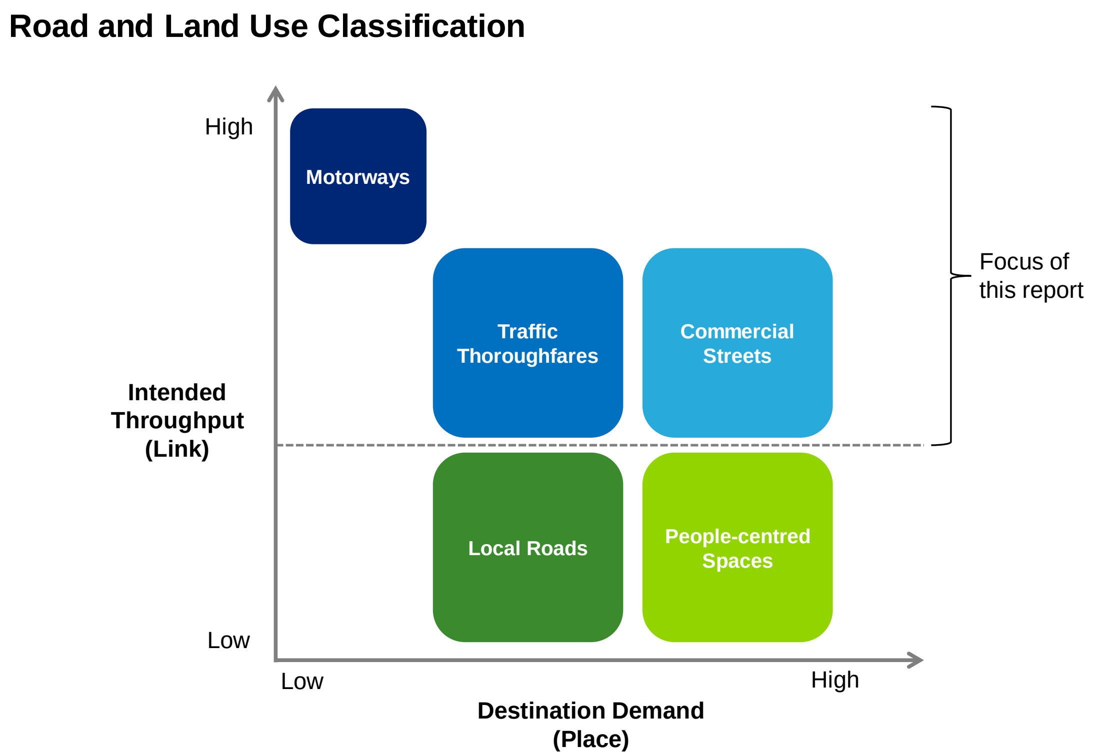
- Motorways – limited-access roads with separation from surrounding land use, move people and goods over long distances
- Traffic thoroughfares –primary purpose as 'movement corridors' which provide safe, reliable and efficient movement between regional centres and within urban areas
- Commercial streets –act as a centre for commercial operations (e.g. shops or businesses), combine high demand for movement and high pedestrian activity with often limited road space
- Local roads – the fabric of suburban neighbourhoods, facilitate local community access
- People-centred spaces - combine higher pedestrian activity and low levels of vehicle movement, creating places of value for local communities and visitors

Each road type has a varying expected 'level of performance' or 'level of service' from each of the individual road types, i.e. a higher travel speed would be expected/operated in Sydney on the City West Link (traffic thoroughfare) over King Street, Newtown or Military Road, Neutral Bay (commercial streets) primarily due to the importance of the surrounding land use and interaction with other road users (e.g. buses and pedestrians).

This selection criteria is not mutually exclusive. 'Strategic interventions' are appropriate for all types of roads and land-use. High quality planning, modelling and forecasting of demand should cover entire cities. In some cases, interventions that are appropriate for one type of road are also appropriate for others, for example 'stagger work and school hours' could impact the volume of traffic on movement corridors, local streets and vibrant streets. However, when considering the characteristics of local streets versus motorways, there are likely to be differing possibilities interventions; ' tidal flow' and 'HOT/HOV lanes' are unlikely for local streets due to lack of capacity.

117 Australian Transport Council, (2006), 'National Guidelines for Transport System Management in Australia

Exhibit 5.3: Roads and land use can be classified by their intended throughput of traffic and their demand as a destination



5.2.2 Cause-Specific Filtering

Filtering interventions by the causes of congestion that impact ANZ cities aids road and transport agencies in decision-making when they are considering options for congestion management.

Filter B. Type of cause

- Recurrent - volume of road users, infrastructure
- Non-recurrent - weather, incidents, events

Filter C. Nature of impact

- Time delay (from free-flow speed)
- Reliability of travel time

Filter D. Time of day

- Peak – weekdays: 6am to 10am and 3pm to 7pm (differs by city)

Non-peak – weekdays: All other times of day, Weekends: All day

The only selection that is mutually exclusive is 'type of cause' - recurrent or non-recurrent. The other criteria are not mutually exclusive, for example weather can affect both time and reliability, at all times of day. This allows for interventions to be tailored to specific causes.

Exhibit 5.4: Interventions can be filtered based on location and congestion and characteristics

✓ Intervention applicable to characteristic
✗ Intervention not applicable to characteristic

Intervention Category			Intervention	Location Characteristics – Type of Road and Land-Use: Motorways	Traffic Thoroughfares	Commercial Streets	Local Roads	People-centred Spaces	Congestion Characteristics – Type of Cause: Recurrent	Non-recurrent	Nature of Impact: Time	Reliability	Time of Day: Peak	Non-Peak
Improve Planning	Demand	Plan urban land use	Create transit-oriented spaces	✗	✗	✓	✗	✓	✓	✗	✓	✓	✓	✓
			Install housing and business planning controls	✗	✓	✓	✓	✗	✓	✗	✓	✓	✓	✓
			Model and manage road demand forecasts	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✗
		Set economic policy	Model and manage network for population and travel growth	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓
			Align investment decisions to clear strategic and economic outcomes	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✗
	Supply	Formulate strategy and governance	Create a strategic plan and engage stakeholders	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓
			Encourage Transport Management Associates	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓
		Design networks	Improve design of transport network and intersections	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	✓
		Build road capacity	Build new motorways	✓	✓	✓	✗	✗	✓	✗	✓	✓	✓	✓
			Build bypasses/ring roads	✓	✓	✓	✗	✗	✓	✗	✓	✓	✓	✓
			Build new arterial roads	✓	✓	✓	✓	✗	✓	✗	✓	✓	✓	✓
			Widen existing roads	✓	✓	✓	✗	✗	✓	✗	✓	✓	✓	✓
Shift Modes	Demand	Improve public transport reach	Add public transport capacity	✓	✓	✓	✗	✓	✓	✗	✓	✓	✓ [1]	✓
		Incentivise public transport use	Enhance mode interchanges and inter-modal plans	✓	✓	✓	✗	✓	✓	✗	✓	✓	✓	✓
			Improve attractiveness of public transport through cost and convenience	✓	✓	✓	✗	✓	✓	✗	✓	✓	✓	✓
		Shift road freight to rail	Improve the attractiveness of rail freight	✓	✓	✓	✗	✗	✓	✗	✓	✓		✓
		Create walking/cycling initiatives	Create cycle hire schemes	✗	✗	✓	✓	✓	✓	✗	✓ [2]	✓	✓	✓
	Supply	Re-allocate road spaces	Create dedicated cycle lanes	✗	✓	✓	✓	✓	✓	✗	✓ [3]	✓	✓	✓
			Create pedestrianised zones	✗	✗	✓	✗	✓	✓	✗	✓	✓	✓	✓
Change Behaviour	Demand	Modify travel demand	Stagger work/school hours	✓	✓	✓	✓	✗	✓	✗	✓	✓	✓	✗
			Create flexibility in work hours	✓	✓	✓	✓	✗	✓	✗	✓	✓	✓	✗
			Regulate car sharing schemes/technology	✓	✓	✓	✓	✗	✓	✓	✗	✓	✓	✓
			Offer car pooling	✓	✓	✓	✓	✗	✓	✗	✓	✓	✓	✗
		Substitute travel	Establish telework centres	✓	✓	✓	✗	✗	✓	✗	✓	✓	✓	✗
			Deliver ework programs	✓	✓	✓	✗	✗	✓	✗	✓	✓	✓	✗
		Manage freight	Mandate pre-booking of trip plans	✓	✓	✗	✗	✗	✓	✓	✗	✓	✓	✗
			Create emission zones and selective access	✓	✓	✓	✓	✗	✓	✗	✓	✓	✓	✓
		Implement Policy Measures	Mandate city licenses/permits	✗	✗	✓	✓	✗	✓	✗	✓	✗	✓	✓
			Change business expense allowances	✓	✓	✓	✓	✗	✓	✗	✓	✓	✓	✓

Intervention Category			Intervention	Location Characteristics: Type of Road and Land-Use: Motorways	Traffic Thoroughfares	Commercial Streets	Local Roads	People-centred Spaces	Congestion Characteristics: Type of Cause: Recurrent	Non-recurrent	Nature of Impact: Time	Reliability	Time of Day: Peak	Non-Peak
Change Beh.	Supply	Manage freight	Establish dedicated freight lanes	✓	✓	✗	✗	✗	✓	✓	✓	✓	✓	✓
		Control destination choice	Manage roadside parking	✗	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓
			Implement resident parking zones	✗	✗	✓	✓	✓	✓	✓	✓	✗	✓	✗
Optimise Capacity	Demand	Aid travel planning	Disseminate real-time transport	✓	✓	✓	✓	✗	✓	✓	✓	✗	✓	✓
			Capture personal travel history/carbon footprint	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			Implement travel to work plans for businesses	✓	✓	✓	✓	✗	✓	✓	✓	✗	✓	✗
			Establish and manage school travel plans	✓	✓	✓	✓	✗	✓	✓	✓	✗	✓	✗
		Enforce vehicle restrictions	Mandate vehicle ownership controls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Supply	Implement variable road supply	Implement a tidal flow system	✓	✓	✗	✗	✗	✓	✓	✓	✗	✓	✗
			Manage choke and pinch point program e.g. clearways	✓	✓	✗	✗	✗	✓	✓	✓	✓	✓	✗
		Actively manage capacity	Plan for road closures and accidents	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	✓
			Install intelligent incident management systems	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	✓
		Enhance road capacity	Lower permanent speed limits	✓	✓	✓	✗	✗	✓	✓	✗	✓	✓	✓
			Install variable speed control	✓	✓	✗	✗	✗	✓	✓	✓	✓	✓	✓
			Optimise traffic signals	✗	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓
			Install smart ramp metering	✓	✓	✗	✗	✗	✓	✓	✓	✗	✓	✓
Operate Effectively	Demand	Manage events	Create routine in incident/works/event warnings	✓	✓	✗	✗	✗	✗	✓	✗	✓	✓	✓
			Introduce event travel planners	✓	✓	✓	✓	✓	✗	✓	✗	✓	✗	✓
			Increase and promote public transport for events	✓	✓	✓	✓	✓	✗	✓	✗	✓	✗	✓
	Supply	Manage events	Create a roadworks management plan	✓	✓	✓	✓	✗	✗	✓	✗	✓	✓	✓
		Actively manage traffic	Deliver smart motorways	✓	✓ [5]	✗	✗	✗	✓	✓	✓	✓	✓	✓
			Leverage predictive analysis to understand relief routes	✓	✓	✓	✗	✗	✗	✓	✗	✓	✓	✓

Notes: 1. Applies more to peak than non-peak; 2. If used for commuting, may depend on topography of city; 3. As additional lanes 'yes', if taking out traffic lanes 'no'; 4. If implemented at all times of day; 5. On presumption that smart motorways can help relieve congestion on surrounding areas

Interventions with long-term timeframes shown in Exhibit 5.4 such as ‘Improve Planning’, ‘Shift Modes’ and ‘Change Behaviour’ are more appropriate for mitigating recurrent congestion. Short-term timeframe interventions are more appropriate for mitigating non-recurrent congestion such as incidents, events or poor weather. They enable the road capacity and systems to be adapted to real-time information on these causes. Most congestion interventions improve both journey time and journey reliability.

As most congestion occurs during peak hour, congestion interventions are both of use during this time, as they prevent the recurrent increase in demand associated with this time of day. Many of the short-term interventions can be used at any time of day as they respond to real-time information, and can therefore respond to non-recurrent causes of congestion and non-peak times.

The majority of the interventions are applicable to mitigating congestion on motorways, traffic thoroughfares and commercial streets due to the strategic movement function of the roads. Traffic thoroughfares and commercial streets have large overlap due to their similar access characteristics. Congestion on local roads and people-centred spaces can be mitigated through planning of how these interact with the wider network, and through aiding the planning of those that travel through these areas.

5.2.3 City-Specific Considerations

There are also a number of considerations that influence a city’s ability to implement congestion interventions. City-specific criteria allow for further filtering.

City characteristics for filtering include:

Filter E: Budget

Filter F: Population density

Filter G: Geography

Filter H: Stage of Development

These will all inform if an intervention is appropriate for a specific city and can be used to develop interventions for current or future use. Existing interventions in the city must also be considered as this may give evidence of their effectiveness, potential for their duplication or potential for their expansion.

Other factors, considered in Chapter 6 (Capability Requirements), may also inhibit implementation. These include but are not limited to: strategy, community support, political and policy considerations, legal and institutional issues, planning and performance management, procurement, technology, operations, ability to enforce, outreach and communications. Their applicability to interventions is discussed in Chapter 6.3. For the ANZ cities, we presume a ‘best-case scenario’ where solely the budget and scale of the city will affect these additional variables.

Queensland’s Department of Transport and Main Roads has identified the main implementation issues for congestion interventions[118], which must be considered alongside both the Congestion Intervention framework and the Capability Survey in Chapter 6. These include:

- Setting clear goals for the whole network (Local and State roads)
- Providing clear and consistent messaging to users
- Establishing the major problem on the network (Costs of Congestion, Causes of Congestion, Congestion Hotspots)
- Trialing solutions

These must all be considered before any benefit can be realised from the selected congestion interventions.

118 Queensland Department of Transport and Main Roads, (2015), Comments provided to Austroads project team

5.2.4 Combining Interventions

It must also be noted that there is no single 'solution' for improving road congestion. In fact, combining a carefully selected number of interventions may have a greater combined impact than the individual parts. For example, the 2007 OECD report on Managing Urban Traffic Congestion[119] highlighted the benefit-cost evaluation of improved traffic operations and traffic management centres in France in 2004. Benefits were found to be greatest when the different measures were combined, for dense urban areas of high congestion Automatic Incident Detection (AID), Variable Message Signs (VMS) and Dynamic Speed Control (DSC) had BCRs of 1.8-2.6, 1.5-1.7 and 2.1 respectively, but AID + VMS + DSC had a BCR of 3.2-3.7.

Combinations of interventions need not only be centred on one mode of transport or one location. The 2009 Australian Transport Council study, 'Australian Capital City Congestion Management Case Studies'[120] concluded that interventions that are integrated across relevant transport modes, rather than operated independently, tend to be more attractive to users and also deliver better outcomes.

5.2.5 Implications

Given the causes of congestion investigated in Chapter 4, which determined that most congestion is recurrent, appropriate interventions can be prioritised for each ANZ city.

Group 1 cities (Sydney and Melbourne): Group 1 cities are currently investing in building road capacity. Given this, they can focus future efforts on their developed road network demand management, including interventions relating to 'shifting modes', 'changing behaviour' and 'operating effectively'

Group 2 cities (Perth, Brisbane, Adelaide and Auckland): These cities can use 'planning' interventions to determine appropriate investments, considering their populations are likely to grow to that of larger Group 1 cities. This will ensure they invest in providing new capacity and appropriate infrastructure in advance of growth.

Group 3 cities (Darwin, Wellington, Hobart and Canberra): Smaller cities can operate their road network effectively if high-cost supply-side investments are not determined feasible. Due to likely financial constraints, they should focus on 'strategic', 'no regrets' and 'low budget' investments. They can also use planning interventions to determine and plan future budget for appropriate investments, considering their populations are likely to grow to that of larger Group 2 cities

When considering the non-recurrent causes of congestion, unplanned incidents were the most prominent for most cities, compared to maintenance/special events and weather. Therefore, for 'Operate Effectively' interventions, investment focus should be placed on creating routine in incidents, rather than enhancing interventions that target events.

In general, demand-side interventions may be most useful in the short-run to slow down the rise in the use of vehicles, and therefore recurrent congestion. The budget and program for demand-side interventions can be separated from supply-side interventions, to ensure appropriate focus is placed on both.

119 OECD / Transport Strategy Group (2007), Managing Urban Traffic Congestion
120 Australian Transport Council, Urban Congestion Working Group, (2009), Australian Capital City Congestion Management Case Studies

6. Capability Requirements

"Ability is what you're capable of doing.

Motivation determines what you do.

Attitude determines how well you do it"

L. Holtz

Chapter Summary

6.1 Capability Maturity Framework

- The Capability Maturity Framework identifies the **capabilities required to mitigate congestion** and identifies priority areas of improvement for ANZ road agencies based on their current state and goals. The framework includes:
  A. **Strategy and Program**: Land Use & Planning, Transport Strategy & Planning, Program
  B. **Delivery Framework**: Performance & Operating Model, Technology & Information
  C. **Project Delivery**: Development Lifecycle
  D. **Business As Usual (BAU) Operations**: Applications & Services
- The aim of the Capability Maturity assessment is to both evaluate the current capabilities of the road agencies and determine the required 'goal' capabilities to effectively implement interventions and manage congestion

6.2 Relevant Capabilities for Interventions

- Relative to the challenges of congestion, road agencies need to prioritise building capabilities in:
  - **Improve Planning**: Improve long term land use and network design
  - **Change Behaviour:** Focus on customer demand, by providing substitutes and changing incentives
  - **Operate Effectively:** Leverage technology to proactively manage operations

Road agencies have traditionally focused on building roads in response to congestion, with capabilities centred on construction, asset management and engineering. The future of congestion intervention will include improved mitigation technology and greater data availability. To be best placed to address congestion into the future, road agencies need to develop a broader set of capabilities. This is more complex than the past due to changes in car ownership trends and road use characteristics which may extend congestion mitigation activities beyond the realm of an agency's core mandate. The start of this journey is the incorporation of a new capability framework and an assessment of their starting point.

6.1 Capability Maturity Framework

The Capability Maturity Framework identifies and assess the capabilities fundamental to mitigating congestion. The framework covers five high level business processes and functions (as shown in Exhibit 6.1), four of which are assessed in this report:

A. **Strategy & Program** – Capabilities associated with the 'planning' component of a road agency's congestion mitigation. The strategy and resulting program, and their integration with other government agencies who aim for economic growth, are fundamental to setting the direction and prioritisation of congestion interventions. Development of supporting models and an overarching business plan provide evidence for collaboration with stakeholders.

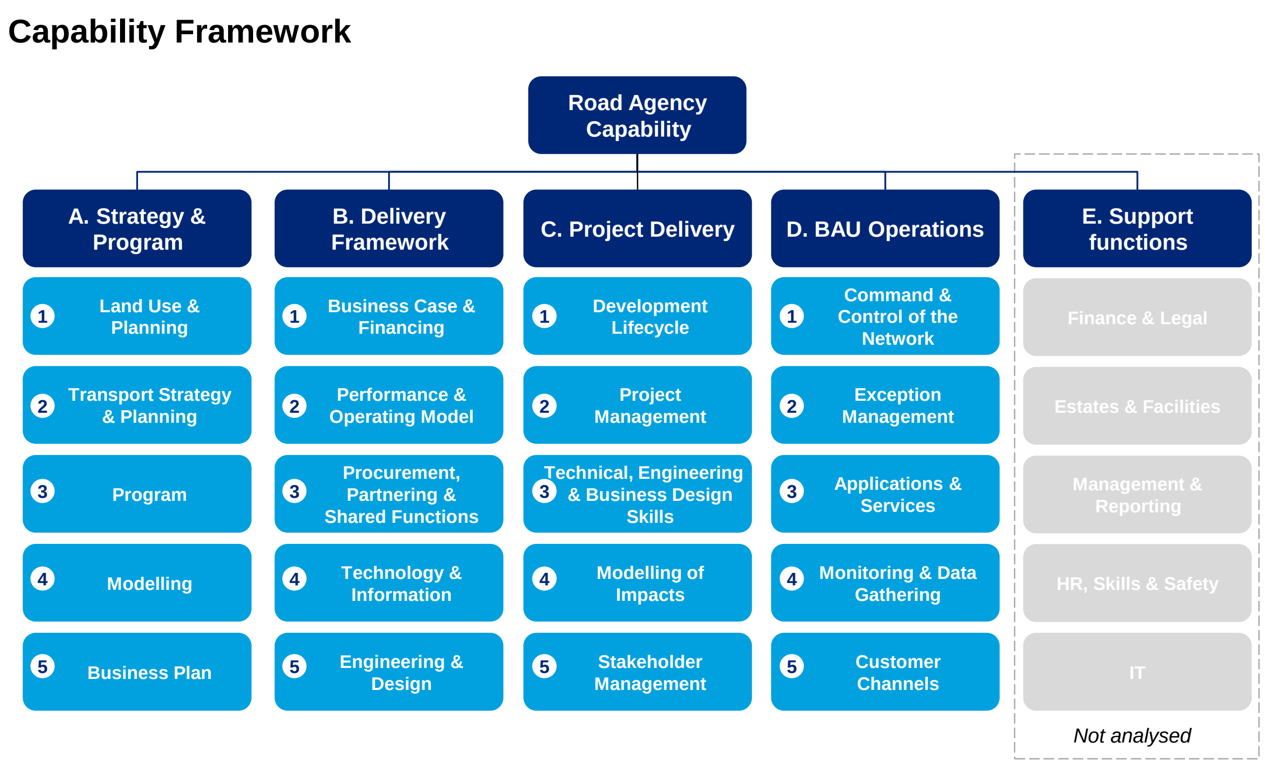
B. **Delivery Framework** – Capabilities associated with the delivery of operations and projects within a road agency, including congestion interventions. A consistent, detailed and applied delivery framework allows a road agency to reduce risk in project management. Uniform business case methodologies, procurement routes, technology incorporation and application of design and engineering skills will ensure that the road agency implements high quality projects in a timely manner.

C. **Project Delivery (Intervention-specific)** – Capabilities that enable the implementation of intervention-specific projects. This includes the management, design and engineering skills of team members (or relevant sub-contract management), the modelling of target outcomes and the required stakeholder management. Methodologies and standardised processes will ensure that such projects are delivered to a high standard and that target outcomes are both appropriate and met.

D. **Business As Usual (BAU) Operations (Intervention-specific)** – Capabilities that enable the delivery of intervention-specific operations within a road agency. These capabilities enable the day-to-day management of the road network and associated congestion, including control-room operations, incident management and communicating with road users. Over time, the prevalence of technology and real-time data insight is becoming fundamental to making incremental improvements in operations.

E. **Support Functions *(not assessed)*** – Capabilities associated with the back-office functions of a road agency, including finance, legal, IT, human resources and general reporting.

Exhibit 6.1: The framework outlines the core capabilities for the dimensions of planning, delivery, operations, projects and support functions



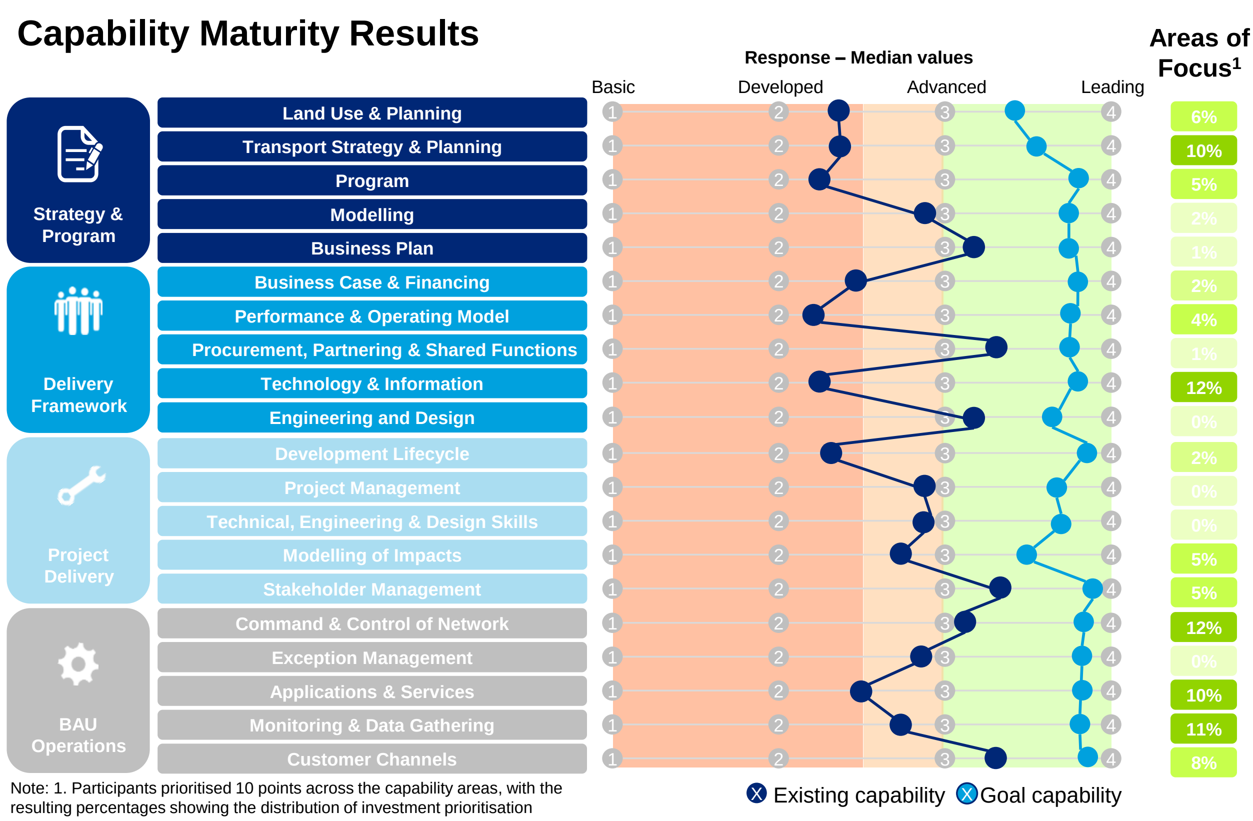
The aim of the Capability Maturity assessment is to both evaluate the **current capabilities** of the road agencies and determine the required **'goal' capabilities** to effectively implement interventions and manage congestion. The goal is to provide a baseline to frame discussion on the appropriate level of maturity required, depending on the size, funding and needs of a city, and the resulting steps required to build these capabilities. The assessment seeks to identify the typical differentiators that may indicate whether an organisation operates a full and mature set of processes.

Feedback from surveys and discussions with agency representatives, as well as with other stakeholders and subject matter experts contributed to the evaluation of capability performance. Capabilities were assessed on a range of Basic to Leading for their current state and their desired future state. Respondents were also asked to identify the key areas where investment into capability was required.

Those agencies described as 'leading' in a competency area are so on a relative basis and are not necessarily the 'best in class' – indeed, the outputs of the survey are not intended to compare agencies or rank any as 'good' or 'bad', but rather to consider what additional capabilities could be put in place with consideration for city size, funding available and specific needs. For example, it may not be considered economically feasible for a small city to invest large funds to build 'leading' capability if congestion is not a prominent issue or can be managed through more cost-effective means.

Exhibit 6.2 details the aggregated ANZ jurisdictional capability assessment current and goal states. The output is based on aggregated responses to the capability maturity surveys, weighted by the population size of each city.

Exhibit 6.2



Strategy and Program. Agencies indicated that the goal state for Strategy and Program capability should be between 'Advanced' and 'Leading'. Broadly there was acceptance that Land Use and Planning strategies were not the sole responsibility of the road agency. In comparison with the goal states, the capability with the highest current state maturity is 'Business Plan', while 'Land Use & Planning', 'Transport Strategy & Planning' and 'Program' were identified as areas requiring improvement.

Delivery Framework. Agencies acknowledged that capabilities in this area should be 'Leading' or very close to 'Leading'. Little gap exists between the current state and goal state of 'Procurement, Partnering and Shared Functions' and 'Engineering and Design', while areas of improvement include 'Performance & Operating Model' and 'Technology & Information'.

Project Delivery (Intervention-specific). The goal states of Project Delivery capabilities are between 'Developed' and 'Leading'. Agencies believe that they perform at least at the 'Advanced' level in Stakeholder Management, which is the best performing capability in this section. The main area for improvement is 'Development Lifecycle' capabilities, where the current state is 'Developed'.

Business As Usual (BAU) Operations (Intervention-specific). As with the Delivery Framework capabilities, BAU Operations' goal states are uniformly 'Leading', yet there are differences in the current states depending on the sub-type. Agencies perform well compared to the goal state in 'Customer Channels' and 'Command & Control of the Network'. The largest area for improvement exists in 'Applications & Services'.

Agency respondents were asked to select their 'areas of focus', as it was deemed that those areas with the largest room for improvement between current state and goal state were not necessarily the areas that were deemed immediate priorities. In aggregate, the cities prioritised 'Command and Control of the Network', 'Technology and Information', 'Monitoring and Data Gathering', 'Transport Strategy and Planning' and 'Applications and Services' as their desired areas of focus and investment.

6.2 Relevant Capabilities for Interventions

Congestion interventions with high BCRs should be prioritised, however these may have strong or weak supporting capabilities. Agencies should focus investment in:

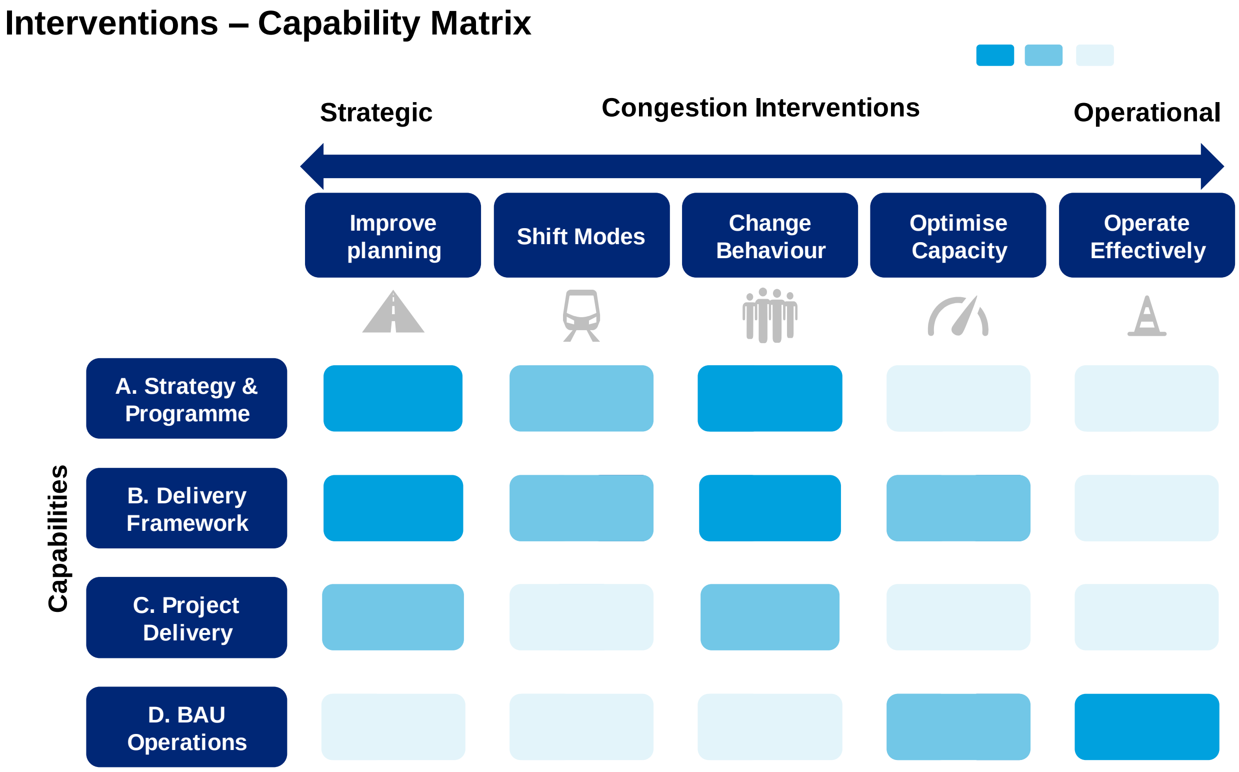
a. capabilities, where a high-BCR intervention has weak supporting capabilities

b. interventions, where a high-BCR interventions has strong supporting capabilities

Cross-referencing capabilities against the interventions framework allows agencies to identify priority capability gaps that require investment, as detailed in Exhibit 6.3. The exhibit has been constructed by considering the BCRs of interventions and the strength of the capabilities. Where BCR is high, but capabilities are low, these areas of capability are 'high priority' for investment. Where BCR is low and capability if low or high, these areas are 'low priority' for investment.

For example, if an agency is considering 'Change Behaviour' as a priority for intervention investment, then it should focus on the capabilities within Strategy & Program and Delivery Framework to achieve this.

Exhibit 6.3: Road agency capabilities are more relevant for certain congestion interventions



Note: 1. Prioritisation calculated by combining scores for intervention category BCRs (high BCR = high priority) with scores for capability category gaps (large gap = high priority)

For all jurisdictions, as identified with benefit-cost analysis in Chapter 5, 'Strategic' interventions should be actioned first, followed by 'No Regrets' interventions.

- **'Strategic interventions'** are largely those associated with **'Improve Planning'**. Here, there is often disconnect between land-use, surrounding infrastructure and roads. Therefore the capabilities relating to **'Strategy & Program'** and **'Delivery Framework'** should be prioritised for investment.
- **'No regrets' interventions** are often those associated with **'Operate Effectively'** and therefore the **'BAU Operations'** capabilities here require investment.
- Many **demand-side 'Change Behaviour'** interventions had relatively **high BCRs**, to ensure these are implemented effectively, focus should be placed on **Strategy & Programme** and **Delivery Framework** as a first priority

Specific areas for capability investment include:

Strategy and Programme:

- Land Use & Planning
- Transport Strategy & Planning
- Program

Delivery Framework:

- Performance & Operating Model
- Technology & Information

BAU Operations:

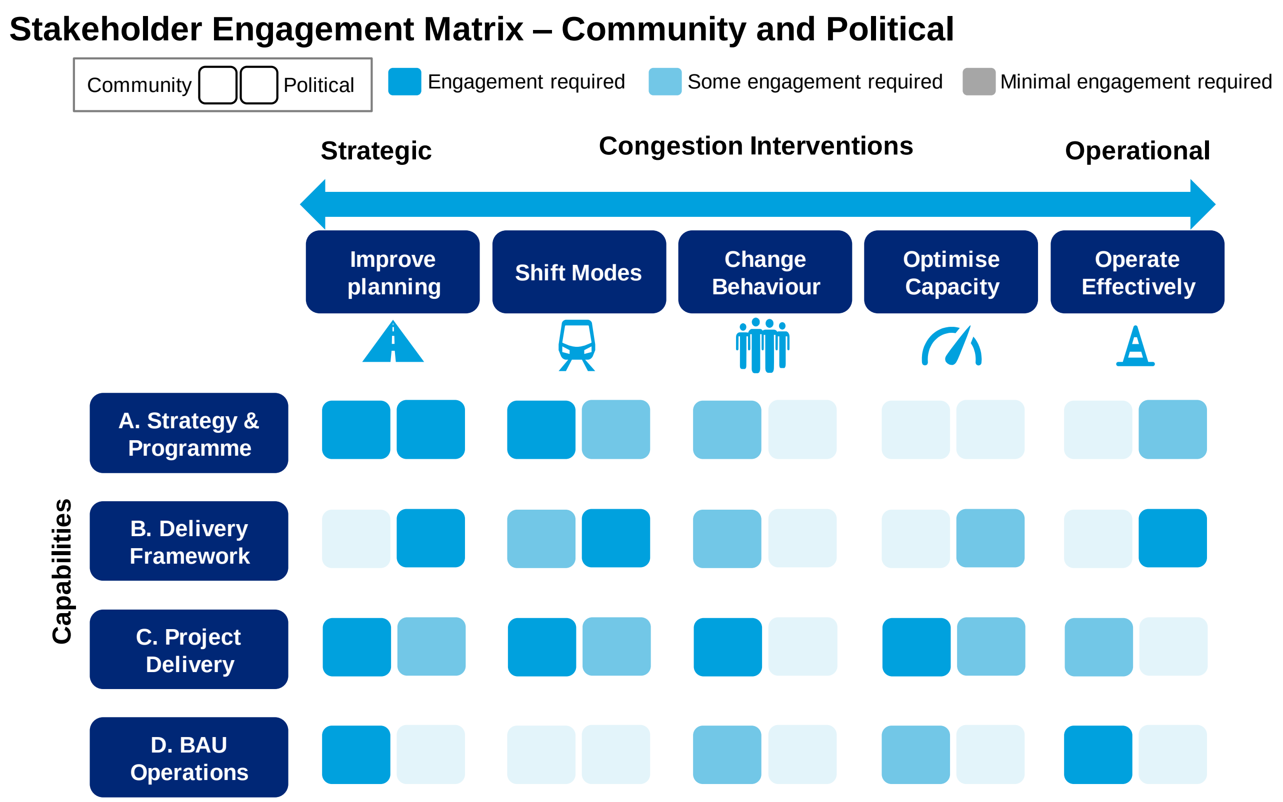
- Exception Management
- Applications & Services
- Monitoring and Data Gathering

As well as an assessment of the relevant capabilities for interventions, it is important to remember that many interventions require ongoing external stakeholder engagement to ensure their success, including political and community support. Exhibit 6.4 outlines the major relevant areas where investment in community and political support is required.

Community Support. Aggregated consumer preferences (even if marginal utility weighted or income weighted) are used to define societal benefits in the assessment of potential interventions. Not only is engagement in the community important for road and transport agencies in the hypothesis and planning stage of an intervention investment decision, it is also necessary throughout the implementation and after the intervention is in place. Buy-in from the community is key in ensuring that the overall reputation surrounding the intervention investment is positive. Community support requires effective consultation, marketing and communications.

Political Support. Buy-in from political stakeholders is key in ensuring that the investment funds are available, if they are not readily accessible from within the road or transport agency. Political buy-in, in terms of the resultant effect that it has on the opinions of consumers, can be more dependent on first aligning investment decisions with communities. The opinion of the project can be two-way: a successful project can be dependent on the backing of a politician that is held in high regard. Or a successful project can obtain political support that can create a politician that is held in high regard. In turn, road agencies may have to align their investment with politically identified performance indicators. Political support comes from gaining policy alignment and ideally devolved powers or legislation, to be able to lead on integrated transport planning and investments.

Exhibit 6.4: Community engagement is required for delivery of all projects; political stakeholders have greatest influence in business cases



7. The Future of Congestion Mitigation

"By 1950, every street in London will be nine feet deep in horse manure"

The Times, 1894

"This 'telephone' has too many shortcomings… the device is inherently of no value"

Western Union, 1876

"Prediction is difficult, especially when dealing with the future"

Danish Proverb

Chapter Summary

7.1 Enhanced Intelligent Transport Systems Infrastructure

- Austroads' **Intelligent Transport Systems** (ITS) Strategic Roadmap establishes a **shared vision** of ITS activities to achieve the **effective development and deployment of ITS** in Australia and New Zealand Road Agencies

7.2 Regulatory Framework

- Establishing an appropriate **regulatory framework** will provide a **platform for transport innovation**, particularly around demand management and intelligent vehicles

7.3 Congestion Relief Innovations

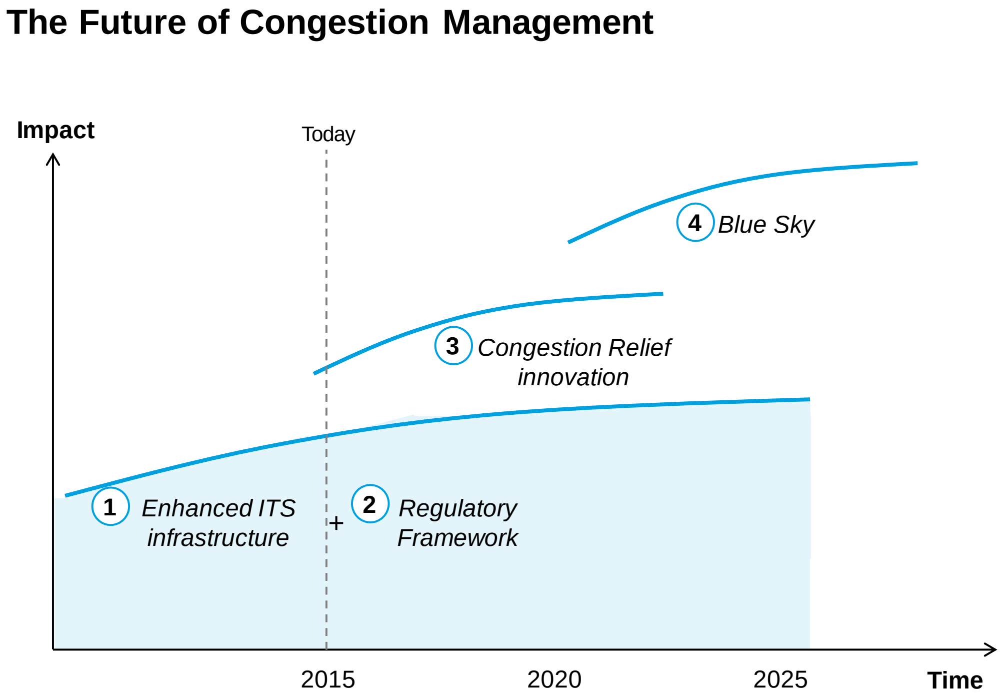
- Road agencies need to plan for the impact of **technological innovation** that may provide significant **new options for managing congestion** in four key areas
  - **New Mobility Services;** incl. car sharing, ride sharing, bike sharing and P2P car rental
  - **New Kinds Of Vehicles;** incl. connected vehicles and autonomous vehicles
  - **Dynamic Demand Management;** incl. smart parking
  - **New Data Services;** incl. multi-modal trip planning and crowd-sourced traffic data

7.4 Blue Sky…2025 onwards

- In the long run, congestion management will be subject to 3 drivers, which will all drive major changes in ANZ urban transport networks:
  - The **value of time** and life will increase relative to goods and services, therefore the cost of congestion and value of safety will increase
  - The **supply of urban land** will remain fixed and its value will increase
  - **Data generation, processing, transmission and storage costs** will continue to fall in price, weight and size

Transport is a critical component of a modern economy, with technology improvements such as canals, railways, roads and air travel driving major investment and productivity booms during and since the industrial revolution. The post-industrial era will similarly be shaped by technology improvements in transportation, this time in the use of real-time data in intelligent vehicles, the road network and intermediary services. Examples include ride and vehicle sharing, the communication of public transport service performance in real-time and the potential for dynamic demand management to set road tolls according to demand. Rapid and full exploitation of these opportunities requires, as with previous innovation cycles, appropriate regulatory and institutional platforms to allow market forces to drive investment and customer value. The major infrastructure investments to deliver these developments, in vehicle-to-infrastructure communications and autonomous vehicles, will mean that these technologies could take a long time to diffuse without these platforms. Exhibit 7.1 provides an overview of the four horizons of likely and required changes to vehicle transportation management, to enable technological advances in transport to drive national productivity.

Exhibit 7.1: The full impact of technology and innovation will be enabled by a platform of regulation and infrastructure



Current and Enhanced Intelligent Transport Systems (ITS) Infrastructure. Austroads has developed an 'ITS Strategic Directions' roadmap of supporting technologies[121], to facilitate a coordinated and integrated national transport and infrastructure system that is efficient, sustainable, accessible and competitive, with priority action areas.

Regulation. ANZ jurisdictions also require the appropriate regulatory structures to support such adoption of technology for both major reform (e.g. demand management) and incremental reform (e.g. ride sharing).

Congestion Management Innovation. Given such regulation, private sector innovators will innovate with capability, offerings and new business models to drive value to customers. Providing a regulatory framework that allows for experimentation will enable the advances required to be world-leading in congestion management.

Blue Sky. Whilst we cannot predict the speed of advances in transport technology, we can confidently assert that land supply will not increase. Therefore to cope with increasing populations, the existing transport corridors will need to be extended / duplicated at increasingly prohibitive costs or leveraged further by technology. This could take the form of demand management or intelligent transportation systems that extend supply.

7.1 Enhanced ITS Infrastructure

Austroads' Intelligent Transport Systems (ITS) Strategic Roadmap[122] has been developed collaboratively by road agencies in Australia and New Zealand to facilitate the alignment of future ITS-related activities. It establishes a shared vision of ITS activities to achieve the effective development and deployment of ITS in Australia and New Zealand. The roadmap, as shown in Exhibit 7.2, details the main categories of development from present day to 2020+ and outlines the responsible parties: collective, agency-led or external.

121 Austroads, (2015), ITS Strategic Directions – A roadmap of ITS activities in Australia and New Zealand

122 Austroads, (2015), ITS Strategic Directions – A roadmap of ITS activities in Australia and New Zealand

ITS Strategy Roadmap categories include:

- Management
- Enforcement
- Financial
- Safety and emergency services
- Traveller information
- Traffic management – Management motorways, Signals and Controllers, Co-operative ITS
- Intelligent vehicles
- Freight and fleet
- Public transport

The Policy Framework for Intelligent Transport Systems in Australia, published by the Standing Council on Transport and Infrastructure (SCOTI) provided the context for developing the roadmap, and outlined a number of priority areas for investigation, to be led by Austroads.

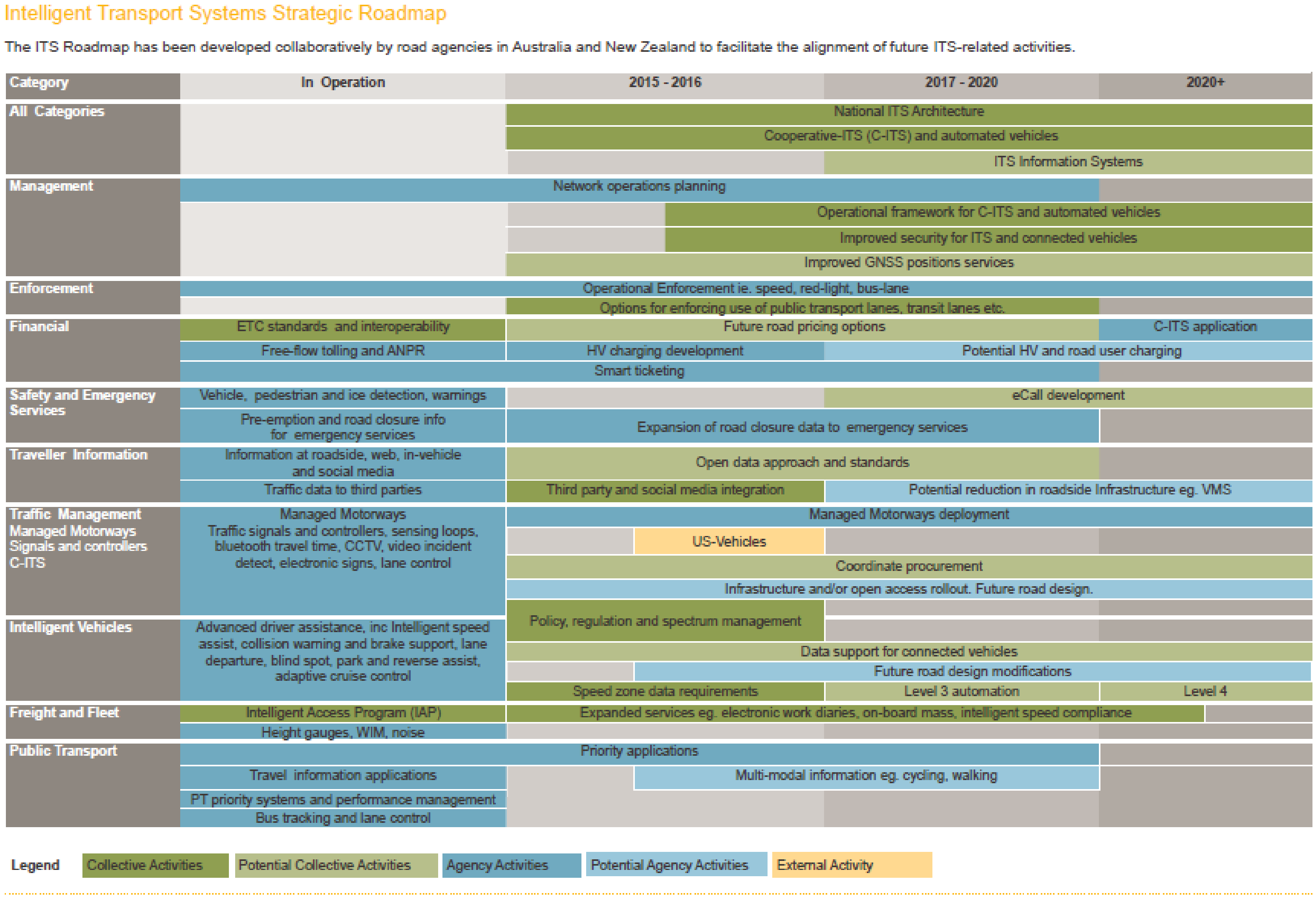
Priority areas of investigation include:

- National ITS architecture
- Cooperative ITS strategy
- 5.9 HGz band
- Innovation
- Privacy
- Economic analysis of smart infrastructure
- Standards development
- Managed motorways
- Governance
- Research and development

A collective, national approach for ITS infrastructure will ensure that research and investment across Australia and New Zealand is not unnecessarily duplicated. Subsequently, the testing and initial implementation of new interventions can be tested in a small group of cities, before rollout to both countries. By coordinating such activities, Austroads can improve the timing and efficiency with which Australia and New Zealand can adopt emerging technology, integrate developments into present systems and align to international practice and standards. This will not only enable reductions in congestion, but will also help to improve safety and reduce vehicle emissions.

A key area of concern in this strategy relates to gaining access to Co-operative ITS (C-ITS) data. Due to the valuable nature of this data, original equipment manufacturers will have incentives to restrict access to such information in order to profit through on-selling or selling proprietary services. Obtaining such data could therefore become costly and difficult to leverage without regulatory intervention.

Exhibit 7.2: Austroads, ITS Strategic Roadmap



7.2 Regulatory Framework

Establishing an appropriate regulatory framework will guide transport innovation, both promoting private sector investment in transportation technology and reducing the risk of post-implementation conflict.

We are already facing problems in setting appropriate regulation for transport technology. For example, in many ANZ cities, the lack of regulation of taxi-like services, such as Uber, has driven conflict with legacy taxi services. Like many innovations before it, Uber has been seen as 'unfair' competition to the historic taxi services, leading to strikes and blocked roadways in protest. In some countries, the courts have clarified the status of these services rather than regulators actively enabling (or deeming them illegal).

In November 2015 the Australian National Transport Commission launched a project to assess the landscape for the introduction of autonomous vehicles. The project, 'Preparing for more automated road and rail vehicles – identifying any regulatory barriers' will look at the current regulatory system to clarify what is required to support the differing levels of autonomous vehicles[123]. The National Transport Commission says that the project's findings will deliver:

- Improved understanding of the current regulatory system and its ability to continue to support increased vehicle automation (both road and rail)
- Identification of any regulatory or operational barriers to be removed or overcome and potential time pressures or options
- A nationally-consistent approach for increased vehicle automation with a single regulatory approach (as far as possible with emerging technology)

As detailed in the NTC's factsheet, delivered to Austroads in November 2015, the proposed approach will consider regulatory barriers and the need to regulate for automated vehicles, based on the lifecycle of a vehicle. There are 12 areas of regulation that are points at which vehicles interact with regulation: design, testing, sale, modification, registration, licensing, use, systems operation, systems monitoring, maintenance, recall and disposal.

Regulatory changes have been made globally to allow for testing and use of autonomous vehicles on public roads. Nevada became the first state in the world to have regulation on self-driving cars enacted in February 2012. This approval came in the form of licenses and license plates administered through the Department of Motor Vehicles (DMV) upon application. Applications are made to the DMV and must demonstrate extensive safety plans for the cars and drivers, detailed descriptions of autonomous technology and minimum driving hours on private roads. Similar changes have since been passed in the US states of California, Florida, Michigan, North Dakota and Tennessee.

Similar models of autonomous driving approval have been implemented in Europe. Taking effect in July 2015, amendments have been made to regulation to allow large scale testing of autonomous passenger cars and trucks on public roads. "Exemptions" decree allows vehicles that do not fall within standard categories to be allowed onto the road. The RDW (Dutch Vehicle Authority) is responsible for admitting these self-driving cars and trucks onto roads through issuing an 'exemption' for these vehicles. This exemption model varies slightly from its American counterpart, with the addition of a practical testing stage in the application process. Beyond the initial written application detailing safety plans and technology, applicants must have their vehicles undergo functionality and stress testing at closed facilities before exemptions are given.

Here, we suggest some possibilities for both major national and incremental jurisdiction regulatory reform.

123 National Transport Commission, (2015), Factsheet: Preparing for more automated road and rail vehicles – identifying any regulatory barriers'

National Reforms:

- **Intelligent vehicles.** Safety will probably be the driver of regulation in intelligent vehicles, including drivers, passengers, cyclists and pedestrians. Following from this, regulation may provide a framework for maintaining the driver 'experience' and mandating certain actions to ensure network efficiency. National leadership and guidance is required in this area, since many vehicles will cross State boundaries. Regulation will be required across the five stages of the roll out of intelligent vehicles:
    1. Partial penetration of intelligent vehicles with partially automated capability
    2. Partial penetration of intelligent vehicles with fully autonomous capability
    3. The convergence of different types of autonomous vehicles, with a fixed road supply
    4. Majority penetration of intelligent vehicles with fully autonomous capability
    5. A fully autonomous vehicle and transportation network
- **Demand management.** Due to the limited land supply for urban roads, some type of demand management may be required to control demand in a more sophisticated way than the inherent cost of congestion. An example of this is congestion pricing. With new technology, pricing can adapt to real-time situations, with higher prices when demand is high. However the 'who', 'when' and 'how' of the system must be provided with regulatory guidance. Perhaps differential regulation could apply to freight, commercial and commuter vehicles, since they have different substitutes and elasticities.

Incremental Reforms:

Different states have myriad, and different, regulations that (while perhaps addressing important issues) are aimed at guiding innovation to mitigate consumer disadvantage. These include regulations to do with vehicle safety and speed. Often, such regulations can act to protect incumbent technologies and organisations from disruption, such as with Uber and incumbent taxi drivers.

In general, stifling innovation reduces productivity growth, so jurisdictions should seek policy reform themselves and be supported with national assistance. A national policy framework should guide decision-making, but primarily, governments should listen to innovators and allow innovators to lobby when they face barriers, otherwise Australia and NZ will lag advances made in other countries.

Changes to these regulations require political consensus, and sometimes a fair balance of the costs and benefits between the winners and losers. In the case of the State Government system in Australia, there is no reason why States must be aligned, however the consequences of misalignment must be duly considered, particularly in regard to cross-border transportation.

