WORKING PAPER

The Congestion Question

Could road pricing improve Auckland's traffic?

Workstream 1

Defining congestion

February 2019

Working draft vD

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1 Purpose

This paper introduces the phenomenon of traffic congestion and describes its causes, how it can be measured and why it is a problem. The phenomenon is discussed in the Auckland context and outlines reasons why traffic demand management polices need to be considered for the city. The concept of congestion charging is introduced as a tool for traffic demand management – and a framework for assessing potential congestion charging options is presented.

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2 Congestion – What is it and why does it occur?

2.1 An introduction to the phenomenon

The term 'congestion' is used frequently by all sections of society including academics, the media, policy makers and the public. However, there remains no universally accepted definition of traffic congestion.

One of the principal reasons for this lack of consensus is that congestion is both[1]:

- **An objective physical phenomenon** of the transport network relating to the manner in which vehicles interact with and impede each other; and
- **A subjective experience** varying from person to person, time to time and place to place.

While there could probably be universal agreement that completely unimpeded travel, essentially by definition, is uncongested, at what level of impediment people consider congestion to start can differ substantially.

2.1.1 The objective phenomenon

Traffic congestion is a condition on road networks that occurs as use increases, and is characterised by slower speeds, longer trip times, and increased vehicular queuing. When traffic demand is large enough for the interaction between vehicles to slow the speed of the traffic, congestion begins to occur. As demand approaches the capacity of a road (or of the intersections along the road), congestion increases.

Work undertaken both in New Zealand[2] and overseas[3] shows a clear relationship between traffic speeds and traffic volume or flow as shown in Figure 1. This relationship in the figure is commonly referred to in traffic engineering as the speed-flow curve.

[1] OECD. (2007). *Managing Urban Traffic Congestion*. Paris, France: OECD Publishing.

[2] Costs of congestion reappraised. NZ Transport Agency research report 489, Wallis, IP and DR Lupton (2013)

[3] Transportation Research Board. (2011). *Transportation Research Circular E-C149: 75 Years of the Fundamental Diagram for Traffic Flow Theory.*

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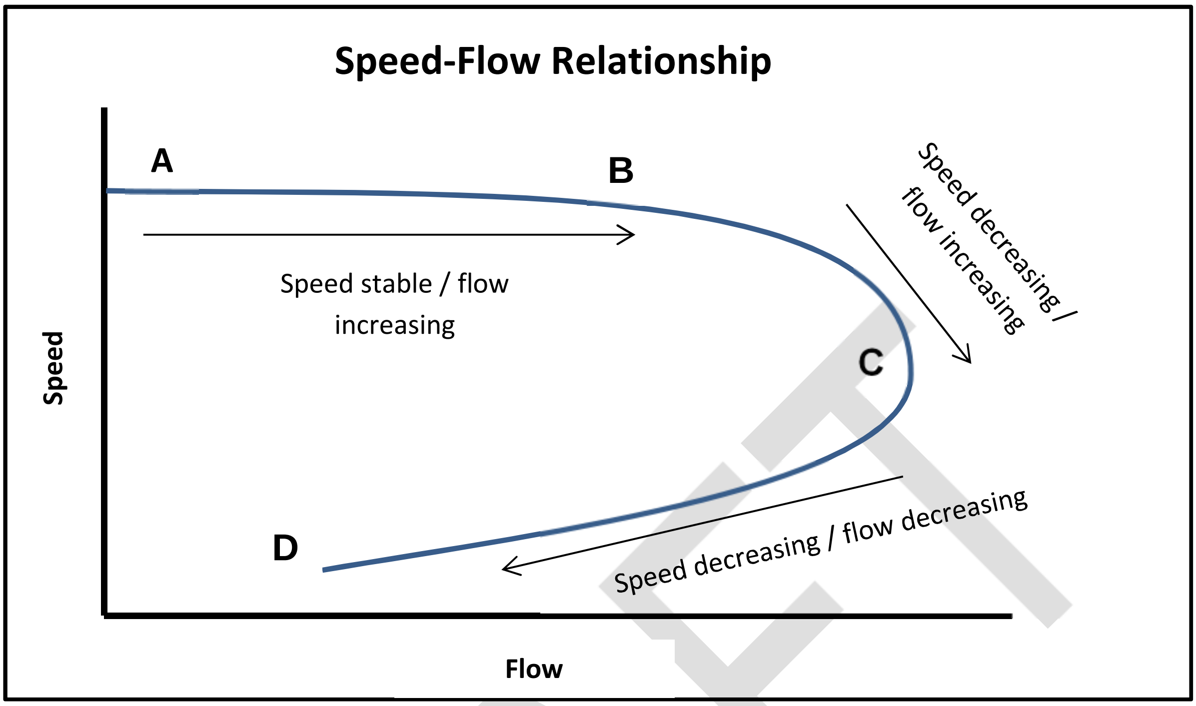
FIGURE 1: SPEED-FLOW RELATIONSHIP