7.3 Congestion Relief Innovations

The road transportation industry is on the cusp of a step-change in the evolution of mobility. Well established business models, processes and practices are on the verge of a major transformation that could result in the emergence of a new business ecosystem of personal mobility. Given the massive embedded capital investment, the extended automotive industry is likely to evolve incrementally towards the future mobility ecosystem, rather than change occurring at a more radical pace. We may be on the threshold of change as great as any the industry has yet seen.

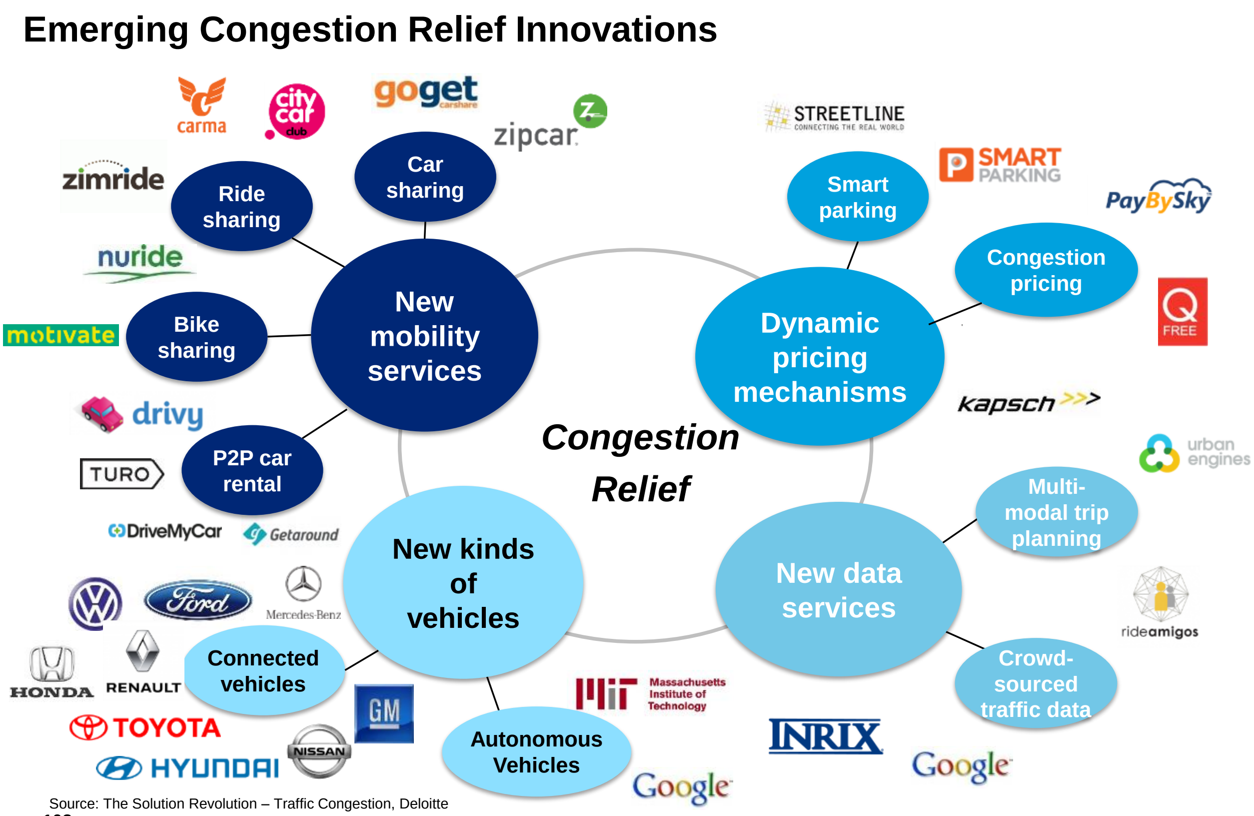
Exhibit 7.3 details the four key categories of transportation technology. Whilst all ANZ cities are starting to engage with the innovations of '**new mobility services'**, **'dynamic pricing mechanisms'** and **'new data services'**, the expected impact of **'new kinds of vehicles'**, where real-time information enables the road and transport network to manage itself autonomously, requires further research and consideration.

- **New mobility services.** Younger generations are leading the way toward pay-per-use mobility (as part of the 'sharing economy') in place of owning a car; nearly 50% of Gen Y consumers use a smartphone app for transport and already plan travel so they can multitask. This will lead to a reduction in vehicles per capita, but potentially an increase in vehicle-kilometres driven

- **New data services:** By crowdsourcing data from all road users, the decisions of others can be better informed and road agencies can adapt provision in relation to demand
- **Dynamic pricing mechanisms.** With the aid of technology advances, there is potential for dynamic pricing mechanisms (e.g. road pricing, insurance pricing and parking pricing) to be manipulated to influence customer demand and associated supply, thus better managing demand
- **New kinds of vehicles.** New vehicles are being outfitted with vehicle-to-infrastructure (V2I), vehicle-to-vehicle (V2V) and communications technologies; allowing vehicles to 'communicate' with infrastructure to prevent incidents and forewarn of changes in speed. V2I and V2V technology will eventually allow for autonomous driving, meaning that vehicles can safely drive at high speeds, mitigating congestion from the volume of traffic; the question is when and how this will become more mainstream and widely adopted

The interventions discussed in Chapter 5 are existing forms of congestion management, already used in many cities globally. While in the short-run, agency planning and strategy should be built around tried and trusted interventions, long-term strategy should also consider technological innovation that may provide significant new options for managing congestion. Road agencies must look to the future to ensure they utilise the most effective congestion interventions.

Exhibit 7.3: New technologies are being introduced around the world to reduce congestion and improve reliability



Source: The Solution Revolution – Traffic Congestion, Deloitte
103

7.3.1 New Mobility Services

New mobility services are founded on the principle of the 'sharing economy', where collaborative consumption is used as an economic arrangement in which participants share access to products or services, rather than having individual ownership[124]. This is derived as a solution to the tragedy of the commons, which refers to the idea that when people act solely in their own self-interest, they deplete the shared resources their need for their own quality of life.

There are three main types of collaborative consumption:

- Product-service systems - where goods are privately owned and can be rented out via peer-to-peer marketplaces
- Redistribution systems – where used or pre-owned goods are passed on from someone who does not want them to someone who does
- Collaborative lifestyles – where people with similar needs or interests banding together to share and exchange less-tangible items such as time, space, skills and money

New transport mobility services are taking advantage of the sharing economy by connecting people through internet and online apps to share transportation. While **ride sharing**, **car sharing**, **bike sharing** and **P2P car rental** are not new, technology reduces their transaction costs, making them easier for customers to accept, therefore allowing them to grow their share of use.

As well as overcoming cultural resistance, many of these technologies use incentives to support uptake amongst car owners; buy-in for car owners is necessary in order for many of the schemes to grow, particularly for product-service systems. Nuride, a United States-based company rewards participants when they carpool, vanpool or take public transport. Rewards can be redeemed at restaurants, retailers, events and attractions.

An example of an Australian product-service system is DriveMyCar, a peer-to-peer service that makes it possible for car owners to rent their car to other people. Owners earn money from their car and renters get access to a wide range of vehicles and save money compared to traditional car rental. As trust and security are key in the operating of the business, insurance and roadside assistance are provided for all rentals.

The Australian government invests in helping to facilitate car sharing schemes, such as 'GoGet', where the car is owned by a company rather than a member of the public. Public car park spaces are reserved specifically for the car sharing club's members. In October 2014, GoGet had over 65,000 members, which was estimated to take 100,000 cars off the road[125]. However, in reality, this also acts as a substitute to public transport, adding demand to the roads.

These mobility services have the potential to decrease (by shifts in mode and time of travel) or increase (by increasing demand for peak car travel) congestion. Road agencies should therefore actively engage and promote those that can reduce peak hour congestion, such as ride sharing. It must however be noted that by decreasing the economic impediments to road use, use of such sharing vehicles for non-commuter trips may increase, as they are seen as a more acceptable method of travel on an ad hoc basis.

124 Hamari, Sjoklint and Ukkonen, (2015), The Sharing Economy: Why People Participate in Collaborative Consumption

125 Bruce, J., University of Technology Sydney, (2015), Trailblazers: Conversation with B. Jeffreys

7.3.2 New Data Services

Whilst road management systems in ANZ have some level of automation, from traffic light priority systems through to variable speed limits, road agencies must look to the future use of real-time information and design infrastructure to respond to road network demands. Vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and infrastructure-to-vehicle (I2V) technology can provide better visibility into urban transport systems and the systems that surround the city. Thanks to these developments, real-time traffic information can help tackle congestion: a vehicle involved in an accident can send its precise location, toll payments are variable and fully automated, freight levels and route can be controlled and drivers can be assisted throughout their journey. So-called 'Smart Cities' will allow the host variables involved in transport coordination to react to each other.

Both **crowd-sourced traffic data** and **multi-modal trip planning** allow congestion to be reduced. Crowd-sourced traffic data, allows information sourced from road users to be:

a. disseminated to other road users so they can better plan their journeys using real-time information (e.g. Google Maps)
b. used by road and transport agencies to adapt services to the current conditions of the road (e.g. using Inrix data to change variable speed limits)
c. used by road and transport agencies to model long-term changes in the use of the road and transport networks, as well as plan for the future via information on re-routing during accidents (e.g. in strategic planning and modelling)
d. used by government service providers to understand the movements of people and the best position for public services (e.g. in the location of childcare for those travelling from the suburbs to the CBD for work)

As sensors become increasingly used to understand the road network and the movements of people, there will be exponential growth in the amount of data that can be accessed. Traffic lights are already often controlled by sensors on concrete pads. With the rise of autonomous vehicles, as discussed later in this chapter, sensors will become increasingly prevalent and will allow congestion interventions to operate autonomously, without need for human intervention in decision-making.

Multi-modal trip planning provides data to road users that enables them to take the best route from origin to destination. Data platforms aggregate information from many alternative sources to find the most efficient trip route. This enables congestion to be mitigated by providing real-time trip information to users, so they can adapt their journeys as required. Platforms such as GoogleMaps already facilitate this, but there is a growing opportunity to use the best possible data to match customers to the most efficient routes via the most efficient roads. Australian road agencies and transport agencies are also looking to such information to facilitate future strategy and planning.

7.3.3 Dynamic Demand Management

Dynamic demand management can be used to match the demand from road users and the supply of road space to prevent network performance from falling below the 'acceptable' level of congestion. An example of this is dynamic or 'fluid' pricing, which refers to the setting of prices to profitability for each unit sold or from the market overall.

Congestion demand management. While adapting pricing based on the demand and supply of road capacity is nothing new, technology is making this process easier and more accurate using GPS data. Today, toll road prices are adapted to respond to the demand put on road space. For example, many road agencies and tolling companies occasionally increase the price of road tolls during peak hour to deter road users from using the roads at the busiest periods of the day. As well as this, pricing is becoming more progressive with distance-based and location-based pricing. There is potential for new methods of pricing, or new circumstances in which prices are tied to demand and supply, will increase in prevalence during the next decade. Agencies may also be able to influence the re-routing of traffic in the case of an incident if it is clear that all traffic will converge on a specific location. Currently in Australia toll roads are used to fund certain major road infrastructure. There is not yet political consensus on whether tolls could also be used to manage congestion.

Smart parking. Smart parking aims to make the parking experience easier for consumers, while making cities and central business districts more efficient and reducing carbon footprint. Analytics platforms are used to enable city planners to visualise parking data including supply and demand fluctuations. They can then in turn understand parking behaviorand make decisions on the price of each space based on the demand and supply in a specific area. Studies show that 40% of traffic in city central business districts could be caused by drivers looking for a place to park[126]. Sensors on parking spaces and mobile apps can help residents and visitors find parking spaces quickly, resulting in reduced traffic congestion as the stop-start nature of cars looking for spaces is eliminated. Knowing in advance that the supply of available parking spaces is low may even dissuade people from driving into a city at busy times. At the same time, smart parking can actually be used to increase revenue through improved capture rates and tickets issued for parking violations.

Barcelona has introduced smart parking, with the authorities inspired by the 'Internet of Things': their vision is to create new connections between people (both the 1.6m residents and tourists), processes, data and things. To make this happen, the city needed a reliable Wi-Fi network, a way to know the location of people and things connected to the network, and sensors. City planners now have a better understanding of where people go and how long they stay, which can in turn be used to plan and develop transportation. Visitors can look up the best routes on touchscreen kiosks at bus stops, they can find and reserve parking spaces from their smartphones, and they can even find out the air quality in different parts of the city, sensors on car park spaces mean that drivers can reserve a space via an app before they get there[127].

For road agencies, pricing technology raises policy issues that require political decision-making. Nevertheless, where pricing mechanisms exist (e.g. for tolling), agencies should ensure they are leveraging the right technology to provide options for policy makers.

7.3.4 New Kinds of Vehicles

Technology is enabling new kinds of vehicles that can promote safety, reduce congestion and raise the alternative capabilities of drivers whilst they are driving. Two new types of vehicles that are appearing on today's roads include 'connected' vehicles and 'autonomous' vehicles.

Connected vehicles. A connected vehicle is a vehicle that is equipped with internet access and usually also with a wireless local area network. This allows the vehicle to share internet access with other devices both inside as well as outside the vehicle. Typically, existing connected vehicles have functions that include music playing, smartphone apps, navigation, roadside assistance, voice commands, and car diagnosis. However connected vehicles are increasingly able to connect with both infrastructure and other vehicles. There are two main types of such connectivity: vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V).

V2I technology, which allows cars to communicate with infrastructure elements, involves attaching both sensors and connectivity (Wi-Fi) to the road network's infrastructure. Such technology can be installed on-road, such as in road reflectors, gantries, sign posts and traffic lights, or outside of the road system on street lights and buildings. It allows the infrastructure to sense and collect information on road user demand and movements and adapt the infrastructure (such as signage) accordingly.

126 Cisco website, (2015), Smart and Connected City Parking – Helping Cities, Citizens and Parking Offices

127 Cisco website, (2015), Smart and Connected City Parking – Helping Cities, Citizens and Parking Offices

An example of the development of such technology exists in the UK Smart Motorways project. This project came in response to congestion problems: in 2014, the average British driver spent 124 hours stuck in gridlock[128] and London is expected to experience a 20% population increase, to 10.1 million by 2030. Therefore in April 2015, the UK government announced a new road class of motorways, part of a £11bn, five-year 'road revolution'. Part of the strategy is the provision of roadside Wi-Fi, which will beam traffic information directly into cars. The motorways will 'talk to' connected cars. Making data available to drivers in real-time means that they too have access to valuable information to make them aware of the traffic situation when they're on the road.

V2V technology allows vehicles to communicate with each other. Vehicles automatically transmit data such as speed, position and direction, and send alerts to each other if a crash seems imminent. Crowd sourcing such data can also allow road agencies to respond with appropriate interventions. While at present this can be most widely used through early warning systems for drivers, the next step is to fully automate communication so that it allows cars to drive autonomously, as discussed below.

Both of these 'connected' technologies improve safety though alerting cars when signals are about to change or when there is a build-up of traffic ahead. This can help to mitigate congestion through smoothing car movements and re-routing traffic where necessary. Furthermore, data collected from sensors can be applied to derive a variety of insights for city planners, such as potential roadwork maintenance, and minimising disruptions caused by roadwork maintenance. Congestion can also be reduced through motorists receiving accurate live traffic data and redirecting motorists through alternate routes.

Autonomous vehicles. Autonomous Vehicles (AVs), with sensors that can self-drive and communicate with other vehicles and road infrastructure, are also on the horizon. Five U.S. States allow AVs to operate on public roads.

By 2010 Google had built a fleet of autonomous vehicles that collectively had travelled 140,000 miles (225,308 kilometres) on roads with other cars, obeying road signs and traffic signals without a single accident. In 2014, a BMW drove itself down the German Autobahn. Also in 2014, Toyota revealed its Prius A.V.O.S (autonomous vehicle operation system), which can be remotely summoned by the rider.

Tientrakool et al (2011) estimated that at 100% presence in the traffic mix, vehicles equipped with automatic braking capability and partial automation features (such as sensors of lead vehicle speed) can increase highway capacity up to 40%[129]. For vehicles equipped with automatic braking, sensors, and V2V communication, they estimate that even a 50% penetration in the traffic mix can increase highway capacity by up to 80%.They will also reduce travel time variability caused by human error and decision-making. Intuitively, minimisation of vehicle headway leads to a greater volume of traffic passing a certain point, hence greater productivity of road use and lower levels of congestion. However, a Philosophical Transactions of the Royal Society study into behavioural determinants of congestion found that small interruptions to tightly packed flows of traffic will be propagated backwards over long distances. Creating larger gaps between cars creates an 'equilibrium spacing" which ensures a steady ride.[130] The effects of this will likely be impact by the proportion of autonomous versus non-autonomous vehicles that are in the mix.

AVs provide non-congestion benefits too – safety is at the forefront of developers' considerations. The World Health Organization reports that 1.2 million people die in automobile accidents worldwide each year. The U.S. Federal Highway Administration recorded that 94% of accidents on roads are driver error. Alcohol-related accidents could potentially be eliminated with computers behind steering wheels. As incidents are the cause of up to 10% of ANZ cities' congestion, an increase in the safety of vehicles will in turn reduce congestion. As well as this, the environmental costs of congestion will also fall as AVs will choose the most efficient traffic routes, with minimal pollution associated with waiting in queues.

128 INRIX website, (2015), Traffic congestion to cost the UK economy more than £300bn over the next 16 years

129 Tientrakool, Patcharinee, Ho, Ya-Chi, and Maxemchuk, Nicolas M., (2011), "Highway Capacity Benefits from Using Vehicle-to-Vehicle Communication and Sensors for Collision Avoidance," Vehicular Technology Conference (VTC Fall) 2011

130 Laval, J., Leclercq, L., Philosophical Transactions of the Royal Society, (2010), A mechanism to describe the formation and propagation of stop-and-go waves in congested freeway traffic.

In addition to safety, autonomous vehicles could also enhance mobility for people such as children, and the elderly and disabled who, due to their physical condition, are unable to acquire a driver's license. With computers driving cars, licenses would not be required, enabling many classes of people to participate in social and community events, where they would not be able to previously because of a lack of convenient transportation options.

However, An OECD study in Lisbon[131] found that AV's and 'taxibots', combined with high capacity public transport, could reduce the number of cars to 10-20% of current levels, but increase vehicle-kilometres travelled during peak periods. The report also addressed the challenges of transition – if only 50% of car travel is shared self-driving vehicles, total vehicle travel could increase by 30–90%.

Future Considerations. While there are numerous advantages associated with the development of new kinds of vehicles, there are a number of considerations that road agencies and the government must consider both before and during their introduction onto public roads.

We must consider how quickly connected and autonomous vehicles will penetrate the existing vehicle fleet. Currently, the 'selling-point' of many consumer vehicles is the driving 'experience', the power of the engine and the ability to customise the vehicle to suit personal desires. With the automation of driving, such attributes will be lost and car companies must consider how they brand and align their strategies. In contrast, vehicles used for freight or commerce do not have such selling points. The desires of their owners and drivers are to enable goods to be transported from origin to destination using the quickest, safest and most cost effective method possible. Automated vehicles will facilitate these desired attributes. New Zealand has one of the oldest vehicle fleets in the OECD. This could have two affects: drivers may either want to purchase Autonomous Vehicles because they are more likely to be ready to update their existing cars, or, they will have no interest in new technology so will not purchase AVs and they will not be able to access the appropriate AV software on their existing cars.

The cultural values of owning and operating legacy vehicles may also impede upon the process of V2V adoption or AV fleet replacement and therefore the realisation of benefits associated with the use of AVs. Even with the potentially vast development of technology that is possible by 2030, which will create greater accessibility of these technologies, it is likely that there will still be many legacy vehicles in operation.

As different road users adapt to autonomous vehicles, there are challenges to consider with how they should be integrated with the existing fleet. For example, where there is support of such vehicles to enable them to drive in connected 'strings', and effectively increase road capacity, should they be allocated dedicated lanes? What qualifications must drivers have to be allowed to drive them? And what standards of computer software must be introduced for them to be allowed on public roads?

The changing nature of vehicle interaction will also change the nature of road network management and its agencies. Traditional functions of road network management agencies are predominantly road design, traffic management and network operations. With automation of vehicle interaction, the removal of human error would also remove with it the traditional role of these practitioners[132].

The possibilities continue. Alongside AVs, the next revolution will be Shared Autonomous Vehicles (SAVs) – so-called 'taxibots'. The OECD (2015) predicts that use of self-driving taxibots could reduce the number of vehicles on roads by 80-90% if they become routine. Simulations by Fagnant et al (2015)[133] reveal that a fleet of SAVs could service intra-urban trips with replacement rates of around one SAV per 9.3 conventional private vehicles. Moreover, the implications for parking and emissions through the use of SAVs are substantial. Shoup (2005) estimated that 31% of central business district space is dedicated to parking. RAND Corp (2014) cites that driverless cars will free land for residential, commercial and recreational use. AVs could strengthen a trend towards more dispersed, low-density land-use patterns surrounding metropolitan regions. Jurisdictions must consider how to adapt to such a landscape.

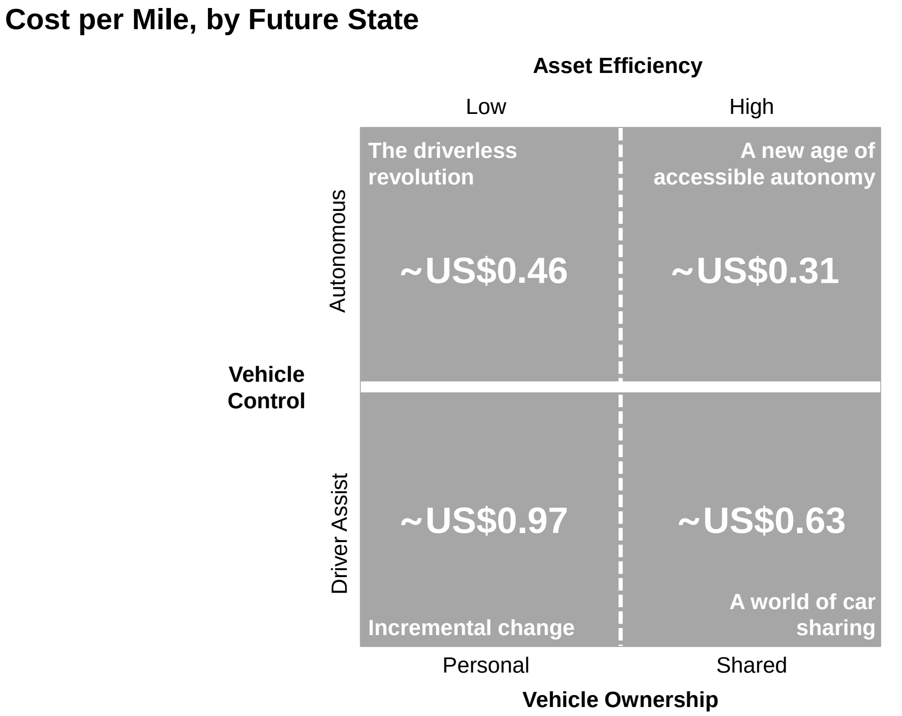
131 OECD International Transport Forum, (2015), Urban Mobility System Upgrade – 'How shared self-driving cars could change city traffic'

132 Main Roads Western Australia, (2015), Connected Vehicles: Are we ready?

133 Fagnant, D., Kockelman, K. and Bansaal, P., (2015), Operations of a shared autonomous vehicle fleet for the Austin, Texas market

Deloitte University examined the likely costs per mile in alternative future states. Personally owned vehicles today impose costs of approximately US$0.97 per mile (including vehicle depreciation, financing, insurance, fuel and individual's time). Exhibit 7.4 details the likely cost per mile of three states based on varying degrees of vehicle ownership (as discussed in 'New Mobility Services') and vehicle control (as discussed in 'New Kinds of Vehicles').

Exhibit 7.4: In a future state of shred vehicle ownership and autonomous vehicles, the cost per mile could be reduced by ~70 percent



Note: 'Cost' includes driver's time, ridesharing profit, cost of hired driver, vehicle maintenance, insurance, fuel, vehicle financing, vehicle depreciation; Fully autonomous drive means that the vehicle's central processing unit has full responsibility for controlling its operation

Source: Deloitte University Press, (2015), 'The future of mobility – How transportation technology and social trends are creating a new business ecosystem'; Deloitte analysis, based on publicly available information (US DOT, AAA, etc.).

7.4 Blue Sky… 2025 onwards

Looking towards the future, it is useful to hypothesise the likely characteristics of road and transportation management. The below points are useful for framing discussions within road agencies, the government and externally with other countries.

7.4.1 Hypotheses: 10+ years

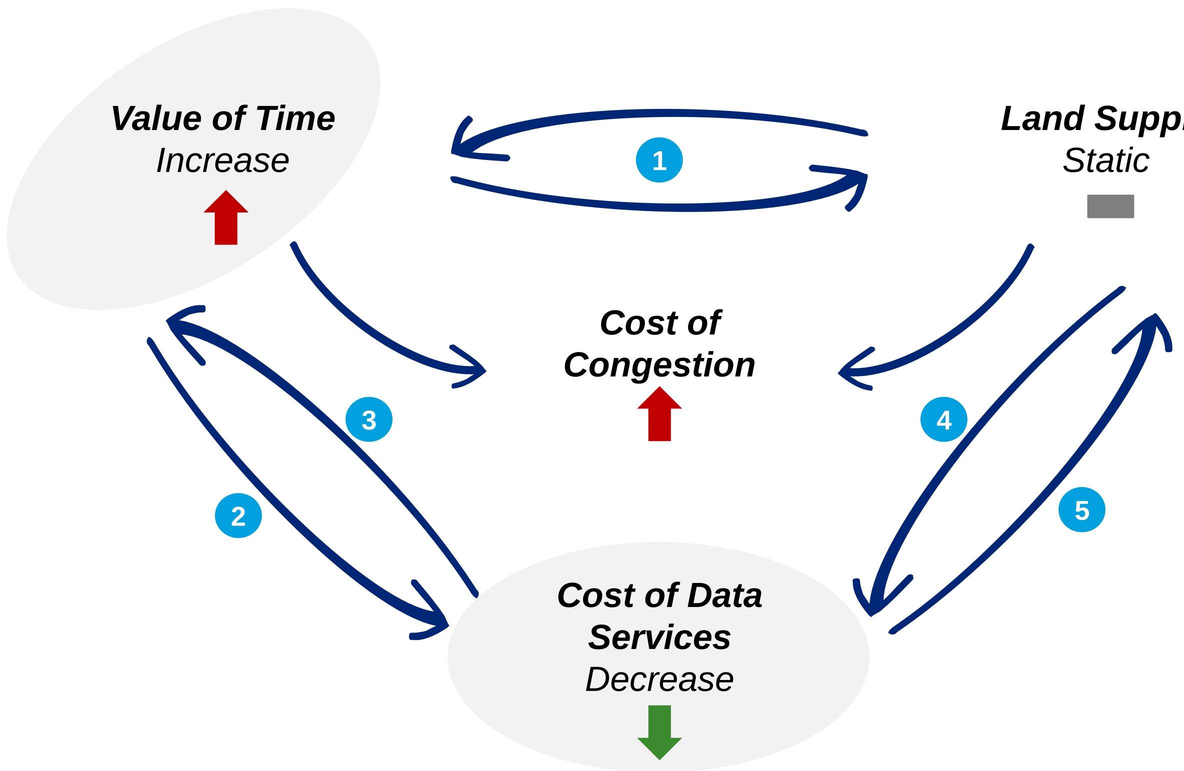
- **IT Economics.** Data generation, processing, transmission and storage costs will continue to fall in price and size, until reaching a theoretical minimum level
- **Value of Time.** The value of time and life will increase relative to goods and services, therefore:
  - The cost of congestion will increase
  - The safety premium will increase

- **Land Supply.** Urban land supply will not increase in Australia and New Zealand (there will unlikely be large scale land reclamation such as in Singapore or the Middle East) to cope with rising populations, therefore:
  - Denser housing will be required
  - Patterns of living and working may change
  - There will be limited space for new roads
  - The cost of land will rise, particularly where required to be bought from private, non-government owners

7.4.2 Major Implications

Exhibit 7.5 shows how the above hypotheses interact with each other, with several consequences for transportation planning and management.

Exhibit 7.5: Blue Sky Dynamics



1. **Value of time / land supply trade-off:** The existing trade-off in journey (commute) time and the proportion of income spent on housing will intensify, unless business locations adapt to be nearer to corresponding residential areas (including working from home). The increase in the value of time will reinforce increases in the demand and resulting value of land in city centres, followed by the suburbs of cities.
2. **Value of time impact on cost of data services:** Increased value of time will cause greater reliance on data services to mitigate delay and leverage travel time.
3. **Cost of data services impact on value of time:** Data services will support the effective processing of real-time information to ensure that road users' decisions are optimised to maximise network productivity.
4. **Land supply impact on cost of data services:** Increased value of land will cause greater reliance on data services to optimise limited travel corridors, reduce travel time and increase travel reliability from outer-residential areas.
5. **Cost of data services impact on land supply:** Data services will support effective decision-making of where to place new roads, housing and associated public services, with the ability to model the impact of major infrastructure and property developments on the transport network.

These interactions will require sophisticated planning to ensure investment decisions are made both efficiently and effectively, to mitigate the resultant impacts on demand for and supply of transport services. Without this, the ANZ population and public sector will not make informed congestion mitigation decisions, resulting in high costs to cities and road networks. As data processing unit price falls, it can in turn be increasingly used to facilitate decision-making. Exhibit 7.6 illustrates the possible impact on the demand and supply of different types of roads.

Exhibit 7.6: Increases in the demand for urban roads are likely to be greater than increases in the supply of urban roads

'Blue Sky' Consequences for Road Demand and Supply

		Value of Time Increases	Land Supply is Static	Cost of Data Services Decreases	Resultant effect
Central Business District (CBD) Roads	**Demand**	People are less likely to travel by slower modes such as bicycle	Denser housing will be required as the population grows	Data and technology will enable people to make informed demand decisions	**The increase in demand is greater than the increase in supply**
	Supply	No / minimal effect	Supply will increase, but will be limited by the scarcity of land	Improved information will allow supply to respond to demand in real-time	
Suburban Roads	**Demand**	An increasing proportion of the population will live in urban areas	Denser housing will be required as the population grows	More informed decisions will be made but car utilisation will be remain high	**The increase in demand is greater than the increase in supply**
	Supply	No / minimal effect	Supply will increase, but will be limited by the scarcity of land	Improved information will allow supply to respond to demand in real-time	
Rural Roads	**Demand**	An increasing proportion of the population will live in urban areas	No / minimal effect	Data and technology will enable people to make informed demand decisions	**The decrease in demand is greater than the increase in supply**
	Supply	No / minimal effect	Supply will increase relative to the increase in population	No / minimal effect	

Legend: Demand increase Small demand increase Small demand decrease Demand decrease

7.4.3 Predictions… 2025 onwards…

Given advances in technology, as described in Chapter 7.3, there are a number of areas of speculation with regard to the transportation 'world' from 2025 onwards. The below is a list of hypotheses for what the future state could look like:

- '**Driver assist' technology will be compulsory in urban areas.** It is likely that the increase in safety from automatic braking in particular will be stark. Cars without this will account for a disproportionate share of accidents, as it penetrates the car fleet, undermining insurance and CTP economics among other things. Once this tipping point is reached, there will be a clear ethical case to mandate use in cars and trucks on arterial or all roads. The politics of this will be similar to seat belts and motorcycle helmets, but with a clearer set of disadvantaged stakeholders.
- **Freight transportation will be automated outside urban areas.** The cost for professional drivers is increasing faster than cost of vehicles or the technology in them. Automation will enable safety, faster journeys, as well as reducing the costs of drivers. This automation is already occurring on truck fleets in mines. Within Urban areas, the greater complexity and risks will likely require a driver to deal with traffic.
- **Autonomous-only lanes.** Currently, higher motorway speed limits do not increase capacity much, because humans need to increase vehicle spacing to be safe at higher speeds. Motorways will commission autonomous only lanes that will safely allow much tighter vehicle spacing, and hence up to 3 times the vehicle capacity.

- **Private car ownerships peaks and will decline into the future.** We have already seen the peak of vehicle kms per capita in 2005. This will be followed by a peak in the absolute vehicle kms around 2025, underpinned by:
  - Increasingly dense residential areas close to CBDs and public transport hubs
  - Decrease in car ownership
  - Increases in car sharing, including autonomous vehicle fleets
- **Cities will implement fully autonomous network management systems.** Currently, ANZ cities generally have incident management systems, and semi-fixed network management (traffic lights and tidal flows). Exponential increases in network data from mobile phones will enable real time network data, and then management algorithms to be developed.
- **Public transport is fully autonomous in Sydney and Melbourne.** New light rail & metro systems underway Sydney will have network control level, rather than vehicle control. Similarly, buses will be able to be autonomous and in principle deliver better reliability than human drivers by leveraging network level management to, for example, slow down to collect full loads to optimise the route versus the individual bus.
- **A fleet of driverless taxis is launched**. Uber or Google will provide a fleet of driverless taxis that can optimise routing, and operate in solo or ride sharing mode.

All of these ‘ideas’ will improve economic productivity and may help to reduce congestion. Some may simply allow drivers to work in transit in autonomous vehicles. They increasingly take the decision-making elements of journey planning and execution away from the driver and towards separate or networked algorithms. This allows greater utilisation of the limited supply of road space, particularly if paired with public transport systems. The key is for jurisdictions to enable and absorb customer focused innovation from the private sector and academia in a much more collaborative way than in the past.

8. Congestion Mitigation Roadmap

"All you need is the plan, the roadmap and the courage to press on to your destination"

Earl Nightingale, 1921-1989

Chapter Summary

8.1 Congestion Mitigation Goals

- Governments should seek to limit growth in congestion costs (currently 5% p.a. over the last 4 years) in cities to less than the rate of population growth (1-2% p.a.)
- in order to maintain or improve quality of life. As 'acceptable' congestion is more often defined by the 'reliability' of journey times, this should be the focus of congestion mitigation actions

8.2 Impact of Technology

- Road agencies should not only investigate how technology will affect ANZ roads and associated infrastructure in the future, but they should consider how their current investments can be best built to ensure that technology can be 'added' to them in the future
- In addition, ANZ cities have significant spare road capacity during non-peak times of day – technology could be used to better consider how this capacity can be utilised, with temporal rearrangement of some activities

8.3 Congestion Mitigation Cycle

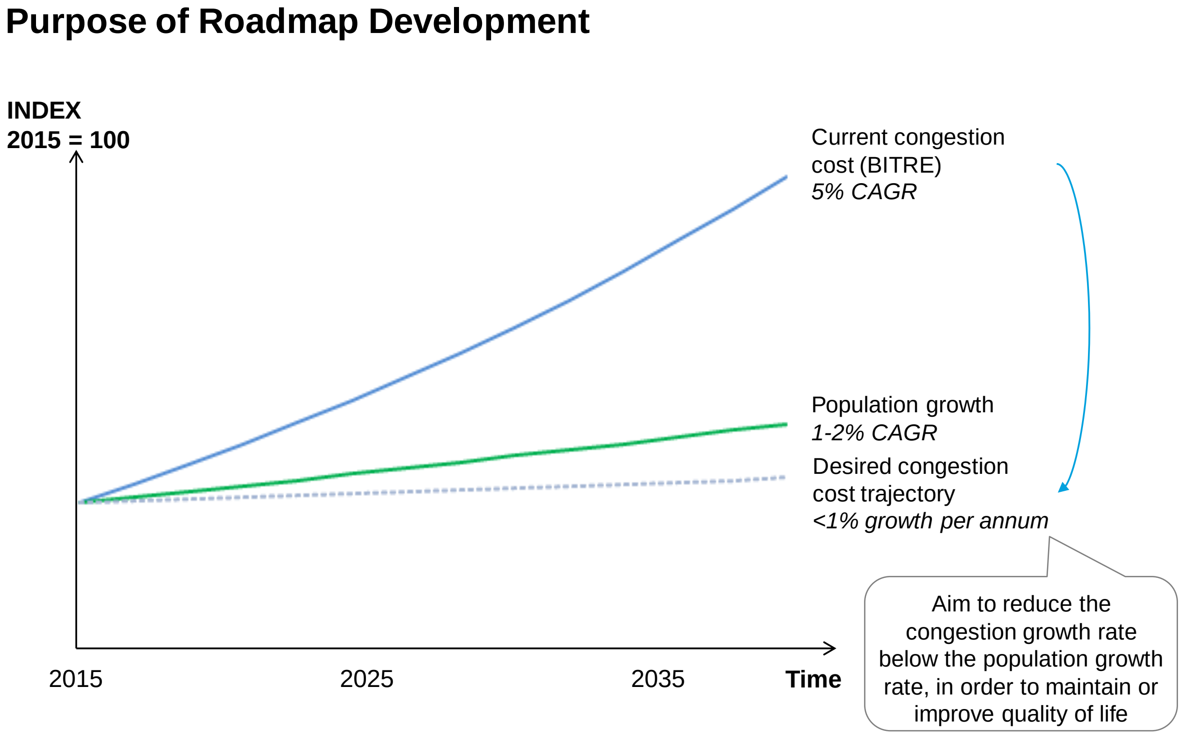
- Mitigating congestion is an iterative, ongoing process, with multiple stages that can be applied at a city, corridor or road level:
  - **Profile Road Users.** Understand the characteristics of demand by road user type
  - **Understand Current Network Performance**. Use analytics to determine current congestion performance
  - **Measure the Causes of Congestion.** Use analytics to understand the recurrent and non-recurrent causes of congestion
  - **Prioritise Interventions** by key causes of congestion, timelines, costs and BCRs
  - **Enhance Capability**. Invest in the appropriate capabilities to support the pursuit of effective interventions
  - **Implement Interventions**. Sequence interventions and measure outcomes
- Throughout the process:
  - Engage with **stakeholders** to gain support
  - Align with and influence the **Policy Framework**

8.1 Congestion Mitigation Goals

Without a well-planned intervention program, congestion cost will continue to increase at a faster rate than population growth, as shown in Exhibit 8.1. The associated congestion will impact the performance of the road system, road user satisfaction and the liveability of cities, and hence be a drag on both economic performance and the wellbeing of the population in ANZ urban areas.

However, constraint in physical road space and financial budget mean that simply increasing road supply in response to congestion is not a feasible nor effective solution on its own. This is clearly demonstrated by the congestion performance of Los Angeles. Rather, as highlighted in Chapters 5 and 6, road agencies need to consider a holistic set of supply and demand side interventions, from long-term strategic planning to more immediate operational management and execution.

Exhibit 8.1: Governments should seek to limit congestion cost growth in cities to a slower rate than population growth



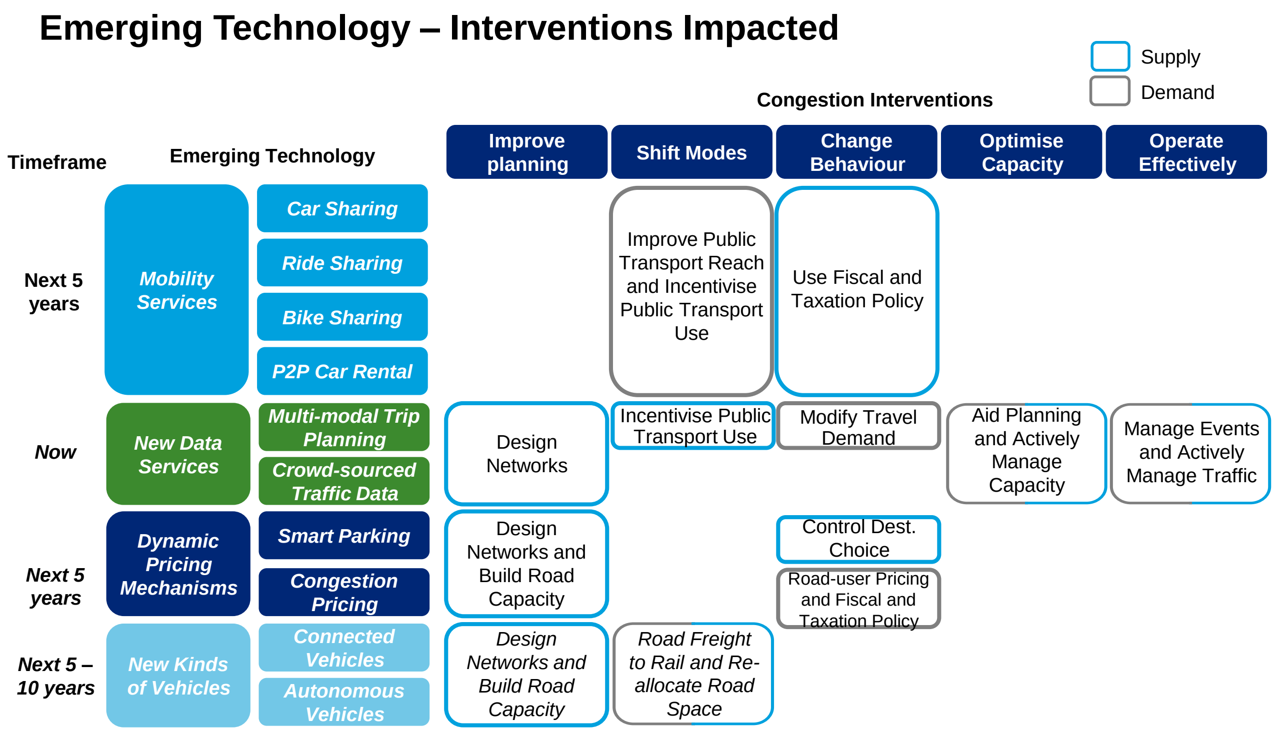
Notes: 1. CAGR = Compound Annual Growth Rate; 2. BITRE average congestion cost growth across selected Australian cities, congestion cost growth is higher in some jurisdictions than others; 3. Population growth may be higher in some jurisdictions than others

Each city should set and publish goals for overall congestion, average trip speeds and peak time scheduling to allow consumers to make informed choices on where to live and work and businesses to make informed choices on where to locate and build infrastructure. These road goals could then flow up and down into city-wide development planning. Brisbane provides a good example of the power of this approach, with development at the airport now fully integrated in the urban motorway network via multiple transport projects. This allows businesses to locate close to efficient transportation networks, but in general, long-term policy commitments are missing to ensure maintenance of the efficiency of road links (probably by demand side measures) into the future.

8.2 Impact of Technology

New technologies will bring progressive change to the way congestion is managed. They will also impact the effectiveness of existing supply-side and demand-side interventions. Exhibit 8.2 details which aspects of the interventions framework will be impacted. Before implementation of interventions can be undertaken, buy-in from stakeholders is required and capabilities must be developed.

Exhibit 8.2: Emerging technology is expected to impact the effectiveness of both supply-side and demand-side interventions



Road agencies should not only investigate how technology will affect ANZ roads and associated infrastructure in the future, but they should consider how their current investments can be best built to ensure that technology can be ‘added’ to them in the future, without need for complete re-design. As well as this, ANZ cities have a lot of spare road capacity during non-peak times of day – technology could be used to better consider how this capacity can be utilised, with temporal rearrangement of some activities.

8.2.1 Mobility Services

Shift Modes. The technology that allows real-time ride sharing can be used to facilitate new types of public transport, such as buses that collect people and adapt routes based on demand. Eventually these could be run autonomously. This will improve public transport reach and incentivise public transport use by making it more convenient. Similarly, bike sharing will enable more people to have access to a bike, or enable people to access bikes for specific, shorter journeys, thereby reducing the use of cars. However, many of those that are switching to the use of bikes through such technology may actually be people that may have walked otherwise.

Change Behaviour. By changing fiscal and taxation policy to encourage car sharing, ride sharing, and peer-to-peer car rental, their prevalence in day-to-day transport mode decisions will increase. For example, encouraging innovation in these areas through tax breaks or subsidies will encourage the development of the facilitating technology.

8.2.2 New Data Services

Improve Planning. As discussed earlier, crowd-sourced traffic information can be used by road and transport agencies to model long-term changes in the use of the road and transport networks, as well as plan for the future via information on re-routing during accidents. This will enable real-time decision-making that will reduce the need for long-term planning. Modelling of road demand can be altered in real-time and decisions made based on that information. Similarly, multi-modal trip planning requires effective network and infrastructure design in order to ensure that the technology is facilitating the best possible transport mode interchanges.

Shift Modes. As discussed earlier, data services can be used by government service providers to understand the movements of people and the best position for public services. This can also allow the public transport routes to be optimised for maximum patronage, revenue or effective use of infrastructure and increased or decreased correspondingly according to the data derived from passengers.

Change Behaviour. If road users can receive reliable, real-time information on the status of the road network and public transport, they will be able to make more informed decisions on the type of transport they use, the route they take and the amount of time they budget. This will make for both reduced time and increased reliability in journey characteristics.

Optimise Capacity. Data and information allows road capacity to be optimised through aiding travel planning and active management. Through the dissemination of real-time transport information and the collation of crowd-sourced data, road users will be able to make effective demand-side decisions, such as when to make their journey, the route they will take and the mode they will use. In turn, historical data and information can be used to optimize school travel plans and travel to work plans for businesses. Capturing personal travel history via personal apps will allow road users to learn from the data collected over the course of their journey history and optimize their routes accordingly. On the supply-side, historical data and information on road users movements given road closures and accidents will allow these to be planned more effective. Similarly data can be collected and used by intelligent information management systems to allow for the road network supply to respond to demand.

Operate Effectively. Real-time data and information derived from road users and the road and transport network allows supply of roads and transport to be matched to demand. Once automated, this will enable ease in creating routing in incident, works and events warnings. Introducing an event travel planner that is optimised based on both the real-time understanding of people's movements allows for people that have not begun their journey yet to adjust their decision-making accordingly. Similarly, smart motorways can be optimised via the data and information they receive, as well as by leveraging predictive analytics to understand relief routes.

8.2.3 Dynamic Pricing Mechanisms

Improve Planning. The effective design of networks and road capacity will ensure that pricing can be best used to match supply to demand. Smart parking, for example, requires sensors to ensure that road users can find supply; these must be planned and implemented in the areas of the road network where they are most required, if not across the entire network. Similarly, planning and designing the infrastructure of the road network to allow for dynamic congestion pricing on the busiest routes requires forward planning and use of data to model the associated consequences of price fluctuations.

Change Behaviour. The effective manipulation of congestion pricing depending on the level of demand for road space requires infrastructure that can detect such demand. This will enable technology that can pre-warn drivers of the amount they are likely to pay when they start their journey.

8.2.4 New Kinds of Vehicles

Improve Planning. Road networks that are both suited to and can reap benefits from the introduction of connected and driverless vehicles should be planned and designed in order to ensure that the demand for such technology is effectively aligned to supply.

- Vehicle-to-Infrastructure (V2I) connected vehicles require infrastructure that facilitates the delivery of information to improve journey time and reliability. Vehicle-to-Vehicle (V2V) connected vehicles also required appropriate planning to ensure that they are operating within the confines of the current road network system.
- Autonomous vehicles, which may eventually be able to move in connected formations at high speeds, require road capacity design that enables their free flow and high speed movement, so that other vehicles do not act as a barrier to benefits.

While most infrastructure may not be implemented for at least five to ten years, road agencies should be considering what impact their prevalence will have on investment decisions. For example, if a new overhead gantry is to be installed across a motorway, consideration should be given to the future technology that could be attached to it to facilitate V2I communications.

Shift Modes. New kinds of vehicles allow for modes of transport to be shifted from current vehicles types, to public transport and more efficient vehicle types where public transport is not available. While there are many benefits derived from new kinds of personal vehicles, it is possible that long-distance freight may be either first, or most impacted by this trend. For example, a heavy goods vehicle travelling from Adelaide to Melbourne could be automated for the rural sections of the route, with a driver in control for the urban areas of the journey. As such, in terms of shifting modes, the shift is rather of one from non-autonomous to autonomous vehicles, which while having similar polluting characteristics, are less likely to cause congestion. This is likely to occur in freight before commercial and personal vehicles. Similarly, public transport (i.e. buses) could be some of the first vehicles to convert – particularly where bus lanes allow for the vehicles to travel without interruption at high speeds. Autonomous buses could also communicate with infrastructure such as bus stops that automatically request the bus stop when a passenger is present.

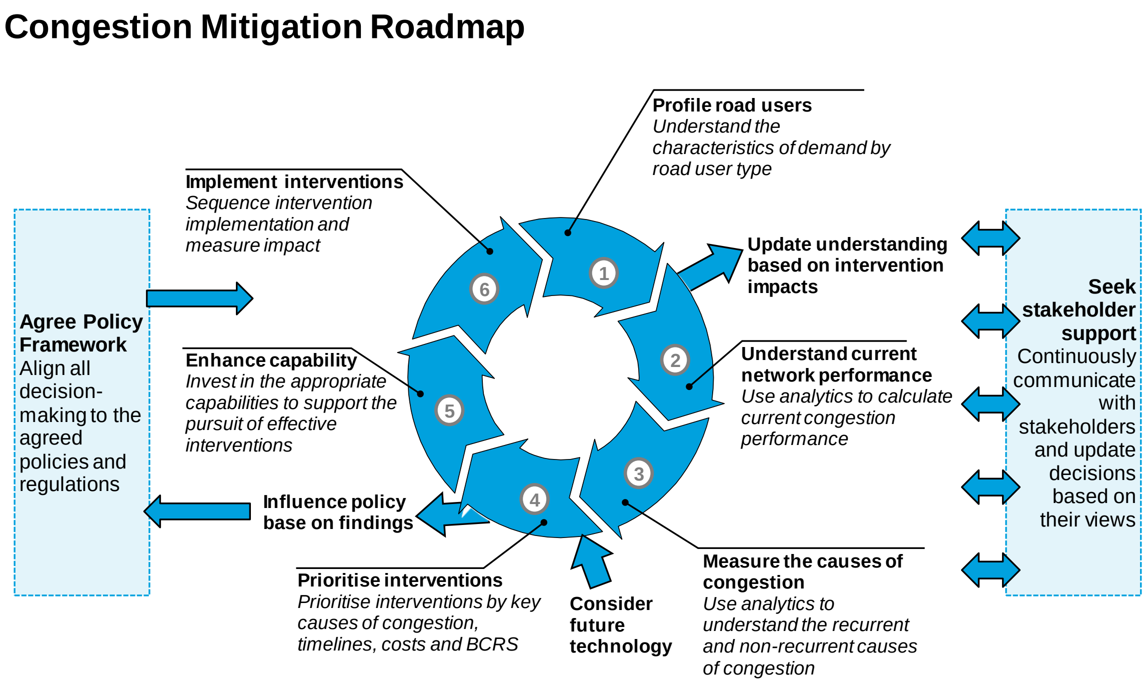
8.3 Congestion Mitigation Cycle

As innovation penetrates transportation, road agencies will increasingly be looked upon to advise on how technology will be integrated from a legal, as well as a technical standpoint. As such, each road agency should consider its role and capabilities to ensure Australia and New Zealand are at the forefront of innovation, to reduce congestion and improve the liveability of cities.

The congestion mitigation roadmap in Exhibit 8.3 sets out the principles to achieve effective congestion mitigation. A firm understanding of road user demand, the causes of congestion and future technological change are required before interventions are considered. Following this, interventions should be prioritised by their benefit-cost ratios and capabilities must be developed over time to allow appropriate interventions to be pursued. Investments should be sequenced for alignment with forecast congestion levels. Throughout the process, engagement with road agencies, transport associations, the community and the private sector are necessary to determine both opportunities for investment and buy-in for interventions. This approach could be applied at a project, corridor or whole of city level.

Currently, the approach to steps 1-5 is somewhat limited, with a greater focus on step 6 – delivering projects on time and on-budget. This is important of course, but perfect delivery of the wrong project will not provide the same benefit of even average delivery of the right project.

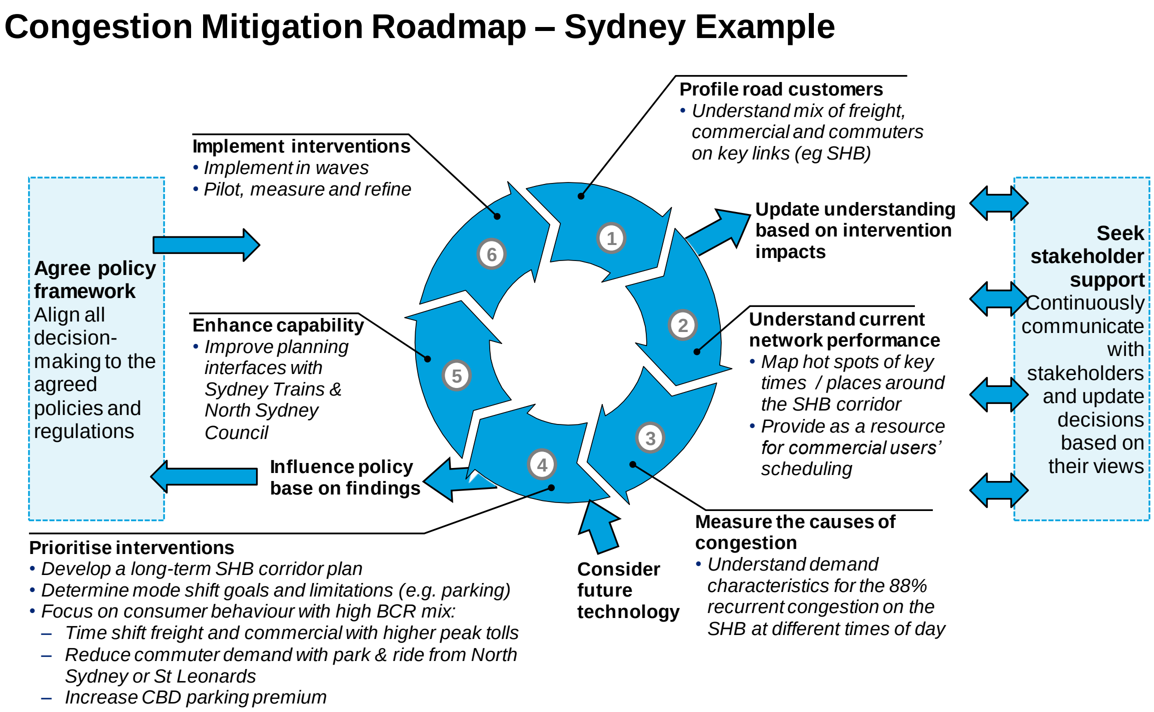
Exhibit 8.3: Mitigating congestion is an iterative process, with support from stakeholders required throughout



Source: Deloitte Experience

Exhibit 8.4 shows how this approach could be applied on a single corridor in Sydney. In this theoretical example, interventions include changes to public transport outside the corridor to reduce traffic in the corridor. Multiple, integrated projects could be required to deliver the overall corridor goal.

Exhibit 8.4: All cities can tailor this iterative process to their own road user, congestion and road network characteristics



Such a holistic, continuous improvement approach is commonplace in many other industries leading to rapid innovation in everything from mobile phones to automobiles. In this case, the objective is not increased profits, but to improve a scorecard of congestion measures that increase public good, with a flow through into the urban economy.

Given that a long term, strategic approach is required, stakeholder support and an agreed policy framework across the political spectrum is essential. Otherwise, it can be politically appealing for Oppositions to campaign against projects that have diffuse gains, but concentrated losses, and for Governments to prioritise short term projects than deliver benefits within an election cycle over long term planning. Both our major cities have destroyed hundreds of millions of dollars in potentially productive investment.

Our research has shown that congestion management is a journey, rather than a destination, with focused ongoing investment required to maintain the liveability of cities as they grow. Often, the benefits of this investment will flow to future generations, and we can only ponder how improved some of our cities could be if past generations had implemented some of the visionary transportation plans that have fallen by the wayside. We hope this work triggers a commitment to embrace the potential of the next wave of transportation innovations.

Appendix A Methodology

A.1 Google Data Context

A.1.1 Source of Data

- Data was obtained from Google Maps Distance Matrix Application Programming Interface (API), a web service[134] that calculates travel distance and real-time "duration in traffic" for a given set of origin and destination coordinates
- The origin and destination coordinates for the road segments were derived from geospatial "shape files" provided by road travel agencies

A.1.2 Google Application Programming Interface

Each interaction with the Google Distance Matrix API consists of a "Request", generated and sent to Google, and a Response, generated by Google and sent back.

1. Request

An API request contains the following attributes:

1. **Origin** –latitude and longitude values for the starting point of the road segment
2. **Destination** –latitude and longitude values for the end point of the road segment

3. Response

The Google API response contains the following attributes:

1. **Origin Address** – specifies the physical address for the starting point of the given road segment. Google automatically converts the latitude and longitude from the original request to the corresponding physical address
2. **Destination Address** – specifies the physical address for the end point of the given road segment. Google automatically converts the latitude and longitude from the original request to the corresponding physical address
3. **Duration in seconds** – length of time it takes to travel a given road segment expressed in seconds. This takes into account current traffic conditions
4. **Distance in metres** – total distance of the road segment expressed in metres

A.1.3 Data Specification

- The road network within each jurisdiction was divided into segments, each approximately 1 kilometre in length. This resulted in 17,457 individual road segments within Australia and New Zealand cities
- Each road segment was individually sent to the API following a schedule:
  - "Peak hour", Monday to Friday: every 15 minutes
  - All other times: every 30 minutes
- The schedule was executed 24 hours a day for 60 days during September and October 2015
- Road segments were also monitored in 16 international cities with the equivalent collection frequency to Australian and New Zealand jurisdictions. Each city was scheduled to execute for a two week period during September and October

134 A "web service" is a system that accepts specially formatted messages over a network (for example, the Internet) and responds with data or information

- Over this 60 day period, approximately 100 million requests were sent to the Google API.
- Time zone differences between jurisdictions were accounted for in the scheduled collection process

A.1.4 Data Integration Methodology

- Each jurisdiction in Australia and New Zealand provided the following data:
  - Incidents, events and road closures
  - Traffic counter statistics
- Deloitte acquired weather and rainfall data covering each jurisdiction.
- The data sets provided by each jurisdiction were integrated with the relevant Google response data and exported in a consistent format
- The integrated data set for each jurisdiction provided a consolidated view of vehicle volume, travel time, rain fall and incident proximity, on a common time base of 30 minutes

A.1.5 Use of the Data Output

- Using Google as the data source for travel time data allows for real-time data collection that can be used to measure real-time road performance
- The data is crowd-sourced, and as such, average travel times recorded will be more reliable than measurements from individual reports or the road agencies themselves
  - For example, in the event of an accident, there will be an immediate impact on the travel times for the surrounding vehicles and road agencies can be assured that a change in the average recorded travel time is impact many vehicles rather than just one
  - It is estimated that of the 9.95m smartphones in NSW, 7.3m have Google Maps apps with location services switched on
- When this data is integrated with other data sources such as rainfall data from weather agencies or traffic count and incident data from road agencies, this can provide us with immediate insights on unusual episodes of congestion and the causes driving these
- Over time, there will be an increasing role for road agencies in quickly identifying bottlenecks and putting real-time mitigation plans in place to help road users find optimal alternative routes
- In addition, while road agencies may have a detailed view of the congestion performance of their own roads, the Google travel time data can provide insights into the performance of roads beyond their own network. This enables benchmarking of performance between cities.
- This information can help the relevant authorities minimise or even prevent congestion, in operational and strategic contexts

A.2 Road Agency Data Requests

A.2.1 Agencies Contacted

To gather the data and information required for our analysis, a data request was prepared and sent to the road agencies within each jurisdiction. The agencies contacted for information were:

- Transport for NSW (Sydney)
- Roads and Maritime Services, NSW (Sydney)
- Transport and Main Roads, Queensland (Brisbane)
- Main Roads Western Australia (Perth)
- VicRoads (Melbourne)
- ACT Territory and Municipal Services Directorate (Canberra)
- SA Department of Planning, Transport and Infrastructure (Adelaide)
- NZ Transport Agency (Auckland and Wellington)
- Department of State Growth, Tasmania (Hobart)
- Department of Transport NT (Darwin)

A.2.2 First Round Data Request

The initial request for information that was sent to the agencies was divided into three priorities.

Priority 1 involved the identification of congested routes in each city. We asked agencies to provide us with a map or list of roads that were representative of the network and congestion across the city, including arterials and other major roads. Subsequent analysis on travel times and traffic counts are based on the identified roads. In this priority, agencies were also asked for a list of traffic count sites located along the identified roads, and metadata on the information collected (e.g. frequency of data, timespan, mode of data capture).

Priority 2 asked agencies to send through samples of historical data that could be provided from the identified traffic count sites. We also requested information on the available historical data that agencies have on contributors to congestion such as incidents and accidents, roadworks and maintenance, and road closures due to major public events. In addition, agencies were asked to send through any relevant reports and analysis that may have been conducted internally (e.g. road user surveys) on congestion within the city's roads network.

Priority 3 was about recent interventions aimed at reducing congestion that had been implemented within each city. Agencies were asked to identify major interventions and provide information on the type of intervention, associated costs, and any available data or studies on the effectiveness of the intervention in reducing congestion on the impacted roads.

A copy of the initial data request is attached below in Exhibit A.2.1.

This initial data request was sent out in mid July, requesting that information for priorities 1, 2 and 3 be sent through by July 22, July 31 and August 14 respectively. These were followed up with a conversation with representatives from each individual agency to clarify the data being requested and tailor the request to each particular jurisdiction. These phone conversations were conducted between Deloitte and agency representatives between late July and early August.

Following these conversations, agencies began sending data throughout August, which allowed us to select the relevant roads for our analysis. Given that the collection of Google data depended on the completion of the road selection process, the focus of the initial data request was heavily on priority 1. Once the roads were identified and the Google data capture commenced, we sent out second round data requests to follow up on the gaps from the other priorities in the initial request for information.

Exhibit A.2.1: First Round Data Request

Deloitte.

Austroads

Congestion & Reliability Review – Data Request

Background

Deloitte has been commissioned by Austroads to prepare a report on congestion and reliability on Australia and New Zealand's roads. This work is split into three broad streams:

- Understand the causes of congestion and the impact on reliability including benchmarking against other international cities;
- Understand the effectiveness of best practice interventions and strategies to improve congestion and reliability; and
- Understand the constraints and opportunities to improve capability and governance.

That cities that will be considered in the report are: Adelaide, Auckland, Brisbane, Canberra, Darwin, Hobart, Melbourne, Perth, Sydney, and Wellington.

Objectives

The goal of the project is to deliver the road agencies a better understanding of how congestion affects reliability on their network including what level of congestion could be considered acceptable. As well as an understanding of the range of capabilities and maturity of road agencies around Australia to implement best practice approaches to dealing with congestion. The analysis will be completed by around December 2015 and workstreams one and two will possibly be made public.

This project has represents a significant investment by Austroads and a significant commitment by your road agency to conducting leading research. Its success relies on the timely provision of data and information by your road agency. This means that this project will require Deloitte to gather data from your road agency as well as undertake a number of consultations. The consultations will likely focus on policy, governance and capabilities within your organisation and will be arranged over the coming month.

Data Request Overview

The data request is currently split into three priorities which should be processed in order. Each priority level has a date for completion. We understand that your data team is likely to be bust and have capacity constraints so if these dates aren't achievable then please let us know as early as possible.

The aim of our data request is to gather the best available data on congestion levels from each jurisdiction. We will then merge this with data that we will be gathering from Google and with data from other sources, such as the Bureau of Meteorology, to allow identification of the factors that contribute to congestion.

This document sets out a data request to support the first two streams of work. We are happy to talk through the data request with you over the next week to ensure that our data requirements are well understood.

Priority 1

- **Timing:** Due by 22 July

- **Data:** major congested routes
  - Description
    - Identification of top 200km of roads in relevant cities for use in this analysis.
    - Identification of next 400km of roads in relevant cities for use in this analysis
  - Considerations
    - Routes should be selected to provide a fair view of the level of congestion in your location.
    - Routes should include different road types
    - Routes should take into account the road users perspective by considering what routes are most critical for road users
  - Data format
    - Preferable: GIS file of selected routes
    - Acceptable: Text file specifying road names
    - If issuing a text file helps meet the timing set out above then this is preferable.

- **Data:** Traffic counters
  - Description
    - For the 600 km of road identified above, provide information on the traffic count data that is available.
    - If this is in the form of a fixed traffic counter please provide the location of the counter.
    - For each traffic count data point that is available please provide meta data on mode of data capture, frequency of data capture, timespan over which data is available and data items (count, speed) that can be measured from each counter
  - Data format
    - GIS or text file of points where traffic count is available

Priority 2

- **Timing:** Due by 31 July

- **Data:** Relevant Reports and road user surveys
  - Description
    - Please provide relevant reports and analysis relating to congestion on your jurisdictions road networks
    - Please provide any relevant survey results or data that relate to customer experience of congestion on your network
  - Data format
    - Pdf, doc, excel – as required.

- **Data:** Traffic count data
  - Description
    - For each of the traffic counters previously identified please provide data on vehicle counts
    - Data should be provided for previous 3 years
    - Data should include, where possible
      - Traffic volume (by vehicle class)
      - Travel speed
  - Data format
    - CSV or excel

- **Data:** Contributors to congestion
  - Description
    - Please provide data on
      - Incidents;
      - Maintenance; and
      - Major public events/road closures
    -
  - Considerations
    - An update to this data will need to be provided in September to cover the period over which we will be gathering data from Google.
  - Data format
    - CSV or excel according to following layout

Type	Date	Time	Location	Detail	Notes
Incident			(lat, long)	Breakdown/Crash/Clean up/Other	Free text notes (optional)
Maintenance				Planned/Unplanned	
Event				Recurring/Non-recurring	

Priority 3

- **Timing:** Due by 14 August

- **Data:** Identify recent interventions to reduce congestion
  - Description
    - Please provide a list of relevant interventions to reduce congestion that have bene made in the relevant city over the past 5 years
    - Interventions should be assigned to categories such as
      - Pinchpoints
      - Network capacity improvements
      - Change configuration
      - Modify layout
      - Turning movements
      - Traffic signal retiming
      - New route/bridge/infrastructure
      - Change to road space allocation
      - Introduce toll/road pricing
  - Considerations
    - A range of interventions is desirable including small projects, IT related projects or management projects.
    - For use in later analysis we will need to have traffic data available for both before and after the intervention so the list of interventions should take this data availability into account
    - For use in later analysis we will need to have costs available so the list of interventions should take this data availability into account
  - Data format
    - Text document according to the following layout

Name	Type	Date	Indicative cost	Traffic data available	Description
	Pinchpoints		$m	Yes/No	Free text
	Network capacity improvements				
	Change configuration				
	Modify layout				
	Turning movements				
	Traffic signal retiming				
	New route/bridge/infrastructure				
	Change to road space allocation				
	Introduce toll/road pricing				

A.2.3 Second Round Data Request

In early to mid-September, a second round of data requests was sent to agencies for information in the initial request that had not yet been provided. This second round was divided into two separate requests, with both being tailored towards specific jurisdictions based on the material that had been sent through thus far.

The first request was sent to the relevant persons in charge of the data within each agency. It provided agencies with a map of the roads selected for analysis and a list of traffic counters on these roads, and asked some questions about the format, timing and types of data that could be provided. The request noted that data on traffic counts and incidents on the selected roads for September will be requested from the agencies at the end of the month, and again for October data at the end of that month. The data from these two months will be used in the modelling for each jurisdiction.

The second request was sent to the person on the Working Group from each agency. This provided agencies with a list of interventions that had already been identified as having been implemented in the jurisdiction to address traffic congestion over recent years. The agencies were asked to provide information on any interventions that had not been included in the list, as well as any reports on the effectiveness and/or cost of implementation associated with each intervention.

A copy of these second round data requests are attached below in Exhibit A.2.2.

Exhibit A.2.2: Second Round Data Request – Example Output for Brisbane

First request

Thanks for the data you have sent through on Brisbane's road network and traffic counters so far. We have been through this information and selected the roads that we wish to consider in our analysis (attached shapefile for reference) – this has been based off the NPI Links file that you provided.

Just wanted to give you a heads up that we will require traffic count data from the counters relevant to the selected roads for 1 September to 30 October. I have attached a list of the count sites that we will need data for (based on the NPI Links identifier rather than using coordinates of the counters following our earlier discussion). We are hoping to receive this data in 2 batches – September data as soon as possible after the end of September, and October data as soon as possible after the end of October.

We understand that this will be a very large dataset. Are you able to clarify for us:

- At what frequency will traffic count data be available for these sites (we ideally would like 15 minute intervals)?
- What format will the count data be provided in?
- How soon after the end of each month would the count data take to collect and be provided?
- Can you confirm that speed or travel time data is available for these sites?

We will also require data on traffic incidents, roadworks, special events, etc. that take place on these roads over the 2 months. As mentioned earlier, we are primarily interested in large-scale projects or events that could disrupt traffic.

Again we understand that this could be a large volume of information, so could you let us know:

- What format will the incidents data be provided in?
- How soon after the end of each month would the incidents data take to collect and be provided?

Thanks again for your assistance so far. Please don't hesitate to get in touch if you have any questions.

Second request

Thanks again for you and your team's input so far into the Austroads congestion study. We are currently examining recent interventions that have been implemented in Brisbane to address traffic congestion. I've attached a summary list of the interventions that have been provided to us so far. Would you be able to take a look through the list of the different types of interventions and mark up the "Any other information available?" column if you can think of other interventions from the last 3 years or so within each category that have not been noted already, and which are likely to have good data available for analysis?

In addition, if further information (such as post implementation reviews, benefit capture, business cases, or traffic analysis) is available on any of these interventions with respect to the effectiveness, benefits and/or costs of implementation, we would appreciate it if you could send it through.

Could you please try and get back to us by 24 September.

Our plan is to then select a number of case studies from around Australia and New Zealand to give a good view of effectiveness across a range of interventions. This means that we may select one or two case studies from Brisbane. We will let you know which ones we select and will be in touch again if we require further information on the case study.

Please let me know if you have any questions.

A.3 Comparator City Selection

The 10 capital cities in this analysis were benchmarked against 87 international cities based on a number of characteristics which broadly reflect the key features influencing a city's transport system. These included:

- total population;
- population density;
- GDP per capita;
- total CO2 emission share from the transport sector;
- travel to work share – private motor vehicle; and
- travel to work share – public transport.

A.3.1 Data Sources

Data availability was a key issue in the conducting the analysis. There is an inherent trade off in between the available data and the number of characteristics being considered. The initial analysis included more than 230 cities from the OECD database, however as more characteristics are added to the analysis, key characteristics for cities that were not readily observable were dropped from the analysis. Table 1.1 lists the key characteristics and their respective data sources.

Exhibit A.3.1: Data Sources

Variable	Year	Unit	Source
Population	2012	persons	OECD metropolitan database, ABS regional database, Eurostat
Population density	2012	persons per km2	OECD metropolitan database, ABS regional database, Eurostat
Income per capita	2010	$US/person constant 2010 price, PPP	OECD metropolitan database, ABS regional database, Eurostat
Transport share of CO2 emission	2008	% of total	OECD metropolitan database, ABS regional database, Eurostat
Travel to work mode share	Various	% of total	Eurostat urban audit, US Census, ABS census

A.3.2 Clustering Analysis

A 'k-means' clustering analysis was performed on the dataset to identify baskets of cities that are broadly comparable based on our chosen characteristics. 'k-means' analysis has the ability to segment cities in our sample into predefined number (k) of partitions. Cities are partitioned in such a way that the variance of city characteristics within each cluster is minimised and that variance between clusters are maximised.

The number of predefined clusters is an important input parameter into the clustering analysis. As an inappropriate choice of k may yield erroneous results. Diagnostic checks were conducted on each dimension of the city characteristics to ensure the number of cluster is properly defined. In this analysis we have chosen to partition cities into 6 unique clusters.

Computationally, the analysis could be characterised by the following function:

$$\underset{\mathbf{S}}{\arg\min} \sum_{i=1}^{k} \sum_{\mathbf{x} \in S_i} \left\| \mathbf{x} - \boldsymbol{\mu}_i \right\|^2$$

Where x is a vector of city chracteristics, and μ_i is the mean of the cluster i.

A.3.3 Post Clustering Ranking

Clustering analysis provided a good starting point in determining which international cities are comparable to the Australian cities. We then perform nearest-neighbour analysis for cities within the same cluster to assess their relative proximity to their Australian counterpart.

The process involved computing the sum of squared differences between each attribute of a given city and an Australian city. Cities are then ranked based on this distance for each of the eight Australian city comparators.

Other factors also overlaid this analysis, to "sense-check" the comparable cities and ensure the ones chosen were most appropriate. These factors included city geography (whether cities were coastal or otherwise) and consideration of their public transport system.

In addition, other Alpha world cities are also considered in this analysis for completeness.

A list of international comparator cities is listed in Table 1.2.

Exhibit A.3.2: Data Sources

ANZ cities	International comparators
Sydney Melbourne	Seattle Philadelphia Boston San Francisco
Perth Brisbane Adelaide Auckland	Indianapolis Ottawa Las Vegas Hamburg
Darwin Wellington Hobart Canberra	Eindhoven Halifax Le Havre Brest
Other Alpha world cities	London Singapore Los Angeles

A.4 Road Selection

A.4.1 Australian and New Zealand Cities

There were three key inputs into road selection for Australian and New Zealand cities, including:

- information provided by jurisdictions in response to the data request;
- Google Maps' traffic layer; and
- shape files of cities.

As noted in section A.1, the data requests asked jurisdictions to identify the major congested routes in each city, up to 600km where relevant. These were used as a basis for road selection and to sense-check the identified roads.

Concurrent with this stage, data was manually collected from Google Maps for each of the ANZ cities in this research. The 'traffic layer' was switched on to identify the highly congested roads (identified as those marked in red) for peak travel periods. For this high-level analysis, the 'typical traffic' option was toggled to identify the congested roads in the greater capital city, during the AM and PM weekday peaks, as well as on Saturday morning and Sunday afternoon. Congested roads were identified, noted, and compared with the roads suggested by the jurisdictions themselves.

For the jurisdictions that did not identify the congested roads in their data request, shape files for city roads were used in conjunction with the Google Maps road selection above to identify the congested routes for consideration.

A.4.2 Comparator cities

For the comparator cities, primary and motorway routes were selected for consideration.

Shape files for each of the regions were downloaded from Geofabrik OpenStreetMap Data Extracts (http://download.geofabrik.de/index.html). The regions were narrowed down to the relevant city regions through comparison with Google Maps, and primary and motorways only were selected for analysis.

The routes selected for ANZ jurisdictions and the comparator cities were then segmented for data capture from Google, as discussed in the following section.

A.5 Road Segmentation and Data Capture from Google

A.5.1 Re-Projection

Selected roads from the previous section were re-projected into conformal projections that approximately preserved distances around the areas of interest. Exhibit A.5.1 lists the cities studied and the map projections used to measure distances.

Exhibit A.5.1: AU–NZ City Re-Projection

City	Projection	ESPG Code
Adelaide	GDA94 / MGA Zone 54	28354
Auckland	NZGD2000 / New Zealand Transverse Mercator	2193
Brisbane	GDA94 / MGA Zone 56	28356
Canberra	GDA94 / MGA Zone 56	28356
Darwin	GDA94 / MGA Zone 52	28352
Hobart	GDA94 / MGA Zone 55	28355
Melbourne	GDA94 / MGA Zone 55	28355
Perth	GDA94 / MGA Zone 50	28350
Sydney	GDA94 / MGA Zone 56	28356
Wellington	NZGD2000 / New Zealand Transverse Mercator	2193

A similar transformation was applied to road network layers from comparator cities. The corresponding list of cities and map projections is provided Exhibit A.5.2

Exhibit A.5.2 – Comparator City Re-Projection

City	Projection	ESPG Code
Boston	NAD83(NSRS2007) / Massachusetts Mainland	3585
Brest	ETRS89 / UTM zone 30N	25830
Eindhoven	ETRS89 / UTM zone 32N	25832
Halifax	NAD83(CSRS) / UTM zone 20N	2961
Hamburg	ETRS89 / UTM zone 31N	25831
Indianapolis	NAD83(NSRS2007) / Indiana East	3532
LA	NAD83(NSRS2007) / California zone 5	3497
Las Vegas	NAD 1983 HARN StatePlane Nevada East FIPS 2701	102307
Le Havre	ETRS89 / UTM zone 31N	25831
London	OSGB 1936 / British National Grid	27700
NY	NAD83(NSRS2007) / New York East	3625
Ottawa	NAD83(NSRS2007) / UTM zone 18N	3725
Philly	NAD83(NSRS2007) / Pennsylvania South	3651
San Fran	NAD83(NSRS2007) / California zone 3	3493
Seattle	NAD83(NSRS2007) / Washington North	3689
Singapore	SVY21 / Singapore TM	3414

A.5.2 Segmentation

The re-projected road network layers were then segmented at 1km intervals. Segments at the end of a road that were shorter than 1km were retained at this stage. These segments were then saved as a list of origin and destination coordinates.

A.5.3 Validation

The process of validating the list of segments involved an iterative process of selection and adjustment. Segments deemed acceptable were then added to the list of segments on which data was collected.

A.5.4 ANZ segments and comparator cities

The ANZ segments were run through the entire process of validation. Data from the following comparator cities were only run through part of the process of validation in the interests of expediency:

- New York
- Singapore
- Eindhoven
- Las Vegas
- Halifax

Exhibit A.5.3 presents the date ranges for data capture for each city in the analysis.

Exhibit A.5.3 – Data collection from Google

City	Start date (first observation)	End date (last observation)
Adelaide	14/09/2015	23/10/2015
Auckland	14/09/2015	23/10/2015
Boston	22/09/2015	23/10/2015
Brest	23/09/2015	23/10/2015
Brisbane	14/09/2015	23/10/2015
Canberra	14/09/2015	23/10/2015
Darwin	15/09/2015	29/10/2015
Eindhoven	9/09/2015	23/09/2015
Halifax	14/09/2015	22/09/2015
Hamburg	9/11/2015	17/11/2015
Hobart	14/09/2015	23/10/2015
Indianapolis	12/10/2015	23/10/2015
LA	22/09/2015	23/10/2015
Las Vegas	14/09/2015	22/09/2015
Le Havre	23/09/2015	23/10/2015
London	9/11/2015	17/11/2015
Melbourne	14/09/2015	23/10/2015
NY	14/09/2015	22/09/2015
Ottawa	22/09/2015	23/10/2015
Perth	14/09/2015	23/10/2015
Philly	12/10/2015	23/10/2015
SF	9/11/2015	26/11/2015
SG	9/09/2015	23/09/2015
Seattle	12/10/2015	23/10/2015
Sydney	15/09/2015	23/10/2015
Wellington	14/09/2015	23/10/2015

A.6 Average Speed Methodology

The purpose of this analysis is to describe the average speed of road segments within a city in a useful and succinct way.

A.6.1 Measuring City-wide Average Speeds

There are several ways of measuring city-wide speeds. The first method used in this report is to examine the average speed across the road-network in a given city. This was done by summing the average travel time across all segments, and dividing it by the sum of the length of all road segments.

The use of a network-wide average however, fails to capture the distribution of average speeds across road segments in the network. Thus, two cities with the same average speed can be vastly different, with one city having some segments with significantly higher than average speeds and other segments having significantly lower than average speeds, while the other city has all of its segments having approximately the average speed of the network.

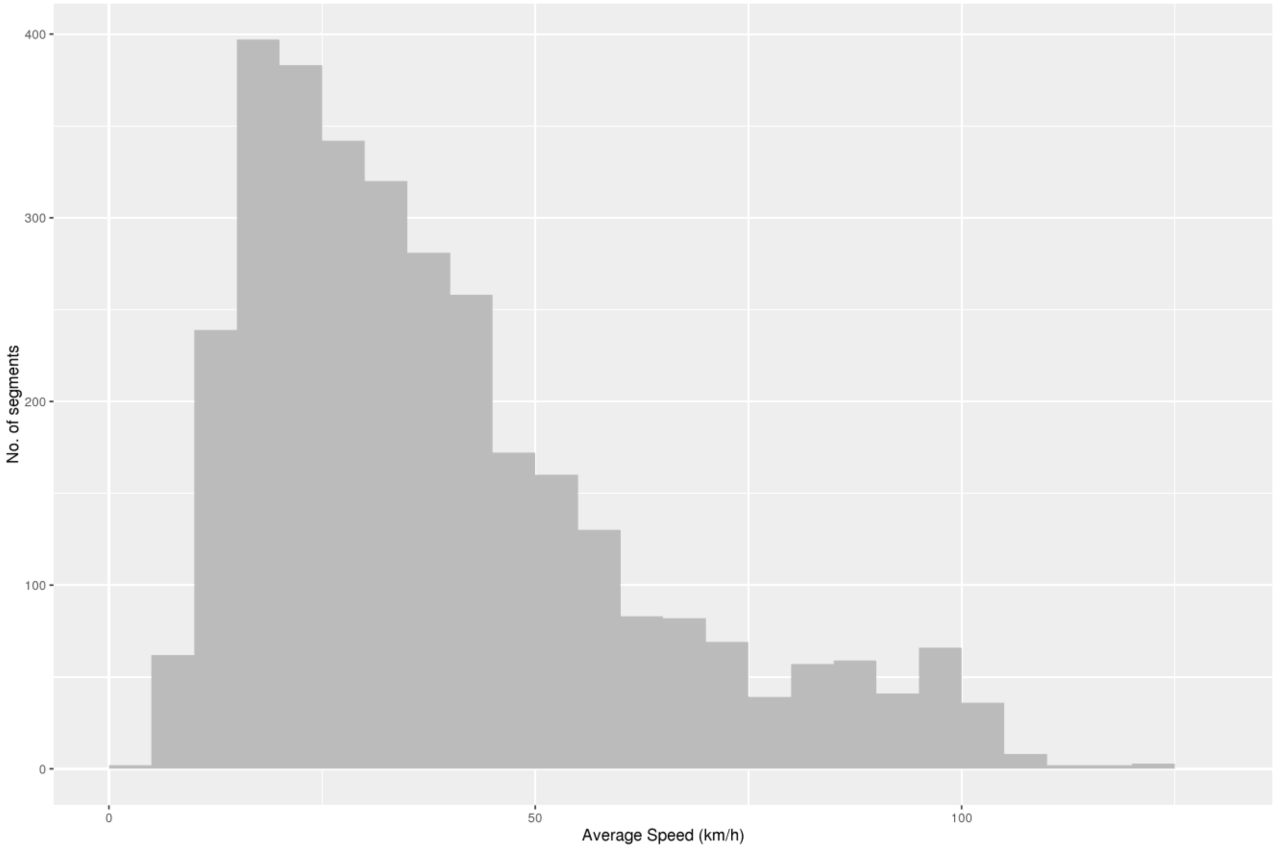
Thus we will explain the use of density curves as a result of a desire to measure:

- The distribution of road segment speeds within a city;
- Comparability across cities; and
- To avoid problems associated with discreteness and bin selection.

A.6.2 The Distribution of Road Segment Speeds Within a City

A simple way of representing this is to include a histogram of the average speed of road segments within a city. As an example, we will examine the distribution of road segments in Sydney.

Histogram of Sydney Road Segments

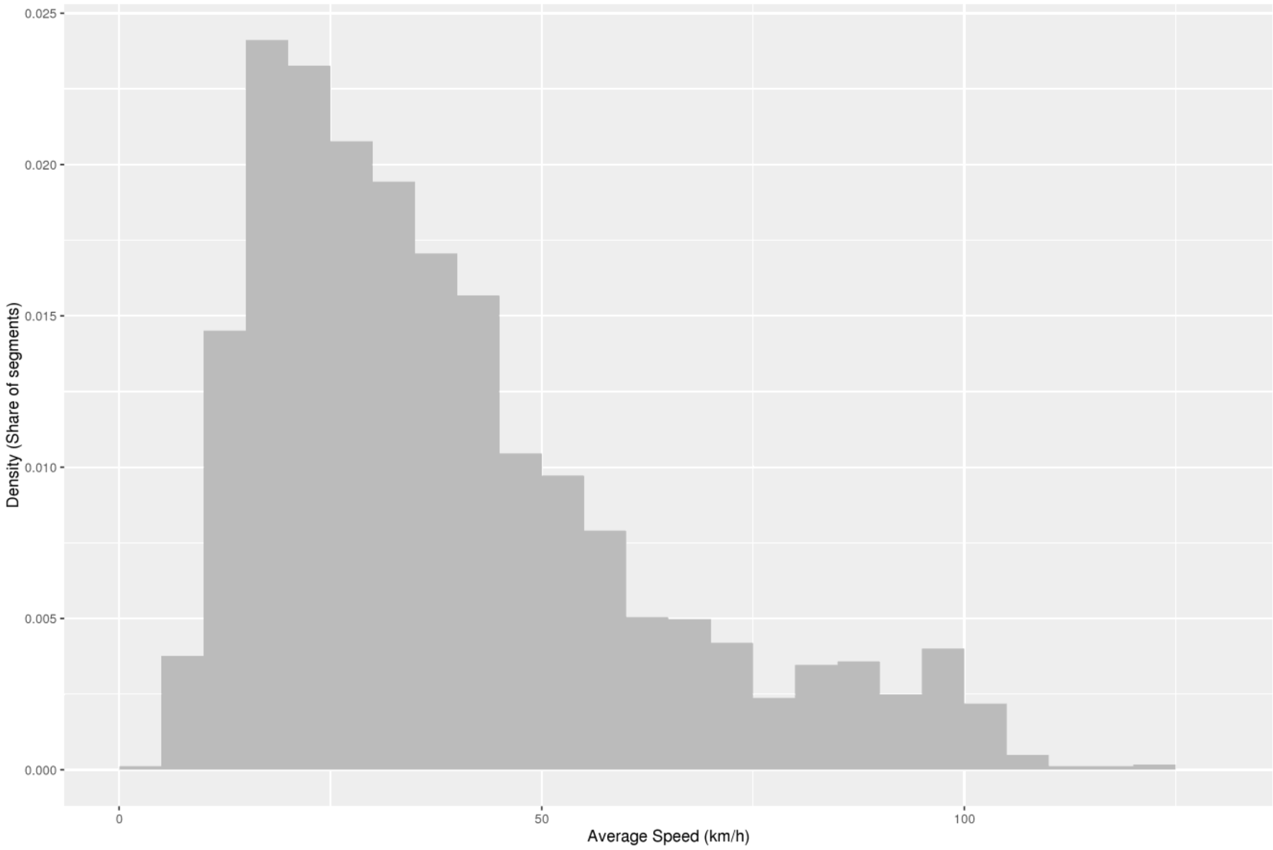


The above diagram provides a histogram of segments and the average speed of segments within Sydney. This allows for a visual understanding of the distribution of the average speed of road segments across Sydney.

A.6.3 Comparability Across Cities

However, it is often more important to compare the distribution of the average speed of road segments across multiple cities. As the number of road segments examined in each city is not equal, it is difficult to compare histograms which use the *absolute* number of road segments on the y-axis. It is therefore more useful to specify the y-axis to be in density, or the relative share of road segments in the city being examined.

Histogram (Density) of Sydney Road Segments



The chart of Histogram (Density) of Sydney Road segments is identical to a regular histogram, except that its y-axis is now specified in terms of density. This makes comparison across jurisdictions more meaningful as it accounts for the fact that different cities had different numbers of segments examined.

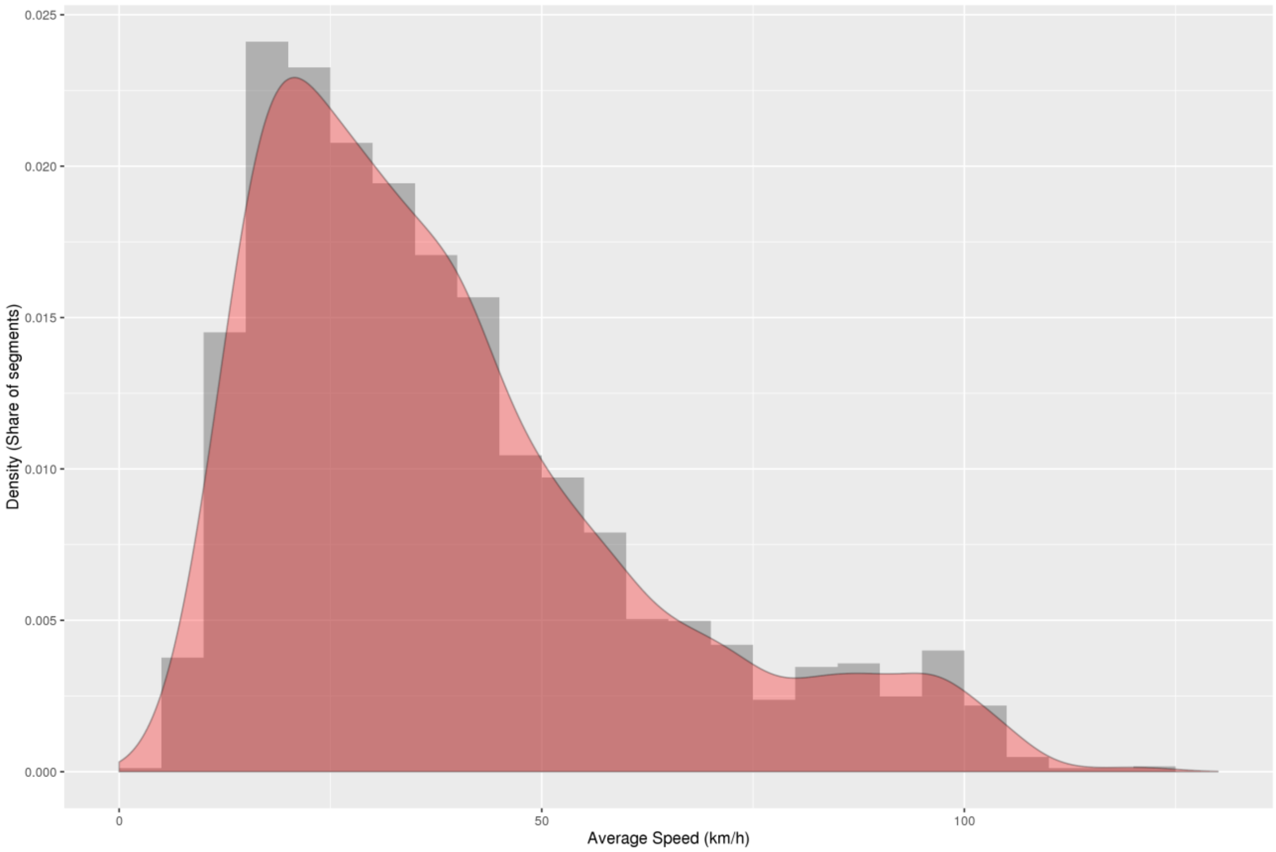
However, it should also be noted that differences in the sizes of jurisdictions' road networks mean that there were differences in the road segments selected for each jurisdiction, which can limit cross-jurisdiction comparability between cities with significantly different network sizes even when using density histograms. Specifically, jurisdictions were asked to identify up to 600km of the most congested routes in their city to be used in the analysis. In large cities such as Sydney or Melbourne, these 600km of roads are primarily highways, arterials and other major roads. In contrast, in smaller cities such as Hobart or Darwin, the 600km includes a larger share of local roads. This means that any comparison between the results across jurisdictions of different sizes should be made with caution.

A.6.4 Avoiding Discreteness

Finally, histograms segment the sample into discrete bins. This produces a discrete set of bins that are used to classify road segments. The granularity of a histogram can thus be adjusted by changing the width of bins used.

However, given that we want to be able to visually examine the overall distribution of segment speeds, it is often more useful to examine a smoothed representation of a histogram.

Histogram and density curve of Sydney Road Segments



A density curve provides a smoothed estimate of the shape of a histogram, which thus allows for an examination of the overall distribution of segment speeds, and abstracts away from problems associated with granularity and bin width selection.

A.6.5 Interpretation in this Context

In this project, we have provided density charts of highway only road segments (road segments with maximum speeds of 80km/h or greater).

The density curves illustrate several properties of each city.

Firstly, the density curves are primarily double-peaked rather than single-peaked. Double-peaked curves imply that there are two distinct classes of highway segments that are qualitatively different in terms of their average speed.

Secondly, the extent to which the peaks dominate a given distribution visually represents the extent to which congestion is being managed. A segment speed distribution which showed a large smear of speeds would be associated with a city in which average speeds varied across roads, likely due to traffic congestion. Road networks with the ability to manage traffic across a network (through for example, congestion demand management) would be better placed to push traffic onto less used roads, or onto different times of day, thus resulting in a distribution with more pronounced peaks, as road segments would be managed into having identical (and ideally optimal) average speeds.

A.7 Congestion Cause Methodology

A.7.1 Model inputs

Congestion is a complex phenomenon that may be attributed to a number of factors. To empirically determine the relative contribution of these factors, we collected data on the potential drivers of congestion discussed previously across road segments in each of the 10 jurisdictions. This data on drivers was then matched against the observed travel time (used as an indicator of road congestion) associated with a vehicle travelling on these segments at the same time.

Data inputs to the model were collected at a half-hourly interval where available, with the time period spanning across September and October 2015. Each ‘observation’ in the model therefore has a spatial identifier (i.e. the road segment) and a temporal identifier (i.e. the half-hourly time interval).

More information on the variables for which data were collected across each road segment and time interval can be found in the table below.

Variable	Data source	Units	Description
Travel time	Google	Seconds	Time taken to travel from the start to the end of the road segment, given current and recent historical local traffic conditions in a particular time interval
Traffic count	Road agencies	Number of vehicles	Number of vehicles passing the traffic counter located on the road segment in a particular time interval
Unplanned incidents	Road agencies	Number of incidents	Scaled indicator for the number of unplanned incidents (e.g. traffic accident, vehicle breakdown, signal outage) within a 1 kilometre radius of the road segment in a particular time interval
Planned incidents	Road agencies	Number of incidents	Scaled indicator for the number of planned incidents (e.g. roadworks, special event, scheduled closures) within a 1 kilometre radius of the road segment in a particular time interval; only single-day planned incidents were included due to identification problems for multi-day incidents
Rainfall	BoM (AU) & NIWA (NZ)	Millimetres of rain	Amount of rainfall recorded at the closest weather station within a 25 kilometre radius of the road segment in a particular time interval

A.7.2 Model Specification

The following functional form is used to estimate the impact that observable congestion drivers have on travel time.

$$TT_t = \mu + \alpha \cdot TT_{t-1} + \sum_{i=1}^{4} \sum_{j=0}^{2} \beta_{i,j} x_{i,t-j} + \gamma \cdot weekday + \varepsilon_t$$

Where:

- TT_t denotes the observed travel time for a given road segment at time t;
- $x_{i,t-j}$ denotes the i^{th} congestion driver in the sample, lagged by j periods; and
- γ captures the fixed effects associated with systematic variations between weekdays and weekends

The rationale for the various elements of our model specification is outlined below.

Lag and autoregressive structures of the model

The dynamic nature of how travel time responds to the various drivers of congestion requires us to consider autoregressive properties and distributed lags in specifying the model. In particular, travel time responds to the drivers of congestion not just with respect to current conditions, but also with respect to previous conditions. For example, precipitation could cause contemporaneous reductions in vehicle speed due to decreased visibility, but it can also cause a reduction in vehicle speeds in subsequent periods due to road surfaces remaining wet for hours after the initial rainfall.

To capture this persistent response, we introduce a distributed lag structure to the regression model for each of the independent variables (i.e. the congestion drivers). An appropriate lag structure for the independent variables was chosen based on an examination of the relevant t-statistics; ultimately, two lags have been included in the model for each of the congestion drivers.

However, the resulting finite lag model imposes strong and possibly incorrect restrictions on the lagged response of the dependent variable (travel time) to changes in an independent variable (one or more of the congestion drivers). Specifically, the model requires that the random errors are serially independent – that is, random errors across time must not be correlated. This assumption is likely to be violated since the random error associated with the current period's travel time is likely to be a result of unobserved traffic behaviorand its impact is likely to persistent over time.

Without correcting for this error, the model estimates are likely to be biased and inconsistent. In order to account for this, we therefore introduce a one-period lag of the travel time dependent variable into the regression, to capture the possible autoregressive characteristics of the random errors.

Structural breaks in the travel time-traffic volume relationship

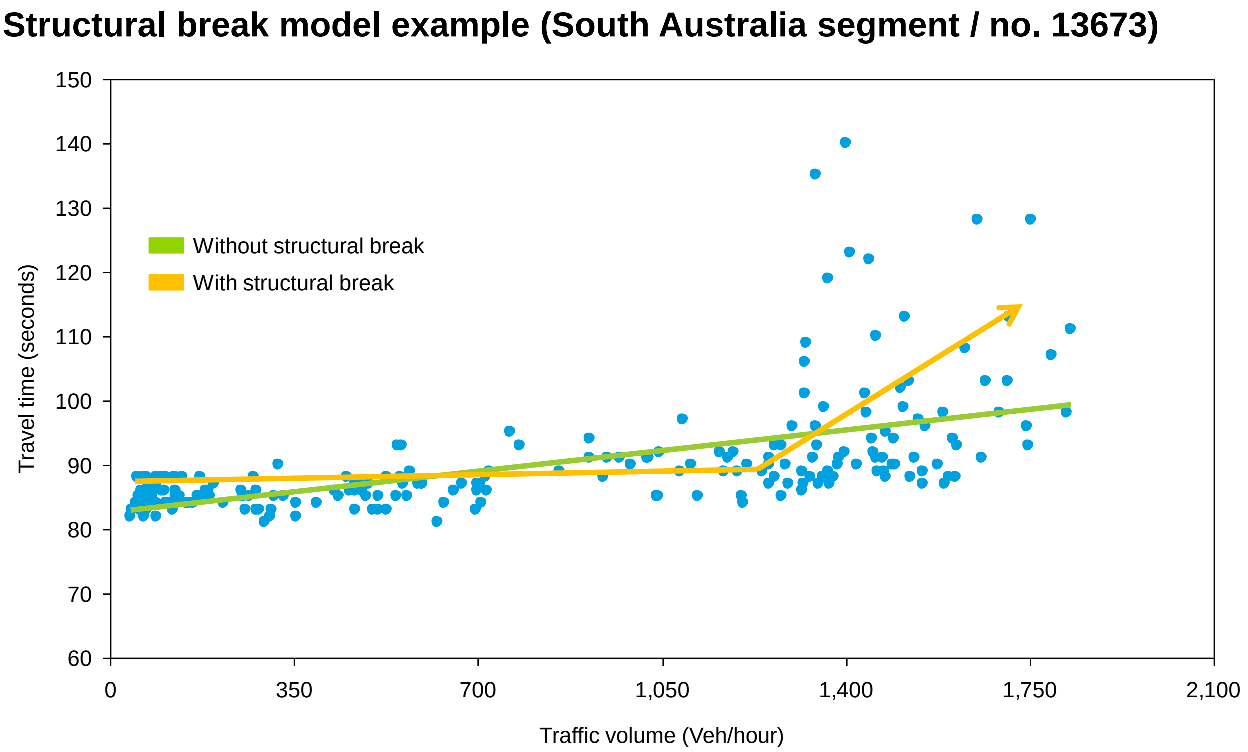
The relationship between travel time and traffic volume is complex. When a road is below full capacity, additional vehicles are not expected to impact upon travel times. However, the impact of extra vehicles on travel time when a road is at or above full capacity is likely to be significant. As such, the relationship between travel time and traffic volume is closer to an exponential function than a linear one.

For example, Exhibit A.6.1 shows that travel time displays little relationship with traffic volume until the road approaches full capacity, at around 1200 vehicles per hour. In other words, there is a 'structural break' in the relationship around the point where the road reaches full capacity.

We capture this structural break in the model by introducing an additional 'excess traffic volume' variable. This variable measures traffic volumes above the 90th percentile of all observed traffic volumes for each road segment.[135] The inclusion of this excess traffic volume variable allows the model to identify the impact that traffic volumes above a certain threshold have on travel time, without compromising any pre-existing relationship for traffic volumes below this threshold.

Exhibit A.5.1 also depicts how the model measures the relationship between traffic volume and travel time both with and without the structural break. Including the excess traffic volume variable to account for the structural break, as represented by the yellow line, clearly results in a better fit to the data.

Exhibit A.6.1: Travel time displays little relationship with traffic volume until roads approach full capacity, when traffic volume impact starts increasing exponentially



Fixed effects associated with weekdays and weekends

There are several factors that are likely to systematically vary between weekdays and weekends in impacting on travel times and traffic conditions. This can include traffic management tools that are used to manage congestion, such as clearways and traffic light signals. It also includes driver behaviour, which can be significantly different between weekdays and weekends. We use a fixed effects estimator that differentiates between weekdays and weekends to account for such variations across these two types of days.

Computing the relative impacts of the drivers of congestion

The output from running the regression model is a set of coefficients that estimate the relationship between travel time and the various congestion drivers. We then need to use these results to calculate the relative contribution of the different congestion drivers to variations in travel time, i.e. explain the relative impact of the drivers on overall congestion.

135 Excess traffic volume above the 90th percentile is used as a proxy for the road being at approximately full capacity, given we cannot observe the capacity of each road in the sample. In the event that traffic volumes do not reach full capacity for any given road over the period where observations were collected, the excess traffic volume variable will exhibit no statistically significant relationship with travel time, meaning that the relationship is the same as for traffic volumes below the 90th percentile.

This breakdown can be calculated using Shapley-Owen ("Shapley") values, which are used to decompose the relative impact of each independent variable (i.e. each congestion driver) on the dependent variable (i.e. travel time). It is important to note here that the Shapley decomposition is computed based on the R^2 of the model estimation. This means that it only measures the relative contribution of independent variables to the *explained* variation in the dependent variable. Unexplained variations (i.e. random errors) are not accounted for in the decomposition.

The Shapley value for a particular independent variable x_i calculates the marginal contribution that including x_i in the model has on the explained variation in the dependent variable, as measured by the R^2. This is then weighted by the number of permutations represented by this sub-model for x_i, with the partial R_i^2 for variable x_i given by:

$$R_i^2 = \sum_{T \subseteq Z \{x_i\}} \frac{k! \cdot (p-k-1)!}{p!} [R^2(T \cup \{x_i\}) - R^2(T)]$$

Where:

- T is the model with k variables but without variable x_i;
- $T \cup \{x_i\}$ is the same model but with x_i included; and
- Z is the set containing all models with all possible combinations of regressors.

The Shapley value for a particular variable x_i requires the computation of all 2^p possible models, one for each k combination of models with p variables. Computationally, all 2^p of the partial R_i^2 values can be calculated efficiently from the variance-covariance matrix. Once a vector of these values is available, the Shapley values can be computed by iterating over each variable and summing the weighted marginal contributions.

The inclusion of an autoregressive term in our model specification slightly complicates the computation of the Shapley value, as the autoregressive term reflects the persistence of congestion, but does not directly add any explanatory value to the congestion driver variables. We address this by further decomposing the relative contribution of the autoregressive term to the R^2 using the Shapley values of the other independent variables. This approach can be considered as a geometric convergence process, where the R^2 contribution of each explanatory variable is repeatedly applied to the R^2 contribution of the autoregressive term for each sample period.

Aggregation of segment results for each jurisdiction

The regression model was fitted for each road segment using the data collected for that segment over the September and October 2015 observation period. Shapely values were subsequently computed for each of the independent variables (i.e. each congestion driver).

To aggregate the results from each road segment for each of the 10 jurisdictions in this analysis, we take a weighted average of the Shapley values for each congestion driver across all road segments relevant to a particular jurisdiction. The weights used are based on the total deviation of observations from the minimum travel time and the respective traffic volumes. This means that roads that are relatively more congested and have relatively higher traffic volumes will have larger weights in calculating the relative impacts of each congestion driver at the overall jurisdiction level.

Appendix B Congestion Performance Outputs – City-Specific

Chapter 3 outlined the congestion performance of ANZ cities. This section details the congestion performance outputs for each individual city.[136]

B.1 Sydney Congestion Performance

Sydney's CBD is on the harbour, with secondary CBDs in Parramatta, North Sydney, Bankstown and Liverpool. Its location means that the main CBD is serviced by harbour crossings, with a network of roads supporting population sprawl to the west. Sydney has a main orbital road network, largely made up of toll roads, running from the airport to the North Shore, to the Hills District in the west, and Prestons in the South. The extensive road network directly supports around 75% of the 17.6 million trips made every weekday.[137] Only roads greater than 5km long are included in this analysis, to reduce the impact of smaller roads with lower speed limits affecting the analysis.