Source: Wallis, IP and DR Lupton (2013) Costs of congestion reappraised. NZ Transport Agency research report 489.

As the figure illustrates, when there is a low traffic flow (point A), vehicles are able to travel at a constant speed –referred to as the 'free-flow' speed - even as traffic flow begins to slowly increase (between points A and B). As vehicle numbers rise, they increasingly interact with each other and reduce the speed at which they can all travel. Despite this decrease in speed, and due to factors such as the decreased space required between each vehicle when travelling at a slower speed, the flow of traffic along the stretch of road can continue to increase (between points B and C).

However, beyond a certain level of traffic flow (beyond point C on the chart), each additional car that joins the stretch of road will have both an adverse impact on the capacity of the road and the speed at which vehicles can travel. Beyond point C – the maximum capacity for the stretch of road – the flow of traffic breaks down because of the interactions between the vehicles and speed and flow continue to reduce (between points C and D).

This objective relationship is well established and is an important concept in traffic engineering. However, while it is measurable and provides an understanding of the phenomenon, it does not identify any particular point as the start of congestion. In fact, there are a range of points along the curve where one might consider congestion to start, of which two of the most common are[4]:

[4] Costs of congestion reappraised. NZ Transport Agency research report 489, Wallis, IP and DR Lupton (2013)

1. Where interactions between cars begin to impact/slow each other down (beyond point B in Figure 1).
2. At maximum flow, where the addition of another vehicle starts to reduce the capacity of the road (beyond point C in Figure 1).

2.1.2 The subjective experience

Equally important to the more formalised and measurable objective phenomenon of congestion is the concept of perceived or subjective congestion.

While the objective description of how congestion develops, described in section 2.1.1, is generally agreed, actual perceptions of congestion can differ substantially. This perception of congestion and level of dissatisfaction with it, will depend on people's personal experiences and expectations. For instance:

- A person from outside Auckland may consider a motorway travelling at 50-60km per hour highly congested; however, a regular driver on that route who frequently experiences portions of their commute at 30km per hour (or even lower) would consider this relatively uncongested.
- The level of traffic and delay a person could experience before considering they are in congestion on a rural road would likely be far less than on a major urban arterial.
- Likewise, the acceptability of travelling at 60km per hour on a motorway at 4:30pm would significantly differ from travelling the same speed at 4:30am.

Perceived congestion therefore could begin at any downwards point along the Speed-Flow curve depending on the person asked and the specific spatial and temporal situation. For this reason it is generally not suitable to use in determining an absolute measure, but can be an important perspective to keep in mind in the design and development of any congestion management scheme.

2.1.3 How is congestion defined?

At its most basic level, traffic congestion is when speeds on roads decline and queues of vehicles appear as a result of interactions between vehicles on the road.

Three possible ways of defining congestion are identified in the literature[5]:

1. Economists commonly define congestion as the presence of interactions between vehicles on the road. In effect, all roads that carry significant traffic volumes have some level of congestion.
2. Users perceive roads to be congested when speeds fall below an acceptable level, which may differ from person to person, by location and over time.
3. Engineers classify a road as congested when more vehicles are attempting to use the road than it has capacity to carry.

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[5] Costs of congestion reappraised. NZ Transport Agency research report 489, Wallis, IP and DR Lupton (2013)

The engineering definition provides a clearly defined measure that best encapsulates what people understand by congestion. Based on the above, the proposed definition of congestion, for the purposes of The Congestion Question project is thus:

Congestion occurs when the demand for the road exceeds its designed capacity.