City Characteristics - Sydney

Source: Google Maps

136 TMR notes that results from the department's strategic transport modelling and traffic count program do not align with the Report's analysis as presented here, nor are they reflective of current network performance data which is used to prioritise future investment

137 http://www.parliament.nsw.gov.au/Prod/parlment/publications.nsf/0/BCAA5CD768F85900CA257E6F0000536E/$File/Sydney%20 Roads%20-%20Briefing%20Paper%20FINAL.pdf

Average Speed

Sydney Slowest Roads[1]

Km / hr

Rank	Road	City	Avg Speed
1	Harris St	Sydney	14.5
2	Cleveland St	Sydney	17.1
3	South Dowling St	Sydney	17.2
4	Stacey St	Sydney	18.3
5	Military Rd	Sydney	18.7
6	Lane Cove Rd	Sydney	18.9
7	Church St	Sydney	19.5
8	Oxford St	Sydney	20.4
9	Parramatta Rd	Sydney	20.6
10	New South Head Rd	Sydney	21.9

Sydney Fastest Roads[1]

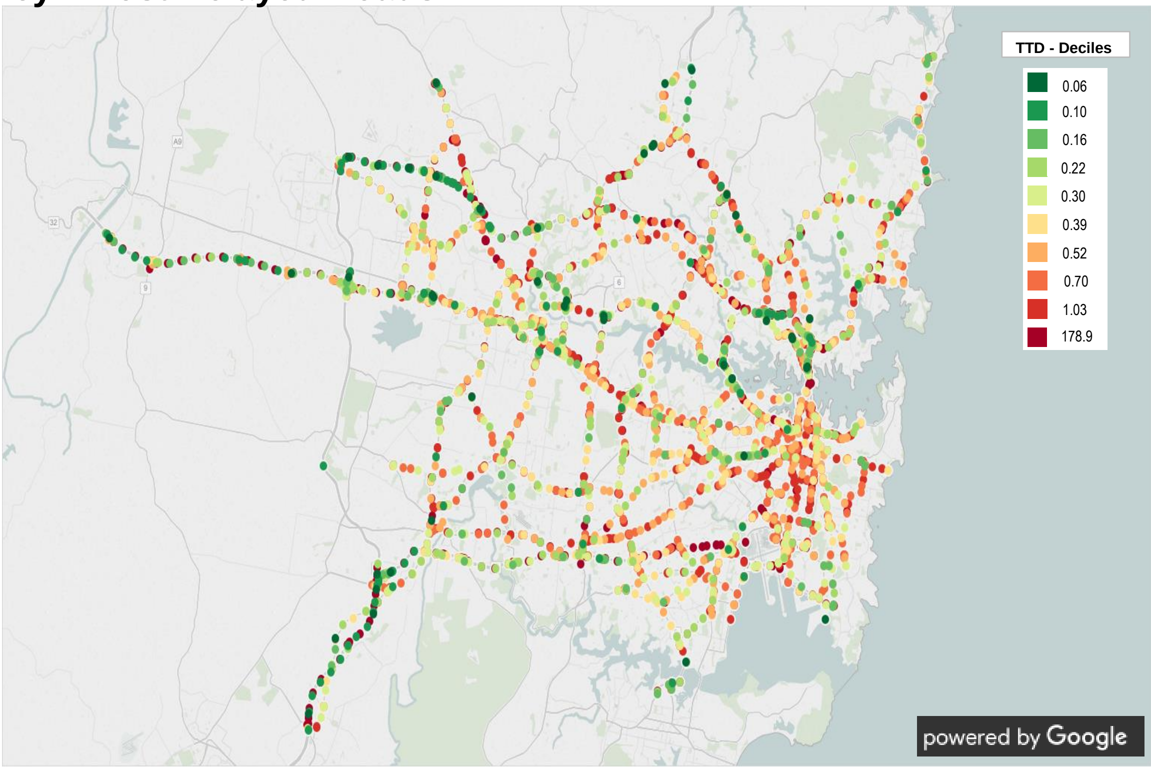
Km / hr

Rank	Road	City	Avg Speed
1	Hume Mtwy	Sydney	97.9
2	M7 (West)	Sydney	86.5
3	Pacific Mtwy	Sydney	81.1
4	South Western Mtwy	Sydney	76.6
5	M7 (North West)	Sydney	70.3
6	M2 Hills Mtwy	Sydney	69.5
7	Gore Hill Freeway	Sydney	64.8
8	M4 Western Mtwy	Sydney	62.8
9	Warringah Freeway	Sydney	53.2
10	Campbelltown Rd	Sydney	51.5

Note: 1. For roads longer than 5km
Source: Google maps data 2015-09-09 to 2015-10-29

Travel Time Delay

Sydney - Most Delayed Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Sydney Most Delayed Roads[1]
% of Min Time

Rank	Road	City	Delay
1	Centenary Drive	Sydney	77.4
2	M5 East Freeway	Sydney	69.2
3	Lane Cove Rd	Sydney	64.9
4	Epping Rd	Sydney	63.6
5	Homebush Bay Drive	Sydney	63.0
6	Eastern Distributor Mtwy	Sydney	60.2
7	Cahill Expressway	Sydney	59.4
8	Southern Cross Drive	Sydney	58.4
9	Cleveland St	Sydney	53.2
10	New South Head Rd	Sydney	49.7

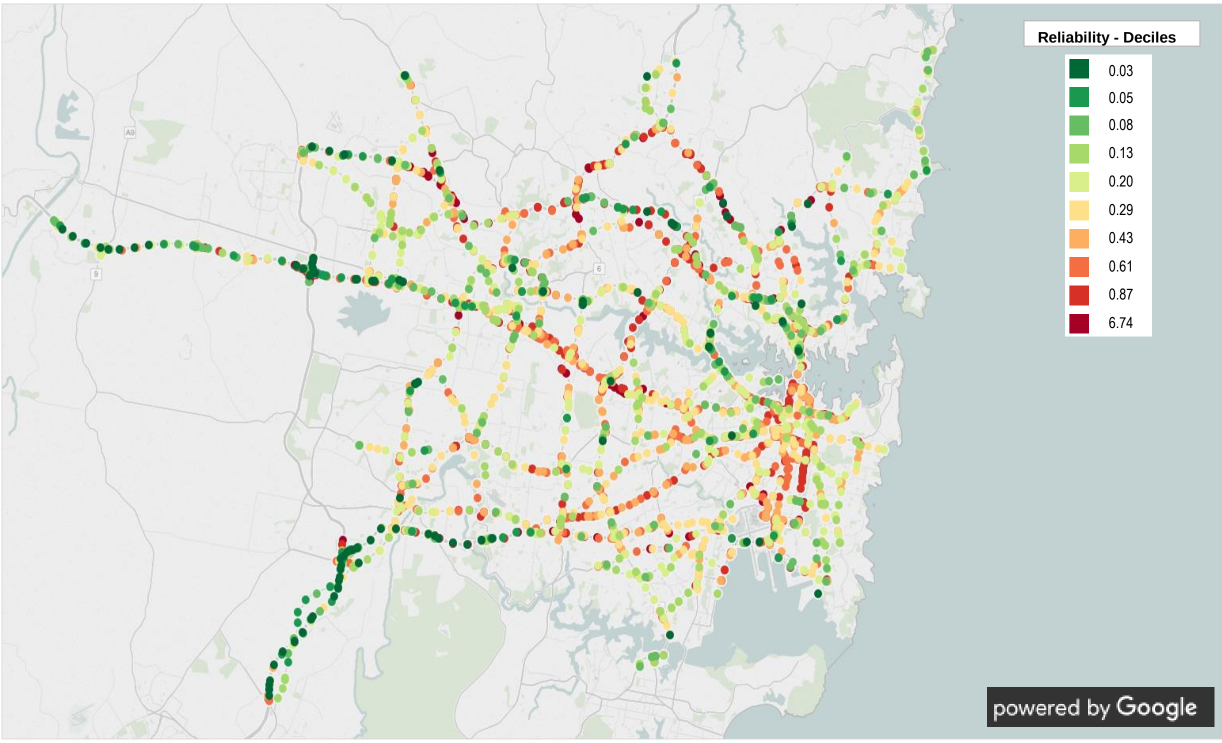
Sydney Least Delayed Roads[1]
% of Min Time

Rank	Road	City	Delay
1	Hume Mtwy	Sydney	5.3
2	M7 (West)	Sydney	10.7
3	Campbelltown Rd	Sydney	12.6
4	Pacific Mtwy	Sydney	13.3
5	Burns Bay Rd	Sydney	16.1
6	Gore Hill Freeway	Sydney	17.4
7	M7 (North West)	Sydney	21.8
8	South Western Mtwy	Sydney	22.0
9	Richmond Rd	Sydney	22.8
10	Pittwater Rd	Sydney	22.9

Note: 1. Delay defined as (mean travel time for 24 hours/minimum travel time for 24 hours) -1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Reliability (3pm to 7pm)

Sydney - Most Reliable Afternoon Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Sydney Least Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Bradfield Highway	Sydney	72.3
2	M7 (North West)	Sydney	71.6
3	Warringah Freeway	Sydney	62.2
4	Cahill Expressway	Sydney	60.3
5	Western Distributor Freeway	Sydney	58.4
6	Foreshore Road	Sydney	44.0
7	M7 (West)	Sydney	43.6
8	M2 Hills Mtwy	Sydney	43.2
9	Southern Cross Drive	Sydney	40.7
10	Lane Cove Road	Sydney	39.5

Sydney Most Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Campbelltown Road	Sydney	3.4
2	Pittwater Road	Sydney	5.1
3	Richmond Road	Sydney	5.5
4	Bunnerong Road	Sydney	5.6
5	Hume Mtwy	Sydney	6.8
6	Prospect Highway	Sydney	7.9
7	Oxford Street	Sydney	8.1
8	Alison Road	Sydney	8.5
9	Victoria Road	Sydney	9.1
10	Woodville Road	Sydney	9.2

Note: 1. Reliability measured as (standard deviation for 3pm to 7pm/mean travel time for 3pm to 7pm) - 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Mean Scheduling (3pm to 7pm)

Sydney Worst Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	M7 (North West)	Sydney	116.5
2	Warringah Freeway	Sydney	102.3
3	Bradfield Highway	Sydney	86.9
4	Cahill Expressway	Sydney	85.9
5	Western Distributor Freeway	Sydney	76.7
6	Foreshore Road	Sydney	71.5
7	Homebush Bay Drive	Sydney	68.9
8	M2 Hills Mtwy	Sydney	63.0
9	Lane Cove Road	Sydney	62.9
10	Southern Cross Drive	Sydney	62.7

Sydney Best Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Ryde Road	Sydney	0.9
2	Hume Mtwy	Sydney	2.9
3	M7 (West)	Sydney	3.3
4	Pacific Mtwy	Sydney	3.6
5	Campbelltown Road	Sydney	4.0
6	Fairford Road	Sydney	7.0
7	Bunnerong Road	Sydney	8.5
8	Pittwater Road	Sydney	9.5
9	Richmond Road	Sydney	10.9
10	Alison Road	Sydney	10.9

Note: 1. (90th Percentile for 3pm – 7pm/mean travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Scheduling (3pm to 7pm)

Sydney Worst Afternoon Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Cahill Expressway	Sydney	196.4
2	Warringah Freeway	Sydney	175.4
3	Homebush Bay Drive	Sydney	175.3
4	Bradfield Highway	Sydney	171.9
5	Lane Cove Road	Sydney	168.6
6	M7 (North West)	Sydney	163.6
7	Southern Cross Drive	Sydney	157.7
8	Epping Road	Sydney	156.4
9	Centenary Drive	Sydney	154.6
10	Western Distributor Freeway	Sydney	151.3

Sydney Best Afternoon Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Hume Mtwy	Sydney	8.4
2	M7 (West)	Sydney	14.4
3	Campbelltown Road	Sydney	17.1
4	Pacific Mtwy	Sydney	17.4
5	Gore Hill Freeway	Sydney	31.0
6	Bunnerong Road	Sydney	34.3
7	Pittwater Road	Sydney	34.5
8	Burns Bay Road	Sydney	34.9
9	Richmond Road	Sydney	36.1
10	Ryde Road	Sydney	36.6

Note: 1. (90th Percentile for 3pm – 7pm/minimum travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

25 Most Delayed Roads – All Congestion Measures

Road	Avg Speed (km)	Travel Time Delay (%)	Aft. Peak Mean Scheduling (%)	Morn. Peak Scheduling (%)	Aft. Peak Scheduling (%)	Morn. Peak Unreliability (%)	Aft. Peak Unreliability (%)
Centenary Drive	31.4	77.4%	43.5%	137.7%	154.6%	34.2%	32.2%
M5 East Freeway	43.5	69.2%	26.5%	123.8%	113.9%	26.0%	17.8%
Lane Cove Road	18.9	64.9%	62.9%	104.2%	168.6%	27.2%	39.5%
Epping Road	33.2	63.6%	56.7%	119.3%	156.4%	35.6%	34.7%
Homebush Bay Drive	31.0	63.0%	68.9%	51.4%	175.3%	12.9%	37.1%
Eastern Distributor Mtwy	31.3	60.2%	43.9%	96.0%	130.6%	52.6%	28.9%
Cahill Expressway	38.1	59.4%	85.9%	127.7%	196.4%	45.1%	60.3%
Southern Cross Drive	46.7	58.4%	62.7%	122.2%	157.7%	43.3%	40.7%
Cleveland Street	17.1	53.2%	34.0%	82.9%	105.2%	26.4%	23.6%
New South Head Road	21.9	49.7%	22.3%	92.2%	83.0%	26.6%	19.5%
Canterbury Road	24.6	47.7%	29.2%	60.7%	90.9%	14.5%	16.9%
Military Road	18.7	46.8%	25.6%	70.4%	84.4%	12.3%	21.2%
Punchbowl Road	27.3	46.6%	48.3%	45.5%	117.4%	23.2%	27.4%
Concord Road	30.4	46.4%	37.1%	76.9%	100.6%	26.0%	29.7%
Harris Street	14.5	45.9%	12.6%	73.1%	64.3%	20.5%	17.7%
Silverwater Road	24.4	45.6%	53.4%	50.4%	123.4%	15.5%	27.8%
Bradfield Highway	43.7	45.5%	86.9%	113.7%	171.9%	44.2%	72.3%
South Dowling Street	17.2	45.0%	17.5%	69.0%	70.3%	21.3%	15.3%
Forest Road	23.6	44.1%	12.3%	55.7%	61.8%	13.6%	13.1%
Anzac Parade	25.6	42.8%	12.1%	75.7%	60.1%	23.4%	11.1%
Windsor Road	27.6	42.6%	23.7%	79.6%	76.4%	23.6%	15.6%
Western Distributor Freeway	44.9	42.2%	76.7%	131.5%	151.3%	52.4%	58.4%
Stacey Street	18.3	42.0%	23.0%	62.2%	74.7%	16.7%	15.6%
Oxford Street	20.4	40.6%	12.6%	54.6%	58.3%	13.8%	8.1%
Old Windsor Road	36.7	39.4%	24.1%	75.7%	73.0%	21.9%	15.6%

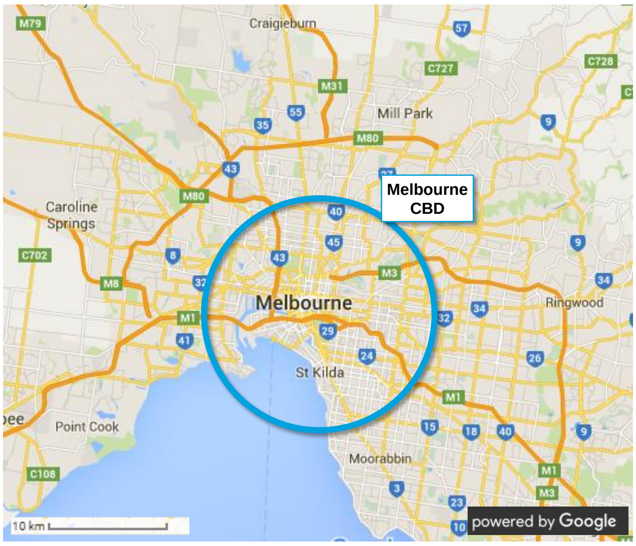
Source: Google maps data 2015-09-09 to 2015-10-29

B.2 Melbourne Congestion Performance

The Melbourne CBD is north of the Yarra River, with the majority of the city to the north, west and east, allowing for expansion despite it being close to the sea. The city centre is well serviced by trams, which share the roads with cars and buses. The CBD has a grid network structure reflecting a degree of urban planning.

Only roads greater than 5km long are included in this analysis, to reduce the impact of smaller roads with lower speed limits affecting the analysis.

City Characteristics – Melbourne



Average Speed

Melbourne Slowest Roads[1]
Km / hr

Rank	Road	City	Avg Speed
1	Punt Rd	Melbourne	16.1
2	Oriel Rd	Melbourne	19.7
3	Burke Rd	Melbourne	20.6
4	Williams Rd	Melbourne	23.6
5	McIntyre Rd	Melbourne	23.9
6	Middleborough Rd	Melbourne	24.2
7	Toorak Rd	Melbourne	25.5
8	Doncaster Rd	Melbourne	25.8
9	Sydney Rd	Melbourne	26.2
10	Milleara Rd	Melbourne	27.2

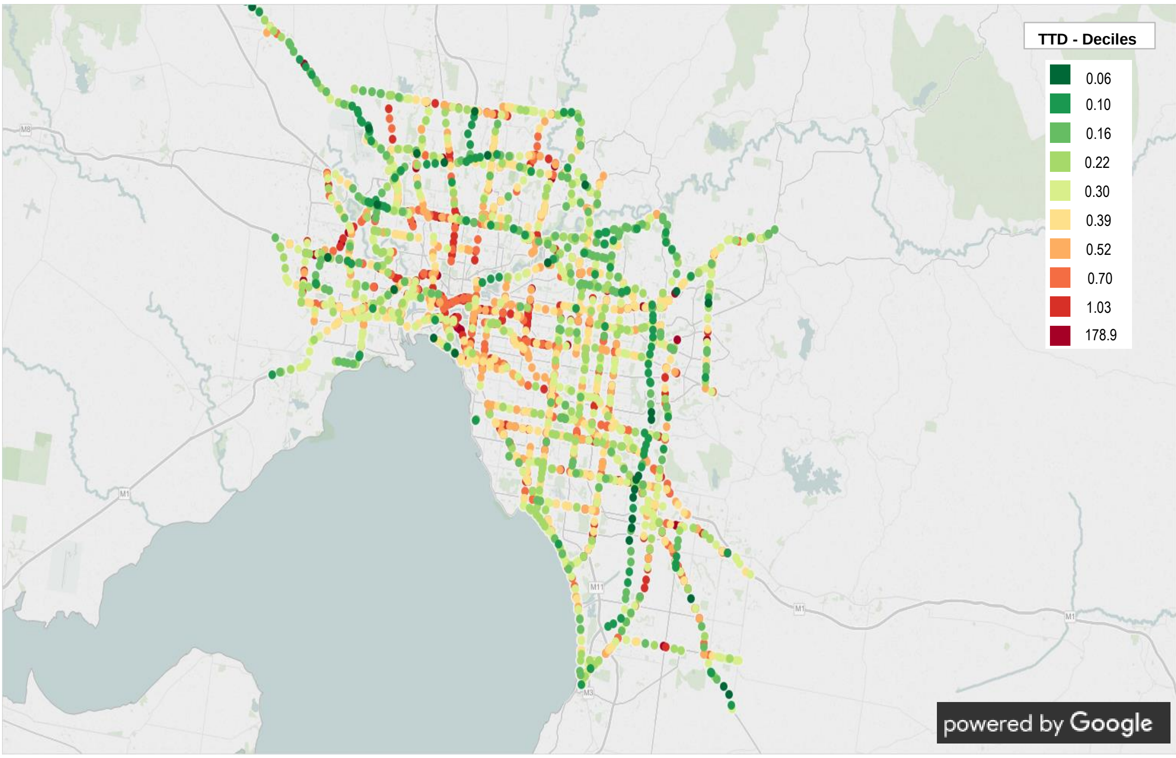
Melbourne Fastest Roads[1]
Km / hr

Rank	Road	City	Avg Speed
1	Eastlink	Melbourne	93.5
2	Western Freeway	Melbourne	90.9
3	Metropolitan Ring Rd	Melbourne	85.4
4	Princes Freeway	Melbourne	81.6
5	Eastern Freeway	Melbourne	80.7
6	Riddell Rd	Melbourne	80.2
7	Calder Freeway	Melbourne	78.3
8	Sunbury Rd	Melbourne	73.1
9	Tullamarine Freeway	Melbourne	71.4
10	Western Ring Rd	Melbourne	69.1

Note: 1. For roads over 5km
Source: Google maps data 2015-09-09 to 2015-10-29

Travel Time Delay

Melbourne - Most Delayed Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Melbourne Most Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Burke Rd	Melbourne	79.8
2	Punt Rd	Melbourne	71.1
3	Toorak Rd	Melbourne	67.2
4	Sydney Rd	Melbourne	57.8
5	Ferntree Gully Rd	Melbourne	47.2
6	Bell St	Melbourne	43.7
7	Monash Freeway	Melbourne	41.7
8	Hotham St	Melbourne	41.4
9	Plenty Rd	Melbourne	41.0
10	Williams Rd	Melbourne	40.0

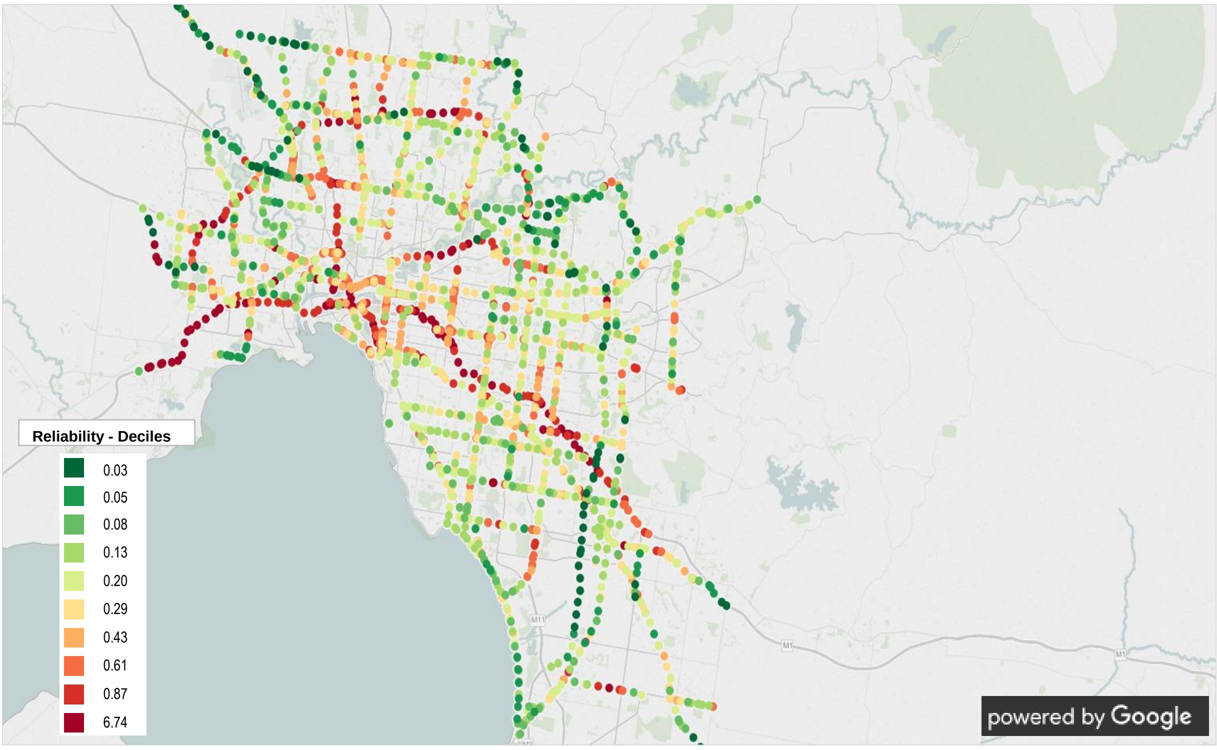
Melbourne Least Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Riddell Rd	Melbourne	2.4
2	Eastlink	Melbourne	4.7
3	Eastern Freeway	Melbourne	6.5
4	Sunbury Rd	Melbourne	9.1
5	Civic Parade	Melbourne	11.3
6	King St	Melbourne	13.1
7	Metropolitan Ring Rd	Melbourne	14.5
8	Oriel Rd	Melbourne	14.6
9	Yan Yean Rd	Melbourne	14.8
10	Thompsons Rd	Melbourne	15.7

Note: 1. Delay defined as (mean travel time for 24 hours/minimum travel time for 24 hours) -1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Reliability (3pm to 7pm)

Melbourne - Most Reliable Afternoon Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Melbourne Least Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Princes Freeway	Melbourne	183.8
2	West Gate Freeway	Melbourne	59.7
3	Monash Freeway	Melbourne	55.0
4	Eastern Freeway	Melbourne	50.0
5	Citylink	Melbourne	45.0
6	Metropolitan Ring Road	Melbourne	44.3
7	Western Freeway	Melbourne	43.4
8	Western Ring Road	Melbourne	39.4
9	Bell Street	Melbourne	34.9
10	Hall Road	Melbourne	34.4

Melbourne Most Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Riddell Road	Melbourne	0.9
2	Civic Parade	Melbourne	3.3
3	Eastlink	Melbourne	3.3
4	Heidelberg-Warrandyte Road	Melbourne	3.5
5	Oriel Road	Melbourne	5.1
6	King Street	Melbourne	5.1
7	Nepean Highway	Melbourne	5.4
8	Maroondah Highway	Melbourne	5.4
9	Berwick-Cranbourne Road	Melbourne	5.6
10	Sherbourne Road	Melbourne	5.6

Note: 1. Reliability measured as (standard deviation for 3pm to 7pm/mean travel time for 3pm to 7pm) - 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Mean Scheduling (3pm to 7pm)

Melbourne Worst Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Monash Freeway	Melbourne	115.5
2	West Gate Freeway	Melbourne	87.5
3	Citylink	Melbourne	69.6
4	Eastern Freeway	Melbourne	63.8
5	Bell Street	Melbourne	62.0
6	Hall Road	Melbourne	56.7
7	Western Ring Road	Melbourne	53.2
8	Fitzsimons Lane	Melbourne	52.5
9	Burke Road	Melbourne	42.6
10	Cooper Street	Melbourne	37.7

Melbourne Best Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Calder Freeway	Melbourne	-8.6
2	Western Freeway	Melbourne	-7.9
3	Riddell Road	Melbourne	0.4
4	Eastlink	Melbourne	1.0
5	Sunbury Road	Melbourne	3.0
6	Heidelberg-Warrandyte Road	Melbourne	3.2
7	Geelong Road	Melbourne	3.3
8	Beach Road	Melbourne	3.8
9	Civic Parade	Melbourne	5.1
10	Warrandyte Road	Melbourne	5.2

Note: 1. (90th Percentile for 3pm – 7pm/mean travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Scheduling (3pm to 7pm)

Melbourne Worst Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Monash Freeway	Melbourne	205.3
2	West Gate Freeway	Melbourne	157.8
3	Burke Road	Melbourne	156.5
4	Bell Street	Melbourne	132.8
5	Citylink	Melbourne	127.8
6	Toorak Road	Melbourne	123.6
7	Punt Road	Melbourne	121.7
8	Fitzsimons Lane	Melbourne	108.0
9	Hall Road	Melbourne	104.2
10	Western Ring Road	Melbourne	103.9

Melbourne Best Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Riddell Road	Melbourne	2.8
2	Eastlink	Melbourne	3.8
3	Calder Freeway	Melbourne	7.9
4	Western Freeway	Melbourne	8.1
5	Sunbury Road	Melbourne	10.6
6	Civic Parade	Melbourne	13.5
7	Heidelberg-Warrandyte Road	Melbourne	14.8
8	Beach Road	Melbourne	20.4
9	Oriel Road	Melbourne	21.0
10	King Street	Melbourne	22.1

Note: 1. (90th Percentile for 3pm – 7pm/minimum travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

25 Most Delayed Roads – All Congestion Measures

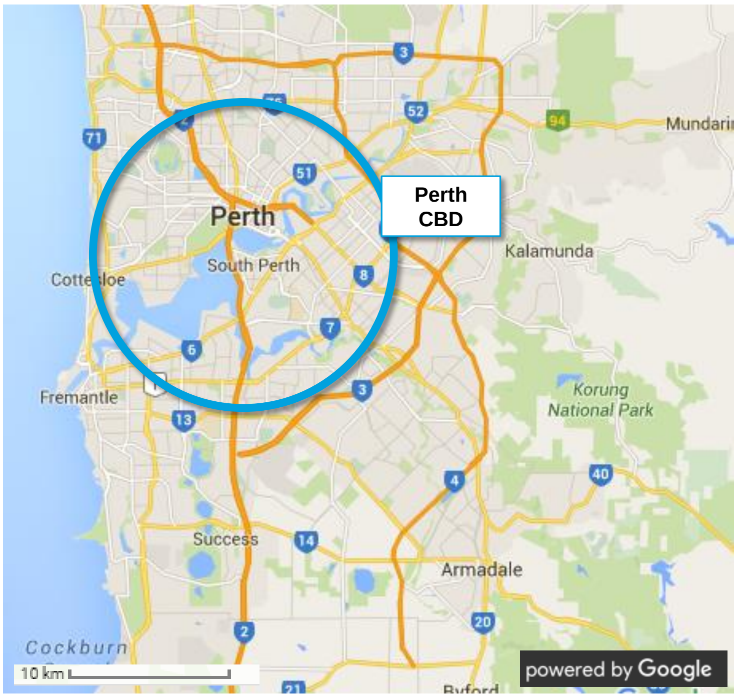
Road	Avg Speed (km)	Travel Time Delay (%)	Aft. Peak Mean Scheduling (%)	Morn. Peak Scheduling (%)	Aft. Peak Scheduling (%)	Morn. Peak Unreliability (%)	Aft. Peak Unreliability (%)
Burke Road	20.6	79.8%	42.6%	106.5%	156.5%	27.9%	24.6%
Punt Road	16.1	71.1%	29.6%	99.9%	121.7%	24.8%	21.6%
Toorak Road	25.5	67.2%	33.8%	103.0%	123.6%	30.0%	22.8%
Sydney Road	26.2	57.8%	19.9%	65.7%	89.2%	17.0%	13.0%
Ferntree Gully Road	28.9	47.2%	33.8%	69.3%	96.9%	25.2%	22.3%
Bell Street	28.5	43.7%	62.0%	55.7%	132.8%	19.5%	34.9%
Monash Freeway	62.2	41.7%	115.5%	35.1%	205.3%	14.1%	55.0%
Hotham Street	28.5	41.4%	11.7%	98.2%	58.0%	32.4%	12.1%
Plenty Road	29.4	41.0%	17.2%	73.2%	65.3%	25.3%	11.3%
Williams Road	23.6	40.0%	30.0%	46.6%	82.0%	15.3%	18.2%
Cooper Street	40.1	38.5%	37.7%	40.7%	90.7%	10.5%	21.1%
Barkers Road	28.8	38.4%	20.1%	62.1%	66.2%	19.0%	14.4%
West Gate Freeway	60.1	37.5%	87.5%	20.9%	157.8%	8.1%	59.7%
Middleborough Road	24.2	37.1%	20.0%	56.1%	64.5%	18.4%	12.0%
Police Road	27.8	36.8%	19.9%	70.0%	64.0%	22.2%	14.8%
Fitzsimons Lane	37.3	36.4%	52.5%	66.1%	108.0%	26.7%	33.0%
Doncaster Road	25.9	36.0%	20.7%	44.3%	64.1%	15.5%	15.9%
North Road	29.8	34.6%	19.7%	65.9%	61.1%	22.7%	12.8%
Citylink	55.8	34.3%	69.6%	48.3%	127.8%	18.8%	45.0%
Western Ring Road	69.1	33.1%	53.2%	61.2%	103.9%	26.7%	39.4%
Springvale Road	32.3	32.8%	23.4%	48.9%	63.9%	15.3%	12.6%
Mitcham Road	35.6	32.7%	21.8%	43.0%	61.6%	12.2%	12.6%
Whitehorse Road	32.6	32.7%	14.1%	48.2%	51.4%	13.2%	9.4%
Centre Road	28.4	31.4%	12.9%	37.5%	48.4%	13.8%	7.4%
Station Road	29.7	31.3%	30.0%	41.7%	70.7%	20.5%	19.3%

Source: Google maps data 2015-09-09 to 2015-10-29

B.3 Perth Congestion Performance

Perth is north of the Swan River. The city has room for expansion despite its location on the west coast of Australia. Urban planning since its foundation has provided it with a grid network structure.

City Characteristics – Perth



Source: Google Maps

Average Speed

Perth Slowest Roads[1]
Km / hr

Rank	Road	City	Avg Speed
1	Shepperton Rd	Perth	31.2
2	Stirling Highway	Perth	33.0
3	Karrinyup Rd	Perth	37.9
4	Canning Highway	Perth	38.1
5	Morley Drive	Perth	38.3
6	Orrong Rd	Perth	40.6
7	South St	Perth	41.6
8	Kenwick Link	Perth	42.8
9	Guildford Rd	Perth	43.4
10	Leach Highway	Perth	49.8

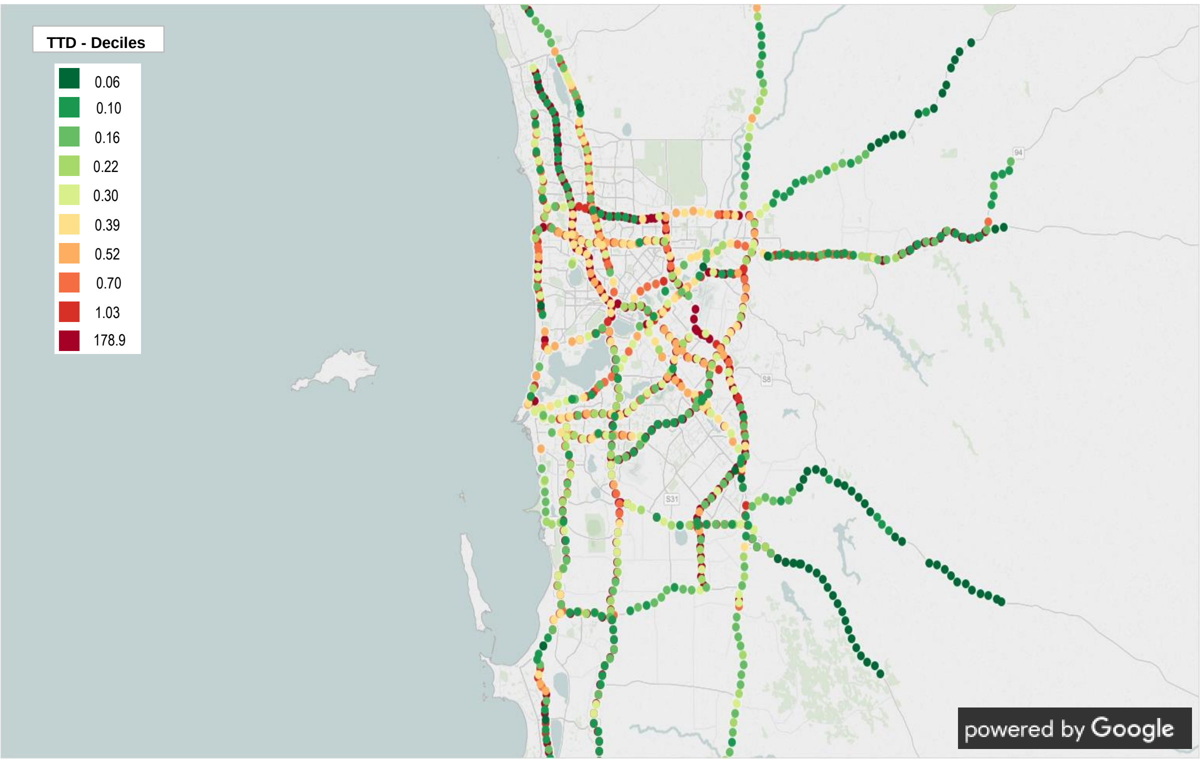
Perth Fastest Roads[1]
Km / hr

Rank	Road	City	Avg Speed
1	Brookton Highway	Perth	86.4
2	Kwinana Freeway	Perth	84.2
3	Toodyay Rd	Perth	82.2
4	Mitchell Freeway	Perth	76.2
5	Great Northern Highway	Perth	75.8
6	Graham Farmer Freeway	Perth	74.1
7	South Western Highway	Perth	73.7
8	Mandurah Rd	Perth	71.9
9	Roe Highway	Perth	71.0
10	Ennis Ave	Perth	67.8

Note: 1. For roads over 5km
Source: Google maps data 2015-09-09 to 2015-10-29

Travel Time Delay

Perth - Most Delayed Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Perth Most Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Reid Highway	Perth	32.9
2	Tonkin Highway	Perth	32.7
3	Orrong Rd	Perth	32.3
4	Canning Highway	Perth	27.9
5	Karrinyup Rd	Perth	27.0
6	Shepperton Rd	Perth	26.5
7	South St	Perth	25.0
8	Mitchell Freeway	Perth	24.1
9	Morley Drive	Perth	23.7
10	Stirling Highway	Perth	23.4

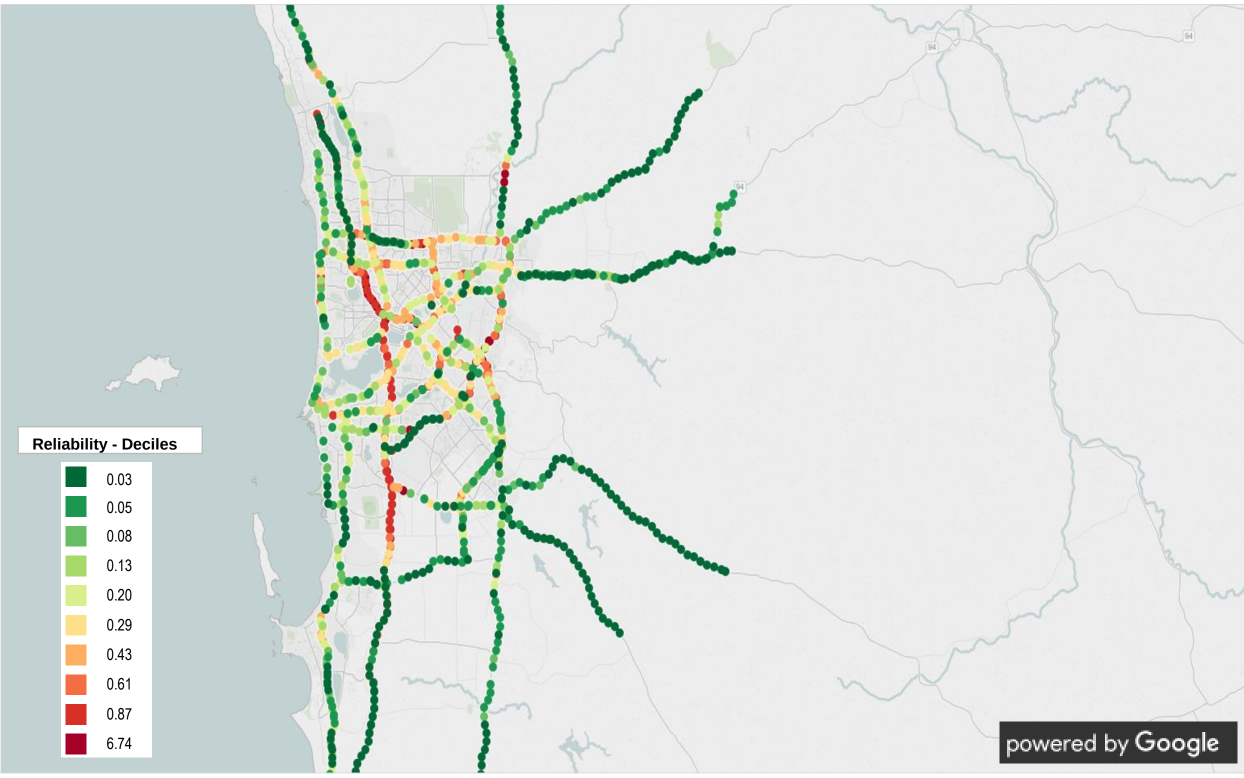
Perth Least Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Brookton Highway	Perth	1.6
2	Toodyay Rd	Perth	3.7
3	South Western Highway	Perth	5.8
4	Graham Farmer Freeway	Perth	7.3
5	Thomas Rd	Perth	8.9
6	Mandurah Rd	Perth	9.8
7	Mounts Bay Rd	Perth	10.0
8	Great Northern Highway	Perth	10.2
9	Great Eastern Highway	Perth	10.4
10	Patterson Rd	Perth	10.5

Note: 1. Delay defined as (mean travel time for 24 hours/minimum travel time for 24 hours) -1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Reliability (3pm to 7pm)

Perth - Most Reliable Afternoon Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Perth Least Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Graham Farmer Freeway	Perth	33.2
2	Mitchell Freeway	Perth	26.4
3	Kwinana Freeway	Perth	24.6
4	Orrong Road	Perth	14.8
5	Roe Highway	Perth	14.4
6	Reid Highway	Perth	14.2
7	Tonkin Highway	Perth	12.6
8	West Coast Highway	Perth	11.8
9	Morley Drive	Perth	11.6
10	Kenwick Link	Perth	11.1

Perth Most Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Brookton Highway	Perth	0.6
2	Toodyay Road	Perth	0.7
3	Thomas Road	Perth	1.8
4	South Western Highway	Perth	2.1
5	Cockburn Road	Perth	2.2
6	Mandurah Road	Perth	2.7
7	Marmion Avenue	Perth	3.7
8	Albany Highway	Perth	3.8
9	Great Eastern Highway	Perth	3.9
10	Wanneroo Road	Perth	5.9

Note: 1. Reliability measured as (standard deviation for 3pm to 7pm/mean travel time for 3pm to 7pm) - 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Mean Scheduling (3pm to 7pm)

Perth Worst Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Mitchell Freeway	Perth	39.4
2	Kwinana Freeway	Perth	28.6
3	Reid Highway	Perth	20.2
4	Orrong Road	Perth	18.8
5	West Coast Highway	Perth	18.6
6	Morley Drive	Perth	17.6
7	Tonkin Highway	Perth	16.9
8	Roe Highway	Perth	13.8
9	Canning Highway	Perth	12.3
10	Kenwick Link	Perth	12.1

Perth Best Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Toodyay Road	Perth	0.0
2	Brookton Highway	Perth	0.4
3	Thomas Road	Perth	1.6
4	South Western Highway	Perth	1.9
5	Cockburn Road	Perth	2.8
6	Mandurah Road	Perth	3.4
7	Patterson Road	Perth	4.4
8	Great Eastern Highway	Perth	4.8
9	Marmion Avenue	Perth	5.0
10	Albany Highway	Perth	5.6

Note: 1. (90th Percentile for 3pm – 7pm/mean travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Scheduling (3pm to 7pm)

Perth Worst Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Mitchell Freeway	Perth	72.9
2	Reid Highway	Perth	59.7
3	Orrong Road	Perth	57.2
4	Tonkin Highway	Perth	55.1
5	Kwinana Freeway	Perth	53.8
6	Morley Drive	Perth	45.5
7	Canning Highway	Perth	43.6
8	Shepperton Road	Perth	41.8
9	Karrinyup Road	Perth	40.0
10	South Street	Perth	38.4

Perth Best Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Brookton Highway	Perth	2.1
2	Toodyay Road	Perth	3.7
3	South Western Highway	Perth	7.8
4	Thomas Road	Perth	10.7
5	Mandurah Road	Perth	13.5
6	Cockburn Road	Perth	13.6
7	Graham Farmer Freeway	Perth	14.4
8	Patterson Road	Perth	15.3
9	Great Eastern Highway	Perth	15.6
10	Mounts Bay Road	Perth	17.3

Note: 1. (90th Percentile for 3pm – 7pm/minimum travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

25 Most Delayed Roads – All Congestion Measures

Road	Avg Speed (km)	Travel Time Delay (%)	Aft. Peak Mean Scheduling (%)	Morn. Peak Scheduling (%)	Aft. Peak Scheduling (%)	Morn. Peak Unreliability (%)	Aft. Peak Unreliability (%)
Reid Highway	53.2	32.9%	20.2%	52.1%	59.7%	13.8%	14.2%
Tonkin Highway	59.1	32.7%	16.9%	51.3%	55.1%	12.9%	12.6%
Orrong Road	40.6	32.3%	18.8%	49.9%	57.2%	15.3%	14.8%
Canning Highway	38.1	27.9%	12.3%	38.0%	43.6%	16.5%	8.1%
Karrinyup Road	37.9	27.0%	10.2%	38.6%	40.0%	10.6%	7.2%
Shepperton Road	31.2	26.5%	12.0%	34.1%	41.8%	11.3%	10.5%
South Street	41.6	25.0%	10.7%	32.8%	38.4%	8.6%	10.2%
Mitchell Freeway	76.2	24.1%	39.4%	67.9%	72.9%	30.1%	26.4%
Morley Drive	38.3	23.7%	17.6%	30.2%	45.5%	9.7%	11.6%
Stirling Highway	33.0	23.4%	10.6%	42.1%	36.5%	15.3%	7.7%
Leach Highway	49.8	22.7%	9.6%	39.4%	34.5%	12.5%	10.4%
Guildford Road	43.4	22.6%	9.6%	35.9%	34.4%	11.8%	9.8%
Kwinana Freeway	84.2	19.7%	28.6%	49.9%	53.8%	19.7%	24.6%
Roe Highway	71.0	19.2%	13.8%	35.4%	35.6%	13.9%	14.4%
Kenwick Link	42.8	19.2%	12.1%	31.5%	33.5%	10.1%	11.1%
Great Eastern Highway Bypass	61.5	18.6%	10.0%	25.9%	30.5%	8.0%	8.5%
West Coast Highway	52.4	16.5%	18.6%	26.3%	38.2%	10.5%	11.8%
Wanneroo Road	55.0	15.1%	8.9%	20.0%	25.4%	6.9%	5.9%
Stock Road	50.4	15.0%	7.0%	19.9%	23.0%	6.7%	6.9%
Armadale Road	50.7	13.4%	7.9%	16.3%	22.4%	7.1%	8.6%
Rockingham Road	62.6	13.4%	6.0%	22.7%	20.2%	6.3%	7.6%
Ennis Avenue	67.8	13.2%	7.9%	17.0%	22.1%	5.9%	6.5%
Albany Highway	55.6	12.9%	5.6%	13.6%	19.3%	3.7%	3.8%
Marmion Avenue	57.9	11.9%	5.0%	18.8%	17.5%	7.0%	3.7%
Cockburn Road	65.5	10.5%	2.8%	12.7%	13.6%	2.0%	2.2%

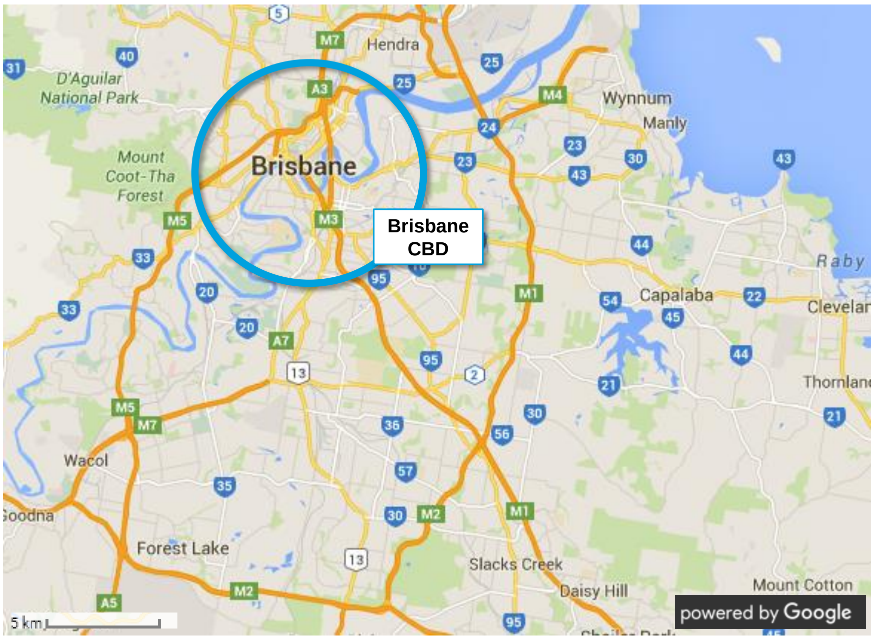
Source: Google maps data 2015-09-09 to 2015-10-29

B.4 Brisbane Congestion Performance

The Brisbane CBD is located on the Brisbane River, next to the sea. In total, there are nine road bridges and one road tunnel, mostly in the inner city area.

The city's growth has largely been to the west of the city. Brisbane's road network has been planned around main road corridors (such as Logan Road, Moggill Road, Old Cleveland Road and Gympie Road) linking suburbs to the CBD. Cross suburban motorways link arterial roads and main highways.

City Characteristics – Brisbane



Source: Google Maps

Average Speed

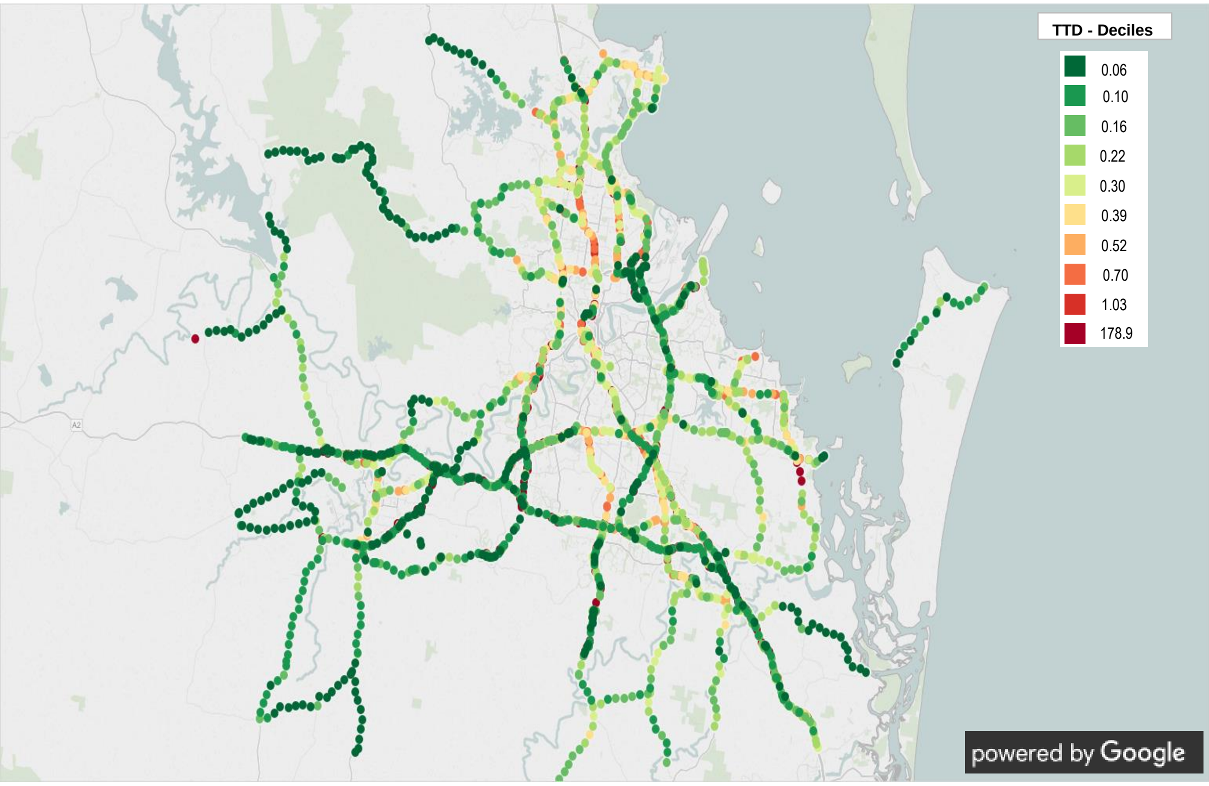
Brisbane Slowest Roads[1] Km / hr			
Rank	**Road**	**City**	**Avg Speed**
1	Logan Rd	Brisbane	33.7
2	Wembley Rd	Brisbane	34.2
3	Sandgate Rd	Brisbane	36.0
4	Warwick Rd	Brisbane	36.1
5	South Pine Rd	Brisbane	36.9
6	Albany Creek Rd	Brisbane	37.8
7	Mount Gravatt-Capalaba Rd	Brisbane	38.2
8	Gympie Rd	Brisbane	38.2
9	Birkdale Rd	Brisbane	38.6
10	Anzac Ave	Brisbane	40.1

Brisbane Fastest Roads[1] Km / hr			
Rank	**Road**	**City**	**Avg Speed**
1	Warrego Highway	Brisbane	91.4
2	Logan Mtwy	Brisbane	91.2
3	Cunningham Highway	Brisbane	89.8
4	Ipswich-Rosewood Rd	Brisbane	88.1
5	Wivenhoe-Somerset Rd	Brisbane	84.9
6	Ipswich-Boonah Rd	Brisbane	81.3
7	Centenary Highway	Brisbane	80.8
8	Serpentine Creek Rd	Brisbane	80.5
9	Ipswich Mtwy	Brisbane	80.0
10	Port of Brisbane Mtwy	Brisbane	79.6

Note: 1. . For roads over 5km
Source: Google maps data 2015-09-09 to 2015-10-29

Travel Time Delay

Brisbane - Most Delayed Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Brisbane Most Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Gympie Rd	Brisbane	36.9
2	Logan Rd	Brisbane	36.5
3	Western Freeway	Brisbane	35.6
4	Sandgate Rd	Brisbane	33.0
5	Riawena Rd	Brisbane	32.6
6	Wemberly Rd	Brisbane	30.2
7	Kessels Rd	Brisbane	30.0
8	Beaudesert Rd	Brisbane	29.1
9	Gympie Arterial Rd	Brisbane	29.0
10	South Pine Rd	Brisbane	26.8

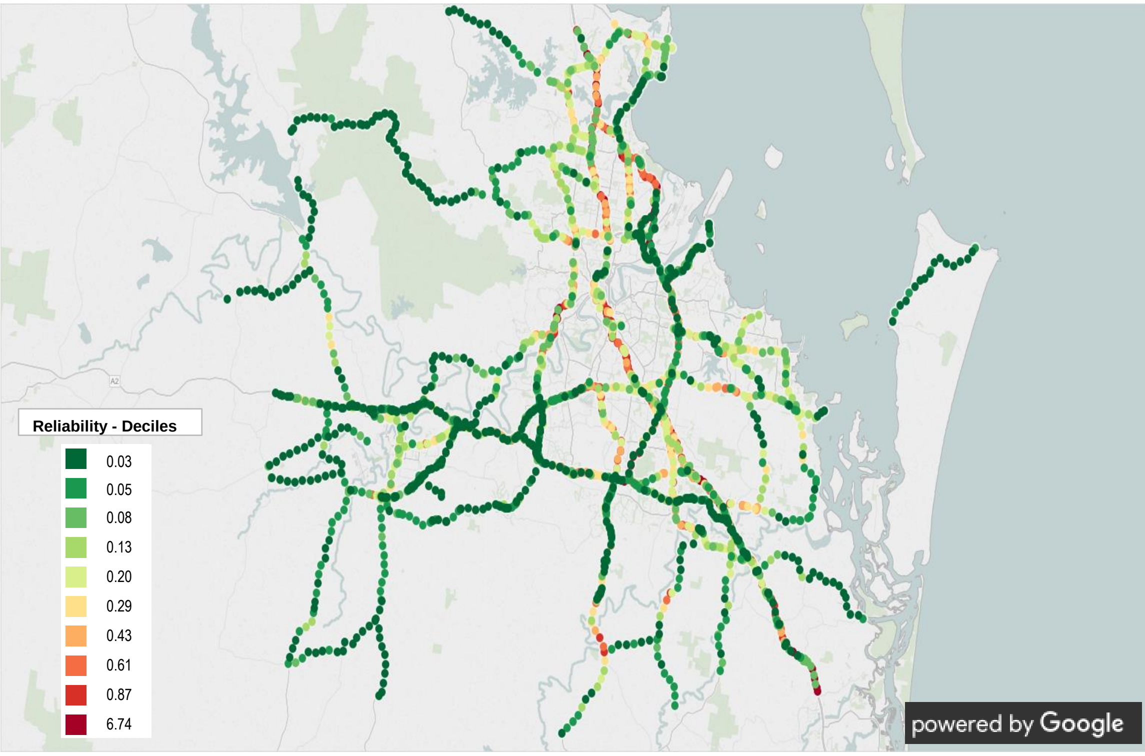
Brisbane Least Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Northbrook Parkway	Brisbane	0.7
2	Mount Glorious Rd	Brisbane	1.0
3	Ipswich-Rosewood Rd	Brisbane	1.2
4	Forest Hill-Ferndale Rd	Brisbane	1.2
5	Warrill View-Peak Crossing Rd	Brisbane	1.3
6	Karrabin Rosewood Rd	Brisbane	1.6
7	East Coast Rd	Brisbane	1.8
8	Wivenhoe-Somerset Rd	Brisbane	2.2
9	Warrego Highway	Brisbane	2.8
10	Cunningham Highway	Brisbane	3.2

Note: 1. Delay defined as (mean travel time for 24 hours/minimum travel time for 24 hours) -1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Reliability (3pm to 7pm)

Brisbane - Most Reliable Afternoon Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Brisbane Least Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Bruce Highway	Brisbane	75.3
2	Western Freeway	Brisbane	64.7
3	Gympie Arterial Road	Brisbane	47.8
4	Gateway Mtwy	Brisbane	31.4
5	Southern Cross Way	Brisbane	29.1
6	Pacific Mtwy	Brisbane	26.0
7	Riawena Road	Brisbane	23.5
8	Wembley Road	Brisbane	22.5
9	Gympie Road	Brisbane	17.8
10	Centenary Mtwy	Brisbane	17.5

Brisbane Most Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Ipswich-Rosewood Rd	Brisbane	0.4
2	Mount Glorious Road	Brisbane	0.5
3	East Coast Road	Brisbane	0.7
4	Karrabin Rosewood Rd	Brisbane	0.7
5	Wivenhoe-Somerset Rd	Brisbane	0.7
6	Forest Hill-Fernvale Rd	Brisbane	0.8
7	Northbrook Parkway	Brisbane	0.9
8	Warrill View-Peak Crossing Road	Brisbane	1.0
9	Centenary Mtwy	Brisbane	1.1
10	Ipswich-Boonah Road	Brisbane	1.2

Note: 1. Reliability measured as (standard deviation for 3pm to 7pm/mean travel time for 3pm to 7pm) - 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Mean Scheduling (3pm to 7pm)

Brisbane Worst Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Western Freeway	Brisbane	122.8
2	Gympie Arterial Road	Brisbane	72.8
3	Wembley Road	Brisbane	38.9
4	Southern Cross Way	Brisbane	36.3
5	Gateway Mtwy	Brisbane	34.0
6	Riawena Road	Brisbane	32.1
7	Logan Road	Brisbane	30.1
8	Pacific Mtwy	Brisbane	29.7
9	Boundary Road	Brisbane	28.5
10	Gympie Road	Brisbane	25.5

Brisbane Best Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Deagon Deviation	Brisbane	-1.7
2	Port Of Brisbane Mtwy	Brisbane	-0.9
3	Bruce Highway	Brisbane	-0.6
4	Ipswich-Boonah Road	Brisbane	-0.2
5	Forest Hill-Fernvale Road	Brisbane	0.3
6	Cunningham Highway	Brisbane	0.4
7	Wivenhoe-Somerset Road	Brisbane	0.5
8	Ipswich-Rosewood Road	Brisbane	0.5
9	Warrill View-Peak Crossing Road	Brisbane	0.5
10	Mount Glorious Road	Brisbane	0.5

Note: 1. (90th Percentile for 3pm – 7pm/mean travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Scheduling (3pm to 7pm)

Brisbane Worst Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Western Freeway	Brisbane	202.2
2	Gympie Arterial Road	Brisbane	122.9
3	Wembley Road	Brisbane	80.9
4	Logan Road	Brisbane	77.6
5	Riawena Road	Brisbane	75.2
6	Gympie Road	Brisbane	71.8
7	Sandgate Road	Brisbane	63.4
8	Pacific Mtwy	Brisbane	60.3
9	Gateway Mtwy	Brisbane	57.2
10	Boundary Rd	Brisbane	56.4

Brisbane Best Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Northbrook Parkway	Brisbane	1.3
2	Forest Hill-Fernvale Road	Brisbane	1.5
3	Mount Glorious Road	Brisbane	1.5
4	Ipswich-Rosewood Road	Brisbane	1.6
5	Warrill View-Peak Crossing Road	Brisbane	1.8
6	Karrabin Rosewood Road	Brisbane	2.4
7	East Coast Road	Brisbane	2.4
8	Wivenhoe-Somerset Road	Brisbane	2.6
9	Ipswich-Boonah Road	Brisbane	3.5
10	Cunningham Highway	Brisbane	3.6

Note: 1. (90th Percentile for 3pm – 7pm/minimum travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

25 Most Delayed Roads – All Congestion Measures

Road	Avg Speed (km)	Travel Time Delay (%)	Aft. Peak Mean Scheduling (%)	Morn. Peak Scheduling (%)	Aft. Peak Scheduling (%)	Morn. Peak Unreliability (%)	Aft. Peak Unreliability (%)
Gympie Road	38.2	36.9%	25.5%	57.0%	71.8%	17.6%	17.8%
Logan Road	33.7	36.5%	30.1%	46.1%	77.6%	14.1%	17.1%
Western Freeway	59.6	35.6%	122.8%	22.0%	202.2%	46.8%	64.7%
Sandgate Road	36.0	33.0%	22.9%	58.3%	63.4%	19.9%	16.6%
Riawena Road	44.0	32.6%	32.1%	63.9%	75.2%	19.9%	23.5%
Wembley Road	34.2	30.2%	38.9%	37.8%	80.9%	15.5%	22.5%
Kessels Road	40.7	30.0%	18.6%	38.2%	54.2%	14.0%	11.2%
Beaudesert Road	47.0	29.1%	16.8%	47.6%	50.8%	16.3%	16.3%
Gympie Arterial Road	74.0	29.0%	72.8%	59.4%	122.9%	40.9%	47.8%
South Pine Road	36.9	26.8%	15.3%	53.9%	46.2%	23.5%	10.4%
Birkdale Road	38.6	26.7%	10.8%	39.6%	40.4%	11.3%	6.8%
Bruce Highway	77.5	25.6%	-0.6%	172.0%	24.9%	70.9%	75.3%
Mount Gravatt-Capalaba Road	38.2	24.7%	15.5%	40.7%	44.0%	12.3%	10.4%
Moreton Bay Road	50.0	24.3%	22.9%	25.8%	52.8%	8.4%	15.2%
Kingston Road	40.3	24.0%	12.1%	34.1%	39.1%	10.4%	8.6%
Pacific Mtwy	71.7	23.6%	29.7%	61.1%	60.3%	26.5%	26.0%
Anzac Avenue	40.1	21.9%	11.1%	33.6%	35.5%	12.8%	8.8%
Finucane Road	45.5	21.9%	12.1%	34.0%	36.7%	11.4%	9.0%
Boundary Road	54.1	21.7%	28.5%	26.6%	56.4%	23.0%	16.9%
Cleveland-Redland Bay Road	42.1	21.5%	10.2%	28.4%	34.0%	6.6%	7.1%
Old Northern Road	48.4	20.8%	12.9%	37.6%	36.4%	17.4%	8.6%
Houghton Highway	66.6	20.0%	6.4%	21.9%	27.6%	7.1%	5.0%
Beenleigh-Redland Bay Road	55.7	19.8%	8.7%	38.3%	30.2%	13.7%	15.3%
Logan River Road	54.3	18.2%	7.5%	22.8%	27.0%	5.7%	5.7%
Brisbane Rd	41.6	17.9%	7.1%	27.5%	26.2%	9.1%	6.6%

Source: Google maps data 2015-09-09 to 2015-10-29

B.5 Adelaide Congestion Performance

Adelaide, the capital of South Australia, is located next to the sea with limited space for expansion. While it is not surrounded by an orbital network, the CBD is planned in a grid structure.

City Characteristics – Adelaide

Source: Google Maps

Average Speed

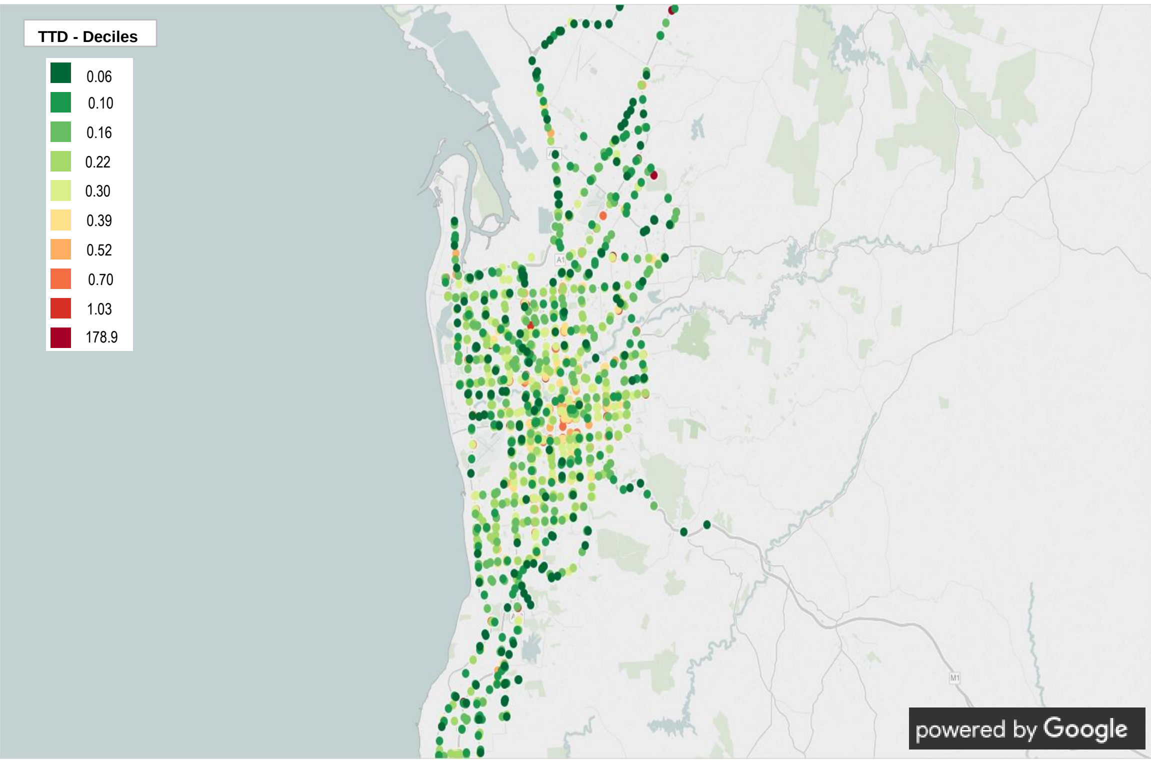
Adelaide Slowest Roads[1] Km / hr			
Rank	Road	City	Avg Speed
1	King William St	Adelaide	13.5
2	North Terrace	Adelaide	16.2
3	East Terrace	Adelaide	19.9
4	Cross Rd	Adelaide	20.3
5	Greenhill Rd	Adelaide	20.7
6	Shepherds Hill Rd	Adelaide	22.6
7	Portrush Rd	Adelaide	23.0
8	Unley Rd	Adelaide	23.1
9	Fullarton Rd	Adelaide	23.2
10	Daws Rd	Adelaide	23.7

Adelaide Fastest Roads[1] Km / hr			
Rank	Road	City	Avg Speed
1	Northern Expressway	Adelaide	93.8
2	Southern Expressway	Adelaide	72.5
3	Port Wakefield Rd	Adelaide	53.8
4	Frederick Rd	Adelaide	39.6
5	Hampstead Rd	Adelaide	36.6
6	Dyson Rd	Adelaide	34.2
7	Victoria Rd	Adelaide	33.9
8	Days Rd	Adelaide	33.0
9	Panalatinga Rd	Adelaide	32.9
10	O'Sullivan Beach Road	Adelaide	32.7

Note: 1. For roads over 5km
Source: Google maps data 2015-09-09 to 2015-10-29

Travel Time Delay

Adelaide - Most Delayed Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Adelaide Most Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	King William St	Adelaide	39.1
2	North Terrace	Adelaide	35.6
3	Portrush Rd	Adelaide	26.5
4	Hampstead Rd	Adelaide	21.3
5	Fullarton Rd	Adelaide	20.6
6	Unley Rd	Adelaide	20.5
7	Prospect Rd	Adelaide	19.9
8	The Parade	Adelaide	19.6
9	Cross Rd	Adelaide	19.4
10	Torrens Rd	Adelaide	19.1

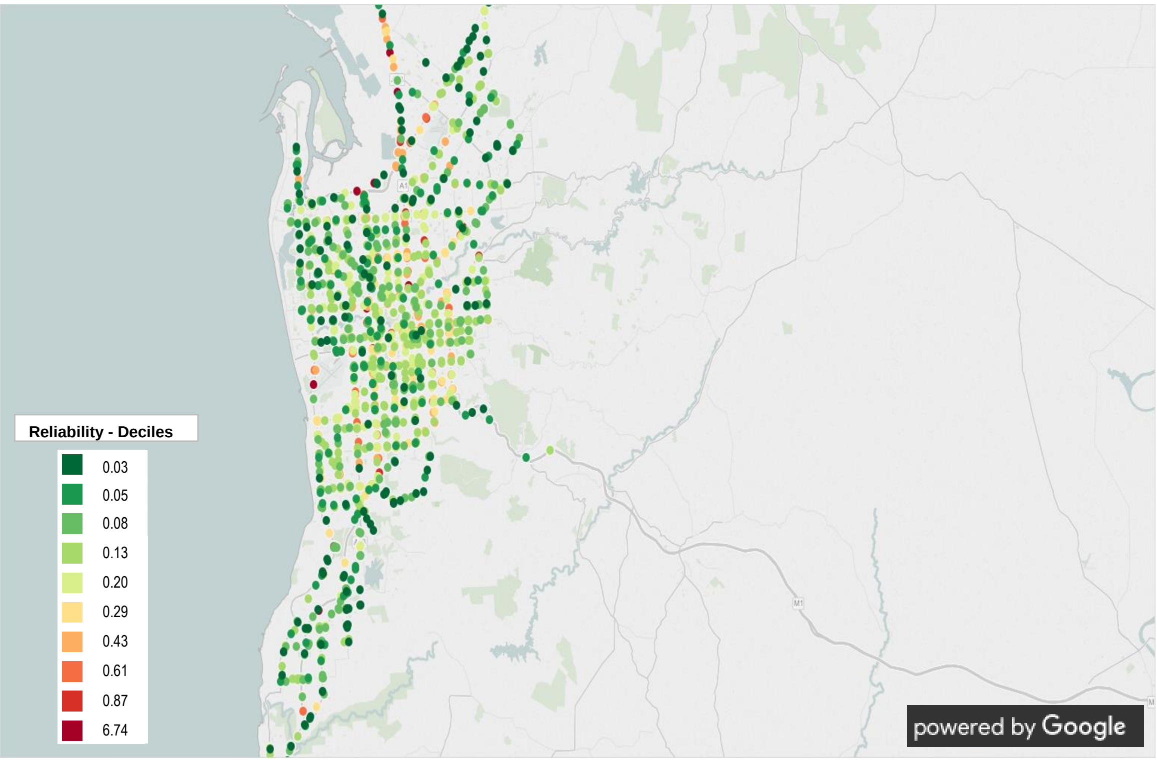
Adelaide Least Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Northern Expressway	Adelaide	2.8
2	Shepherds Hill Rd	Adelaide	4.6
3	Southern Expressway	Adelaide	4.6
4	Main South Rd	Adelaide	6.8
5	Commercial Rd	Adelaide	6.9
6	Panalatinga Rd	Adelaide	7.4
7	O'Sullivan Beach Rd	Adelaide	7.6
8	Bridge Rd	Adelaide	7.6
9	Old Port Rd	Adelaide	8.0
10	Dyson Road	Adelaide	8.3

Note: 1. Delay defined as (mean travel time for 24 hours/minimum travel time for 24 hours) -1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Reliability (3pm to 7pm)

Adelaide - Most Reliable Afternoon Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Adelaide Least Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Hampstead Road	Adelaide	23.3
2	Port Wakefield Road	Adelaide	18.9
3	Marion Road	Adelaide	14.7
4	Portrush Road	Adelaide	14.4
5	The Parade	Adelaide	13.3
6	North Terrace	Adelaide	12.5
7	King William Street	Adelaide	12.4
8	East Terrace	Adelaide	9.8
9	Sir Donald Bradman Drive	Adelaide	9.6
10	Cross Road	Adelaide	9.6

Adelaide Most Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Northern Expressway	Adelaide	1.3
2	Victoria Road	Adelaide	2.5
3	Main South Road	Adelaide	2.5
4	Panalatinga Road	Adelaide	2.5
5	Southern Expressway	Adelaide	2.8
6	Old Port Road	Adelaide	3.0
7	Commercial Road	Adelaide	3.1
8	Shepherds Hill Road	Adelaide	4.0
9	Frederick Road	Adelaide	4.1
10	Days Road	Adelaide	4.2

Note: 1. Reliability measured as (standard deviation for 3pm to 7pm/mean travel time for 3pm to 7pm) - 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Mean Scheduling (3pm to 7pm)

Adelaide Worst Afternoon Peak Mean Scheduling Roads[1]
% of Average Time

Rank	Road	City	Scheduling %
1	Portrush Road	Adelaide	56.4
2	Marion Road	Adelaide	45.5
3	King William Street	Adelaide	64.7
4	Cross Road	Adelaide	40.8
5	Hampstead Road	Adelaide	42.0
6	North Terrace	Adelaide	57.4
7	The Parade	Adelaide	36.3
8	Sir Donald Bradman Drive	Adelaide	31.7
9	Morphett Road	Adelaide	26.7
10	Regency Road	Adelaide	29.5

Adelaide Best Afternoon Peak Mean Scheduling Roads[1]
% of Average Time

Rank	Road	City	Scheduling %
1	Northern Expressway	Adelaide	0.6
2	Southern Expressway	Adelaide	0.8
3	Victoria Road	Adelaide	2.1
4	Panalatinga Road	Adelaide	3.0
5	Main South Road	Adelaide	3.5
6	Frederick Road	Adelaide	4.0
7	Days Road	Adelaide	4.1
8	Commercial Road	Adelaide	4.1
9	O'Sullivan Beach Road	Adelaide	4.4
10	Old Port Road	Adelaide	4.4

Note: 1. (90th Percentile for 3pm – 7pm/mean travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Scheduling (3pm to 7pm)

Adelaide Worst Afternoon Peak Scheduling Roads[1]
% of Minimum Time

Rank	Road	City	Scheduling %
1	King William Street	Adelaide	64.7
2	North Terrace	Adelaide	57.4
3	Portrush Road	Adelaide	56.4
4	Marion Road	Adelaide	45.5
5	Hampstead Road	Adelaide	42.0
6	Cross Road	Adelaide	40.8
7	The Parade	Adelaide	36.3
8	Unley Road	Adelaide	32.7
9	Prospect Road	Adelaide	32.4
10	Fullarton Road	Adelaide	31.7

Adelaide Best Afternoon Peak Scheduling Roads[1]
% of Minimum Time

Rank	Road	City	Scheduling %
1	Northern Expressway	Adelaide	3.4
2	Southern Expressway	Adelaide	5.4
3	Shepherds Hill Road	Adelaide	10.0
4	Main South Road	Adelaide	10.5
5	Panalatinga Road	Adelaide	10.5
6	Commercial Road	Adelaide	11.4
7	O'Sullivan Beach Road	Adelaide	12.3
8	Old Port Road	Adelaide	12.7
9	Days Road	Adelaide	12.9
10	Dyson Road	Adelaide	13.1

Note: 1. (90th Percentile for 3pm – 7pm/minimum travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

25 Most Delayed Roads – All Congestion Measures

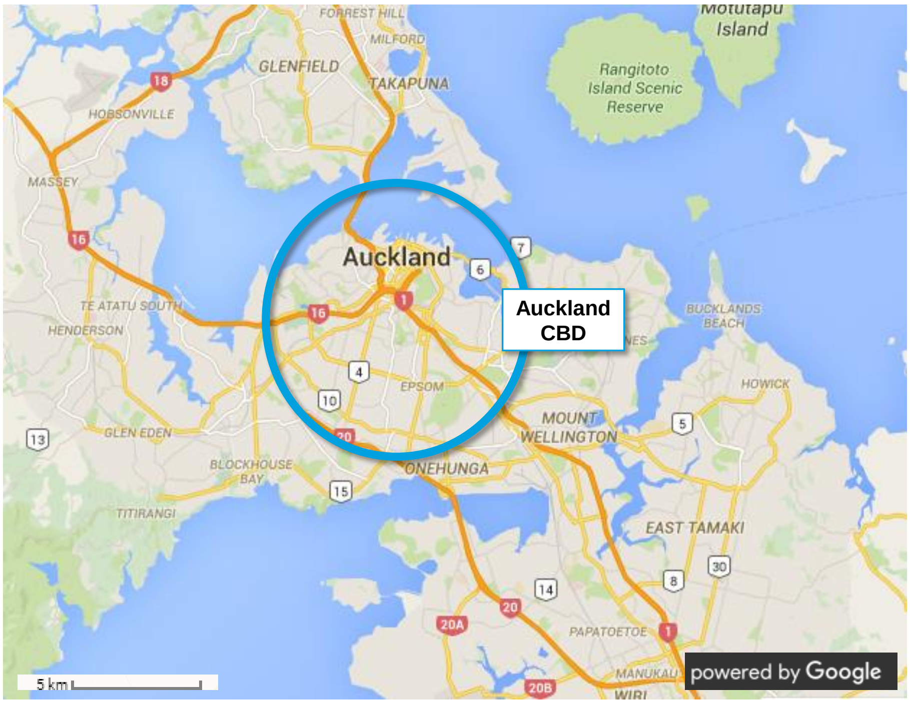
Road	Avg Speed (km)	Travel Time Delay (%)	Aft. Peak Mean Scheduling (%)	Morn. Peak Scheduling (%)	Aft. Peak Scheduling (%)	Morn. Peak Unreliability (%)	Aft. Peak Unreliability (%)
King William Street	13.5	39.1%	18.4%	49.7%	64.7%	15.3%	12.4%
North Terrace	16.2	35.6%	16.1%	50.5%	57.4%	16.7%	12.5%
Portrush Road	23.0	26.5%	23.6%	40.8%	56.4%	16.7%	14.4%
Hampstead Road	36.6	21.3%	17.1%	36.4%	42.0%	29.3%	23.3%
Fullarton Road	23.2	20.6%	9.2%	47.7%	31.7%	19.8%	9.0%
Unley Road	23.1	20.5%	10.1%	30.3%	32.7%	11.5%	8.1%
Prospect Road	30.6	19.9%	10.4%	24.8%	32.4%	10.4%	7.7%
The Parade	24.7	19.6%	14.0%	32.7%	36.3%	12.8%	13.3%
Cross Road	20.3	19.4%	18.0%	26.0%	40.8%	10.4%	9.6%
Torrens Road	25.7	19.1%	9.6%	29.1%	30.5%	10.5%	6.6%
Marion Road	27.4	18.5%	22.8%	30.1%	45.5%	14.4%	14.7%
Grange Road	24.8	17.9%	10.1%	33.8%	29.8%	12.9%	8.1%
East Terrace	19.9	17.9%	10.7%	22.6%	30.5%	8.4%	9.8%
Anzac Highway	24.5	17.8%	10.8%	30.1%	30.5%	11.7%	7.7%
Greenhill Road	20.7	16.8%	8.1%	28.9%	26.2%	11.3%	5.8%
Richmond Road	23.8	16.5%	9.5%	26.8%	27.5%	9.4%	8.6%
South Road	23.8	16.4%	11.2%	28.4%	29.5%	11.3%	8.2%
Sir Donald Bradman Drive	26.0	16.3%	13.2%	23.5%	31.7%	8.8%	9.6%
Port Road	25.7	16.2%	6.3%	30.4%	23.4%	12.0%	5.9%
Hanson Road	25.9	15.7%	5.8%	21.2%	22.4%	6.5%	5.5%
Regency Road	24.2	15.7%	11.9%	18.9%	29.5%	8.0%	8.3%
Payneham Road	23.9	15.5%	10.1%	21.7%	27.2%	10.1%	6.6%
Kensington Road	26.3	15.5%	10.8%	22.0%	28.0%	8.8%	8.5%
Park Terrace	24.6	15.3%	6.8%	30.6%	23.1%	12.2%	5.6%
Magill Road	24.6	15.0%	7.8%	23.5%	23.9%	8.6%	7.2%

Source: Google maps data 2015-09-09 to 2015-10-29

B.6 Auckland Congestion Performance

Auckland, located on a peninsula and surrounded by water, has limited room for expansion. The road network involves a series of highways leading into the city centre, which is surrounded by a ring road.

City Characteristics – Auckland



Source: Google Maps

Average Speed

Auckland Slowest Roads[1]

Km / hr

Rank	Road	City	Avg Speed
1	Saint Lukes Rd	Auckland	22.0
2	Wairau Rd	Auckland	22.6
3	Lake Rd	Auckland	27.0
4	Ti Rakau Drive	Auckland	27.7
5	Mount Wellington Highway	Auckland	27.8
6	Albany Highway	Auckland	28.3
7	Great North Rd	Auckland	28.5
8	Great South Rd	Auckland	28.9
9	New North Rd	Auckland	32.1
10	East Coast Rd	Auckland	32.1

Auckland Fastest Roads[1]

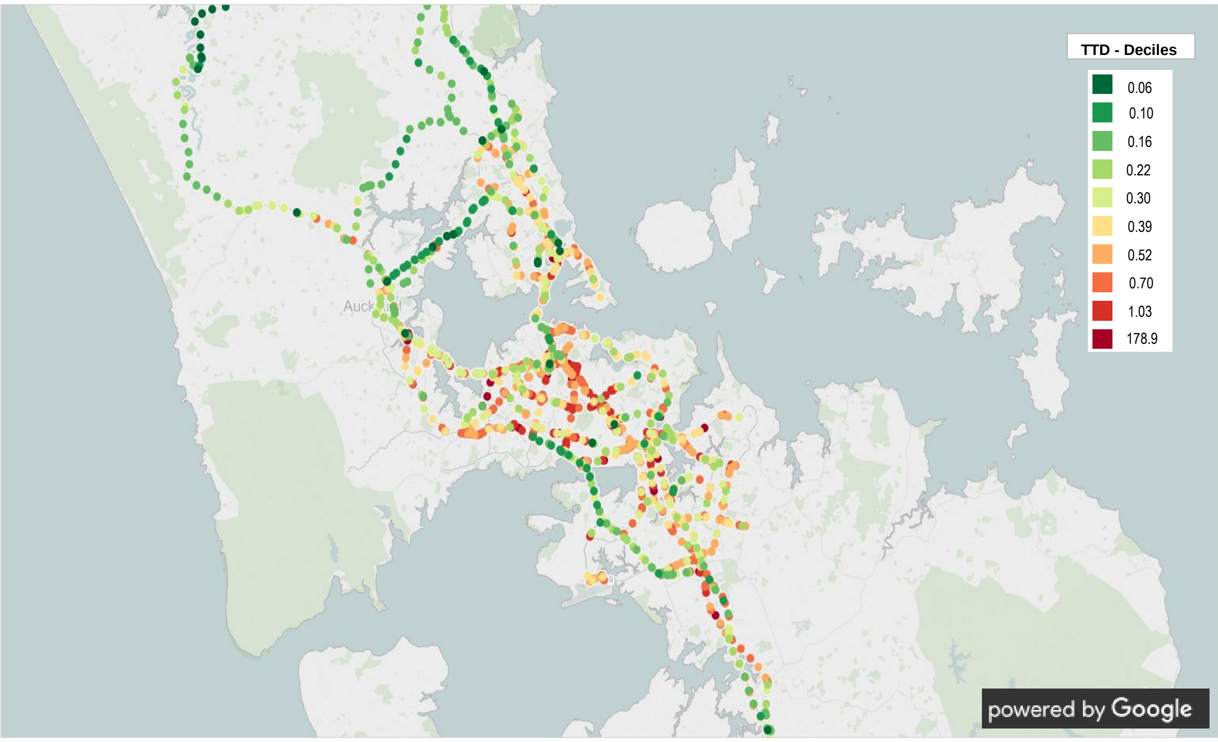
Km / hr

Rank	Road	City	Avg Speed
1	Northern Gateway Toll Rd	Auckland	98.8
2	Upper Harbour Mtwy	Auckland	94.5
3	SH 16	Auckland	82.7
4	Northern Mtwy	Auckland	81.3
5	South-Western Mtwy	Auckland	80.5
6	Glenbrook-Waiuku Rd	Auckland	78.5
7	Glenbrook Rd	Auckland	77.9
8	Kaipara Coast Highway	Auckland	75.8
9	Auckland-Kumeu Mtwy	Auckland	73.0
10	Southern Mtwy	Auckland	67.5

Note: 1. For roads over 5km
Source: Google maps data 2015-09-09 to 2015-10-29

Travel Time Delay

Auckland - Most Delayed Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Auckland Most Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Saint Lukes Rd	Auckland	43.1
2	South-Eastern Highway	Auckland	41.0
3	Mount Wellington Highway	Auckland	37.9
4	Southern Mtwy	Auckland	36.9
5	Ti Rakau Drive	Auckland	34.1
6	North-Western Mtwy	Auckland	34.0
7	New North Rd	Auckland	33.4
8	Te Irirangi Drive	Auckland	31.2
9	Great South Rd	Auckland	28.4
10	Great North Rd	Auckland	27.9

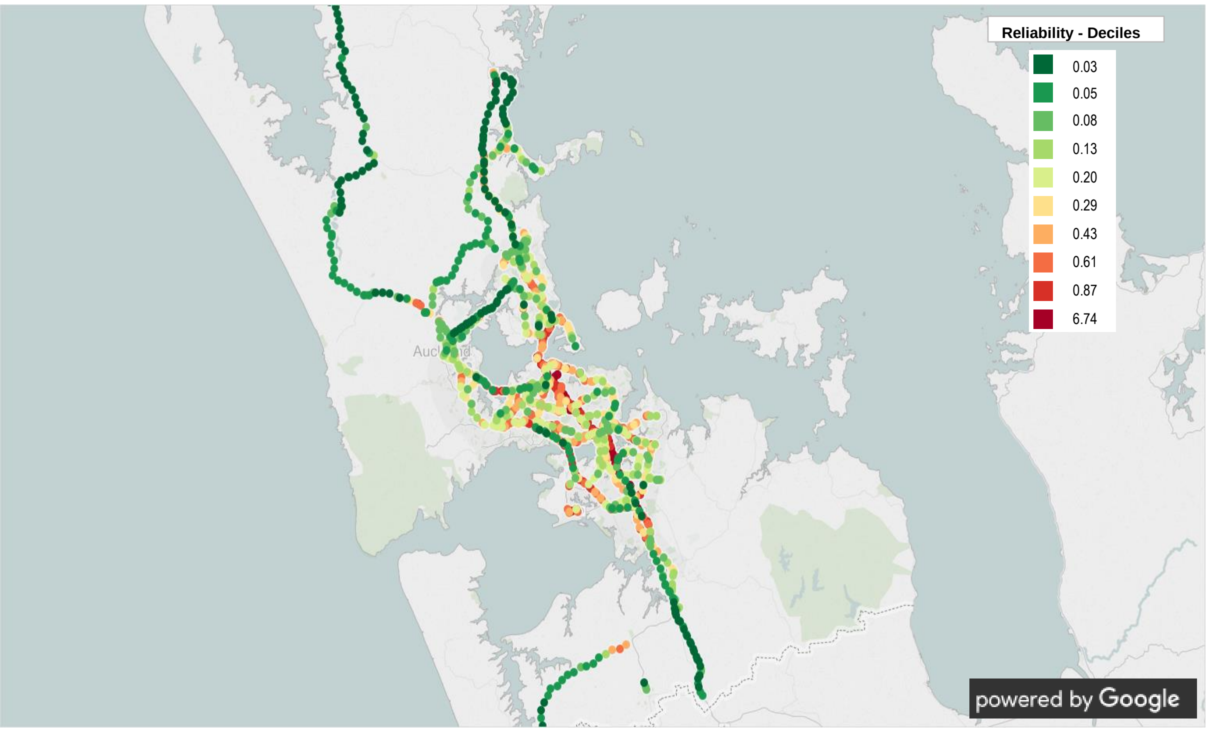
Auckland Least Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Kaipara Coast Highway	Auckland	0.6
2	Coatesville-Riverhead Highway	Auckland	5.8
3	Northern Gateway Toll Rd	Auckland	5.9
4	Upper Harbour Mtwy	Auckland	7.5
5	Dairy Flat Mtwy	Auckland	8.2
6	SH 16	Auckland	9.5
7	Hibiscus Coast Highway	Auckland	12.0
8	Oteha Valley Rd	Auckland	13.2
9	State Highway	Auckland	15.6
10	Glenbrook-Waiuku Rd	Auckland	16.6

Note: 1. Delay defined as (mean travel time for 24 hours/minimum travel time for 24 hours) -1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Reliability (3pm to 7pm)

Auckland - Most Reliable Afternoon Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Auckland Least Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Highbrook Drive	Auckland	37.0
2	Southern Mtwy	Auckland	36.1
3	Auckland-Kumeu Mtwy	Auckland	35.9
4	North-Western Mtwy	Auckland	35.5
5	South-Western Mtwy	Auckland	25.5
6	Northern Mtwy	Auckland	22.5
7	New North Road	Auckland	20.3
8	Saint Lukes Road	Auckland	19.8
9	South-Eastern Highway	Auckland	19.3
10	Ti Rakau Drive	Auckland	19.2

Auckland Most Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Kaipara Coast Highway	Auckland	0.4
2	Upper Harbour Mtwy	Auckland	1.0
3	Glenbrook-Waiuku Road	Auckland	1.6
4	Coatesville-Riverhead Highway	Auckland	2.3
5	Dairy Flat Highway	Auckland	2.3
6	SH 16	Auckland	4.9
7	Lake Road	Auckland	6.7
8	Wairau Road	Auckland	6.8
9	Great North Road	Auckland	8.0
10	Glenbrook Road	Auckland	8.7

Note: 1. Reliability measured as (standard deviation for 3pm to 7pm/mean travel time for 3pm to 7pm) - 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Mean Scheduling (3pm to 7pm)

Auckland Worst Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Auckland-Kumeu Mtwy	Auckland	60.0
2	North-Western Mtwy	Auckland	57.8
3	Highbrook Drive	Auckland	54.6
4	Southern Mtwy	Auckland	50.5
5	South-Western Mtwy	Auckland	43.3
6	Saint Lukes Road	Auckland	38.2
7	New North Road	Auckland	35.2
8	Ti Rakau Drive	Auckland	33.5
9	Mount Wellington Highway	Auckland	25.4
10	Great South Road	Auckland	22.2

Auckland Best Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Upper Harbour Mtwy	Auckland	-0.5
2	Northern Gateway Toll Road	Auckland	0.0
3	Kaipara Coast Highway	Auckland	0.5
4	Dairy Flat Highway	Auckland	0.9
5	Coatesville-Riverhead Highway	Auckland	1.2
6	Glenbrook-Waiuku Road	Auckland	1.4
7	SH 16	Auckland	6.0
8	Lake Road	Auckland	8.8
9	Glenbrook Road	Auckland	8.9
10	Wairau Road	Auckland	9.8

Note: 1. (90th Percentile for 3pm – 7pm/mean travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Scheduling (3pm to 7pm)

Auckland Worst Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	North-Western Mtwy	Auckland	111.5
2	Southern Mtwy	Auckland	106.1
3	Saint Lukes Road	Auckland	97.7
4	Auckland-Kumeu Mtwy	Auckland	95.3
5	Highbrook Drive	Auckland	90.5
6	New North Road	Auckland	80.4
7	Ti Rakau Drive	Auckland	79.1
8	Mount Wellington Highway	Auckland	72.9
9	South-Western Mtwy	Auckland	70.2
10	South-Eastern Highway	Auckland	68.2

Auckland Best Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Kaipara Coast Highway	Auckland	1.1
2	Northern Gateway Toll Road	Auckland	5.8
3	Upper Harbour Mtwy	Auckland	6.9
4	Coatesville-Riverhead Highway	Auckland	7.1
5	Dairy Flat Highway	Auckland	9.2
6	SH 16	Auckland	16.1
7	Glenbrook-Waiuku Road	Auckland	18.3
8	Oteha Valley Road	Auckland	25.6
9	Hibiscus Coast Highway	Auckland	27.7
10	Lake Road	Auckland	28.1

Note: 1. (90th Percentile for 3pm – 7pm/minimum travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

25 Most Delayed Roads – All Congestion Measures

Road	Avg Speed (km)	Travel Time Delay (%)	Aft. Peak Mean Scheduling (%)	Morn. Peak Scheduling (%)	Aft. Peak Scheduling (%)	Morn. Peak Unreliability (%)	Aft. Peak Unreliability (%)
Saint Lukes Road	22.0	43.1%	38.2%	66.8%	97.7%	25.4%	19.8%
South-Eastern Highway	39.6	41.0%	19.3%	86.9%	68.2%	27.6%	19.3%
Mount Wellington Highway	27.8	37.9%	25.4%	43.0%	72.9%	9.9%	14.0%
Southern Mtwy	67.5	36.9%	50.5%	76.1%	106.1%	25.7%	36.1%
Ti Rakau Drive	27.7	34.1%	33.5%	63.9%	79.1%	23.3%	19.2%
North-Western Mtwy	62.2	34.0%	57.8%	77.5%	111.5%	35.8%	35.5%
New North Road	32.1	33.4%	35.2%	32.9%	80.4%	7.6%	20.3%
Te Irirangi Drive	40.6	31.2%	19.2%	43.8%	56.4%	17.1%	10.5%
Great South Road	28.9	28.4%	22.2%	37.1%	57.0%	11.2%	13.2%
Great North Road	28.5	27.9%	10.9%	43.2%	41.8%	13.8%	8.0%
Albany Highway	28.3	27.0%	17.8%	59.6%	49.6%	25.4%	11.9%
Highbrook Drive	47.7	23.2%	54.6%	23.6%	90.5%	9.0%	37.0%
Auckland-Kumeu Mtwy	73.0	22.1%	60.0%	13.0%	95.3%	16.2%	35.9%
Whangaparaoa Road	47.0	21.5%	19.1%	19.5%	44.7%	4.4%	10.5%
Wairau Road	22.6	20.1%	9.8%	38.6%	31.9%	15.1%	6.8%
East Coast Road	32.1	20.1%	19.6%	30.5%	43.5%	8.4%	10.4%
Northern Mtwy	81.3	19.4%	20.7%	55.5%	44.1%	23.1%	22.5%
South-Western Mtwy	80.5	18.8%	43.3%	24.4%	70.2%	19.7%	25.5%
Glenbrook Road	77.9	18.5%	8.9%	25.1%	29.1%	7.4%	8.7%
Lake Road	27.0	17.7%	8.8%	22.7%	28.1%	5.5%	6.7%
Glenbrook-Waiuku Road	78.5	16.6%	1.4%	20.3%	18.3%	4.9%	1.6%
State Highway	57.1	15.6%	14.4%	22.0%	32.3%	9.8%	12.3%
Oteha Valley Road	36.2	13.2%	11.0%	15.3%	25.6%	5.9%	8.9%
Hibiscus Coast Highway	44.3	12.0%	14.0%	13.2%	27.7%	4.8%	8.8%
SH 16	82.7	9.5%	6.0%	9.8%	16.1%	1.3%	4.9%

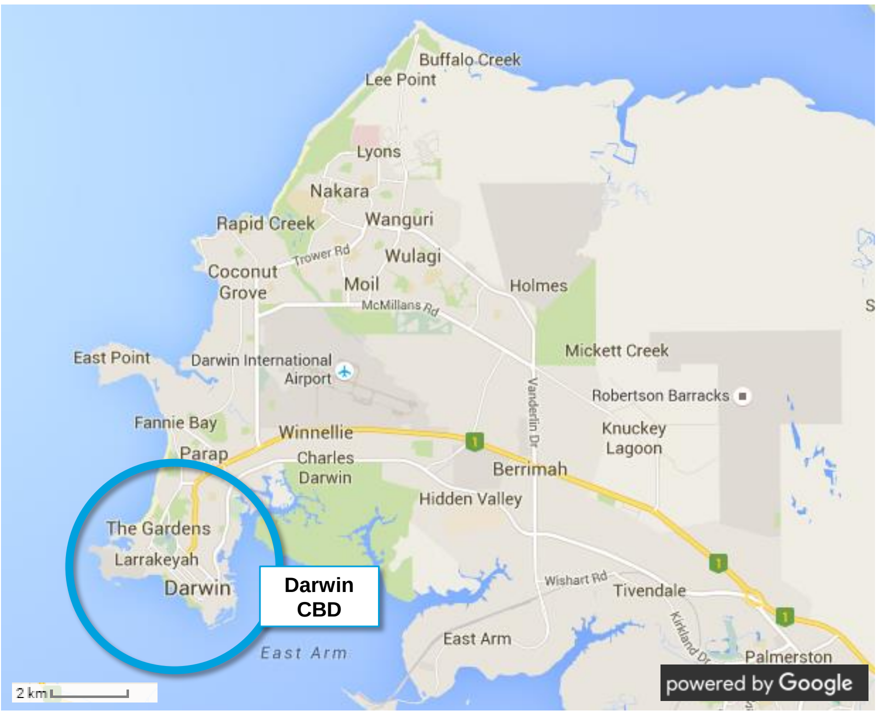
Source: Google maps data 2015-09-09 to 2015-10-29

B.7 Darwin Congestion Performance

Darwin, the capital of the Northern Territory, is located next to the water with significant space for urban expansion. There city road network has a grid structure. The City of Darwin owns around 400km of municipal roads, connected by a system of State-owned main roads and highways.

As Darwin is one of the smaller cities in this study by geographic size, it was found that there were fewer relevant roads for analysis. For the purposes of this study, we consider only roads greater than 5km in length; to rule out local roads which are likely to have lower speed limits which may otherwise affect the analysis. Similarly, smaller roads were excluded as they may not be meaningful to the overall description of a city's road network. For example, a particularly fast or slow travel time on a very short stretch of road is unlikely to be significant in considering the whole road network. For these reasons, the comparisons in this chapter are limited to a 'Top 3' and 'Bottom 3'.

City Characteristics – Darwin



Source: Google Maps

Average Speed

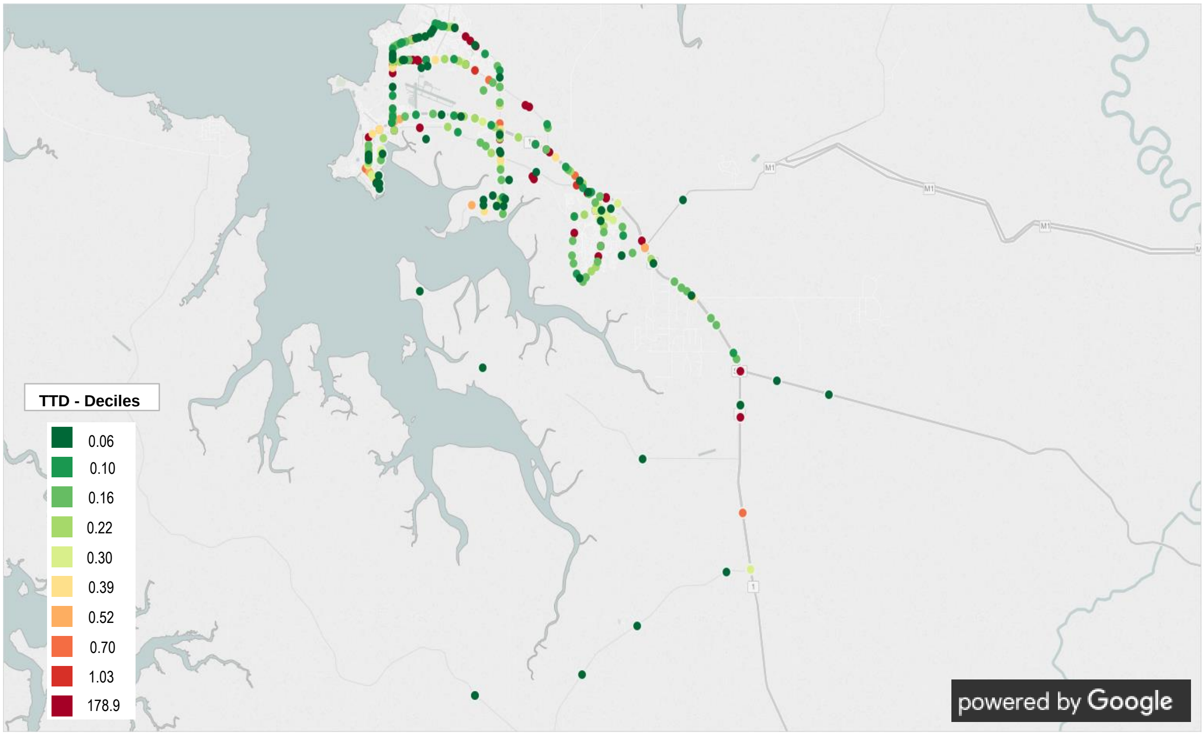
Darwin Slowest Roads[1] Km / hr			
Rank	**Road**	**City**	**Avg Speed**
1	Roystonea Ave	Darwin	31.6
2	Vanderlin Drive	Darwin	37.0
3	McMillans Rd	Darwin	39.7

Darwin Fastest Roads[1] Km / hr			
Rank	**Road**	**City**	**Avg Speed**
1	Cox Peninsula Rd	Darwin	79.8
2	Tiger Brennan Drive	Darwin	52.7
3	Stuart Highway	Darwin	41.2

Note: 1. For roads over 5km
Source: Google maps data 2015-09-09 to 2015-10-29

Travel Time Delay

Darwin - Most Delayed Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Darwin Most Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Stuart Highway	Darwin	13.7
2	Roystonea Ave	Darwin	12.6
3	Tiger Brennan Drive	Darwin	10.9

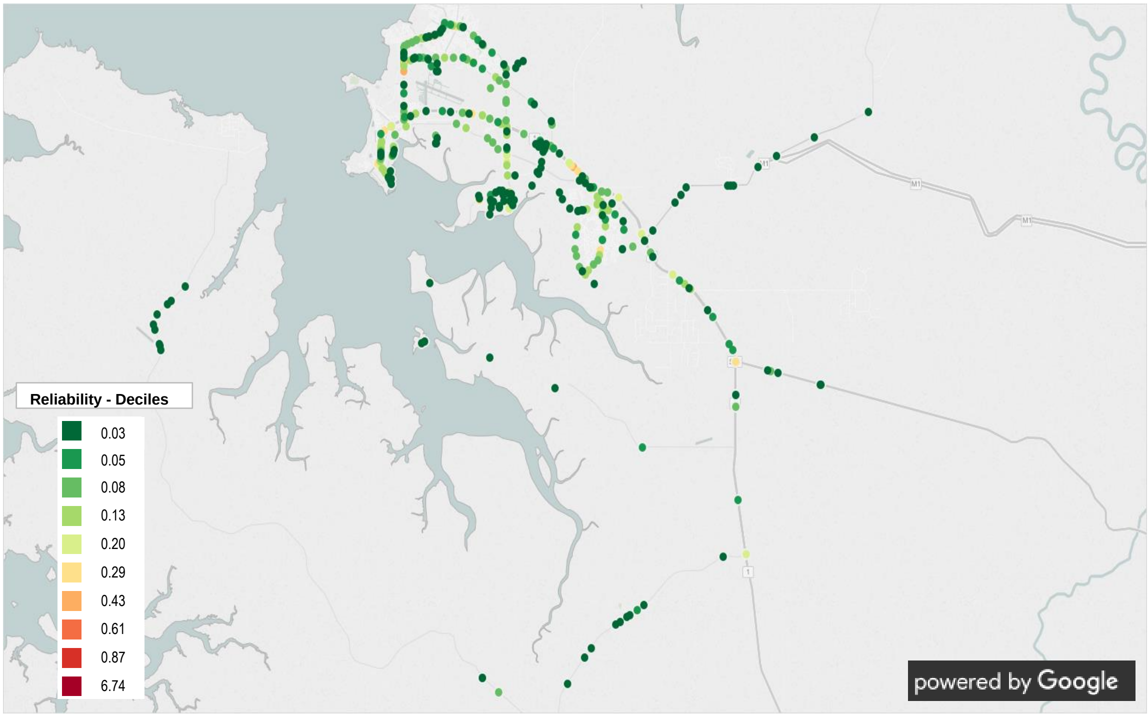
Darwin Least Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Cox Peninsula Rd	Darwin	0.8
2	Vanderlin Drive	Darwin	4.3
3	McMillans Rd	Darwin	7.1

Note: 1. Delay defined as (mean travel time for 24 hours/minimum travel time for 24 hours) -1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Reliability (3pm to 7pm)

Darwin - Most Reliable Afternoon Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Darwin Least Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Stuart Highway	Darwin	7.1
2	Roystonea Avenue	Darwin	6.6
3	Tiger Brennan Drive	Darwin	4.2

Darwin Most Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Cox Peninsula Road	Darwin	0.6
2	Vanderlin Drive	Darwin	2.1
3	McMillans Road	Darwin	3.5

Note: 1. Reliability measured as (standard deviation for 3pm to 7pm/mean travel time for 3pm to 7pm) - 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Mean Scheduling (3pm to 7pm)

Darwin Worst Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Roystonea Avenue	Darwin	10.1
2	Stuart Highway	Darwin	5.5
3	Tiger Brennan Drive	Darwin	3.9

Darwin Best Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Cox Peninsula Road	Darwin	0.4
2	Vanderlin Drive	Darwin	2.2
3	McMillans Road	Darwin	3.8

Note: 1. 90th Percentile for 3pm – 7pm/mean travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Scheduling (3pm to 7pm)

Darwin Worst Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Roystonea Avenue	Darwin	24.0
2	Stuart Highway	Darwin	20.0
3	Tiger Brennan Drive	Darwin	15.2

Darwin Best Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Cox Peninsula Road	Darwin	1.2
2	Vanderlin Drive	Darwin	6.6
3	McMillans Road	Darwin	11.2

Note: 1. (90th Percentile for 3pm – 7pm/minimum travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

Most Delayed Roads – All Congestion Measures

Road	Avg Speed (km)	Travel Time Delay (%)	Aft. Peak Mean Scheduling (%)	Morn. Peak Scheduling (%)	Aft. Peak Scheduling (%)	Morn. Peak Unreliability (%)	Aft. Peak Unreliability (%)
Cox Peninsula Road	79.8	0.8%	0.4%	1.2%	1.2%	0.6%	0.6%
McMillans Road	39.7	7.1%	3.8%	10.9%	11.2%	3.6%	3.5%
Roystonea Avenue	31.6	12.6%	10.1%	13.8%	24.0%	3.5%	6.6%
Stuart Highway	41.2	13.7%	5.5%	19.6%	20.0%	6.7%	7.1%
Tiger Brennan Drive	52.7	10.9%	3.9%	14.2%	15.2%	3.3%	4.2%
Vanderlin Drive	37.0	4.3%	2.2%	4.9%	6.6%	1.6%	2.1%

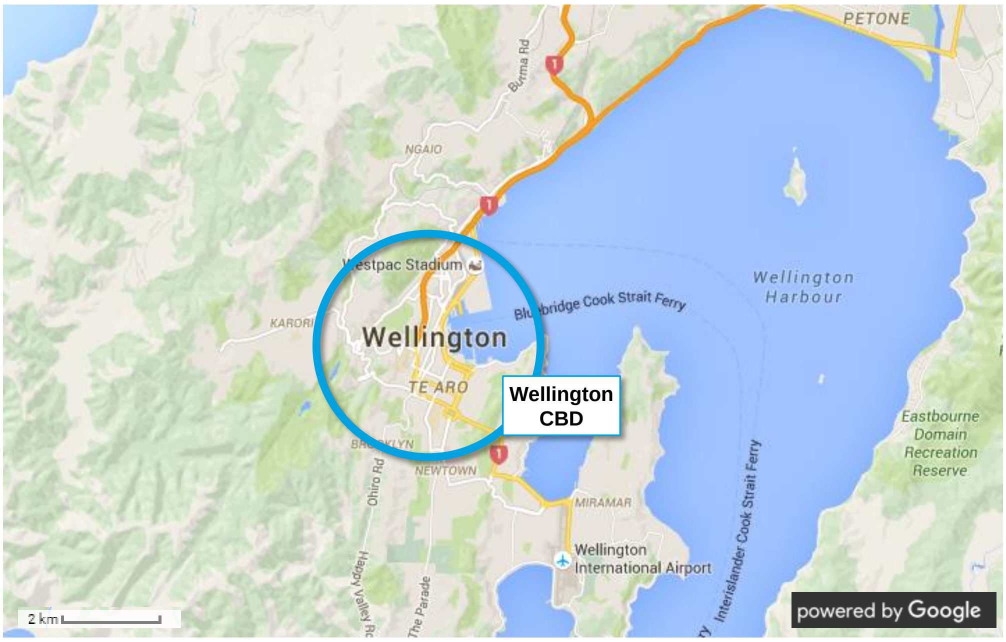
Source: Google maps data 2015-09-09 to 2015-10-29

B.8 Wellington Congestion Performance

Wellington, the capital of New Zealand is located between a bay and mountains on the southern end of the North Island. It has very limited space for urban or road expansion between these geographic borders.

As Wellington is one of the smaller cities in this study by geographic size, it was found that there were fewer relevant roads for analysis. For the purposes of this study, we consider only roads greater than 5km in length; to rule out local roads which are likely to have lower speed limits which may otherwise affect the analysis. Similarly, smaller roads were excluded as they may not be meaningful to the overall description of a city's road network. For example, a particularly fast or slow travel time on a very short stretch of road is unlikely to be significant in considering the whole road network. For these reasons, the comparisons in this chapter are limited to a 'Top 5' and 'Bottom 5'.