This definition relates to point C on the speed-flow curve in Figure 1.

2.2 The causes of congestion

Simplistically, congestion occurs when more vehicles are attempting to use part of the road network than it is designed to handle. It is an example of demand (for the road space) exceeding supply (of the road space). Interactions between vehicles, different human behaviours and increasing numbers of vehicles on the road all contribute to congested traffic conditions.

2.2.1 Types of congestion

The economist William Vickrey identified six causes of congestion, which is considered the starting point for the modern study of congestion[6]:

1. **Simple interaction on homogeneous roads:** where two vehicles travelling close together delay one another (effectively where one slower vehicle causes vehicles following it to be delayed).
2. **Multiple interaction on homogeneous roads:** where the effect of different speeds of vehicles causes delay (often seen on motorways when traffic volumes get heavy and vehicles speed up or slow down to change lanes).
3. **Bottlenecks:** where more vehicles are trying to pass through a point where capacity reduces than it can accommodate.
4. **'Trigger neck' congestion:** where a source of congestion generates a queue of vehicles, which in turn delays a vehicle trying to pass through part of the queue on a journey in a different ultimate direction (e.g. to enter a turning bay).
5. **Network control congestion:** where traffic signals, roundabouts or give way/stop signs used for safety and traffic management start to generate queues in other directions of flow, or indeed the main flow.
6. **Congestion due to network changes:** where attempts to manage congestion (e.g. by increasing capacity) in one location may cause an increase in downstream congestion, because the upstream capacity has been increased.

In the past when roads were congested, a common approach was to widen them to increase capacity. However, there are limits to the physical expansion of the network to increase capacity. While this may have provided some immediate extra capacity and reduced delays in the short term, over time, depending on the circumstances, this improvement disappears until congestion returns to levels similar to

[6] Congestion Theory and Transport Investment, William Vickrey, American Economic Review, 1969, vol. 59, issue 2, 251-60

those existing before it was widened. This effect called the 'fundamental law of road congestion'[7] has been widely observed[8].

2.2.2 Behaviours of individuals

In most spheres of our lives when demand for a product or service exceeds supply, the price rises to a level where demand and supply meet (e.g. the price of strawberries on Christmas Eve or the price of airline flights during the school holidays). This is not the case for roads (and some other utilities), where the monetary cost of driving does not vary by time or location.

Currently, Aucklanders pay a range of vehicle and fuel related fees as well as other charges in relation to private vehicle travel:

- A flat charge per vehicle for registration and licensing;
- A charge that (either directly or indirectly) reflects distance driven (Road User Charges - RUC and Fuel Excise Duty - FED), plus the recent addition of the Regional Fuel Tax; and,
- Rates that are largely based on property value, which contribute to funding road and transport services.

Travelling on a congested road increases the overall cost that drivers face. Increased fuel and maintenance costs are incurred, as well as the additional time it takes and the reduced reliability of the journey time. The decision to travel by an individual driver is based on their own travel costs (private or internal costs). Their decision does not consider the impact to all other car users (external costs). When private costs are less than the full cost (internal and external) of driving, this is inefficient and consequently too much of a good (in this case travel) is consumed. Drivers continue to choose to travel during peak periods and once a section of the road network reaches capacity, each additional vehicle that attempts to join the road will reduce the speed that vehicles can travel, increase the variability and time it takes to travel, and have an exponential impact on the level of congestion that everyone experiences.

Some individuals may choose to change their behaviour to reduce their exposure to severe congestion. Changes in behaviour may vary and could include opting to travel at a less congested time of day, using a different mode of transport to make a journey, working from home or travelling via an alternative route. A congestion charge would further encourage these individual behavioural changes and work towards reducing congestion.

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[7] Duranton, G, and Turner, M. (2011). "The Fundamental Law of Road Congestion: Evidence from US Cities." *American Economic Review*, 101 (6): 2616-52.

[8] Litman, T. (2018). *Generated Traffic and Induced Travel*. Retrieved 10 July 2018, from http://www.vtpi.org/gentraf.pdf.