City Characteristics – Wellington



Source: Google Maps

Average Speed

Wellington Slowest Roads[1]
Km / hr

Rank	Road	City	Avg Speed
1	Cambridge Terrace	Wellington	34.5
2	Titahi Bay Rd	Wellington	37.3
3	Fergusson Drive	Wellington	37.8
4	Centennial Highway	Wellington	53.0
5	Eastern Hutt Rd	Wellington	53.1

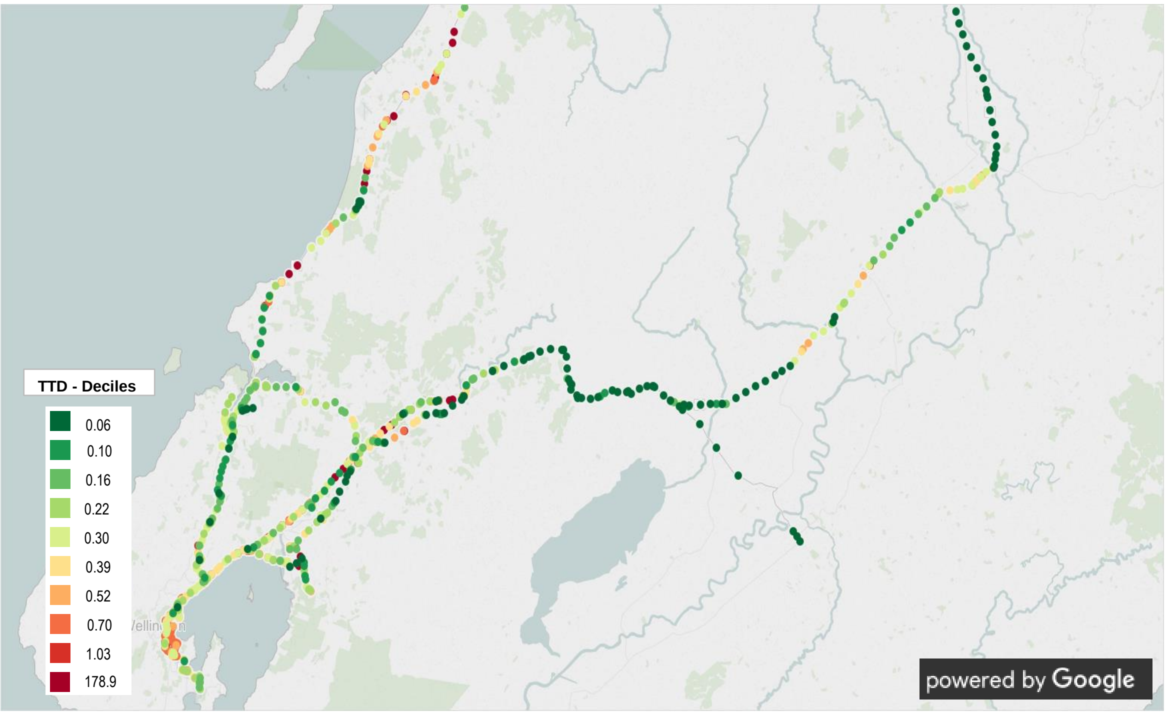
Wellington Fastest Roads[1]
Km / hr

Rank	Road	City	Avg Speed
1	SH 2	Wellington	85.9
2	Johnsonville Porirua Mtwy	Wellington	82.0
3	State Highway 53	Wellington	80.0
4	SH 1 North	Wellington	72.5
5	River Rd	Wellington	69.4

Note: 1. For roads over 5km
Source: Google maps data 2015-09-09 to 2015-10-29

Travel Time Delay

Wellington - Most Delayed Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Wellington Most Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Hutt Rd	Wellington	25.4
2	Wellington Urban Mtwy	Wellington	25.0
3	Titahi Bay Rd	Wellington	22.8
4	Main Rd	Wellington	20.8
5	Centennial Highway	Wellington	19.3

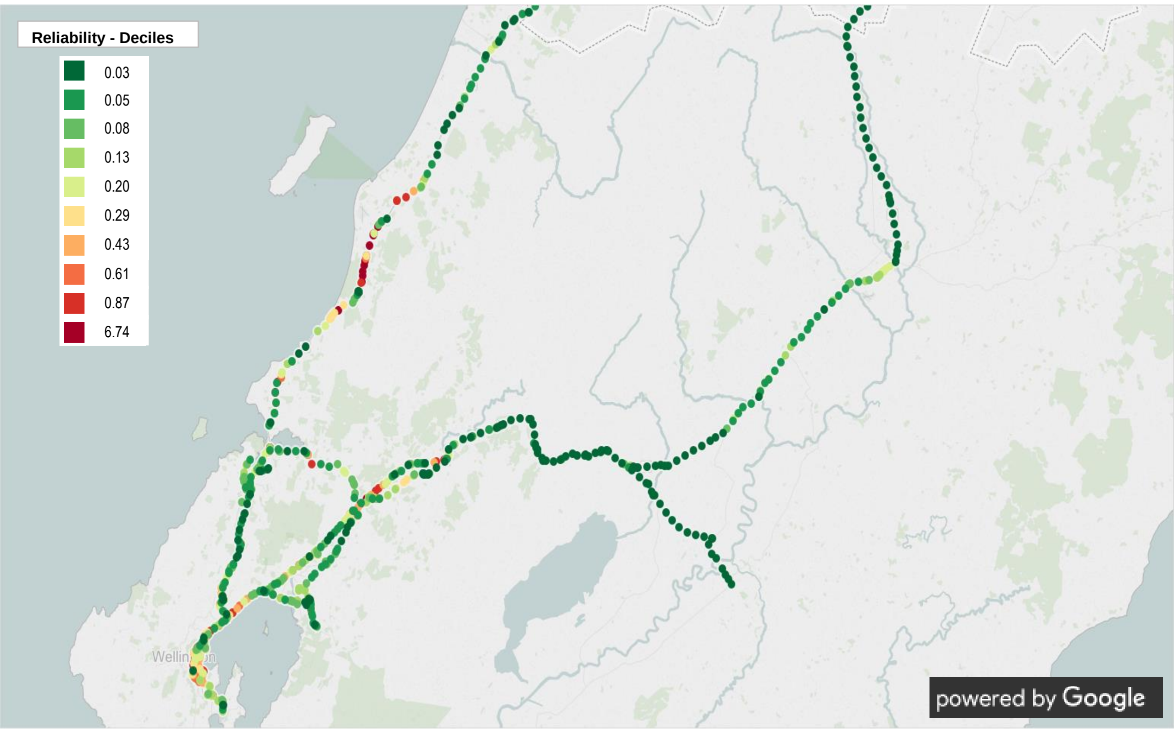
Wellington Least Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	State Highway 53	Wellington	0.0
2	SH 2	Wellington	3.7
3	Eastern Hutt Rd	Wellington	4.4
4	State Highway	Wellington	6.3
5	Johnsonville Porirua Mtwy	Wellington	8.8

Note: 1. Delay defined as (mean travel time for 24 hours/minimum travel time for 24 hours) -1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Reliability (3pm to 7pm)

Wellington - Most Reliable Afternoon Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Wellington Least Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	SH 1 North	Wellington	38.6
2	Main Road	Wellington	35.8
3	Wellington Urban Mtwy	Wellington	29.9
4	Hutt Road	Wellington	26.6
5	River Road	Wellington	16.1

Wellington Most Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	State Highway 53	Wellington	0.1
2	SH 2	Wellington	0.8
3	Johnsonville Porirua Mtwy	Wellington	3.2
4	Wainuiomata Road	Wellington	3.9
5	Cambridge Terrace	Wellington	5.1

Note: 1. Reliability measured as (standard deviation for 3pm to 7pm/mean travel time for 3pm to 7pm) - 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Mean Scheduling (3pm to 7pm)

Wellington Worst Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Hutt Road	Wellington	35.0
2	SH 1 North	Wellington	34.0
3	Wellington Urban Mtwy	Wellington	33.1
4	Main Road	Wellington	32.5
5	Titahi Bay Road	Wellington	16.6

Wellington Best Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Johnsonville Porirua Mtwy	Wellington	-0.7
2	State Highway 53	Wellington	0.2
3	SH 2	Wellington	1.2
4	Wainuiomata Road	Wellington	1.5
5	Paremata Haywards Road	Wellington	2.4

Note: 1. (90th Percentile for 3pm – 7pm/mean travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Scheduling (3pm to 7pm)

Wellington Worst Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Hutt Road	Wellington	69.3
2	Wellington Urban Mtwy	Wellington	66.5
3	Main Road	Wellington	60.0
4	SH 1 North	Wellington	53.4
5	Titahi Bay Road	Wellington	43.3

Wellington Best Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	State Highway 53	Wellington	0.2
2	SH 2	Wellington	4.9
3	Johnsonville Porirua Mtwy	Wellington	8.1
4	Eastern Hutt Road	Wellington	11.4
5	Wainuiomata Road	Wellington	12.5

Note: 1. (90th Percentile for 3pm – 7pm/minimum travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

25 Most Delayed Roads – All Congestion Measures

Road	Avg Speed (km)	Travel Time Delay (%)	Aft. Peak Mean Scheduling (%)	Morn. Peak Scheduling (%)	Aft. Peak Scheduling (%)	Morn. Peak Unreliability (%)	Aft. Peak Unreliability (%)
Hutt Road	58.7	25.4%	35.0%	61.8%	69.3%	26.8%	26.6%
Wellington Urban Mtwy	60.3	25.0%	33.1%	84.7%	66.5%	32.0%	29.9%
Titahi Bay Road	37.3	22.8%	16.6%	24.6%	43.3%	7.1%	8.2%
Main Road	59.8	20.8%	32.5%	18.5%	60.0%	3.3%	35.8%
Centennial Highway	53.0	19.3%	8.5%	80.7%	29.4%	33.7%	14.2%
River Road	69.4	18.8%	12.3%	26.0%	33.4%	23.5%	16.1%
Western Hutt Road	59.9	16.9%	4.8%	55.4%	22.4%	22.8%	6.7%
SH 1 North	72.5	14.5%	34.0%	9.5%	53.4%	2.1%	38.6%
Paremata Haywards Road	69.3	14.1%	2.4%	16.8%	16.8%	3.1%	10.0%
Wainuiomata Road	61.9	10.8%	1.5%	11.8%	12.5%	2.3%	3.9%
Fergusson Drive	37.8	10.8%	7.2%	11.8%	18.8%	5.8%	5.1%
Cambridge Terrace	34.5	10.6%	7.9%	13.4%	19.4%	5.3%	5.1%
Johnsonville Porirua Mtwy	82.0	8.8%	-0.7%	47.1%	8.1%	27.5%	3.2%
State Highway	68.0	6.3%	8.0%	4.6%	14.8%	15.2%	15.5%
Eastern Hutt Road	53.1	4.4%	6.7%	4.6%	11.4%	1.8%	5.7%
SH 2	85.9	3.7%	1.2%	4.0%	4.9%	0.9%	0.8%
State Highway 53	80.0	0.0%	0.2%	0.2%	0.2%	0.1%	0.1%

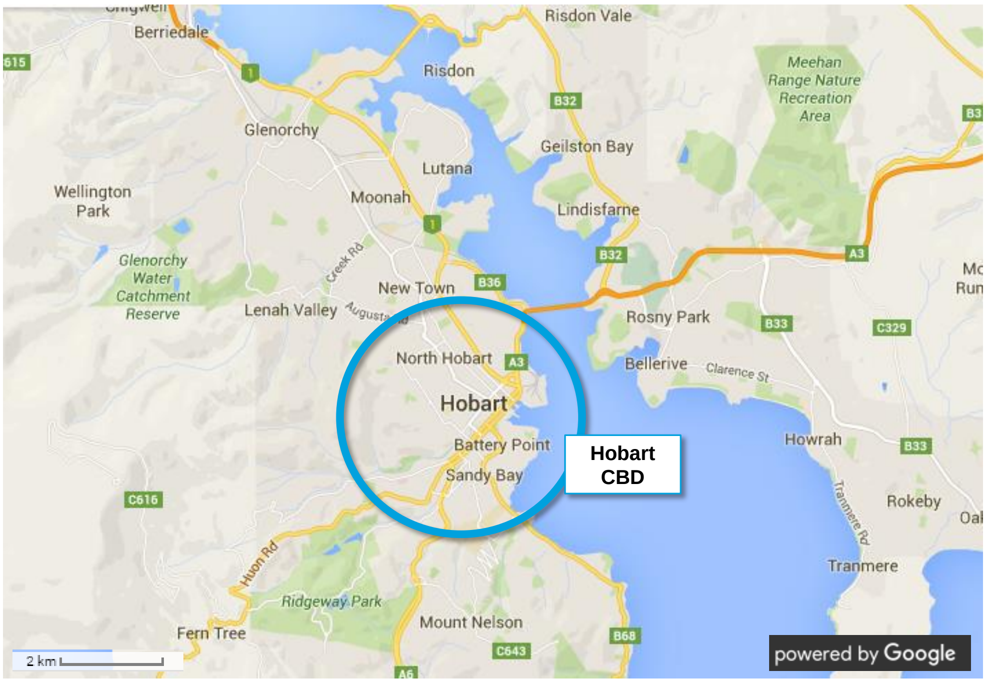
Source: Google maps data 2015-09-09 to 2015-10-29

B.9 Hobart Congestion Performance

Hobart is located between the ocean and the hills. It does not have an orbital network structure. Within the city, the Hobart City Council is responsible for 284km of roads, including 67 bridges. The city is also serviced by four major highways operated by the State Government, namely The Southern Outlet, Tasman Highway, Domain Highway and Brooker Avenue.

As Hobart is one of the smaller cities in this study by geographic size, it was found that there were fewer relevant roads for analysis. For the purposes of this study, we consider only roads greater than 5km in length; to rule out local roads which are likely to have lower speed limits which may otherwise affect the analysis. Similarly, smaller roads were excluded as they may not be meaningful to the overall description of a city's road network. For example, a particularly fast or slow travel time on a very short stretch of road is unlikely to be significant in considering the whole road network. For these reasons, the comparisons in this chapter are limited to a 'Top 3' and 'Bottom 3'.

City Characteristics – Hobart



Source: Google Maps

Average Speed

Hobart Slowest Roads[1]
Km / hr

Rank	Road	City	Avg Speed
1	Brooker Ave	Hobart	36.7
2	Cambridge Rd	Hobart	47.6
3	Goodwood Rd	Hobart	55.8

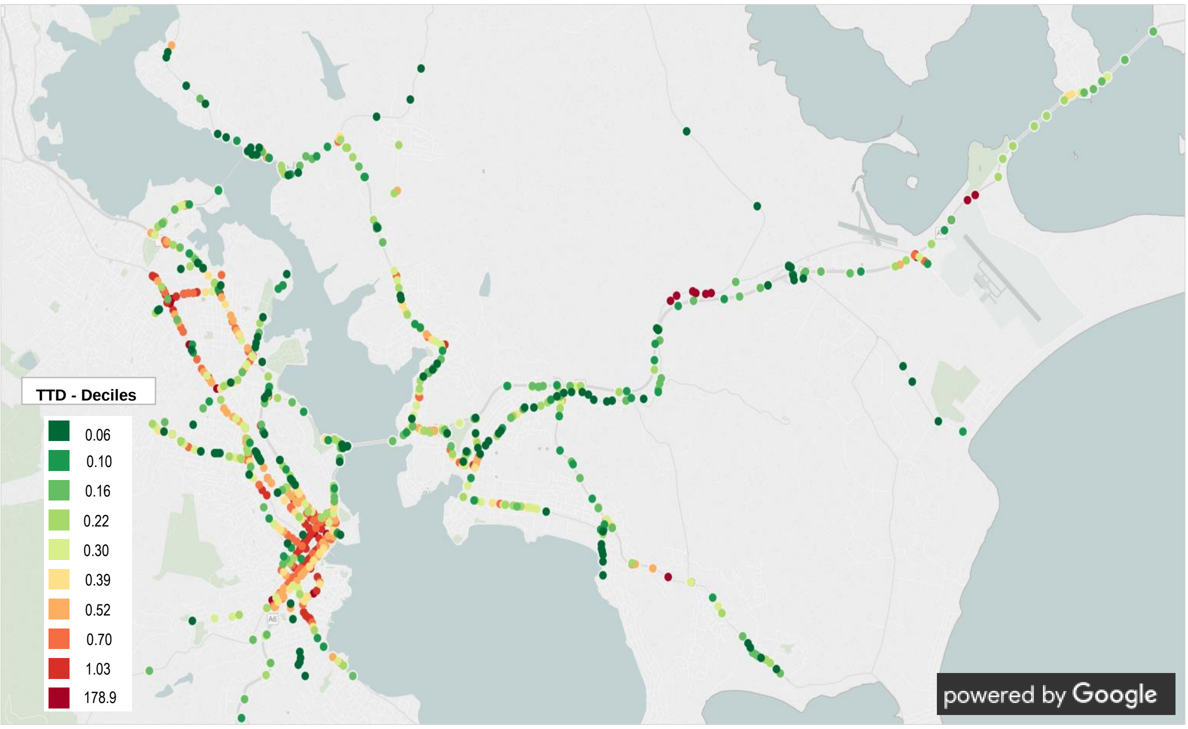
Hobart Fastest Roads[1]
Km / hr

Rank	Road	City	Avg Speed
1	Tasman Highway	Hobart	77.6
2	East Derwent Highway	Hobart	61.2
3	Acton Rd	Hobart	59.3

Note: 1. For roads over 5km
Source: Google maps data 2015-09-09 to 2015-10-29

Travel Time Delay

Hobart - Most Delayed Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Hobart Most Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Brooker Ave	Hobart	17.4
2	South Arm Highway	Hobart	9.6
3	Tasman Highway	Hobart	8.7

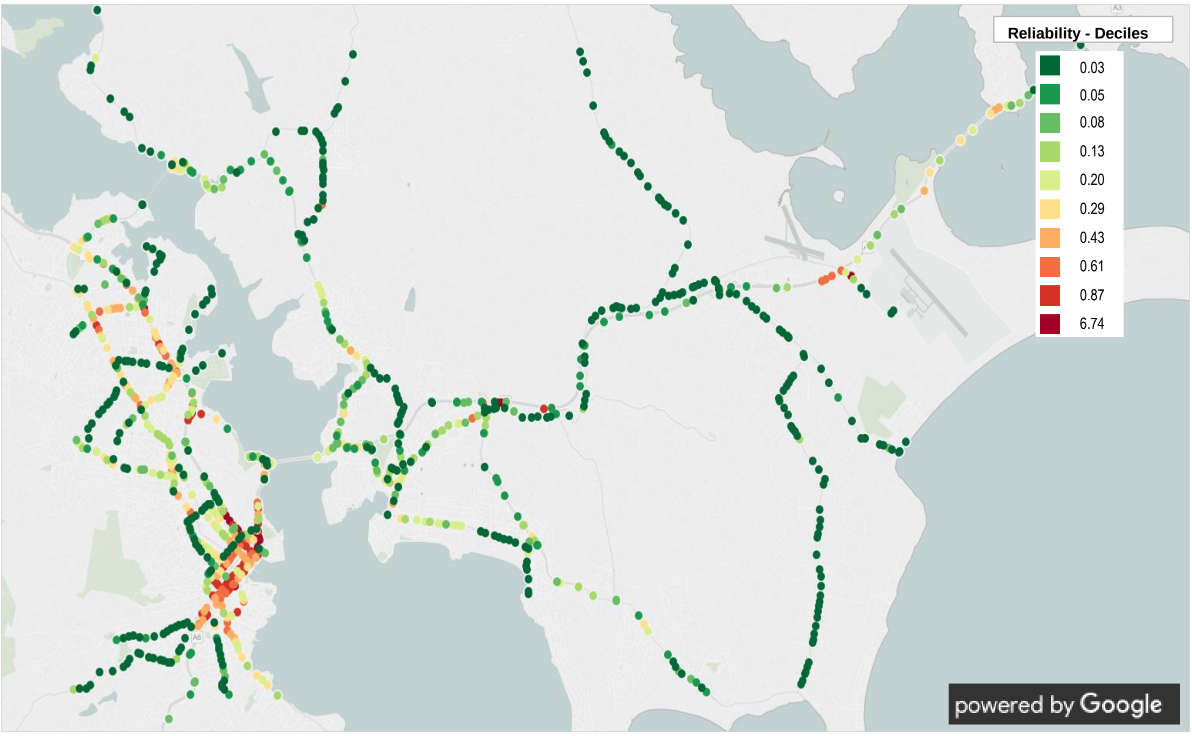
Hobart Least Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Richmond Rd	Hobart	0.0
2	Acton Rd	Hobart	0.3
3	Cambridge Rd	Hobart	2.1

Note: 1. Delay defined as (mean travel time for 24 hours/minimum travel time for 24 hours) -1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Reliability (3pm to 7pm)

Hobart - Most Reliable Afternoon Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Hobart Least Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Brooker Ave	Hobart	10.5
2	Tasman Ave	Hobart	6.2
3	Goodwood Rd	Hobart	3.3

Hobart Most Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Richmond Rd	Hobart	0.0
2	Acton Rd	Hobart	0.2
3	Cambridge Rd	Hobart	1.2

Note: 1. Reliability measured as (standard deviation for 3pm to 7pm/mean travel time for 3pm to 7pm) - 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Mean Scheduling (3pm to 7pm)

Hobart Worst Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Brooker Ave	Hobart	13.8
2	Tasman Highway	Hobart	5.4
3	Goodwood Rd	Hobart	3.4

Hobart Best Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Richmond Rd	Hobart	0.0
2	Acton Rd	Hobart	0.1
3	Cambridge Rd	Hobart	1.3

Note: 1. (90th Percentile for 3pm – 7pm/mean travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Scheduling (3pm to 7pm)

Hobart Worst Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Brooker Avenue	Hobart	33.6
2	Tasman Highway	Hobart	14.5
3	South Arm Highway	Hobart	12.6

Hobart Best Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Richmond Road	Hobart	0.0
2	Acton Road	Hobart	0.4
3	Cambridge Road	Hobart	3.4

Note: 1. (90th Percentile for 3pm – 7pm/minimum travel time for 24 hours)- 1
Source: Google maps data 2015-09-09 to 2015-10-29

Most Delayed Roads – All Congestion Measures

Road	Avg Speed (km)	Travel Time Delay (%)	Aft. Peak Mean Scheduling (%)	Morn. Peak Scheduling (%)	Aft. Peak Scheduling (%)	Morn. Peak Unreliability (%)	Aft. Peak Unreliability (%)
Brooker Avenue	36.7	17.4%	13.8%	23.8%	33.6%	9.7%	10.5%
South Arm Highway	57.8	9.6%	2.7%	10.7%	12.6%	10.4%	2.3%
Tasman Highway	77.6	8.7%	5.4%	17.2%	14.5%	8.6%	6.2%
Goodwood Road	55.8	8.0%	3.4%	11.9%	11.7%	9.5%	3.3%
East Derwent Highway	61.2	4.6%	1.5%	8.2%	6.1%	3.4%	1.3%
Cambridge Road	47.6	2.1%	1.3%	3.1%	3.4%	1.5%	1.2%
Acton Road	59.3	0.3%	0.1%	0.4%	0.4%	0.2%	0.2%
Richmond Road	58.4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Source: Google maps data 2015-09-09 to 2015-10-29

B.10 Canberra Congestion Performance

Canberra, the capital of the Australian Capital Territory and Australia, is located inland (landlocked and surrounded by hills) with space for suburban expansion. The city has a planned road network, but not a grid structure. The network is set up with extensive cycleways and wide streets facilitating transport via bicycle.

City Characteristics – Canberra

Source: Google Maps

Average Speed

Canberra Slowest Roads[1]
Km / hr

Rank	Road	City	Avg Speed
1	Northbourne Ave	Canberra	32.0
2	Belconnen Way	Canberra	38.2
3	State Circle	Canberra	38.5
4	Gundaroo Drive	Canberra	39.9
5	Kings Ave	Canberra	40.5
6	Barry Drive	Canberra	45.1
7	Hindmarsh Drive	Canberra	45.5
8	Coulter Drive	Canberra	45.5
9	Pialligo Ave	Canberra	47.1
10	Canberra Ave	Canberra	47.5

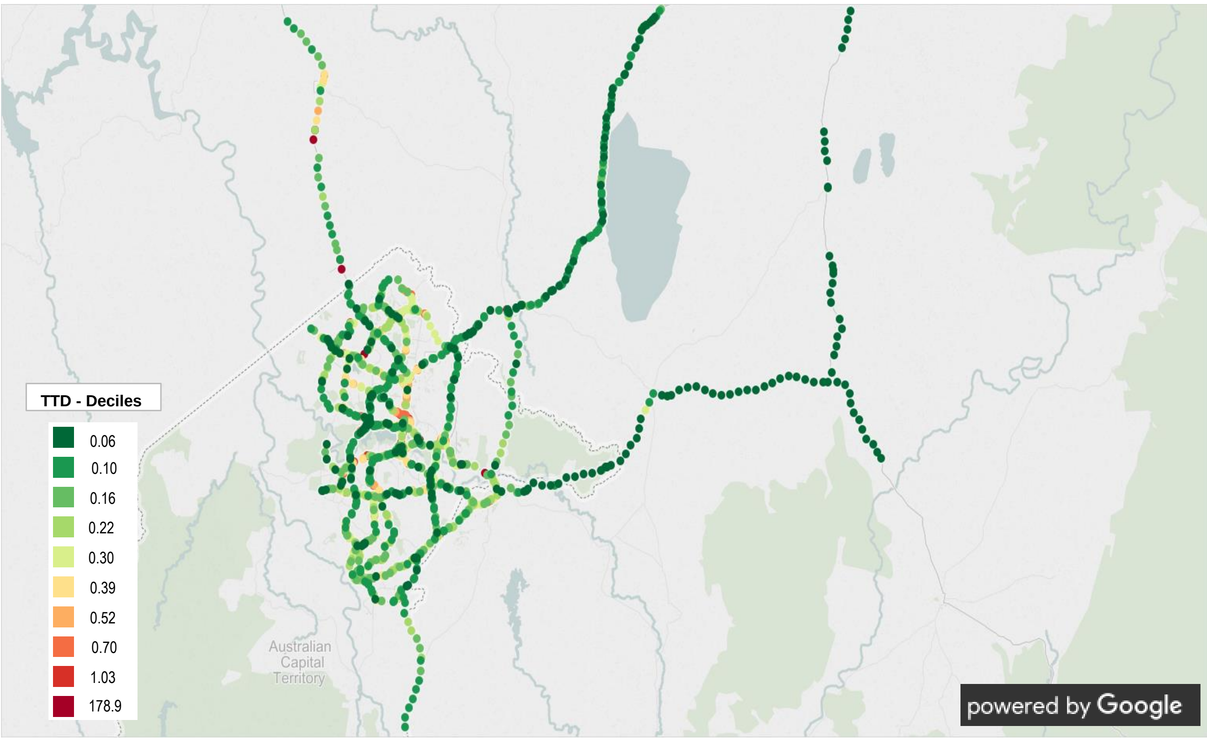
Canberra Fastest Roads[1]
Km / hr

Rank	Road	City	Avg Speed
1	Federal Highway	Canberra	98.1
2	Kings Highway	Canberra	89.7
3	Tuggeranong Parkway	Canberra	86.4
4	Caswell Drive	Canberra	84.2
5	Sutton Rd	Canberra	82.3
6	Monaro Highway	Canberra	80.6
7	Barton Highway	Canberra	75.0
8	Yarra Glen	Canberra	72.9
9	William Hovell Drive	Canberra	70.9
10	Adelaide Ave	Canberra	68.5

Note: 1. For roads over 5km
Source: Google maps data 2015-09-09 to 2015-10-29

Travel Time Delay

Canberra - Most Delayed Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Canberra Most Delayed Roads[1]
% of Min Time

Rank	Road	City	% Delay
1	Northbourne Ave	Canberra	40.0
2	Barry Drive	Canberra	35.4
3	Parkes Way	Canberra	30.8
4	Yamba Drive	Canberra	20.8
5	Kings Ave	Canberra	19.9
6	Belconnen Way	Canberra	19.4
7	Cotter Rd	Canberra	19.1
8	Gundaroo Drive	Canberra	18.9
9	Coulter Drive	Canberra	18.8
10	William Slim Drive	Canberra	17.8

Canberra Least Delayed Roads[1]
% of Min Time

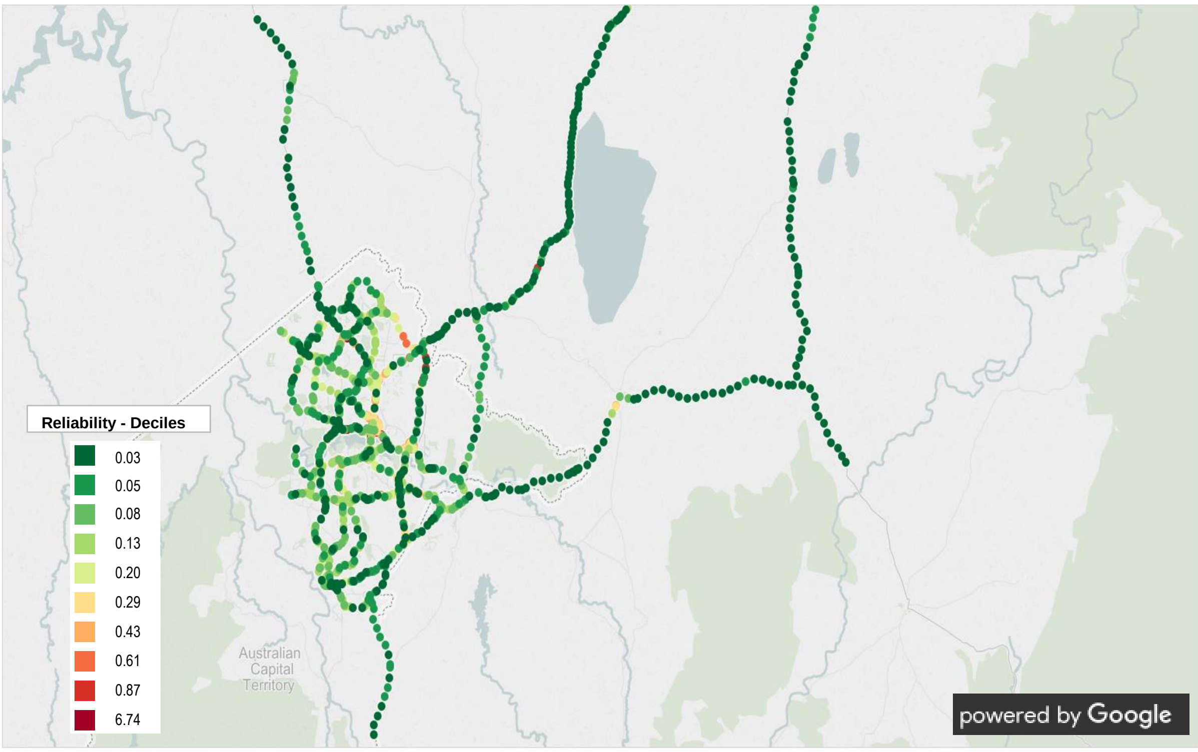
Rank	Road	City	% Delay
1	Kings Highway	Canberra	1.2
2	Federal Highway	Canberra	3.6
3	Yarra Glen	Canberra	5.6
4	Monaro Highway	Canberra	5.6
5	Kingsford Smith Drive	Canberra	5.7
6	Sutton Rd	Canberra	5.8
7	Lanyon Drive	Canberra	5.9
8	Caswell Drive	Canberra	6.8
9	Adelaide Ave	Canberra	6.9
10	Erindale Drive	Canberra	7.4

Note: 1. Delay defined as (mean travel time for 24 hours/minimum travel time for 24 hours) -1

Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Reliability (3pm to 7pm)

Canberra - Most Reliable Afternoon Roads



Source: Google maps data 2015-09-09 to 2015-10-29

Canberra Least Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Parkes Way	Canberra	109.8
2	William Slim Drive	Canberra	25.8
3	Barry Drive	Canberra	19.8
4	Majura Parkway	Canberra	16.8
5	Adelaide Avenue	Canberra	13.8
6	Horse Park Drive	Canberra	12.9
7	Northbourne Avenue	Canberra	12.6
8	Pialligo Avenue	Canberra	9.8
9	Cotter Road	Canberra	9.0
10	State Circle	Canberra	8.4

Canberra Most Reliable Afternoon Roads[1]

% of Average Time

Rank	Road	City	Unreliability
1	Kings Highway	Canberra	0.5
2	Braidwood Road	Canberra	0.6
3	Goulburn Road	Canberra	0.9
4	Federal Highway	Canberra	1.8
5	Tuggeranong Parkway	Canberra	2.1
6	Erindale Drive	Canberra	2.4
7	Lanyon Drive	Canberra	2.8
8	Caswell Drive	Canberra	3.0
9	William Hovell Drive	Canberra	3.4
10	Monaro Highway	Canberra	3.5

Note: 1. Reliability measured as (standard deviation for 3pm to 7pm/mean travel time for 3pm to 7pm) - 1
Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Mean Scheduling (3pm to 7pm)

Canberra Worst Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	William Slim Drive	Canberra	34.3
2	Horse Park Drive	Canberra	20.4
3	Barry Drive	Canberra	15.8
4	Northbourne Avenue	Canberra	13.6
5	Drakeford Drive	Canberra	11.7
6	Athllon Drive	Canberra	10.2
7	State Circle	Canberra	9.6
8	Kings Avenue	Canberra	9.2
9	Yamba Drive	Canberra	8.6
10	Belconnen Way	Canberra	8.0

Canberra Best Afternoon Peak Mean Scheduling Roads[1]

% of Average Time

Rank	Road	City	Scheduling %
1	Parkes Way	Canberra	0[2]
2	Kings Highway	Canberra	0.4
3	Braidwood Road	Canberra	0.6
4	Goulburn Road	Canberra	0.7
5	Federal Highway	Canberra	1.2
6	Tuggeranong Parkway	Canberra	1.7
7	Sutton Road	Canberra	2.0
8	Majura Parkway	Canberra	2.5
9	Erindale Drive	Canberra	2.5
10	Lanyon Drive	Canberra	2.8

Note: 1. (90th Percentile for 3pm – 7pm/mean travel time for 24 hours)- 1; 2. Parkes Way has a scheduling % of 0 due to low afternoon congestion and morning congestion, with a travel time leap due to an incident at 11pm on 22nd October 2015

Source: Google maps data 2015-09-09 to 2015-10-29

Afternoon Peak Scheduling (3pm to 7pm)

Canberra Worst Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Northbourne Avenue	Canberra	59.0
2	William Slim Drive	Canberra	58.2
3	Barry Drive	Canberra	56.8
4	Horse Park Drive	Canberra	37.9
5	Yamba Drive	Canberra	31.2
6	Kings Avenue	Canberra	30.9
7	Belconnen Way	Canberra	29.0
8	State Circle	Canberra	28.9
9	Gundaroo Drive	Canberra	28.4
10	Cotter Road	Canberra	28.0

Canberra Best Afternoon Peak Scheduling Roads[1]

% of Minimum Time

Rank	Road	City	Scheduling %
1	Kings Highway	Canberra	1.6
2	Federal Highway	Canberra	4.8
3	Sutton Road	Canberra	8.0
4	Lanyon Drive	Canberra	8.9
5	Tuggeranong Parkway	Canberra	9.6
6	Yarra Glen	Canberra	10.0
7	Erindale Drive	Canberra	10.1
8	Monaro Highway	Canberra	10.2
9	Kingsford Smith Drive	Canberra	10.4
10	Caswell Drive	Canberra	10.6

Note: 1. (90th Percentile for 3pm – 7pm/minimum travel time for 24 hours)- 1

Source: Google maps data 2015-09-09 to 2015-10-29

25 Most Delayed Roads – All Congestion Measures

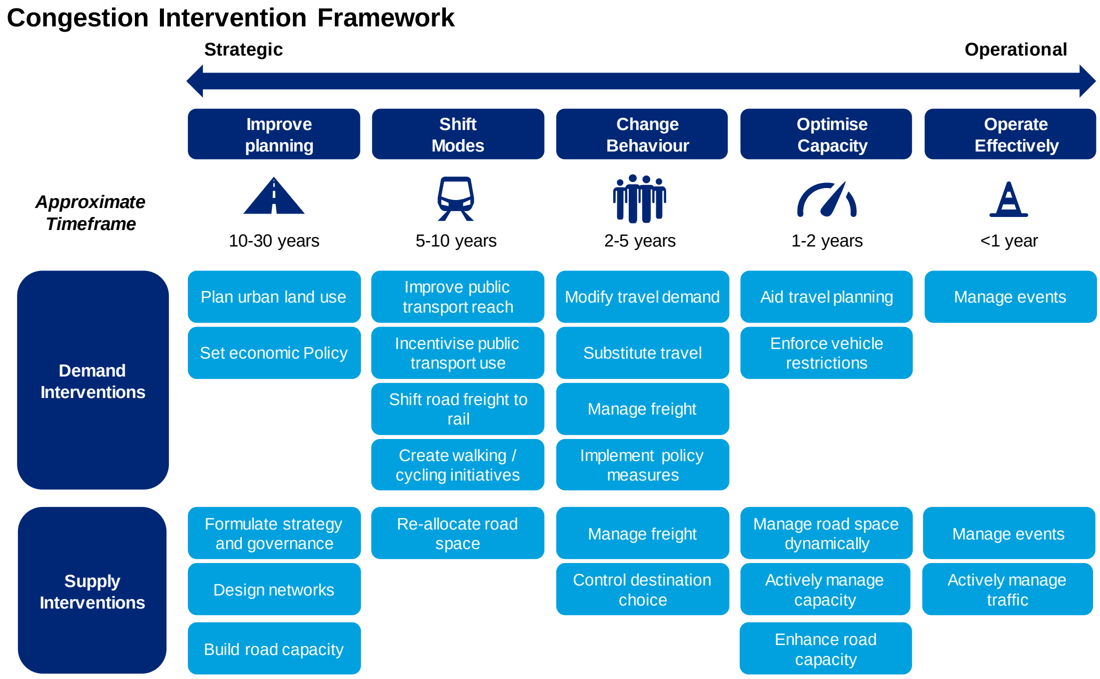
Road	Avg Speed (km)	Travel Time Delay (%)	Aft. Peak Mean Scheduling (%)	Morn. Peak Scheduling (%)	Aft. Peak Scheduling (%)	Morn. Peak Unreliability (%)	Aft. Peak Unreliability (%)
Northbourne Avenue	32.0	40.0%	13.6%	74.6%	59.0%	28.1%	12.6%
Barry Drive	45.1	35.4%	15.8%	61.4%	56.8%	24.2%	19.8%
Parkes Way	59.6	30.8%	-10.5%	67.5%	17.1%	96.5%	109.8%
Yamba Drive	50.5	20.8%	8.6%	28.9%	31.2%	10.4%	5.7%
Kings Avenue	40.5	19.9%	9.2%	28.4%	30.9%	9.1%	7.6%
Belconnen Way	38.2	19.4%	8.0%	28.6%	29.0%	11.2%	6.4%
Cotter Road	48.8	19.1%	7.4%	38.5%	28.0%	14.5%	9.0%
Gundaroo Drive	39.9	18.9%	8.0%	42.5%	28.4%	18.7%	7.2%
Coulter Drive	45.5	18.8%	7.1%	21.9%	27.2%	7.7%	4.6%
William Slim Drive	50.1	17.8%	34.3%	13.4%	58.2%	6.1%	25.8%
State Circle	38.5	17.5%	9.6%	24.5%	28.9%	9.4%	8.4%
Canberra Avenue	47.5	16.9%	5.5%	26.1%	23.3%	9.4%	5.0%
Pialligo Avenue	47.1	15.4%	7.4%	24.6%	23.9%	11.3%	9.8%
Horse Park Drive	48.8	14.5%	20.4%	17.1%	37.9%	6.7%	12.9%
Hindmarsh Drive	45.5	14.4%	6.6%	21.8%	22.0%	9.8%	4.8%
Athllon Drive	50.3	12.7%	10.2%	16.2%	24.3%	4.5%	6.3%
Ginninderra Drive	54.5	12.5%	6.9%	17.6%	20.3%	6.1%	4.4%
Drakeford Drive	49.9	12.3%	11.7%	17.4%	25.4%	7.6%	7.2%
Gungahlin Drive	59.0	11.7%	6.1%	30.1%	18.5%	17.2%	5.2%
Isabella Drive	62.9	11.4%	4.9%	15.4%	16.8%	4.9%	3.9%
William Hovell Drive	70.9	8.0%	4.0%	12.3%	12.3%	5.4%	3.4%
Barton Highway	75.0	7.8%	5.7%	12.8%	14.0%	6.3%	4.8%
Tuggeranong Parkway	86.4	7.8%	1.7%	17.3%	9.6%	8.7%	2.1%
Erindale Drive	64.2	7.4%	2.5%	12.9%	10.1%	6.2%	2.4%
Adelaide Avenue	68.5	6.9%	4.5%	21.4%	11.7%	7.1%	13.8%

Source: Google maps data 2015-09-09 to 2015-10-29

Appendix C Congestion Interventions

The intervention framework provided in Chapter 5 (as detailed in Exhibit C.1) provides a framework for classifying interventions that are currently used in many developed cities. An understanding of the interventions, current examples of their use and associated benefit-cost ratios can help in decision-making on their relevance and benefit-cost. Appendix C.1 provides details on each intervention-type that sits within the framework and Appendix C.2 details the benefit-cost ratios used in the analysis.

Exhibit C.1: The framework groups interventions by approximate timeframe, from long-term, strategic changes to short-term operational management



C.1 Intervention Framework Details

Within each segment of the framework there are a number of interventions, details of which are provided here, with an overview of their use in mitigating recurrent and non-recurrent causes of congestion, their impact on time and/or reliability and their applicability to peak and non-peak times of day.

C.1.1 A. Improve Planning (10-30 years)

'Improving planning' allows road and transport agencies to construct their strategy and resulting decision-making with the future economic, political and social direction of the city in mind. This activity generally requires broad consultation and collaboration with other agencies and government service providers, so is difficult to effectively implement.

Demand-side: Plan Urban Land Use

On the demand side, agencies can plan urban land use to mitigate the congestion consequences associated with future increases in demand for travel. Good planning, with subsequently strong implementation, is the biggest single factor determining future levels of congestion and therefore the liveability of cities. Too often, sound plans have been abandoned due to political intervention, where concerns about the negative opinions of road users override the detailed quantitative analysis.

a) Create transit-oriented urban spaces

Creating transit-oriented urban spaces enables future populations to move efficiently between desired origins and destinations. It allows for timely access to public transport and road infrastructure, both lowering the cost of access to the user and the time-related opportunity cost of movement. Creating such space will improve both the time and reliability of journeys. It will directly influence the recurrent causes of congestion by manipulating the choices of the road users, with greatest impact during peak hours.

An example strategy for creating transit-oriented urban spaces is Hobart and how it has been impacted by the Southern Tasmania Regional Land Use Strategy (2010-2035)[138.] This long-term land use strategy has a focus on presenting a more defined regional vision, giving overarching strategic direction and including a set of regional planning policies. The strategy acknowledges that Greater Hobart is one settlement and that major land use planning decisions in one part of Greater Hobart have consequences that impact the whole metropolitan area and often across the entire Southern region of Tasmania. Without coordinated regional planning, the committee believe they will find that living and working in towns and cities is more expensive than it need be. The strategy emphasises the need to 'focus employment, retail and commercial uses, community services and opportunities for social interaction in well-planned, vibrant and accessible regional activity centres that are provided with a high level of amenity and with good transport links with residential areas'.

The ongoing operational cost of planning ensures thorough consideration of interventions that can deliver a high level of benefits to road users. If these interventions are the result of sound consideration, they will most likely be worth their investment once implemented.

b) Implement housing and business planning controls

Implementing housing and business planning controls manages both the origin and destination of travel demand, as well as the absolute size of travel demand, by altering the location of residential and commercial property. Often, such property is located in disparate areas, however bringing these together so that people do not need to travel as far to work can help drive efficiency in the transport network.

Considering land use is important when planning cities. For example, the cluster and connect model (an approach to integrated transport and land use planning) is subject to significant guidance in terms of urban design to achieve better integration at the regional, corridor and local area levels[139]. The approach has a strong place-making focus at the neighbourhood level, by consolidating community facilities around public transport.

Implementing housing and business planning controls has a major affect in reducing recurrent congestion as demand will be dispersed; it will also result in a consequent reduction in non-recurrent congestion. Both peak and off-peak congestion will be mitigated and, if businesses and housing are located in the same area as personal, social and commercial journeys will be shortened.

138 South Tasmania Regional Planning Project, (2013), Southern Tasmania Regional Land Use Strategy
139 Transport and Infrastructure Council, (2015), 2015 National Guidelines for Transport System Management in Australia

c) Model and manage road demand forecasts

With all land use planning, future road demand must be modelled. Road demand can be a factor of alternative transport, vehicle-use and vehicles per capita. Understanding how these will change, and how they inter-relate, will enable modelling of demand and its associated impact on the road and transport networks. In turn, this will allow strategy to be best aligned with customer behaviour. At present, most models include vehicle demand, but not necessarily pedestrians, cyclists and different types of vehicles such as freight. Transport planning tools need to improve considerably to capture the broader interpretations of congestion in the variables related to the various individual, household and freight-related choices. At a minimum, there should be some measure of the role of travel time components (such as free flow, congested) and trip time variability (standard deviation of travel time). MetroScan software is an example of how modelling can recognise feedback between land use/location and transport, and also how firms and households respond in respect of location and relocation where congestion outcomes are part of the package of outputs.

While the cost of such modelling is relatively low in comparison to the cost of new infrastructure, the awareness and sharing of such information can lead to a sustainable future-oriented transport strategy. Using modelling allows interventions to be best targeted so that journey time is predicted and managed, or optimized at best. It will mainly influence recurrent congestion as it will model the volume of vehicles and how they can be best managed. It can also be used to model the broader road network and routes around a city that different vehicles make. In general, it helps mitigate overcrowding during peak periods, where an ability to forecast demand is most necessary.

An example of a large-scale model is the UK Department for Transport's National Transport Model which focusses on traffic demand, congestion and emissions up to the year 2040. The forecasts are based on the current understanding of how people make travel choices, the expected path of key drivers of travel demand and no change in government policy beyond that already announced. Road transport forecast results are produced yearly from the model[140.]

Demand-side: Set Economic Policy

Alongside land use planning, economic policy can be set to directly influence changes in the demand for transport and supply of infrastructure.

a) Model and manage network for population and travel growth

Prior to investment decision-making, modelling the resulting impacts on the network from population and travel growth is important to provide an understanding of how the economics of the city, both human-natured and monetary, are influenced by such changes. While this in itself will not have a direct impact on congestion, it is a pre-requisite to setting economic policy.

This can be exemplified Rui's modelling and land-use simulation of the City of Toronto. Given increasing population numbers the model tracks land usage and is a good indicator of continuous urban sprawl[141]. Most previous urban growth models applied fixed transport networks, and this model focused on the evolution of road networks. The model demonstrated that three main types of agents: residential, developer and the government, interact with each other and have a reciprocal influence with the environment.

When modelling the costs and benefits of setting economic policies, it must be recognised that low costs can lead to high impact subsequent investment decisions. Consequently, high BCRs are likely.

b) Align investment decisions to clear strategic and economic outcomes

Transport policy and investment decisions should be tied back to the overall economic strategy of government departments, whether transport-related or otherwise. Urban economic strategies will centre on tying the locations of jobs to the locations that people want to live. Incentives to develop local services and jobs are crucial.

140 Department for Transport, (2013), Road Transport Forecasts 2013
141 Rui, Y., (2013), Urban modelling based on land-use changes and road network expansion

Here, both time and reliability can be impacted. For example, if an economy is supported by tourism and events, these non-recurrent causes of congestion can be tied into the investment decisions that the city makes to support such business (including transport infrastructure). Similarly, there is a need to understand how investing in infrastructure will be linked to economic outcomes to ensure efficient use of taxpayer funds.

An example is the Western Sydney Infrastructure Plan (Australian Government) which includes investments of $2.9bn over the next ten years to focus on major infrastructure improvements that will boost regional liveability. This is predominantly related to the construction of Western Sydney Airport and its associated road access. Western Sydney poses the challenges of jobs growth lagging population growth and a daily commute for most workers into the centre of Sydney. The investment decisions for the Western Sydney area are aimed at providing the infrastructure to facilitate an active jobs market, transport to connect different thriving areas in the region, and government services to support a growing population. Consequently, pressure on the existing infrastructure will be relieved and economic capacity in the region unlocked[142]. Investment is funded mostly from Federal Government, and also from State Government, Councils, developers and others.

Supply-side: Formulate Strategy and Governance

a) Create a strategic plan and engage stakeholders

Formulating a strategy and its associated governance for how future demand will be provided for, whether through road infrastructure, transport infrastructure or even through relocation of jobs and homes, is necessary to ensure that supply can meet demand and congestion is mitigated. Engagement with a wide range of stakeholders will be key when planning for future supply-side interventions. It will ensure that they have the knowledge and resources to understand which interventions have the highest BCRs, so that they are aligning their direction with the best possible outcomes.

Strategic plans can be used for mitigating time and reliability problems resulting from congestion, and they can be targeted at mitigating recurrent and non-recurrent, as well as peak and off-peak congestion. Formulating strategy and governance will incur low costs due to the nature of investment through operational cost rather than materials. High potential benefits will result in high BCRs.

b) Encourage Transport Management Associations

Transport Management Associations (TMAs) are non-profit, member-controlled organisations that provide transportation services in a particular area, such as a commercial district, mall, medical centre or industrial park. They are generally public-private partnerships, consisting primarily of business areas with local government support. Their aim is to switch demand from use of cars to public transport. TMAs are usually more cost-effective than programs managed by individual businesses and allow small employers to provide commute trip reduction services comparable to those offered by large companies. They can provide a variety of services including access management, pedestrian and bicycle planning, shuttle services, telework support, parking management and brokerage and transportation access guides.

TMAs avoid problems associated with government-run programs, since they are controlled by members[143]. They provide a variety of services that encourage more efficient use of transportation and parking resources, including access management, pedestrian and bicycle planning, shared parking coordination, transit improvements and marketing. TMAs provide an institutional structure to deliver various demand and supply management strategies.

The resulting intervention can help to alleviate the time taken and reliability of journeys. It is most likely applied to recurrent congestion at peak times, but can be used in specific cases where off-peak movement requires detailed forward-planning, for example in the case of movements of large number of people at a specific time of day.

142 Australian Government Department of Infrastructure and Regional Development, (2015), Western Sydney Infrastructure Plan
143 Victoria Transport Policy Institute, (2015), TDM Encyclopaedia – Transport Management Associations

Supply-side: Design networks

a) Improve design of transport network and intersections

Designing networks to ensure optimal interaction between modes will improve the efficient connection of single and multi-modal routes. Once design is complete and investment decisions are made, consequent long-term construction projects can be delivered in strategically significant places, for example where maximum economic benefit can be derived from connecting origins and destinations. Designing and modelling of roads and public transport networks must be linked. Nielsen and Lange outline in 'Network Design for Public Transport Success' the key properties of a successful public, transport network: service frequency, investment in transfer and interchange points, network simplicity and common trunk line sections in small cities[144.]

The design of transport networks is also important because it can directly add to congestion. For example, while introduction of a bus lane may potentially increase the level of congestion on other lanes, overall throughput of people may increase – here a trade-off exists. Similarly, more priority for pedestrians resulting in the slowing of vehicle movements can be the right thing to do in dense urban areas with commercial and pedestrian activity. Network Operating Planning can be used to optimise the operation of roads.

Designing networks effectively will help to mitigate both time and reliability effects of congestion and is most likely to impact recurrent congestion as it will influence customer decisions, and will affect both peak and off-peak route decision-making. It will help to reduce bottlenecks and take traffic from clogging arterial roads.

Supply-side: Build Road Capacity

The 2015 National Guidelines for Transport System Management in Australia[145] use infrastructure project and asset typology of: Strategic, Structural and Follower. Strategic infrastructure includes works that are almost exclusively in the transport domain and have the power to shift relative accessibility (e.g. motorways). They drive investment in where businesses locate and people live. Structure infrastructure includes trunk facilities and networks that forma region's urban framework (e.g. arterial roads). Follower infrastructure includes services and facilities with localised service catchments (e.g. local roads).

a) Build new motorways

Statistics on throughput and accidents indicate that motorways are the most direct and speed efficient road option; providing unhindered flow of traffic, with no traffic signals, intersections or property access. Opposing directions of traffic are generally separated by a central reservation barrier, eliminating the sources of potential conflicts with other directions of travellers to improve safety. In general, Australian motorway speed limits are 110 km/h and New Zealand motorway speed limits are 100 km/h.

A 2007 report by the Royal Automobile Club Foundation (UK) found that only 4% of all accidents occur on motorways, making them the safest type of road[146]. Urban and Urban 'A' roads accounted for 35% and 26% of accidents respectively, rural 'A' roads for 18% and other rural roads for 16%.

Motorways increase both time and reliability as they are designed for high-speed movement, with minimal opportunity for conflict to occur between vehicles. They improve the flow of traffic in both peak and off-peak periods, however implementation must be carefully considered to ensure that supply does not induce demand and supply is aligned with forecasts of demand. Adding bus lanes, and to a lesser extent, transit lanes can significantly increase peak hour capability, so should be considered in the initial road design.

An example is Sydney's WestConnex, a major infrastructure project with 33km of interconnected road projects. WestConnex includes an extension of the M4, a widening of the M5 and a tunnel link between the two motorways in the inner western suburbs of Sydney. While the estimated capital costs are approximately $15 billion, the project is expected to have benefits of $27 billion, and a BCR of 1.8 (however this figure does not include the c.$2bn cost of arterial road congestion mitigation works).

144 Nielson, G. and Lange, T., (2008), Network Design for Public Transport Success
145 Transport and Infrastructure Council, (2015), 2015 National Guidelines for Transport System Management in Australia
146 Royal Automobile Club (RAC) Foundation UK, (2007), Roads and Reality

BCRs identified for building new motorways are typically around 2.0 (including Melbourne City Link with 2.0 and Sydney NorthConnex with 2.12)[147].

b) Build bypasses / ring roads

A bypass is a road that avoids or 'bypasses' a congested place to allow traffic flow without interference from local traffic. This place is generally a destination such as a CBD, high street, shopping centre or sports ground. Care must be taken: if there are no strong land use controls, buildings can be built along a bypass, converting it into an ordinary road and therefore the bypass might become congested itself.

A ring road is a road or a series of connected roads encircling a town or city. Construction of fully circumferential ring roads has generally occurred more recently than bypasses, beginning in the 1960s in many areas. The benefits of ring roads include that they shorten travel time when drivers want to completely bypass a city, they steer traffic towards unpopulated areas and they can allow further development with good transport links.

Both bypasses and ring roads can improve the time and reliability elements of congestion, as they more efficiently move traffic around a city and mitigate incidents through reducing the build-up of traffic on radial roads. They enhance these aspects in both peak and off-peak times, and will ensure that the recurrent volume of road users on arterials is reduced.

c) Build new arterial roads

An arterial road is a high-capacity urban road. The primary function is to deliver traffic between urban centres at the highest level of service possible. For more recently built arterial roads, intersections are often reduced to increase traffic flow, however this is not the case for many arterial roads in ANZ cities. Traffic signals are used at most intersections and speed limits are typically between 50 and 80 km/h. The benefit-cost analysis when considering building a new arterial road must consider whether supply will induce demand and whether public transportation infrastructure may be a more appropriate solution for transporting passengers in existing urban areas. In new and rapidly growing urban areas arterial roads are fundamental to facilitating connectivity.

Arterial roads allow for direct access between high-demand origins and destinations, improving both the time and reliability of journeys in peak and off-peak times.

d) Widen existing roads

When considering whether to widen existing roads, both in the city and on routes into the city, agencies should model and investigate whether the resulting increase in supply will induce demand. Widening existing roads can be costly – particularly in built-up areas there may be major land use prohibitors such as shops, housing and other protected land. It is likely that business and people will have centred around popular road routes and without prior planning widening the road may not be possible. Widening a road will increase capacity and therefore could reduce the number of incidents as cars have more space to manoeuvre, as long as demand is controlled. Both peak and off-peak time and reliability measures will be improved, however the cost-benefit is low due to the required investment (largely land value).

Various examples for widening existing roads have been included in the benefit-cost analysis of this report. An example to call out is the M2 Widening in NSW (2010) with a BCR of 3.4, costs of $500m and a benefit of approximately $1.7bn. Other widening projects outline even higher BCRs with 4.5 for Sladen Street in Victoria and 5.5 for the City Link to Tullamarine Widening project in Victoria[148].

147 For BCR calculation, capital costs were adjusted for inflation and the relative construction costs of a country. The direct environment of where such building construction took place and the population density of surrounding areas was included. It was assumed that the higher the population density in a specific area the higher the costs for the infrastructure project. As an additional dimension, the unit costs and benefits per kilometre of road length were compared for the various building road capacity projects

148 Infrastructure Australia, (2014-15), Assessment Briefs – Benefit-Cost Analysis

In 2014/15 the Queensland Government proposed a series of upgrades to the Gateway Motorway North, including widening of approximately eleven kilometres of the motorway from four to six lanes. The project sought to address the increased congestion and accident rates on the Gateway Motorway North stemming from an increasing number of commuter car trips and activity expansions across the Australian Trade Cost precinct and Port Of Brisbane. In 2011, this motorway carried over 75,000 vehicle per day. The objective of the project was to support the economic growth potential of the Australia Trade Cost precinct, Port of Brisbane and the adjoining commercial areas; to provide a safe and efficient urban bypass road enabling access between markets, production and distribution centres, the Port and the Airport; and to reduce input costs to business and industry. The resulting assessment determined a benefit-cost ratio of 5.5:1.

C.1.2 Shift Modes (5-10 years)

Intervening in customer habits and shifting the modes of transport that they use, requires not only the provision of the appropriate infrastructure, but a cultural shift that can take years to prepare and manage. As explored earlier, Australia and New Zealand are particularly car-dependent countries and enabling a shift to other modes could mitigate much of the recurring congestion in cities. A shift to public transport may require bus lanes, procurement of fleet, new infrastructure technology and promotion. For commercial and freight transportation, a shift from road to rail or shipping requires infrastructure provision and incentives.

Demand-side: Improve Public Transport Reach

a) Add public transport capacity

Adding public transport capacity can be in the form of additional capacity on existing public transport routes, the creation of additional routes in new locations or prioritisation of public transport on existing road networks. If this additional provision is seen as a service improvement for those that are normally drive personal vehicles, there will be a reduction in demand for road capacity. However, often the make-up of patronage on new services may comprise new passengers (due to induced demand), with people switching from other public transport services or modes and car passengers.

Overcrowding is a major disincentive to use public transport for many commuters in ANZ cities, who see the personal space and convenience of a car as a preferred mode. Incentivising the use of public transport through more convenient, faster or less crowded routes is essential to significantly increase the relative and absolute number of people who use public transport as our cities grow.

Providing public transport will improve the time and reliability of car journeys as the number of people using the road capacity will decrease; recurrent congestion will be improved. However, transport planners must consider the impact on congestion from additional buses and bus routes, which can cause bottlenecks due to the stop-start nature of their movement. Providing bus lanes to support additional capacity could be required. While these changes can lead to benefits for bus users through a reallocation of resources from another mode (e.g. lane space), they can lead to costs for other modes through their associated loss of space and as such, benefits may not accrue. Adding public transport capacity can prevent both peak and off-peak congestion, but is likely to have greatest impact during peak time.

Overall, adding public transport capacity has an average BCR of slightly higher than 1. Several examples for adding public transport capacity in Australia have been included in the analysis of benefit-cost ratios. BCRs start from 0.25 for a higher bus frequency in Hobart[149] and includes1.12 for the proposal of a light rail in Hobart[150], 1.20 for offering additional train services in Melbourne during peak hours[151] and 1.34 for the Brisbane Cross-River Rail. This finding is undoubtedly influenced by the lower efficiency of public transport in Australia and New Zealand than in comparable countries. A full list of BCRs can be found in Appendix C.2.

149 Tasmanian Government Department of State Growth, (2015), Transit Corridors analysis
150 Tasmanian Department of Infrastructure, Energy and Resources / Riverline, (2014) Riverline – Hobart Light Rail Strategic Assessment
151 Infrastructure Australia, (2012-13), Assessment Brief – Melbourne Metro

Demand-side: Incentivise Public Transport Use

a) Enhance modal interchanges and inter-modal plans

Enhancing modal interchanges relates to public transport, vehicle, walking, cycling and other mode-type connections. Enhancing mode interchanges will allow for more efficient long distance journeys, as the speed of connection between different 'legs' of the journey will increase. Often, train lines may not extend to the suburban areas of cities and therefore bus journeys are required to access a train station with a high-speed line to a city centre. In general, research shows that customers prefer not to interchange during their journey, even if the travel time is slightly longer by a single mode of transport. Ensuring that this smooth transfer of mode type requires minimum effort on the part of the customer, will incentivise people to travel via public transport, rather than make the entire journey in their personal car. Bus routes that converge on similar points, which allow for ease of transfer at centralised interchanges, will cut transit time for multi-leg journeys. Similarly, if the person cannot access public transport close to their home, providing car parks will ensure that they don't make an entire journey by car. Increasing convenience will raise the demand for the associated public transport.

Enhancing mode interchanges will reduce the recurrent nature of congestion by increasing demand for public transport use and therefore decreasing demand for car transportation. Both the time and reliability of road transportation will improve if there is less demand on the road. People will use the enhanced public transport in largely in peak times.

The Hobart Central Bus Interchange Planning Study is one example – a joint partnership between the Hobart City Council, Dept. of Infrastructure Energy and Resources, Metro Tasmania and Tasmania Bus Association. The project is planning a study that aims to identify optimal arrangements for public transport access across the Hobart CBD, including location of a central interchange and bus stops, improvement of the amenity of bus travel, provision of public transport access points that better meet the needs of users, improvement in reliability of bus services and integration of regular transport services into a single interchange facility or set of adjacent facilities.[152]

b) Improve attractiveness of public transport through cost and convenience

By lowering the cost of public transport to the user, or increasing its convenience by matching supply to route demand, customers are more likely to switch from road use to public transport use. Provision of low cost, convenient public transport is of particular appeal in growing cities, and may reduce the incentive for younger drivers to buy a car, if they deem that public transportation is as convenient and less expensive. This is already the case in many global cities where suburban car ownership is low.

Victoria Transport Policy Institute examined the price elasticity[153] of public transport travel for use in public transit planning. They concluded that no single transit elasticity value applies in all situations: various factors affect price sensitivities including type of user and trip, geographic conditions and time period[154]. Available evidence suggested that the elasticity of transit ridership with respect to fares was usually in the -0.2 to -0.5 range in the short run (first year), and increased to -0.6 to -0.9 over the long run (five to ten years). An elasticity less than 0 means that the percentage change in quantity demanded is less than the percentage change in price, therefore significant price changes are required to grow demand, reducing overall revenue. They also found that:

- The response of demand to a change in price is higher for dependent users than for discretionary ('choice') users
- Off-peak and leisure travel demand is more responsive to price than peak and commute travel demand
- The responsiveness of changes in demand between public transit and automobile travel, to price, are relatively low in the short run, but increase over the long run

152 Tasmania State Growth website, (2015), Hobart Centre Bus Interchange Planning Study
153 Price elasticity of demand is a measure used in economic to show the responsiveness, or elasticity, of the quantity demanded of a good or service to change in its price, ceteris paribus
154 Victorian Transport Policy Institute, (2015), Transit Elasticities and Price Elasticities

- A relatively large fare reduction is generally needed to attract motorists to transit, since they are discretionary users; such travellers may be more responsive to service quality (such as speed, frequency and comfort)

Encouraging public transport use will improve both travel time and reliability for road users, as less people choose to drive personal cars. This should help to reduce recurrent congestion in both peak and off-peak times. The London Congestion Charging system (launched 2003) encouraged use of alternate transport through implementation of fees to motorists operating in congestion zones during peak hours. Five years on from its launch, traffic in central London was reduced by over 20% and public transport use increased by 2%[155].

Recent Australian examples include the Greater Adelaide East-West Bus Corridor with a BCR of 1.7[156] and the Sydney Light Rail with a BCR of 2.5[157]. The bus corridor is aiming to improve the efficiency and service quality of commutes, while the light rail is aiming to increase the efficiency and service quality of services that are used to transport people for parts of their journey or for short journeys. The Adelaide bus corridor is explicitly looking to improve the service quality of the existing bus services. The Sydney Light Rail is hoping to encourage public transport patronage by improving the convenience of short journeys around the CBD and suburbs.

Demand-side: Shift road freight to rail

a) Improve the attractiveness of rail freight

Shifting modes is not attributed to personal journeys only, it also applies to commercial transportation. For freight, some road freight can be transferred to rail (largely dependent on the material being transported), if the infrastructure to support rail transportation is available. As discussed by BITRE's report entitled 'Road and rail freight: competitors or complements', until the 1960s, railways dominated all but the shortest land-based freight task, but as road vehicle productivity and road infrastructure quality increased, the gradual removal of regulations restricting road freight and the growth of interstate trade broadened the range of freight tasks for which road is better suited[158]. However, there is rarely a suitable substitute for light commercial vehicles – the equipment that must be transported by independent workers cannot be transported on foot, and therefore not on public transport.

BITRE's report also states the factors that influence mode choice, and therefore the factors that rail freight must improve upon in order to move freight from road to rail. These include transit time, reliability and service availability/frequency. Transport time offerings include express (next day), economy (day-definite, 2-5 working days), general (non-definite) and customised (non-standard mass/dimension freight, dangerous goods or special temperature). In general, rail freight can meet economy but not express time targets[159]. Similarly, freight transport and costs are significant factors influencing choice. Reducing the cost of rail freight will enable more companies to switch from road to rail.

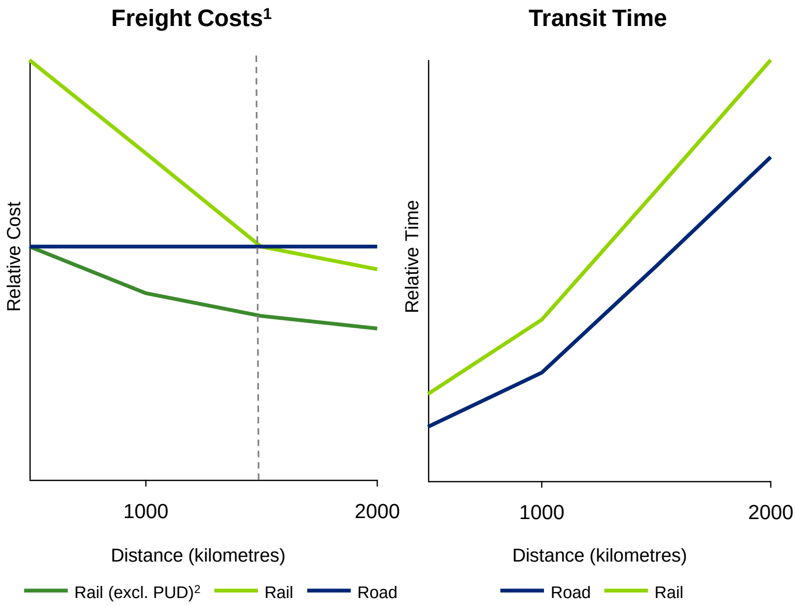
However, the impact of such intervention might not have a great impact on peak-time congestion in ANZ cities, as freight often travels in off-peak hours (in reality, this is often not mandated). Time taken and reliability will be improved where large amounts of freight travel on specific routes, however what is traditionally perceived as peak congestion might not be addressed.

For light urban freight and personal motorised trips related to the transport of goods, it must also be noted that cargo bicycles can be a viable alternative option.

155 Transport for London , (2008), Central London Congestion Charging Impacts Monitoring, Sixth Annual Report, July 2008
156 Infrastructure Australia, (2012-13), Assessment Brief – East-West Bus Corridor Greater Adelaide
157 Westralia Infrastructure, (2014), Metro Area Express Light Rail
158 BITRE, (2009), Road and rail freight: competitors or complements?
159 BITRE, (2009), Road and rail freight: competitors or complements?

Exhibit C.2: Marginal freight costs decrease with distance for rail freight transportation, but are linear for road transportation

Australian Intercapital Road and Rail Freight



ANZ Road Route Length

	km
Sydney – Canberra	285
Wellington - Auckland	649
Melbourne - Canberra	671
Melbourne - Adelaide	724
Sydney – Melbourne	907
Sydney - Brisbane	932
Melbourne – Brisbane	1,799
Adelaide – Perth	2,697
Brisbane - Darwin	3,430

Notes: 1. Rail freight costs excluding pick up and delivery with average freight costs for oil prices at approximately US$30-50 per barrel; 2. Pickup and delivery

Source: BITRE report 'Road and Rail Freight – Competitors or Complements'

Create Walking / Cycling Initiatives

Encouraging active transport such as walking and cycling has benefits beyond transportation, in health and lifestyle improvements. A study commissioned by the Department of Transport and Main Roads (Queensland) in 2011 explored conventional ways in which transport infrastructure is valued and how the omission of other benefits like health may lead to an inefficient allocation of funds. The failure to capture and monetise the health benefits directly associated with the use of active transport leads to an underestimation for the value of infrastructure in this area. With a benefit-cost ratio between 0.3-2.4, the study considered a range of benefits including vehicle operating cost savings, decongestion, air quality and health benefits. Approximately 90% of benefits to the individual are attributed to health improvements in cyclists and pedestrians[160].

As well as the congestion mitigation benefits derived from promoting walking and cycling for entire journeys, road and transport agencies can also seek to promote walking and cycling for parts of journeys. For example, reducing the use of cars to travel to train stations and reducing the demand for taxis when people arrive in CBDs will help prevent congestion. Walking and cycling facilities are also desirable in suburban areas and suburban centres, not just CBDs, as part of city wide networks for these modes.

Encouraging just a few people to use bikes rather than cars can make a difference to traffic flows. On the congestion 5km Petone to Ngauranga section State Highway 2, Wellington, research suggests that only 10-30 vehicles out of the 150-280 vehicles occupying the space at congested times are causing congestion[161].

The key note of caution is around topography – a hilly city (for example, Sydney) cannot hope to replicate the performance of geographically flat cities such as London and Amsterdam for entire commute journeys from the suburbs to the centre. Within the CBD, however, interchanges and facilities to promote walking and cycling are desirable. In turn, hilly topography is becoming less of an issue due to the availability of electric bicycles.

160 PriceWaterhouseCoopers and SinclairKnightMerz, (2011), Benefits of the inclusion of active transport in infrastructure objectives
161 Money, C., Hyder Consulting (NZ) Ltd, (2009), The Importance of Making Best Use of Existing Networks in Promoting Productivity

a) Create cycle hire schemes

Cycle hire schemes allow participants to hire bikes, for a cost, on a daily basis. The schemes require the infrastructure for automated access, with automated bike racks that allow for payment and secure locking of the bikes when not in use. The objective is not necessarily to stop people from driving but instead to shift modes from other public transport and walking trips. In this way, capacity on public transport for shorter trips can increase.

One such initiative is the London Cycle Hire Scheme, that provides access to over 10,000 bicycles for hire at over 750 locations across an area of 100km^2. Recent customer research found that 49 percent of members said that the scheme prompted them to start cycling London and in July 2014[162], a record 73,000 hires were recorded in a single day.[163] The feasibility report for the cycle scheme[164] stated the objectives as:

- Provision of an emissions-free individual transport system that will enable short-trips within central London
- **Address barriers to cycling** such as access to a bicycle and theft
- Increase modal share of cycling
- Help create a more walking and cycling focussed city with **less motorised traffic**
- Health benefits associated with increased levels of cycling
- Journey time and journey time **reliability benefits**
- **Reduction in overcrowding** on buses and the Underground
- Promote tourism

All of these combine to ensure a city with liveability at its centre, with promotion of the environment, active lifestyles and reduced crowding. London Cycle Hire cyclists are three times less likely to be injured per trip than an average cyclist - so even less non-recurrent incidents result than if cyclists use their own bikes. This is attributed to the extra caution that road users take with these cyclists, as they believe they are less experienced. The impact may be greater for public transport than road use, but will impact both peak and off-peak hours. However, in some areas, road capacity was reduced to allow for extra cycle lanes and facilities, so there are opposing effects from the scheme on the time and reliability of vehicle travel (though throughput of people could increase).

Despite the attributed positive impacts of a cycle hire scheme, the TfL Finance and Policy Committee's Phase 2 post-implementation report detailed that the combined outturn BCR for Phases 1 & 2 and Cycle Hire Expansion and Intensification (CHEI) was 0.7:1 (based on income and expenditure), less than the initial prediction of 1.2:1 for Phases 1 & 2 and 0.7:1 for CHEI[165]. This seven-year BCR measurement was lower than expected due to the original prediction of 70% of trips falling within the 30 minute 'free' period; in reality 90% of trips were during this time.

162 ITV News, (2014), Boris bikes extended to SW London
163 Transport for London, (2015), London celebrates five successful years of the cycle hire scheme
164 Transport for London, (2008), Cycle hire scheme feasibility full report
165 Transport For London, Finance and Policy Committee, (2014), Cycle Hire Implementation – Phase 2 and CHEI Project Close

Supply-side: Re-allocate road space

a) Create dedicated cycle lanes

Dedicated cycle lines increase incentives to cycle by providing a safe, allocated space for cycling. The effect may have demand consequences on public transport and walking that are greater than the reduction in car use, however if parking spaces are removed to make way for cycle lanes, the demand for vehicle use may reduce too. Creating cycle lanes also redistributes space, either from pedestrians (pavement) to cycle lane or from motorised vehicles to bicycles. In 2014 the New Zealand government announced investments of $100m in urban cycle networks over three years[166]; together with investments from Local Authorities and the NZ Transport Agency, the total investment will be $333m. This includes significant investments in cycle networks in hilly cities such as Auckland and Wellington.

Creating dedicated cycle lanes will improve journey time by aiding in the segmentation of different forms of transport, therefore creating a safer and more efficient route for road users. It will impact both peak and off-peak congestion, but will have the greatest benefits during peak time. Uptake of bicycles over cars will only happen if there is an accompanied shift in perception where they are seen as a safe, efficient and reliable alternative.

The New South Wales Cycling Study evaluated the costs and benefits to the community of financial investment in cycling programs and projects in NSW. Nine of the twelve missing links of the Sydney Metropolitan Strategic Cycle Network were assessed. Using the most conservative assumptions in all cases, the estimated net benefits of cycling were found to be 48.22 cents per bicycle kilometre. Combined with the demand forecasts and expected track configurations the results indicated the projects were economically viable, producing a net present value of incremental benefits of $30m and a BCR of 1.3[167].

However, the quantification of benefits is rather complex for creating dedicated cycle lanes, a study which analysed the BCR for cycle lanes in Portland, Oregon, outlined a BCR between 1.2 and 3.8. The upside benefits were largely derived from reduced healthcare costs and fuel savings[168].

b) Create dedicated bus lanes

Bus lanes give priority to buses and cut down on journey times for bus users where roads are congested with other traffic. Creating dedicated bus lanes can reduce congestion by encouraging a shift from private to public transport. By reassigning road space away from private vehicles to public vehicles, congestion may worsen for personal vehicles before behavior adapts, but the overall throughput of people will increase. In Australia there are two main types of bus lanes: ‘bus only lanes’ which are for the exclusive use of buses and ‘bus lanes’ which can also be used by taxis, motorcycles, bicycles, emergency vehicles, special purpose vehicles and hire cars. General traffic can also travel in a ‘bus lane’ for up to 100m to turn left or right, enter or leave property or pass another vehicle.

The Department of Infrastructure, Energy and Resources commissioned an evaluation of peak-period bus lanes on the Southern Outlet approach to Macquarie Street, Hobart[169]. The aim of the evaluation was to assess the relative performance of buses and general traffic using the road during the operation of the bus lane. The report found that the bus lane generally facilitated faster travel by buses to cars travelling at the same time. The maximum travel time recorded for a bus was 80 seconds faster than the maximum travel time for a car; the benefit of the bus lane is most pronounced when traffic was heaviest, usually in the period between 8am and 8.30am.

Bus lanes predominantly aid the recurrent causes of congestion. They are primarily of use during peak travel times to increase the throughput of people through the use of public transport.

166 New Zealand Transport Agency website, (2014), Urban Cycleways Programme

167 Roads and Traffic Authority of NSW and the Department of Environment and Climate Change, (2009), Evaluation of the costs and benefits to the community of financial investment in cycling programs and projects in New South Wales

168 Transport Innovation Deployment for Europe, (2012), Methodologies for cost-benefit and impact analyses in urban transport innovations

169 GHD, (2010), Report for Southern Outlet: Bus Lane Evaluation

c) Create pedestrianised zones

Pedestrianised zones prohibit the movement of traffic and therefore re-allocate road space from vehicle use to pedestrian use. The objective of this is as per the reverse Braess paradox, the opposite of supply induced demand – enforcement aims to reduce demand as the supply of road space falls, with the aim of switching car drivers to public transport. Pedestrianised areas also ensure there is the right level of space (and therefore level of service) in areas of high pedestrian demand.

This was particularly effective in Stroget, a pedestrianised, car-free shopping area in Copenhagen, Denmark. The pedestrianised road is one of the longest pedestrian shopping streets in Europe, at 1.1.km. Since the change in 1962, the city moved to a place with a much greater emphasis on pedestrian and bicycle access to the city at the expense of cars. About 80,000 people use Stroget every day at the height of the tourist season in summer[170].

Re-allocating road space to pedestrians can reduce the demand pressure on roads in city centres by deterring people from driving, instead promoting public transport use and walking. This will improve both the time and reliability of car journeys for those that do continue to travel, in both peak and off-peak times.

C.1.3 Change Behavior (2-5 years)

It can readily be observed that humans are creatures of habit and we change our behaviours slowly in the face of changing circumstances. For congestion, this change includes lifestyle factors such as where to live and work, as well as transport choices.

Demand-side: Modify travel demand

a) Stagger work/school hours

Staggering work and school hours aims to change the patterns of both car and public transport demand, to change both the peak and the spread of use. By enforcing differing school hours, and influencing different work hours, peak hour recurrent congestion can be mitigated. Knock-on impacts also include a reduction in the overcrowding of public transport, resulting in improved quality and therefore increased desire to use public transport instead of personal cars.

Jansson and Ljunberg studied staggered school hours and their benefits and costs on the public transport system[171]. Benefit-cost analysis was made for two changes in school hours: a one hour later school day for half of the pupils and a staggered start to the school day with pupils divided in thirds. The benefit-cost output detailed that both had benefit-cost ratios of less than one (0.94 and 0.71 respectively), because the cost of the additional transportation and the time cost of differing patterns outweighed the benefit for this small cohort of five high schools. However, if this was to be performed on a higher scale, the benefits could outweigh the costs.

For businesses staggering hours is likely to be more difficult to implement and enforce. Many businesses are moving to models of ‘flexible’ working, where employees can choose their start and finish times. Enforcing a staggered start to the day removes the decision-making element from the control of the employee.

b) Create flexibility in work hours

Allowing flexibility in work hours aims for similar results as staggering work and school hours, but rather than mandating the hours, allows people to choose whether they work in compact days (i.e. four long days instead of five normal days), work weekends rather than weekdays, or choose their own patterns of working in the office and from home. Flexibility will allow for a larger spread of, and reduced, peak in demand. It impacts on recurrent congestion, and will improve both time and reliability.

170 The Ottawa Citizen, (2008), The Stroget Solution
171 Jansson and Ljungberg, (2007), Staggered School Hours to Spread Peak Demand for Public Transport – Benefits and Costs

Brisbane ran the Flexible Workplace Program Pilot in 2009. The pilot concluded that flexible work arrangements can reduce peak hour travel and result in an overall reduction in travel[172]. The pilot eliminated peak hour travel by 34% in the morning and 32% in the afternoon peak period amongst pilot participants. Demand for public transport travel amongst pilot participants decreased by 33% in the morning and 27% in the afternoon peak period. Car trips decreased by 43% in the morning and 45% in the afternoon amongst participants. With increased telecommuting among participants, the pilot resulted in a 31% decrease in vehicle-kilometres travelled for car trips and 19% decrease in public transport trips. It enhanced the work life balance of 87% of pilot participants and improved work productivity, with strong support – 92% of participants indicated they would like to continue their flexible working arrangements in the following three months.

There are many barriers to implementing flexible work hours. Often the nature of the job requires routine hours (for example in the service professions). The company and the employee may not have the technological equipment to allow for flexibility, for example Wifi to allow people to work from home. Many private businesses may be opposed to introducing flexible working if they fear that it will reduce productivity.

c) Regulate car sharing schemes / technology

Car sharing is a model of car rental where people rent cars for short periods of time, often by the hour. In Australia and New Zealand examples include GoGet and CityHop. They are attractive to customers who make only occasional use of a vehicle. The organisation renting the cars may be a commercial business or the users may be organised as a company, public agency, cooperative or ad hoc grouping. The introduction of technologies and business models like Uber can further increase the use of car sharing services. Through mobile app technology, drivers of cars are better able to connect with potential users. The development of ride sharing services with low barriers for licensing can in fact encourage more drivers to generate business with their cars than before.

The benefit-cost analysis of providing car share member parking bays in the city of Sydney found benefits for both users and the wider community. User benefits included the related car purchase savings, reduction in parking time, health benefits from increased use of walking / cycling and improved transport choice options. The wider community experienced reduced travel time on roads and reduced travel externalities due to the lower number of cars on the road. By providing such spaces, the only cost to the government included loss in parking revenues from the otherwise paid parking bays, the costs of converting the bays to ‘car share only’, the planning and administration costs and the knock-on cost of increased public transport use. The benefit-cost ratio was estimated at 19.4, however this does not include the costs of the car share company who provides the cars – it is merely the government’s BCR in providing the car parking bays.

Regulating car sharing will mainly influence non-recurrent congestion as it reduces the number of car users on the road. It is most likely to impact occasional, off-peak travel, such as users who decide to drive at the weekend, rather than commuters who are likely to own a car if they drive to work every day. Further, regulating car sharing will improve both travel time and reliability for users who continue to use the road, by contributing to a reduction in the total number of car owners and therefore the total number of car journeys made.

d) Offer car pooling

Car pooling is the sharing of car journeys so that more than one person travels in a car. This can be incentivised through High Occupancy Vehicle lane. By having more people use one vehicle, car pooling reduces each person’s travel costs such as fuel, tolls and the stress of driving. It will mitigate recurrent congestion through reducing the number of cars on the road. It will have the greatest effect during peak-period and is most encouraged during times when congestion is likely.

In the UK, car pooling is promoted by a national UK charity, ‘Carplus’, whose mission is to promote responsible car use in order to alleviate financial, environmental and social costs of motoring. Carplus supports the development of car clubs and 2+ person car pooling schemes and is supported by Transport for London. There are over 185,000 members with access to over 3,000 vehicles[173].

172 Nielsen, (2009), Flexible workplace program – Brisbane central pilot

173 Carplus website, (2015), About Carplus

Demand-side: Substitute travel

a) Establish telework centres

Telework centres allow people to access equipment that enables them to work near their homes, reducing the need for them to travel to a city centre during peak-time traffic, therefore mitigating recurrent congestion. The ideal location for telework centres is close to a resident population of professionals, managers, clerical and administrative workers who face long commutes to their place of employment.[174]

The Institute for Sustainable Futures explored the potential for telework centres in Liverpool, Blacktown and Penrith in Western Sydney. By reducing the amount of peak period travel workers undertake to key centres, even one or two days per week each, the community benefits from the reduced demand on the transport systems. The study found that the marginal public benefit of one less car on the road at peak time is $0.66/km in Sydney, and it predicted that the demand for such telework centres would be 4,525 workers per day across the three locations.

b) Deliver e-work programs

E-working (known as telecommuting / remote working) is the act of working at home using a computer connected to the network of an employer. According to a Reuters poll, approximately one in five workers around the world, particularly employees in the Middle East, Latin America and Asia, e-work frequently and nearly ten percent work from home every day[175]. For communities, e-working can reduce traffic congestion and traffic accidents, relieving pressure on transportation infrastructure. It will reduce the amount of peak-hour, recurrent urban congestion by reducing the demands placed on the transportation system.

Demand-side: Manage freight

a) Mandate pre-booking of trip plans

Mandating pre-booking of freight road trip plans can ensure that demand is controlled – particularly if quotas are used. With quotas, the State authorities will at the very least have an understanding of the amount of freight traffic expected to frequent the urban roads and can plan interventions accordingly. This will help to mitigate recurrent congestion – it may even incentivise freight traffic to better plan and schedule their journeys. It will improve both peak and off-peak reliability for other road users, but particularly the periods just pre-peak and post-peak period in the morning, when deliveries are often made.

By mandating the booking of trips, the number of vehicles on the road can possibly be reduced by avoiding situations where there are large numbers of empty vehicles. An example of how this can be used in practice is Versafleet, a logistics operations software, that companies access to monitor jobs in real-time on one platform across multiple operators. Driver routes can be optimised so that fewer vehicles are driving[176],

b) Create emission zones and selective access

An emission zone is a defined area where access by certain polluting vehicles is restricted or deterred with the aim of improving air quality. Although the aim of the zone is largely to produce environmental results, there will be a resulting impact on congestion as certain vehicles are prevented from using the road (particularly heavy freight) and the associated demand for the roads decreases. The emission zone can be time-based too, so can deliberately manipulate the hours in which polluting vehicles access the city.

174 University of Technology Sydney, Institute for Sustainable Futures, (2014), Smart Work Centres: An Analysis of Demand in Western Sydney
175 Reuters / Reany, P., (2012), About one in five workers worldwide telecommute: poll
176 Versafleet website, (2015)

The Amsterdam Low Emission Zone has 38 entry points and up to one million vehicles travelling into the zone each day[177]. Before the zone was introduced almost one third of all trucks in the city centre exceeded emissions limits. Two years after the automated enforcement system went operational, 99% of all vehicles entering the zone are checked: 89% of these are fully compliant, 9% have obtained a special permit and only 2% receive a fine. Many vehicles are diverted from the city and therefore the overall number of heavy vehicles entering the city has reduced.

In Europe, over 194 cities and towns in nine countries are operating or preparing to operate low emission ones to help meet EU health-based air quality limit values[178]. These will improve both time and reliability for other users, in both peak and off-peak hours.

Demand-side: Implement Policy Measures

a) Mandate city licenses / permits

City licenses and permits limit the number of vehicles allowed into a city. They will reduce recurrent congestion by reducing road demand, thus improving travel time. They will mitigate both peak and off-peak congestion.

During the 2008 Beijing Olympics, authorities implemented a temporary road space rationing policy, allowing cars that had an even last number of their license plates to be able to drive on roads on one day, while cars that had an odd last number of their license plates could drive on roads the following day. This reduced total road demand and led to a 40% daily reduction of vehicle emissions[179]. However, this is a unique example and it would be difficult to replicate in ANZ cities.

b) Change business expense allowances

Changing business expense allowances on car travel will reduce the amount of money that can be ‘claimed’ by, or is ‘tax deductible’ for, individuals and businesses from the government for car travel to and from work. Simultaneously, an increase in expense allowances for public transport use can have the same desired effect, that of switching usage from cars to public transport when travelling for business purposes. This will most likely prevent recurring, non-peak hour daytime congestion for business transportation and is likely to improve both travel time and reliability. It could also reduce peak hour congestion by disincentivising people from driving to work who would then go on to use their car during the day.

The Australian Tax Office[180] states that workers can claim for work-related car expenses when:

- Carrying bulky tools or equipment
- Attending conferences or meetings
- Delivering items or collecting supplies
- Travel between two separate places of employment, e.g. when you have a second job
- Travel from your normal workplace to an alternative workplace and back to your normal workplace or directly home
- Travel from your home to an alternative workplace and then to your normal workplace or directly home
- Performing itinerant work

The New Zealand Inland Revenue[181] has a suggested mileage rate for employers to reimburse staff who use their own vehicle for work. Self-employed workers can expense the mileage rate up to a maximum of 5,000km in one year. For distances greater, a record of actual vehicle expenses must be kept. The reimbursement is exempt from income tax. Further, in New Zealand, car parking provided for employees by the employer is not liable for Fringe Benefit Tax where the car parking is on premises that are owned or permanently leased by the employer.

177 GATSO, (2014), Low Emission Zone – Case Study – Amsterdam, the Netherlands
178 Agence de l’Environnement et de la Maitrise de l’Energie, (2014), Les zones a faibles emissions a travers l’Europe
179 Agencia Xinhua, (2008), “"Pequim vai adotar rodízio de veículos durante os Jogo”
180 Australian Tax Office website, (2015), Car expenses
181 New Zealand Inland Revenue, (2015), Mileage rate for self-employed people and reimbursing employees

Supply-side: Manage freight

a) Establish dedicated freight lanes

Establishing freight lanes seeks to improve connections between the origin of the freight and the destination (e.g. ports or railheads). As well as improving the time and reliability of freight travel, it will also improve road conditions for non-freight traffic. Freight vehicles can take up high amounts of road capacity and disproportionately wear roads, so dedicated lanes will enable increased space for non-freight vehicles, if space is available. This will affect both peak and off-peak hours. It will primarily improve travel times but also improve reliability on roads as safety improves and incidents relating to freight reduce.

The Perth Freight Link is looking to remove the 'missing link' to Fremantle Port by the provision of a 5.2km high standard road freight link, with the overarching goal of facilitating the transport of freight along the metropolitan East-West freight corridor between the city's key industrial areas[182]. The benefit cost ratio relating to the project was calculated to be 2.5:1.

Supply-side: Control destination choice

b) Manage roadside parking controls / costs

Parking management and control refers to the location and price of parking. It has the potential to modify demand on an area-wide basis. It restricts terminating traffic demand, so for those commuting to a CBD for work, limited or expensive parking is likely to be a motivation for mode shift away from vehicles. However it will have little effect on those that drive through the 'problem'-area, or those that are looking to drop off passengers in a specific destination[183]. Altering parking controls may also be seen as a restriction of the 'rights' of the private property owners and a threat to the commercial viability of businesses currently dependent on the convenient customer parking.

Managing parking controls will improve both the time of journey by reducing the recurrent level of road demand, but it will also increase reliability by reducing the number of drivers that are looking for car park spaces. This intervention will have the greatest impact during peak travel time.

Roadside parking should not be considered in isolation from off-street parking. Both need to be regulated by price and time to ensure that travel demand from private cars is restricted during peak periods and the use of public transport is encouraged.

c) Implement resident parking zones

As per the above intervention, implementing resident parking zones will prevent residents from being restricted by parking controls. There are four main types of resident parking: on-street (parking lanes provided within public roads), off-street parking (parking facilities on their own land), surface parking (parking lots directly on land) and structured parking (parking facilities in or under multi-story buildings). The building, reservation and upkeep of such facilities are costly; one urban on-street space costs $453 per year, one sub-urban on-street costs $94 per year and one CBD on-street space can cost $2,265 per year. with a single space costing from $500 upwards[184]. Resident parking is mostly time-based, i.e. others can park for a limited time. In this respect it is the same as the intervention above, with the exception of residents who are not time restricted. Residential parking should also be implemented with an overall context of an integrated parking policy in cities and town centres.

Demand from non-local terminating traffic will reduce, as only residents will be able to park in certain zones. This is likely to be of more effect in residential areas, for example in the suburbs of cities or near to shopping centres, where they are high residency-business ratios. Implementing such zones will impact both peak and off-peak congestion as all user-types will be deterred from driving into the desired zone. As with the above intervention, the time and reliability of journeys for other road users will be improved.

182 Infrastructure Australia, (2014/15), Assessment Brief – Perth Freight Link
183 OECD European Conference of Ministers of Transport, (2007), Managing Urban Traffic Congestion
184 Transportation Economics, (2015), Parking costs

C.1.4 Optimise Capacity (1 to 2 years)

Optimising the capacity of the available road space enables the supply of road space to be appropriately matched to demand. Interventions can range from providing potential road users with accurate information so that they can make informed decisions, to changing road provision according to demand side factors using tidal flow systems.

Demand-side: Aid travel planning

a) Disseminate real-time transport information

As discussed in Chapter 2, receiving real-time transport information is the desire of many road users. This intervention enables users to plan their journey according to the best possible route and mode, allowing them to adjust their expectations accordingly. Real-time transport information is likely to improve the general satisfaction of road users in these circumstances, by improving both the reliability of their journey and the time it takes as they adjust their trip profile according to the provided information.

There are many methods through which such information can be provided, both pre-trip and during trip. Pre-trip, information can be disseminated through transport websites, emails, apps, navigation systems, radio channels and television channels. Road agencies could produce their own app or could encourage the private sector to develop their own by providing open data. For public transport, real-time information can also be provided on screens at public transport stops. However, there are existing apps, such as GoogleMaps, that provide such features. Road and transport agencies will need to consider whether the additional investment from a road agency is not worthwhile if an alternative is already available. It will, however, be important for road agencies to communicate with existing apps to understand how road users are 're-routed' if an incident occurs.

During journeys, information can be disseminated through radio channels, Variable Message Signs (VMS) and navigation systems. In 2004, the French Government undertook a cost-benefit analysis of several traffic operations policies, including VMS. The sources of benefits included travel time, safety and 'other'. In dense urban, high congestion areas, VMS had benefit-cost ratios of 1.5 to 1.7, and in less dense urban, moderately congestion areas, the benefit-cost ratios were 0.8 to 0.9[185]. However, benefits were greatest when VMS were combined with Automatic Incident Detection and Access Management ramps – which will be discussed in the 'Smart Motorways' section of our intervention framework.

Real-time transport information will enable both recurrent congestion (through volume of traffic) and non-recurrent congestion (through incidents and events) to be avoided, therefore changing the decisions of road users and reducing the total number of users on the road in both peak and off-peak times.

In 2010, Translink Transit Authority (Queensland) created a Business Case for the implementation of a 'Customer First Program' that aimed to enhance the quality of information on network performance that was received by TransLink and that given to consumers[186]. This information was to be delivered with 'automatic vehicle location' (AVL) and 'real-time information' (RTI) systems on buses and ferries. High quality data can provide many benefits to two key stakeholders. For Translink, this independent source of data can be used to create a network management tool to readily view and respond to incidents or constraints. For customers, these systems can be an extra level of reliability and confidence through provision of real-time data. The benefit cost ratio of this project is expected to be 3:1 over 12 years (inclusive of sunk project costs).

b) Capture personal travel history / carbon footprint

Capturing personal travel history allows road users to learn from their past travel experiences, allowing them to optimise their route, time of departure and mode of transport. This information is likely to be stored via an app or a website, where the user can either enter their personal travel details, or can be GPS-tracked with more sophisticated technology. Both the time and reliability of the road user will be improved from the learning experience.

185 OECD European Conferences of Ministers of Transport, (2007), Managing Urban Traffic Congestion
186 Queensland Government, Translink Transit Authority (2010) Customer First Programme Business Case

Providing information on the carbon footprint associated with travel dissuades non-essential vehicle-travel, normally at off-peak times. It will encourage the road user to switch from using a personal car to using public transport. Recurrent congestion will be improved as the demand for road space adapts to the learnings of the user, or decreases with the uptake of public transport use. For the user, this recording of information is most likely to be of use during peak hour, when journeys are highly repetitive and learnings are of most use in terms of time and reliability effect to the road user.

c) Implement travel to work plans for businesses

Evidence from the Netherlands and the United States has also shown that even the most 'basic' travel plans can achieve 3-5% reductions in the number of employees travelling to work alone by car. Plans with large discounts on public transport and restrictions or charging for car parking can achieve 15-30% reductions over a period of two to four years post-implementation[187]. Travel plans are also inexpensive methods of interventions – for those organisations in the EU 'Marking travel plans work study'[188], the average cost of running a travel plan was £47 (2002) a year for each full-time employee. The same study found that the most effective travel plans:

- Build partnerships, with local authorities, transport operators and other employers
- Identify site opportunities and barriers
- Encourage progressive change
- Gain staff ownership for the plan
- Raise the profile of travel initiatives
- Reach key groups of staff
- Change aspects of the organisation's culture
- Focus on results

In this case road agencies can either encourage or subsidise businesses to make their own travel plans, or create the travel plans for groups of businesses (depending on location) themselves.

In Auckland, benefit-cost evaluation of the workplace travel planning program 'Travelwise' calculated a BCR of 18.5[189]. This does not flow-on benefits to other trips, other than journey to work. The program was launched in 2005 with the goal of achieving reductions in single occupancy car travel in Auckland. Workplace, institutional and tertiary travel plans reached 44 organisations at the end of 2012, covering 226,250 employees and tertiary students. Travelwise achievements include taking 12,271 car trips off the road each morning peak (commuters and school runs).

By allowing road users to make informed decisions on how they drive to work, peak-time, recurrent congestion will be mitigated, and both time and reliability will be improved for all road users – both those that adapt to a new method of travel and those that do not change their travel characteristics.

d) Establish and manage school travel plans

Similar to the above intervention, establishing and managing school travel plans can improve the time and reliability of peak and afternoon off-peak, recurrent congestion. In Auckland, school travel planning has been found to be associated with an overall reduction in the use of car travel by approximately 5%[190].

187 EU Department for Transport, (2002), Making travel plans work – Lessons from UK case studies
188 EU Department for Transport, (2002), Making travel plans work – Lessons from UK case studies
189 Auckland Transport, (2012), Travelwise Evaluation Report 2011/12
190 Auckland Transport, (2012), Travelwise Evaluation Report 2011/12

In 2014, a study was undertaken in Ontario, Canada by Metrolinx, the University of Toronto and Green Communities Canada, to look at the costs and benefits of school travel planning projects[191]. The study covered 19 schools and the results were extrapolated to estimate the benefits and costs of delivering the projects across the province, based on 643,000 students who were not eligible for student transportation. The study demonstrated that plans contributed towards significant school travel behaviour changes, and provided substantial economic, health and environmental benefits. Overall, the benefit-cost ratio of 1.8 support plans as a cost-effective intervention. However behaviour change results were inconsistent across the sample. The average cost for each project was calculated to be CAN$7,000 for planning and implementation in the first year, CAN$3,236 for monitoring and maintenance in each of the subsequent 10 years, CAN$650 for community costs and CAN$2,000 for provincial level costs – shared among all projects.

The study found that the common factors for success and sustainability are:

- Strong stakeholder engagement and commitment
- Dedicated facilitators within the community
- Enthusiastic internal school champions
- Strong connections with other existing environmental, health and or physical education programs

Demand-side: Enforce vehicle restrictions

a) Mandate vehicle ownership controls

Mandating vehicle ownership controls is an 'extreme' response to problems of congestion, where putting a quota or 'limit' on the number of registered vehicles in a city helps to contain demand for road space. In practice, ownership controls are used in Chinese cities such as Beijing (lottery), Shanghai (auction) and Guangzhou (lottery and auction), as well as in Singapore (auction), where the Certificate of Entitlement scheme has been in place since 1990. The Certificate of Entitlement is a quota license received from a successful winning bid in an open bid uniform price auction, which grants the legal right of the holder to register, own and use a vehicle in Singapore for a period of ten years. When demand is high, the cost of a COE can actually exceed the value of the car itself. COE bidding occurs on the first and third Monday of the month and typically lasts for three days. The scheme has received criticisms based on the fact that it favours the wealthy who can afford to bid with higher prices and can even afford multiple COEs. There are even concerns that owners of COEs feel compelled to use the car intensively during its ten year life.

Vehicle ownership controls can improve both the time and reliability of travelling, by limiting the amount of potential recurring demand. It will impact both peak and off-peak periods through limiting the entire demand placed on the roads.

Supply-side: Manage road space dynamically

a) Implement a tidal flow system

A tidal flow lane is a lane in which traffic may travel in either direction, dictated by signals which depend on certain variables. Typically, it is meant to increase supply in periods of increased demand, therefore improving traffic flow during peak periods, by having overhead traffic lights or automated street signs that notify drivers which lanes are open or closed. Normally, the reversible lane allows traffic to flow towards a city centre during morning peak time, and flow away from the city during the evening peak time. This enables the capacity of the road supply to respond to the demand from road users. Similarly, the presence of lane controls allows authorities to close or reverse lanes in the case of incidents or events, where more lanes may be needed in one direction in order to maintain reasonable road space capacity.

Tidal flow systems can be either automated or manual. In Sydney there are automated tidal flow systems including that which exists on the Sydney Harbour Bridge, in use since the 1940s and automated since 1985. The main disadvantage of a tidal flow system is that they can confuse road users and this is a contributory reason as to why they are not used in more Sydney locations.

191 Metrolinx, University of Toronto and Green Communities Canada, (2014), The Costs and Benefits of School Travel Planning Projects in Ontario, Canada

Evidence for the effectiveness of a tidal flow system was conducted on Coronation Drive, Brisbane in 2002. A five lane street was controlled in am/pm modes. During am, 3 lanes were allocated to 'Eastbound' traffic and the remaining two 'Westbound'. During pm, this configuration was switched where 3 lanes were allocated to 'Westbound' traffic and 2 lanes to 'Eastbound'. Under both controls, Coronation Drive experienced a high level of occupancy. However, the evidence of this study found that the switching of controls between am/pm were not always effective. Occupancy data showed that the 'am mode' configurations were effective at all times while the 'pm mode' cause significant disruption to eastbound traffic in the pm peak.[192]

Both time and reliability of journey times can be improved with a tidal flow system. Most often they are used during peak times, but they are likely to be used to in response to accidents or events in non-peak times. They help to mitigate the scale of congestion due to recurrent road demand. Tidal lanes are particularly cost efficient in relation to building an entire additional lane.

b) Manage choke and pinch point program (e.g. clearways)

Clearways improve both travel time and reliability on existing road networks by restricting stopping or parking on the kerb side lane, allowing for greater road capacity. A 2014 Transport for New South Wales report detailed that there were 780km of clearways on Sydney's road network alone, with operation typically during the morning and afternoon peak periods during the weekdays[193].

In 2014, Transport for New South Wales conducted benefit-cost analysis for three clearways in Sydney. The quantifiable benefits included travel time savings, with improvements in average speeds of 6.8km/h, vehicle operating cost savings realised through increased speeds, accident cost savings and environmental cost savings. The quantifiable costs were capital costs from alternate parking related costs, new signage and new road parks, loss of value for parking, and maintenance. The benefit-cost analysis results concluded ratios of 3.9 for Victoria Road (cost $1.3m), 2.7 for Princes Highway ($7.4m) and 2.2 for King Georges Road ($3.1m).

Supply-side: Actively manage capacity

a) Plan for road closures and accidents

By planning for road closures, congestion can be effectively mitigated through re-routing, provision of alternative transport and dissemination of information. Forward-planning is key in mitigating non-recurrent congestion for road users; planning will increase the reliability of the journey, for both peak and off-peak periods where events and incidents are occurring.

For accidents, a plan of action for road maintenance operators, emergency services and transport agencies will ensure that road users are appropriately re-routed and accidents cleared, restoring supply and allowing disruption to be limited.

b) Install intelligent incident management systems

Intelligent incident management systems allow non-recurrent congestion to be mitigated. It improves the response to incidents, in turn reducing recovery times. The system utilises technology that monitors road conditions and vehicle detection, verification, logging and response to mitigate the impacts of unplanned incidents such as accidents, planned events such as roadworks and equipment faults. As such incidents are non-recurrent, their effect can be felt during both peak and off-peak times.

Benefit-cost ratios for intelligent incident management systems have a wide range. For the Automatic Incident Detection system in France, the BCR depends on the urban density of the area, and the range is from 1.8 in an urban area to 2.6 in a highly dense urban area[194].

192 Brisbane City Council, (2008), Coronation Drive Tidal Flow Decomissioning Preliminary Traffic Assessment
193 Transport for New South Wales, (2014), Economic appraisal of clearways projects and Sydney clearways program – Victoria Road
194 OECD European Conference of Ministers of Transport, (2007), Managing Urban Traffic Congestion

In contrast, the National Managed Motorways Program in Australia analysed the Monash Freeway in Victoria and produced a benefit-cost ratio between 5.2:1 and 10.5:1 depending on the segment of the freeway analysed[195]. The objective of the project is to improve the operational performance, increase the effective capacity and improve the safety of the motorway.

Supply-side: Enhance road capacity

a) Lower permanent speed limits

In 2011, the speed limit on several roads in Hobart was reduced from 60km/h to 50km/h. This was an attempt at mitigating non-recurrent congestion caused by incidents across the CBD. An analysis was performed in February 2014 to compare the months prior to the speed limit change at Macquarie and Davey Streets with the months after[196]. The crash rate pre-change was 151.6 per annum, of which 0.4 were fatal and 2.2 were serious. Post-change, the crash rate was 118.8 per annum, of which 0 were fatal and 0.8 were serious. However, at the same time the number of bicyclists and pedestrians that used the road reduced. Of the 12 roads included in the study, crash rates reduced on average by 18%, with crashes increasing (marginally) for two roads.

As such, lowering the permanent speed limit may reduce both peak and off-peak non-recurrent congestion, through lowering the number of incidents. A caveat should be highlighted here: the accident reduction could also be attributable to enhanced enforcement of the roads in question. Similarly, in terms of average travel time, the measure could be counterproductive. It will only be of an advantage if the number of non-recurrent incidents are dramatically impacting the journey time of the roads, and these are then reduced by the lower speed limit to the extent that travel time increases.

Customers prefer traffic that flows compared to traffic that starts and stops frequently. However, there is a limit to how much speed limits can be reduced and road agencies will need to balance this with optimising road capacity and reducing accidents.

b) Install variable speed control systems

Speed is a critical factor to consider when looking at how vehicles fill available road capacity. Legal speeds are determined with safety in mind. However, on crowded roads, sudden decelerations, uneven accelerations and differences in individual vehicle speeds can all trigger congestion. Slower, more even speeds and less erratic driving behaviorcan all increase flows on roads[197]. Signage, speed humps, chicane and pinch points are all static devices that encourage drivers to slow down. In contrast, dynamic speed control aims to smooth traffic flow by changing speed limits in response to real-time traffic speed and flow data. Sudden disturbances in traffic flow are detected by loop sensors and appropriate reduced-speed limit messages are displayed via variable message signs[198].

A study of variable speed control systems in France by DAEI-SESP[199] on the Autoroute du Sud de la France A7 route, found that the ratio of benefits to public expenditure in dense urban areas with high congestion were 2.1, and in less dense urban areas of moderate congestion were 1.1. In the large urban areas benefits stemmed mainly from the gains in travel time that were made possible by smoothed traffic flows.

Both recurrent and non-recurrent congestion can be mitigated with both time and reliability improved. The transportation system is able to adapt to the conditions of the road, which also includes response to poor weather and incidents. Both peak and off-peak times can be affected by such problems.

195 Infrastructure Australia, (2012-13), Assessment Brief - National Managed Motorways Programme – Monash Freeway
196 Tasmania Road Safety Advisory Council, (2014), Minute to the Road Safety Advisory Council - Evaluating 50km/h on Urban Roads
197 OECD European Conferences of Ministers of Transport, (2007), Managing Urban Traffic Congestion
198 OECD European Conferences of Ministers of Transport, (2007), Managing Urban Traffic Congestion
199 DAEI-SESP, (2005), Les Comptes des Transports en 2004

c) Optimise traffic signals

VicRoads' studies of the optimisation of traffic signals returned high benefit-cost ratios, as high as 21.0:1 for international studies and 15.4:1 for signal route reviews within Victoria[200]. Optimisation of traffic signals uses algorithms to attempt to reduce delays, stops, emissions or some other measure of effectiveness. Most optimisation software uses pre-timed coordination systems. True optimisation uses sources such as inductive loops, cameras or manual counting. Increasingly, devices with Bluetooth can be analysed by on-road sensors, enabling real-time continuous traffic monitoring and adjustments to signal timing. Both the time and reliability of journeys can be improved, at both peak and off-peak times of day. Recurrent congestion can be mitigated by transforming the algorithms to account for the volume of traffic.

While specific examples might lead to higher benefit-cost ratios, the benefit-cost ratio from optimising traffic signals is on average 12:1. This considers research concluding lower levels of benefit such a Portland, Oregon, which exhibits a BCR of 6.0[201]. Network Operating Planning is another tool used to optimize transport operational efficiency – it informs the optimization of traffic signals to achieve service improvements across modes by time of day.

d) Install smart ramp metering

A ramp meter is a device, usually a traffic light or signal, that regulates the flow of traffic entering roads (usually motorways) according to their current traffic conditions. It gives priority to those who are already on the road and therefore keeps the flow of the traffic on the road at a steady speed. Ramp meters are most often used on motorways where there are on and off 'ramps', but can also be used on arterial roads if deemed appropriate.

Within Australia, the largest ramp metering network is used in Melbourne and controlled by VicRoads. The M1 upgrade in Melbourne had 62 ramp meters that are coordinated using the HERO suite of algorithms[202]. In New Zealand, 61 ramp signals have been installed on the Auckland motorway network[203].

The Queensland evaluation of the HERO coordinated ramp metering installation at the M1/M3 freeway[204] (six on-ramps) showed significant improvements in traffic throughput and travel times compared with the previously used fixed-rate ramp-metering system. A rapid economic benefit analysis concluded a benefit-cost ratio of 13.8:1 at a 7% discount rate. The economic payback period for capital expenditure on the pilot was approximately four months.

Ramp metering improves the time and reliability of travel times in both peak and off-peak periods – whenever a motorway reaches capacity from either recurrent or non-recurrent causes of congestion.

C.1.5 Operate Effectively (<1 year)

Interventions with timeframes to realisation of less than one year, in general, are low cost interventions that will help to improve the reliability of road travel. This can include responding to real-time information and managing roadworks and events in an effective manner.

200 VicRoads, (2012), Operations Network Fit Assessment Report,
201 Monk and Booth, (2009), Sustainable Traffic Management Through Route Optimisation
202 VicRoads, (2015), Manage Freeways – Freeway Ramp Signals Handbook
203 New Zealand Transport Agency website, (2015), Ramp Signalling
204 Faulkner, L., Dekker, F., Gyles, I., Papamichaeil, I. and Papageorgiou, M., (2013), Evaluation of HERO Coodinated Ramp Metering Installation at the M1/M3 Freeway in Queensland, Australia

Demand-side: Manage events

a) Create routine in incident / works / events warnings

Routine in incidents, works and event warnings relates to the routine of response by government agencies, as well as the associated understanding of the likely response by road users. By creating routine warnings of incidents, roadworks and events, road users will understand how to access venues, re-route around incidents and respond to roadworks, without the need for intervention on the part of the road agency. Developing such routine in response will allow the road users to better respond to non-recurrent causes of congestion, in a timely manner.

This will lead to improvements in the reliability of travel time, as disruption to road users will be mitigated if they are adequately warned in advance of events. Both peak and off-peak travel times can be improved. However, there may be resultant congestion elsewhere due to a network effect, so the re-routing should be carefully modelled.

b) Introduce event travel planners

Introducing event travel planners, whether via phone apps, on websites or on public display boards, will enable the public to be informed in a timely manner of the impact of an event on their journey, or allow them to respond to how they will travel to and from the event themselves.

For the 2012 London Olympics, Transport for London created an email alert distribution list as well as the existing journey planner website and apps available. Potential road users were strongly encouraged to not drive to events, and it is unlikely that an event of such scale will ever promote car use over public transport. Similarly, Transport for New South Wales launched a website for the 2015 Netball World Cup in Sydney, which connected with the existing 'trip planner' website.

Introducing a travel planner, or incentivising the private sector to with free data, will enable reliability to improve – this is down to being able to meet the expectations of road and public transport users. It mitigates congestion from non-recurrent interventions in both peak and off-peak times.

c) Increase and promote public transport for events

By increasing and promoting public transport for events, demand for road use to access events will decrease. The high demand associated with special events leads to increased stress on the network, and public transport can reduce this. As with general public transport use, both cost and convenience are essential to enticing users. Alongside this, ensuring the there is enough room on the transport system for a comfortable journey may make a large difference in decision for potential users. This is particularly in the case of train journeys, where the stereotype of a journey to an event is that of a crowded train. Despite, crowded transport is likely better than being caught in traffic and having difficulty finding a parking space.

With better access to public transport, and better promotion of its availability, the reliability of journey times will reduce for those continuing to use the road at the time of a non-recurrent event, that wish to travel through an area or use the roads for other purposes.

Supply-side: Manage events

a) Create a roadworks management plan

Creating a roadworks management plan facilitates the smooth running of a works project, allowing all those that are involved to make clear the restrictions they will individually put on the road, as well as state their preference for the best congestion mitigation strategies. A multi-agency plan is critical in the safe management of the road space, and with this plan in place, a timely solution for the works will be provided.

Alongside such a plan, the customer-facing information will help road users to plan their trips accordingly, allowing them to adjust their demand patterns and helping to improve their expectations. Therefore reliability of travelling at the time of the non-recurrent roadworks will improve.

Actively manage traffic

a) Deliver smart motorways

A smart motorway uses a combination of active traffic management techniques to increase capacity. Techniques can include variable speed limits, access management ramps, hard shoulder running, automatic incident detection and variable message signs. The combination of these measures allows the motorway to effectively respond to the volume of traffic and non-recurrent events such as incidents and poor weather.

The optimal combination of interventions on smart motorways was studied in France, in larger French cities, by the French Government in 2004. Motorways with automatic incident detection, variable message signs and access management ramps had benefit-cost ratios in dense urban areas of 4.1 to 4.5:1, compared to those with automatic incident detection, variable message signs and variable speed limits which had benefit-cost ratios in dense urban areas of 3.2 to 3.7:1[205].

b) Leverage predictive analytics to understand relief routes

By leveraging predictive analytics to understand relief routes, through machine learning and intelligence for sensing, inferring and forecasting traffic flows, or through identifying the re-routes that travel apps are sending travellers on, the direction of road user travel can be predicted. Understanding and predicting patterns of movement in both peak and off-peak times will increase the reliability of the road network, as alternative interventions can be put in place accordingly.

205 OECD European Conferences of Ministers of Transport, (2007), Managing Urban Traffic Congestion

C.2 Benefit-Cost Analysis

Exhibit C.3 outlines the methodology used to calculate average benefit-cost ratios for interventions included in the Intervention Framework.

Exhibit C.3: The Benefit-Cost Ratios shown in Chapter 5 are based on the approximate average ratios of example intervention projects

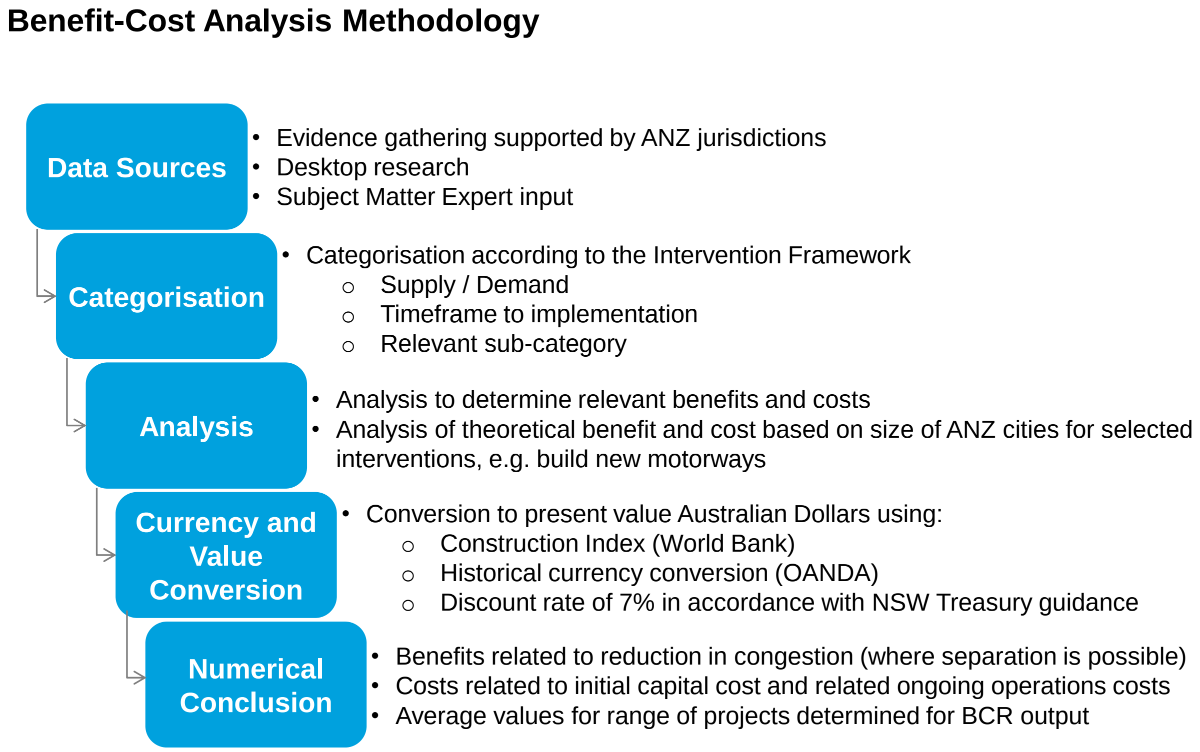


Exhibit C.4 outlines the benefit-cost ratios and relative costs used for the quantitative intervention benefit-cost analysis discussed in Chapter 5.

Exhibit C.4

Intervention Category			Intervention	Cost Range $AUDm	Average BCR
Improve Planning	Demand	Plan urban land use	Create transit-oriented spaces	80-100	4.9
			Install housing and business planning controls	50-75	10
			Model and manage road demand forecasts	60-70	8.7
		Set economic policy	Model and manage network for population and travel growth	70-90	11.1
			Align investment decisions to clear strategic and economic outcomes	10-20	1.7
	Supply	Formulate strategy and governance	Create a strategic plan and engage stakeholders	40-50	8.0
			Encourage Transport Management Associates	50-60	2.7
		Design networks	Improve design of transport network and intersections	2.9-250	1.6
		Build road capacity	Build new motorways	100-15,000	1.8
			Build bypasses/ring roads	4-678	1.1
			Build new arterial roads	250-500	2.0
			Widen existing roads	1.2-1,716	2.1
Shift Modes	Demand	Improve public transport reach	Add public transport capacity	0.8-4,445	1.2
		Incentivise public transport use	Enhance mode interchanges and inter-modal plans	75-100	1.2
			Improve attractiveness of public transport through cost and convenience	66-4,000	1.0
		Shift road freight to rail	Improve the attractiveness of rail freight	500-600	1.2
		Create walking/cycling initiatives	Create cycle hire schemes	0.2-76.7	1.1
	Supply	Re-allocate road spaces	Create dedicated cycle lanes	70-100	3.1
			Create pedestrianised zones	100-130	5.4
Change Behaviour	Demand	Modify travel demand	Stagger work/school hours	1.5-2	0.8
			Create flexibility in work hours	10-20	1.0
			Regulate car sharing schemes/technology	6-12	9.6
			Offer car pooling	50-80	1.3
		Substitute travel	Establish telework centres	5-10	1.4
			Deliver ework programs	50-60	0.9
		Manage freight	Mandate pre-booking of trip plans	10-20	1.8
			Create emission zones and selective access	190-7,800	1.1
		Implement Policy Measures	Mandate city licenses/permits	150-300	1.8
			Change business expense allowances	250-300	1.8

Intervention Category			Intervention	Cost Range $AUDm	Average BCR
Change Beh.	Supply	Manage freight	Establish dedicated freight lanes	750-1,750	4.3
		Control destination choice	Manage roadside parking	80-100	1.7
			Implement resident parking zones	10-20	2.3
Optimise Capacity	Demand	Aid travel planning	Disseminate real-time transport	80-85	1.1
			Capture personal travel history/carbon footprint	30-40	1.0
			Implement travel to work plans for businesses	50-60	1.1
			Establish and manage school travel plans	80-90	1.1
		Enforce vehicle restrictions	Mandate vehicle ownership controls	230-550	6.0
	Supply	Implement variable road supply	Implement a tidal flow system	100-150	2.0
			Manage choke and pinch point program e.g. clearways	1-8	2.7
		Actively manage capacity	Plan for road closures and accidents	30-40	2.6
			Install intelligent incident management systems	150-140	4.2
		Enhance road capacity	Lower permanent speed limits	10-35	1.6
			Install variable speed control	60-100	1.2
			Optimise traffic signals	0.05-7.60	6.3
			Install smart ramp metering	1-15	5.7
Operate Effectively	Demand	Manage events	Create routine in incident/works/event warnings	4-7	3.0
			Introduce event travel planners	3-5	1.2
			Increase and promote public transport for events	10-15	2.3
	Supply	Manage events	Create a roadworks management plan	60-70	1.1
		Actively manage traffic	Deliver smart motorways	10-300	2.5
			Leverage predictive analysis to understand relief routes	70-90	1.1

Appendix D Capability Maturity Assessment

D.1 Group-specific Outputs

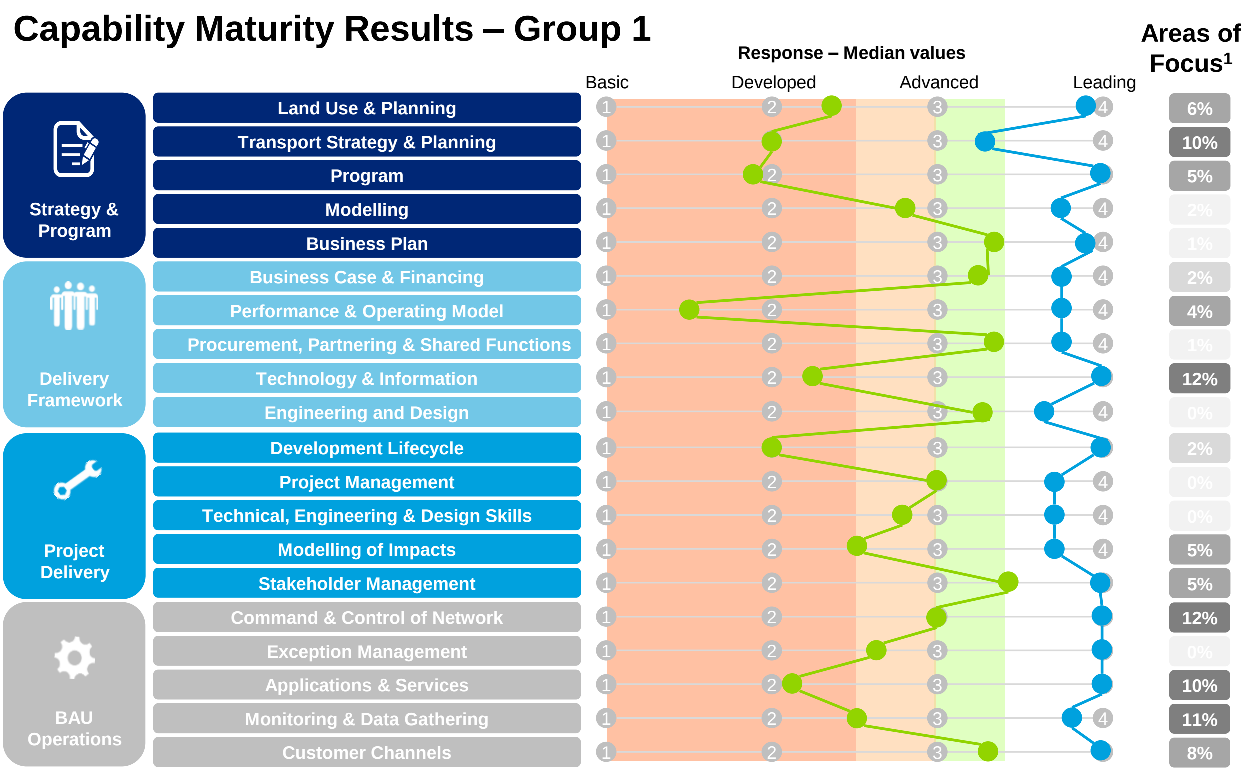
The Capability Maturity Assessment outputs detailed in Chapter 6 include the aggregate view of the self-assessment across all ten jurisdictions. In this appendix we look at the Group-level self-assessments, which here have been aggregated based on the three Groups that segment the ten jurisdictions:

- Group 1: Sydney and Melbourne
- Group 2: Perth, Brisbane, Adelaide and Auckland
- Group 3: Darwin, Wellington, Hobart and Canberra

As can be seen from Exhibits D.1 to D.3, the 'goal' capabilities are highest for Group 1 and lowest for Group 3. This is in line with the expectation that small cities do not necessarily require the capabilities of the large cities when managing congestion, because congestion is unlikely to be as strategic a priority for them.

Similarly, it would be expected that Group 3 cities would have the lowest 'current' level of capabilities, which is true based on the self-assessment on average, but not for every capability type. The Group 3 cities do not have any current capabilities above 'Advanced' level. Group 1's current capability levels vary the most, from 'Performance & Operating Model' assessed between 'Basic' and 'Developed' to 'Business Plan' and 'Procurement, Partnering and Shared Functions' assessed between 'Advanced' and 'Leading'.

Exhibit D.1: For Group 1, the largest areas for improvement exist in 'Performance & Operating Model' and 'Program'



Note: 1. Participants prioritised 10 points across the capability areas, with the resulting percentages showing the distribution of investment prioritisation

Exhibit D.2: For Group 2, areas of improvement exist in 'Performance & Operating Model' and 'Technology & Information'

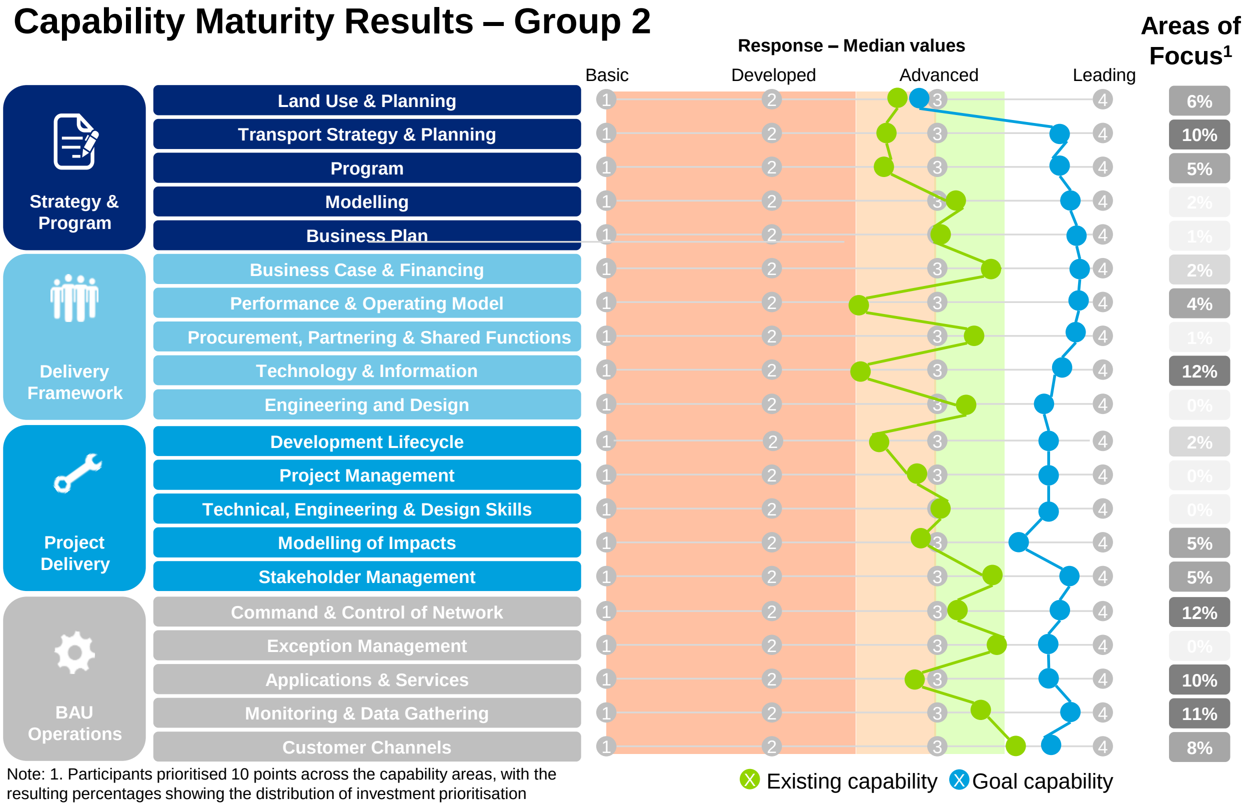
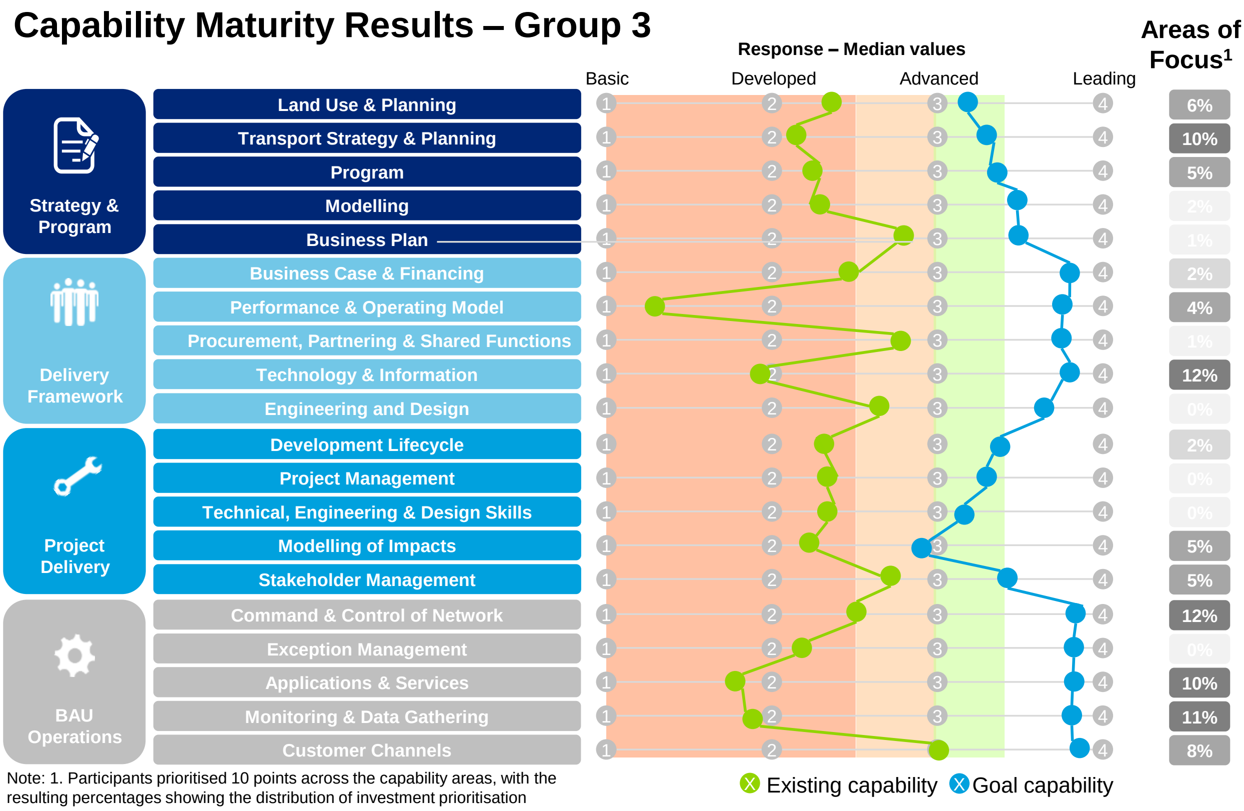


Exhibit D.3: For Group 3, areas of improvement exist in 'Performance and Operating Model' and 'Applications & Services'



D.2 Detailed Capability Overview and Maturity Assessment

D.2.1 Strategy and Program

'Strategy & Program' investigates capabilities associated with the 'planning' component of a road agency's work. Five key areas of capability are assessed, as follows:

Land Use and Planning

Overview. City planning, including both land use and transport infrastructure, is one of the key drivers of congestion, and ultimately liveability and economic success. Integrated city-wide planning is difficult, and requires (in a democracy) cooperation between different tiers of government departments and possibly political parties. It has been demonstrated in Victoria and New South Wales, that abandoning infrastructure projects or re-acquiring land is an expensive business. The ideal situation is a public city strategy that enjoys broad stakeholder supports and leads to a city with a:

- A defined CBD(s) with high density commercial and residential buildings and transport links
- A Motorway-standard ring road with radial links with the CBD(s)
- High density residential and industrial development with multimodal transport links

A traditional approach to Integrated Transport and Land Use Planning is the Cluster and Connect Model. As discussed in the 'draft' 2015 National Guidelines for Transport System Management in Australia[206], this model reflects a more traditional approach. The four-step process involves:

- Integrating transport with land use planning
- Identifying corridors of demand
- Defining the performance required from the transport network
- Moving towards a connected and integrated system

The guidelines identify that 'A Plan for Growing Sydney' (metropolitan plan for Greater Sydney) and 'Plan Melbourne' (metropolitan plan for Greater Melbourne) are two plans that have guidelines for a healthy built environment and objectives that combine land use and transportation.

The capability required to deliver these outcomes involves:

- A 20-30 year plan for commercial, residential and other land development to meet economic and lifestyle objectives, which can be used to derive transport needs and expected flows; for logically prioritised precincts or entire city
- A land use and planning policy which can be used to inform a transport strategy
- A defined planning cycle in which there is review, modelling, reprioritisation and consultation on the transport demands and key outputs

Self-assessment. The self-assessment of each group of cities is similar in output, with each scoring themselves between 'Developed' and 'Advanced'. Agencies identify that their goal state should be between 'Advanced' and 'Leading'.

Group 1 agencies set themselves the highest goal state and consequently have the largest gap between current capability and goal state. They state that work has been undertaken to better link transport and land use but this could be improved with regards to the planning of education, healthcare and government services locations and its integration with transport planning.

206 Transport and Infrastructure Council, (2015), 2015 National Guidelines For Transport System Management in Australia

Group 2 agencies believe that their strategy could be reviewed against social and economic outcomes more effectively, and that it could be tested more frequently. The South Australia Integrated Transport and Land Use plan was cited as a good example of how planning to connect people to places, from weekday commutes to weekend sports matches, shopping and entertainment are fundamental to the development of a thriving city. This was also the case for Group 3 agencies who stated that their target is to promote urban renewal and investigate how public transport and active travel can tie into this land use strategy.

Transport Strategy & Policy

Overview. A transport strategy is fundamental to translating land use planning into the efficient movement of people around cities. If the movement of people between residential, business and commercial areas is inefficient, negative impacts on the economics and liveability of a city will result. A transport strategy and policy plan looks to provision of adequate transport capacity, operations and interventions at a strategic level. Policy should propose a series of principles and criteria to assist planning for urban transport systems[207]. By taking a top-down, policy-led approach, the transport strategy can create strategic transport corridors and therefore influence congestion levels.

Leading practice in transport strategy and policy includes:

- Future scenarios development and a transparent and shared vision, with engagement of community and local government for integration
- A defined planning cycle in which there is review, modelling, reprioritisation and consultation on the transport policy and planned interventions
- Coordination of transport policies and planned interventions across all relevant Government Transport Agencies (i.e. including Public Transport)
- Strategies to implement road and public transport schemes and interventions to match the Land Use and Planning strategy in place and being executed
- Functional responsibilities for the transport strategy and policy

Self-assessment. Whilst not presenting one of the largest capability gaps between current and goal state, Transport Strategy and Planning is an area of high priority for most of the road agencies. The agencies cite that they need to be more proactive and forward-thinking, rather than reactive, including in implementing intelligent transport systems and how they relate to a transport strategy. Much focus to date has been on infrastructure related initiatives, with limited time and funding allocated to operational initiatives.

The Group 1 agencies highlight that funding has often been a constraint due to its recurrent or output-tied nature. The jurisdictions both wish to better engage customers in the setting of strategy and plans, alongside making such output transparent. Both are critical to obtaining support for the forward program of investments and in giving confidence to investors.

One Group 3 agency highlights that the transport strategy could result in more efficient use of existing infrastructure, including in the running of programs that promote active travel and public transport.

Program

Overview. The ‘program’ component of ‘Strategy & Program’ refers to the timetable for delivery of the transport strategy and policies supported by the investment required and scope. A detailed program of implementation is necessary to ensure that stakeholders are aligned on the direction and practical application of the strategy, the necessary timeframes to work to and the critical path of interventions and tasks.

A ‘leading’ program for strategy and policy implementation includes:

- An annual review of the program of interventions with regular reporting stages
- Measures of effectiveness developed and in use to support reviews and planning
- A risk mitigation strategy for the program with mitigations and contingencies

207 Infrastructure Australia, (2013), Urban Transport Strategy

Self-assessment. In general, there is a large gap between the current and goal states of Program capabilities, particularly for Group 1 agencies that have the highest goal state of 'Leading'. NZTA cited its National Prioritised Program, where regional plans and prioritised lists of activities are collated and moderated at workshops involving NZTA key staff[208], as an example of leading Program practice. Tasmania cited that they are currently working their 10-year infrastructure and investment program.

Modelling

Overview. Computer modelling allows a jurisdiction to estimate the number of vehicles or people that will reside in a location, travel along a specific route or use a specific transportation facility in the future. Modelling capability allows planners to assess and refine the impact of the land use policy, transport strategy and program, supported by base data. In the case of cities that are experiencing rapid population growth, without due forecasting of capacity requirements (both road and transport), interventions may not be appropriate for the rapidly changing environment. There are many methods for forecasting future transportation demand, for example four-step models and activity-based models.

Four-step models – The classical urban transportation planning system model includes:

- Trip generation – determines the frequency of origins or destinations of trips in each zone by trip purpose, as a function of land uses and household demographics
- Trip distribution – matches origins with destinations
- Mode choice – computes the proportion of trips between each origin and destination that use a particular transportation mode
- Route assignment – allocates trips between an origin and destination by a particular mode to a route

Activity-based models – Predict for individuals where and when specific activities are conducted. Travel demand is derived from activities that people need or wish to perform, with travel decisions forming part of the scheduling decisions. Travel is then seen as just one of the attributes of a system. The travel model is therefore set within the context of an agenda, as a component of an activity scheduling decision.

Following from this, transportation models can be classified as **microscopic, mesoscopic, and macroscopic.** Microscopic models study individual elements of transportation systems, such as individual traveller behaviour. Mesoscopic models analyse transportation elements in small groups, within which elements are considered homogenous. Macroscopic models deal with aggregated characteristics of transportation elements, such as aggregated traffic flow dynamics and zone-level travel demand analysis.

A 'leading' jurisdiction's modelling capabilities are multi-modal, and would include:

- Computer modelling that draws on base movement data, economic and population projections
- Use of trip demand volumes to forecast future transport needs
- Modelling of the impact of the planned program and interventions
- Regular validation of the model through travel surveys and recalibration of the model against program outcomes

Self-assessment. Group 1 and 2 agencies assess their Modelling capability as close to 'Advanced', whilst Group 3 place their current state between 'Developed' and 'Advanced''. Group 1 agencies cite that they have 'reasonable' modelling capabilities; their models are regularly updated and calibrated with new data, however the development of a mesoscopic model could inform the analysis of better use of existing roads, which is increasingly important. Despite this, the Sydney Travel Model is cited as a leading multi-modal model, which covers the entire metropolitan region, including population and employment statistics.

The Group 2 and 3 agencies are all satisfied with the level of their modelling capability and do not cite specific areas for improvement. One jurisdiction also cited the potential to improve benefits realisation modelling.

208 New Zealand Transport Agency, (2015), Planning and investment knowledge base

Business Plan

Overview. Business planning is essential for the success of any business, and road agencies are not different. A business plan provides direction, keeps the business on track and is usually a requirement for seeking finance. Alongside the detailed program and modelling, a business plan sets the direction for the delivery of a road agency's transport strategy. Alignment with the overarching business plan will enable determination of whether the benefits of a set of consequent actions are realisable at an appropriate cost. The resulting finance, organisation and benefits realisation plan puts the Transport Strategy and Program into action.

Leading practice business plans should, at a minimum, include:

- An organisational, funding, expenditure and revenue plan for the individual projects and business as usual operation
- A benefits realisation plan for each project with identified roles responsible for benefits delivery
- Project risks identified concerning timescale, funding, cost, organisation and benefits delivery

Self-assessment. Business plan-related capabilities were, on average, the most mature capabilities in the Strategy and Program section of the maturity framework. A number of agencies state that they would like to make their plans more transparent, which is critical to obtaining bipartisan support for a forward program of investments (whether infrastructure of reform) and for giving confidence to investors (including the Commonwealth).

For many agencies, there was an agreement that there should be a shift in focus to detailed benefits outlines, and plans should be re-worked when the original estimated benefits are found to be unlikely to be realised.

D.2.2 Delivery Framework

'Delivery Framework' investigates capabilities associated with the delivery of operations and projects within a road agency. A consistent, detailed and adhered to delivery framework allows a road agency to reduce risk in project management. Six key areas of capability are assessed, as follows:

Business Case and Financing

Overview. A consistent approach to the methodology for progressing business cases and their supporting documentation allows road agencies to adequately assess and compare both opposing and complementary investments. Both Australia and New Zealand implement standardised business case frameworks for the approval of investment.

The New Zealand Transport Authority's 'Business Case Approach' progressively builds an investment case by identifying the core problem, the consequences of not addressing it and the benefits to be gained by investing in its solution. The approach includes an assessment of strategic fit, effectiveness and benefit and cost appraisal for funding approval[209].

The Infrastructure Australia Assessment Briefs[210], which sound out the business plan for a particular project, include detail on objectives and strategic alignment, problems the project seeks to address, an understanding of the solution, modelling of the costs and benefits, economic appraisal (including BCR), details of funding sources and high level implementation programs.

'Leading' practice in this area of the delivery framework includes:

- Specific business case methodology and scope required
- A costs and benefits plan, with milestones, decision points and review events
- Benefit Cost Ratio requirements

209 As stated by NZTA representative, December 2015
210 Infrastructure Australia, (2014), Assessment Briefs

- Required reporting of post-implementation benefits realisation

Self-assessment. Each Group of agencies state that their goal state for 'Business Case and Financing' is close to 'Leading'. Group 1 and 2 agencies believe they are performing close to this, however Group 3 cities describe their capability as between 'Developed' and 'Advanced'. The Group 1 agencies both state that they have a robust framework for business cases, which tie to their benefits management frameworks, which are mature and well-regarded.

Most agencies believe that they could improve the post-evaluation of their business cases by using pre- and post- data to undertake an assessment. In this way they could improve their assessments of projects.

Performance and Operating Model

Overview. Road agencies have multiple (and sometimes opposing) strategies, functions and skillsets within one large organisation. The performance and operating model is a mechanism for defining performance targets and monitoring the capacity and performance of the transport network in the context of the BAU operating model and business functions. Without uniform Key Performance Indicators (KPIs), different sub-sections of an organisation may be aiming to achieve misaligned standards across an organisation, on misaligned timescales and with little to no knowledge of the strategies of others. Transparency in performance reviews will ensure this is mitigated.

'Leading' practise in performance and operating model approaches include:

- Operational performance targets (KPIs) which the agency is to achieve on the road network
- Methodology detailing how performance is measured and reported
- An annual performance review supported by six-monthly performance reports for BAU operations and projects
- Performance reviews publicly available
- Adequate mechanisms / resources / organisation to influence what is achieved

Self-assessment. 'Performance and Operating Model' has the largest gap between current state and goal state for the cumulative jurisdictions. Every agency states that their goal state is between 'Advanced' and 'Leading', yet on average they are currently performing between 'Basic' and 'Developed'.

Many agencies state that there is an opportunity to improve the determination of KPI's to guide success, particularly around recurrent operational services. Solutions are often infrastructure based, as opposed to operational improvements, in part due to legacy funding arrangements, and this could be improved. Some state that detailed KPIs could be made publicly available.

Procurement, Partnering and Shared Functions

Overview. Road agency procurement is complex, with contracts for both skills and materials in maintenance, infrastructure development, planning and operations a standard part of day-to-day program delivery. Such contracts entail risk when they create a detachment of responsibility, as the decision-making and motivation for results lie with a third party. A standardised approach to sourcing and resourcing solutions and external services, and contracting with suppliers, is necessary to ensure that appropriate risk mitigation is put in place.

In turn, the decisions of road agencies affect other organisations and the decisions of other organisations affect road agencies. No organisation can influence the economic success of a city is standalone, and as such, each must develop an approach to partnering with other agencies and private sector organisations to deliver their strategy. Road agencies are no different, and without appropriate communication, goal alignment and knowledge-sharing, their strategies are likely to succumb to the activities of others. To deliver the Transport Strategy and Program, partnerships must be formed and joint function may be required for cost effectiveness.

An effective procurement and contracting framework includes:

- A uniform, risk-based approach to procuring solutions and contracting model for BAU operations and new projects supported by standards, templates and contract examples
- Framework contracts for the range of services and supply that the Program and Projects may require
- Market sounding prior to starting the formal procurement to establish feasibility, deliverability, form of contract / financing and likely cost of major projects
- An ecosystem of suppliers to call upon when required

Effective partnering with other organisations involves:

- Collaboration with other non-road agencies to share services
- Knowledge exchange/transfer with other agencies and delivery partners
- Engagement with the private sector to use its skills, resources and know-how where they are not available in-house or where internal skill gaps or operating/ delivery models may delay or weaken the planned intervention or operation
- Shared goals and objectives across the delivery partners/agencies to drive the best behaviour and motivation

Self-assessment. Procurement, Partnering and Shared Functions capabilities are between 'Advanced' and 'Leading', one of the highest current states from the framework, with goal state close to 'Leading'.

Some agencies believe their pre-tender process could be improved, with a risk-based approach which can help determine the appropriate procurement approach. They believe maintenance contracts, which are often signed on a project-by-project basis, could be more efficiently procured. There could also be improvements in the procurement in smaller value goods or services.

Looking to the future, many agencies state that they need to improve how they deal with procurement of innovative technology. Currently, some issue research grants or encourage innovative trials with industry specific IP owners, however this area is difficult to navigate while trying to maintain procurement compliance.

For partnering and shared functions, agencies believe they could improve their partnering outside of the of the transport world. In fact, partnering with the private sector is often more effective than partnering with non-transport government agencies.

Technology and Information

Overview. Incorporating technology and information into the delivery framework is increasingly complex, particularly with the progressing opportunities in data analytics, as discussed in Chapter 7. The vast array of knowledge and information that can be incorporated to improve the accuracy and forecasting of BAU procedures before, during and after their realisation requires a platform that can both combine inputs and inform users. The plan and architecture of information systems required to enable customer access, information flow and applications, services, transactions requires specific skillsets which road agencies must look to develop.

'Leading practice includes:

- A common platform for gathering and distributing information which can be published to external developers and service providers
- Integrated customer access and travel information across modes (ie road and public transport)

Self-assessment. Most agencies rate their Technology and Innovation capabilities close to 'Basic', however they have high aspirations.

Many detail how they have a vast array of information but on many different platforms – each platform provides different information to different people and this needs to be consolidated. The Group 2 agencies in particular stated that they would like to improve the integration of traveller information across modes. Queensland's TMR has the Next Generation Traffic Traveller Information project currently underway as part of this.

Engineering and Design

Overview. Development of set standards for good practice in engineering design is fundamental to building an organisation that is largely responsible for the economic viability of a city. Engineering and design skills require formal study and on-the-job experience to develop, and are key in enabling a road agency to produce positive outcomes for road users. An approach to sourcing the skills and design methods within the agency in such technical disciplines is also required to deliver the Transport Strategy and Program. Without investment in developing standards, incorporating and nurturing talent and making the road agency an attractive place to build a career, skills and capabilities will lack worldwide best practice.

Leading practice in obtaining such skills includes:

- Standards for good practice in the engineering and design areas outlined by road agency (i.e. Austroads national standards)
- Standards for street and location design in the disciplines of urban design, engineering, streetscape, road types, land use, multi-modal considerations
- A plan to ensure capability (incl. engineering and design skill) is available to be able to deliver integrated prioritised programs
- Multi-disciplinary and multi-modal delivery

Self-assessment. Engineering and Design is 'Advanced' for most agencies, with high aspirations of a 'Leading' goal state. Each agencies believe it engage well with the market for engineering service delivery. The only area for improvement is in the post-evaluation of engineering and design projects to enable continuous improvement in such projects.

D.2.3 Project Delivery

'Projects and Progammes' investigates capabilities associated with the delivery of intervention-specific projects and programs within a road agency. Five key areas of capability are assessed, as follows:

Development Lifecycle

Overview. The Development Lifecycle refers to the management approach to the program of work at a macro level, supported by a statement of the program and inter-relations between projects. Best practice Development Lifecycle capabilities involve the use portfolio modelling practices and tools to determine priorities, plan programs and continuously adjust them based on changes in project status, conflicts, financial support etc. There is an awareness that re-organisation and re-design of the program must be made in the event that there is a change in the information provided.

'Leading' practice in this capability area includes:

- Portfolio modelling practice and tools to determine priorities
- Re-prioritising projects by the benefits they will deliver
- Formal change processes to explain changes in priority to stakeholders
- Business case, gating, assurance and post implementation reviews at key milestones
- Coordination with BAU on when projects happen and inter-dependencies and interfaces
- Re-organisation of budget, resources and staffing of projects to fit current priorities and dependencies
- Reporting of program status to a business-wide PMO and communicating the program internally and potentially externally

Self-assessment. Most agencies state they are currently at the 'Developed' level of capability in this area, with aspirations close to 'Leading'. This is a capability gap for most agencies. Both Group 1 agencies believe that they could alter their focus to engaging with problems and opportunities earlier, rather than solely presenting solutions. However, there was also discussion on how, given political realities, it will be difficult for an agency to be truly 'leading', as often prioritising initiatives by the benefits they delivery is not feasible.

They believe there are further opportunities to increase focus on the evaluation and monitoring of benefits realisation in this process.

Many believe that, while due-process in the development lifecycle should be adhered to, there should be an increased understanding of how to fast-track small- and medium-sized projects.

Project Management

Overview. As with any project-based industry, good practice project management should be applied to each specific project or intervention. As well as management within an individual project, a good understanding of cross-cutting dependencies between projects and programs is vital to ensure that milestones are met. While management styles and techniques are a human quality and are person-dependent, the frameworks in place for managing complex projects should allow for high quality, consistent delivery. A standardised procedure allows for risk mitigation.

An assessment by the U.S. National Cooperative Highway Research Program studied a series of projects across different states in the U.S.[211]. They found that some successful best practice projects utilised a single project management who followed a project from cradle to grave, whilst others used hand offs from one project manager to another during successive phases. The effectiveness of these approaches appeared to be the same. All agencies studied held regular project manager training, much of which was developed in-house. Each state had its own version of tools to assist in project management.

'Leading' practice should allow Project Management to respond to a problem, opportunity or objective, and tie the implementation of the program to outcomes. 'Leading' capability includes:

- Program planning and coordination across all plans, projects and interventions
- Critical path and timetable analysis across projects
- Regular reviewing of project status and rescheduling
- Conduct readiness assessments and hand-over into operation
- Applying a standard Project management methodology and reporting standards
- Undertake post implementation reviews of all projects including delivery of project objectives, realisation of project benefits, lessons learnt, which are part of a program of continuous improvement

Self-assessment. The agencies rate themselves close to 'Advanced' in Project Management, with aspirations between 'Advanced' and 'Leading'. There is a good understanding of the critical path to implementation and regular reviewing of project statuses on multiple risk-based measures. There are well-established project management procedures with clear decision-making processes and gateways.

Most believe they have strong project management skills and focus well on project delivery, however this does not necessarily mean that they are delivering the 'right' projects. They cite that perhaps, if resources were scarcer, there would need to be greater deliberation over how money is spent and therefore deeper evaluation. In particular, conventional projects are well delivered, however, with 'unusual' projects there is hesitancy, in particular in the delivery of transport technology solutions. Behavioural and legislative overlay on an engineering project, in the context of congestion interventions, also represents an 'unknown'.

Many agencies state that there should be a greater awareness of technological project management process alternatives, so that less manual work is required. This could also reduce risk in project management, with more automated progress reporting.

Technical, Engineering and Business Design Skills

Overview. Complex congestion intervention projects require a plethora of skills in their delivery. This capability refers to the plan and process for resourcing the technical, engineering and business design and oversight skills required to deliver specific projects. Whilst many of the technical staff will have studied in their chosen field prior to employment at the road agency, for example through an engineering degree program, but these skills must be nurtured through on-the-job training and development. Sourcing such skills requires an attractive proposition to be presented to potential employees.

211 U.S. National Cooperative Highway Research Program, (2012), Best Practices in Project Management Delivery

May Australian road agencies already nurture such skills through their Graduate Programs. For example, the Queensland Department of Transport and Main Roads offers a two-year Graduate Development Program that allows for job rotation so that graduates get an understanding of the different skillsets required within the organisation.

Where there is no budget or resource to hire such skills into a permanent role, there should be highly targeted supplementing with specialist external skills.

'Leading' practice in this area includes:

- Formal training tailored to staff and organisational needs, incl. planning, design and specification skills and methods to support the program and specific projects
- Highly targeted supplementing of in-house capability with specialist external skills

Self-assessment. All agencies believe they are 'Advanced' in this capability, and have aspirations of between 'Advanced' and 'Leading'. One Group 1 agency describes that resource and staff capability remains quite high compared with what exists on other areas of government. Each agency has the formal training programs to develop staff, and buy in skill from the private sector and other agencies where and when required.

Modelling of Impacts.

Overview. As discussed in the Strategy and Program section of this assessment, modelling capability is fundamental to allow for investment decisions to be well-informed. Modelling of impacts as part of intervention-specific projects and programs relates to the modelling required to support specific projects and interventions and assess and project their impacts. As discussed earlier, MetroScan software provides more advanced discrete choice-based systems, which are richer than anything else currently in practice.

Without such modelling, it is difficult for agencies to effectively calculate a benefit-cost ratio for future projects. Decision-making on where to invest would be ill-informed.

Best practice includes:

- Modelling projects/interventions at a macro and detailed level on traffic flow, congestion, customers and public transport and other modes to understand the benefits they will provide
- Calibrating models against actual impacts across the entire city / region, rather than in discrete zones
- Plans utilised in consultation on the reasoning behind a project and its expected outcomes

Self-assessment. Most agencies rate their current capability between 'Developed' and 'Advanced', with aspirations of between 'Advanced' and 'Leading'. Agencies cite that their modelling is reasonably robust, however there are some types of situations where they don't have strong analysis tools, for example in the modelling of signalisation of roundabouts. They also state that they need to improve in modelling the impact of different project options when forming business cases.

Stakeholder Management

Overview. Effective stakeholder management can make the successful running of the project, whether with stakeholders involved in the delivery of the project (such as private sector contractors) or with stakeholders impacted by the project (such as road users). Project specific communications and stakeholder management are vital to gain buy-in from the respective third parties.

Leading practice would include developing a share pipeline of forward investments that key stakeholders and, where possible, the community have a level of buy-in to. As well as this, the customer's problems should be positioned at the centre of all activities. Transparency is key.

In the UK, extensive consultation with stakeholders is mandated under the Greater London Authority Act[212]. The Mayor of London's transport strategy consultation process included leaflets, telephone helplines, a dedicated webpage with a 'supporting documents' section, roadshows (incl. with sign-language interpreters), emails, forums and advertising in local newspapers.

Best practice includes:

- Formal stakeholder management process with targeted stakeholder engagement and understanding of specific customer needs
- Gathering feedback and reporting; continuous throughout delivery and early operation stages

Self-assessment. Most agencies perform at the 'Advanced' level for Stakeholder Management, with goal states largely 'Leading'. It is stated that often the news, peak bodies, Councils, opposition MPs, transport executive leaders and customer focus all of their energy on solutions without any knowledge of the true nature of the problem. With increased stakeholder management and alignment, these parties could be better informed of a particular problem.

Most agencies state that they need to improve on continuing the relationship with customers into operation. They believe they tend to leave the project as-is, therefore the experience for neighbours can be quite disjointed. There also appears to be a lack of principle in engagement with stakeholders at the time of 'events' – there is often communication but rarely prior questioning.

Despite this, agencies believe they are motivated to inform affected parties in a way that is understandable, and they do this in detail and uniformly for every project.

D.2.4 BAU Operations (Intervention-Specific)

Here, 'BAU Operations' capabilities are those associated with the delivery of intervention-specific operations within a road agency. Five key areas of capability are assessed, as follows:

Command and Control of the Network

Overview. Advanced capabilities that enable road agencies to respond, in real-time, to changes in the demand for road space and transportation are increasingly necessary given cities must work to match such demand to a temporarily static or decreasing (in the case of an incident) supply of road capacity. Command and control of the road and transport network allow agencies to respond to changes in the nature of traffic flow in a timely manner, in turn preventing problems from escalating. Relevant capabilities encompass the ability to control the traffic and transport flow on the network and include traffic signals, control rooms and managed/dispatched public transport vehicles.

'Leading' capabilities in this area include:

- A fully integrated, adaptive, Urban Traffic Control system, with performance targets set for certain corridors
- Predictive modelling of short term impacts of breakdowns/minor incidents, lane closures, road works
- Automatic deployment of strategies adapted to manage minor incidents
- A public transport dispatch function

Self-assessment. For Groups 1 and 2, capability in this area was deemed 'Advanced', with minimal distance from the goal state of between 'Advanced' and 'Leading'. One Group 2 agency stated that there was a passion within the organisation to do this well, but they find it difficult to secure funding for operation activities. They are looking to move quickly to bring new tools and technology on line to aid the control of the network, but often there is difficult in integrating large amounts of information from different platforms. As a result there are likely to be major systems integration challenges in the near future. Multiple agencies cite that integration with teams on the ground is often an issue.

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Group 3 deem that congestion is not a 'tactical priority', or large enough issue to require that a complex command and control network is set up to cover the entire city. However, responding to customer needs and incidents is still a key operating target.

Exception Management

Overview. Non-recurrent events, as discussed in Chapter 4, are a major cause of congestion and improved management can help mitigate their effects. The ability to manage unplanned situations such as accidents, road closures and incidents is fundamental to preventing congestion in ANZ cities. Incident management plans should be re-engineered and improved after each episode, so that improvements can be made through accumulated accounts and formal management reports. The management plan can use real-time traffic information, incident reports and information provided by the private sector to generate response plans.

'Leading' exception management includes:

- Cross-agency decision making on disaster recovery including, when to invoke back-up systems / sites and which contingency measures to adopt
- Business Continuity and Disaster Recovery plans in place, reviewed annually and exercised
- Incident detection and response capabilities leveraging emerging technologies to predict, prevent and more effectively respond to incidents
- Emergency Exercises designed to include Public Transport Agencies, private operators and Government Emergency Management Departments (in addition to Emergency Services)
- Competency and Training requirements for key operational personnel defined, implemented and tracked

Self-assessment. For Groups 1 and 2, current performance is deemed as close to 'Advanced' and these agencies have high aspirations for their goal state, as closed to 'Leading'. One Group 1 agency described that road network operators have the ability to respond to, and fine tune, the operation of critical corridors to meet performance objectives relating to both recurrent and non-recurrent congestion and associated incident management, which is integrated across modes and with other service providers.

In contrast, the Group 3 agencies rate their current state as closer to 'Developed'. They do not believe they are particularly agile, and cite an area for improvement as uniformly ensuring they can respond to incidents using readily available information in a contemporary format or medium.

Applications and Services

Overview. This section refers to the applications and services that help customers to plan their use of the transport network. Road agencies are increasingly looking to anticipate the information needs of road users, make the appropriate information readily available in a contemporary format and combine different types of information to produce the best insight. However, as discussed in Chapter 5, road agencies must be careful to not duplicate effort if existing apps and websites with such information exist. For example, Google Maps is often used by road users to check for congested roads and therefore the quickest routes from origin to destination. It may therefore be necessary for road agencies to work with Google, or at least consider the information they are providing, before embarking on their own individual development of apps and services.

Ultimately, applications and services should also be tied into the Intelligent Transport System (ITS) that seek to make users better informed through monitoring – with cameras and sensors. If road users receive real-time information to an app before they embark on a journey, they can adequately re-route and alter their road-choice.

- The development of new applications and services should include:
- Real time traffic data
- Customer alerts when key routes are closed/congested
- Journey planning and mapping tools across network
- Comprehensive traffic map presentation for drivers, including closures / incidents and congestion indicators, covering entire city
- Route planning to avoid congestion, covering entire city

Self-assessment. The Group 1 and 2 agencies state that their current state is between 'Developed' and 'Advanced' in the area of Applications and Services and aim for capabilities that are between 'Advanced' and 'Leading'. One Group 1 agency would like to define a team that seeks opportunities to develop shorter term programs to incorporate new tools, or a program to support such investment. One Group 2 city believes it is leading in customer alerts and real-time traffic tools, but embracing collaboration with partners to provide even more informative information is difficult and time consuming.

The Group 3 agencies state their current capability is between 'Basic' and 'Developed', Again, this is a low priority for these cities, and therefore they have limited resources to support the technological investment required to perform well in this capability.

Monitoring and Data Gathering

Overview. Real-time monitoring and data gathering about the status of the road and transport network is required to feed appropriate information into the command control, exception management, applications and services functions. There are a range of types inputs including manual customer surveys, real-time surveillance through cameras and automated data collection through sensors. With such data input, existing models should be effectively calibrated against actual data. Improvements in the accuracy of forecasting will result.

In the UK, Transport for London is developing bi-direction customer information and crowdsourced datasets[213] to provide fusion with on-street sensor networks. This allows for continuous improvement in rapid decision-making.

Investment in the appropriate monitoring and data gathering technology to enable real-time response, in 'leading' practice, includes:

- On street traffic data capture, for example through SCATS/loops, ANPR cameras, CCTV surveillance
- Vehicle data capture/lookup to enable location access control dependent on congestion
- Capture of vehicle movements (floating vehicle data/probe vehicle data)
- Gathering of bus location data/Auto Vehicle Location
- Road-side interviews and periodic travel surveys
- Links to service providers like INRIX, TomTom, Google Traffic, Bluetooth

Self-assessment. Again, Group 1 and 2 agencies believe they are between 'Developed' and 'Advanced' in Monitoring and Data Gathering capabilities and aim for close to 'Leading' goal states. There is recognition that the people who use the information to make decisions want all of the information in one place and one platform, but that this is not always possible, and as much information as possible should be sought when making investment decisions. The agencies all recognise that they are improving in this area, but there is still some way to go before they are at the 'Leading' level.

One Group 2 agency describes its capabilities of real time monitoring of traffic flows including data sharing with industry partners (both ways) and the re-use of this information to provide real-time traffic information to travellers via multiple channels.

The Group 3 agencies are the least developed in this area, in part due to their smaller size and different priority targets.

213 Deloitte UK Subject Matter Expert interview, (2015)

Customer Channels

Overview. Customer contact channels allow road users to interact with the road agency, both in giving and receiving information. Channels allow road users to gain access to data, services & applications. This will enable them to make more informed decisions about their road use and demand patterns, as well as allowing them to monitor the road agencies performance and provide feedback in real-time. Customer channels can also allow road users to make payments via the internet. Road agency call centres and postal addresses allow for road user questions and feedback. Road agencies are moving from the manual to automated end of the customer channel digital spectrum, in order to cut costs and reduce the manual labour required to serve road users effectively. However, a personalised interaction experience, via a call centre, is likely to be preferred by many customers.

'Leading' practice in Customer Channels are centred around providing the right information to customers at the right time, so they can make choices on how they move around the network in both and informed and predictable manner. This include capabilities such as:

- Web and digital channels to mobiles, tablets, PC to enable all customer interactions
- Contact centre for exceptions/queries
- Survey and feedback tools
- Accessible channels for the disabled

Self-assessment. Again, the agencies believe they are improving in the capabilities associated with 'Customer Channels' – they all believe they are 'Advanced' and target capabilities close to 'Leading'. Most believe that road users have ready access to data to help their decision making pre-trip, on-trip, at modal change points and at destination. However, many agencies believe they must move further into the social media realm in order to convey information on incidents and non-recurrent congestion most effectively.

One Group 2 agency lists its customer channels as web, in-vehicle, roadside VMS and media incl. TV, radio and social media. Another agency describes its target state as being able to monitor, manage and respond to customer needs and anticipate the information that they require. Developing bi-direction customer information through such customer channels will also lead to improved decision-making for the agency, as well as the customers.

Appendix E Additional Travel Time and Variability Analysis

This is a technical appendix that contains the results of a statistical analysis of the relationship between average travel time and variability in travel time in Australia and New Zealand. The information in this appendix will primarily be of interest to analysts within road agencies.

E.1 Introduction

Variability in travel time is of interest to road agencies as road users do not only take travel time into account when considering the costs of a journey, but also travel time reliability. In the presence of travel time unreliability, travellers typically allow more time for their trips in order to reduce the possibility of arriving late at their destination. Increasing travel time reliability means that this extra time allowance can be decreased or avoided completely, presenting a clear user benefit which is distinct to the value of reduced average travel time. This concept is known in the literature as the Value of Reliability (VoR).

It has been argued that, in dollar terms, travel time unreliability costs could be around the same size as travel time costs (the relationship between these two measures is often presented as a ‘reliability ratio’, comparing the valuations of these two factors). It is expected therefore that, in project appraisal, excluding measures of VoR could lead to a significant understatement of the estimated economic benefits of transport initiatives.

De Jong and Bliemer (2015) note that the most widely accepted measure of travel time variability in Cost Benefit Analysis (CBA) is the standard deviation of expected day-to-day travel times. However, it is often the case that road agencies do not gather information on the standard deviation of expected day-to-day travel times. Rather, it is more common to gather data on items such as average travel time, vehicle counts and road characteristics.

As a result, where standard deviations in day-to-day travel times cannot be directly observed, they are normally estimated by statistical analysis of the relationship between observed traffic conditions (like volume capacity ratios) and the standard deviation in travel time. This is the current approach adopted by the Australian Transport Council (2006c) and in New Zealand (NZ Transport Agency, 2010). The current approach used in Australia and New Zealand is primarily based on data from around 2002 and draws on some data and analysis that dates back to 1991.

The statistical models used in international jurisdictions (such as the UK and Netherlands) are generally more straightforward to estimate and apply than the models currently used in Australia and New Zealand. In particular, the UK uses a congestion index (CI) as a key explanatory variable of variability, where CI is defined as the ratio of the mean travel time to the free flow travel time for a journey. This gives model-users a simple way of generating travel time variances from standard data that already exists on mean travel times. Reliability or variability of travel time is then measured as the coefficient of variation (CV = ratio of standard deviation to mean), this standardises the magnitude of the deviation from the empirical observations to ensure that it is consistent across contexts. The UK model was estimated using route data from London and Leeds.

The data that we have gathered as part of this project allows us to update the statistical analysis for Australia and New Zealand using the more straightforward statistical model from the UK. This updated analysis may provide road agencies with a straightforward way to estimate the expected change in reliability from changes in average travel times.

E.2 Data Analysis and Estimation

The UK model predicts congestion variability based on travel time and distance as follows:

$$CV = 0.148\, CI^{0.781} D^{-0.285}$$

where CV, congestion variability, is the standard deviation of travel time divided by the average travel time; CI, a congestion index, is the ratio of average travel time to the free-flow travel time; and D is the road-segment distance.

Based on the approach used in the UK, the following empirical model was estimated for key roads in Australia and New Zealand[214]:

$$\ln \frac{\sigma_i}{\mu_i} = \beta_0 + \beta_1 \ln \frac{\mu_i}{ft_i} + \beta_2 \ln D_i + \varepsilon_i$$

where σ_i is the standard deviation of travel time; μ_i is the average travel time; ft_i is the free-flow travel time; and D_i is the street distance. The i indexes the street and the ε_i character is an error term for statistical estimation.

The parameters to be used in the UK model were estimated based on data gathered from Google Maps, and includes observations of travel time and distance for a large number of road segments throughout Australia and New Zealand. The free flow travel time for a route was calculated as the average of the minimum travel time over the 24 hour period. Travel time variability was defined as the standard deviation of average travel time for each 15 minute segment between 7am and 9am.

E.3 Results

The model was initially estimated using data from the entire sample, across all jurisdictions available in both Australia and New Zealand. 0 presents the results of this initial regression.

Table E.1: Pooled regression results

Coefficient	Estimate	t-statistic
CI	3.959***	(10.41)
D ('00m)	-3.280	(-1.69)
Constant	-3.128***	(-13.30)
Sample size	2702	

*Note: *** indicates a p-value of <0.01, highly significant. Standard errors are clustered at the jurisdiction level.*

The coefficients on CI and distance are of the same sign as the UK model. However, the coefficient on distance is not significantly different from zero, and the coefficient on CI is substantially larger than that estimated for the UK.

A further set of regressions were estimated at the jurisdiction level, allowing both the *CI* and distance coefficients to vary across roads in each jurisdiction. The following table presents these estimates.

214 The UK model is transformed by natural logarithms for estimation purposes.

Table E.2: Jurisdiction level regression results

Jurisdiction	CI	D ('00m)	Constant	Sample size
Adelaide	6.541	-4.08*	-3.374	542
Auckland	2.974	-9.23	-2.466	247
Brisbane	4.342	1.08+	-3.562	345
Canberra	4.793	-0.721+	-3.434	118
Darwin	8.742	-8.6+	-3.52	120
Hobart	5.17	-4.99+	-3.283	114
Melbourne	3.221	-3.18+	-2.814	461
Perth	6.194	-10.3	-2.98	76
Sydney	2.466	-8.16	-2.144	556
Wellington	5.477	-4.83+	-3.587	123

*Note: All variables significant at the 5 per cent level except where specified, * indicates significant at the 10 per cent level, + indicates insignificance at the all standard levels. Robust standard errors reported.*

All of the coefficients on CI were highly significant and of a large magnitude, as in the pooled regression above. Several distance coefficients were significant; however, the magnitude is not consistent across jurisdictions.

E.4 Use and Interpretation

This section presents an example of how the estimated results could be used to estimate the impact of road improvements on travel time variability. The road used in this example is from Sydney, key statistics for which are presented below.

Table E.3: Example road statistics

Variable	Value
Average Travel time (s)	684
Free flow time (s)	528
Standard deviation (s)	75

As an example of how to apply the statistical results above, if it is expected that changes in parking regulations could reduce average travel times by 10% (to 616 seconds) and free flow travel times by 5% (to 502 seconds) then the standard deviation of travel time on the route is expected to decrease from 75 seconds to 55 seconds. The calculation of this figure is shown below:

$$\hat{\sigma} = \sigma \left(\frac{\hat{\mu}}{\mu}\right)^{\beta_1+1} \left(\frac{\widehat{ft}}{ft}\right)^{-\beta_1} = 75\times\left(\frac{616}{684}\right)^{3.959+1} \left(\frac{528}{502}\right)^{-3.959} = 55$$

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