2.2.3 Cities and congestion

These economic theories help us understand the microeconomic effects of individual decisions; however, to provide further understanding it is useful to consider congestion at a city-wide scale.

Regular recurring congestion is restricted almost exclusively to cities. This is a direct result of a city's defining characteristic, proximity. Cities in their very essence or reason for being are about proximity, as described by the economist Edward Glaeser[9]:

> "*Cities are the absence of physical space between people and companies. They are proximity, density, closeness. They enable us to work and play together, and their success depends on the demand for physical connection.*"

Cities and their attraction as places to live and work rely on a density of people that makes some form and level of congestion unavoidable (be it a queue for coffee or the movies, a crowded bus, or traffic congestion). Yet they retain their attraction to us as the best way to share ideas[10], stimulate innovation and access specific skills and services. This can be seen throughout the world, where culturally and economically vibrant cities often have the worst congestion[11].

Therefore, when seen in this light, congestion is an inevitable consequence of proximity, prosperity and growth. It is a result of our desire for social and economic interaction and the benefits we gain from living and working in close proximity to each other. As the population of a city grows, the number of vehicles travelling on a road network increases and further traffic congestion is experienced.

2.3 The congestion problem

As with the causes, the negative impacts of congestion have two components – network efficiency (mobility) effects and region wide (accessibility) consequences.

2.3.1 Network efficiency

As established above, congestion at a microeconomic level can be attributed to the fact that the costs people pay to use a road do not always cover the costs they impose on others. The result of this is that delay impacts on other people are not taken into account. Beyond a certain level of traffic, these impacts on other people do not just reduce vehicle speeds but also actually reduce the capacity of the road so that fewer vehicles can travel along it. The result of this is that many stretches of road end up operating below capacity and in a far less efficient manner than they otherwise could, reducing people's ability to access jobs, education and other opportunities.

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[9] Glaeser, E. (2011). *Triumph of the City: How Urban Spaces Make Us Human*. MacMillan.

[10] Zheng, G. (2016). *Geographic proximity and productivity convergence across New Zealand firms*, New Zealand Productivity Commission Working Paper 2016/04. New Zealand Productivity Commission.

[11] OECD. (2007). *Managing Urban Traffic Congestion*. Paris, France: OECD Publishing.

2.3.2 Regional accessibility

Cities are invaluable as facilitators of possibilities. People gravitate towards them to allow them to access more easily the desirable skills, services and opportunities others can provide. However, congestion can reduce this accessibility, thereby offsetting advantages from proximity[12].

Congestion can also have harmful effects on the environment of a region. Severe congestion can lead to reductions in air quality and have negative impacts on the health of those people living in a congested region.

However it is not as simple as declaring all congestion harmful. The economic literature on congestion and productivity suggests that there is a complicated relationship between the two variables. In an econometric analysis of 88 of the most congested metro areas in the US[13], it was found that:

> *"Congestion may be good in that it's an indicator of active and vibrant urban places. Congestion might be bad in as far as it means that access is impeded, freight deliveries aren't able to happen on time, and people are hating life."*

2.4 Identifying and measuring congestion

Free-flow

Historically, transport system performance was measured by comparing vehicle traffic speeds with free-flow speeds. For example, motorways would be considered congested if speeds fell below 100 km/hr, as that represents freely flowing conditions.

As Auckland grows in population, the critical task of the transport system is to support a larger total amount of travel. Seeking to provide for free-flow traffic and avoid any congestion in the road network would be hugely inefficient and costly, as well as being practically impossible. Instead, the economic evidence on agglomeration and productivity in cities, summarised in section 2.3.2, suggests that because transport can support economic productivity, congestion should only be considered harmful if it significantly impedes the number of people able to use the road network.

Travel throughput

In a 2013 NZTA research report on transport indicators[14], the use of "travel throughput" was advocated as a better indicator of network capability and performance than conventional measures of congestion. It is

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[12] Melo, P., Graham, D., Levinson, D., & Aarabi, S. (2017). Agglomeration, accessibility and productivity: Evidence for large metropolitan areas in the US. *Urban Studies*, Vol. 54(1) 179–195.

[13] Sweet, M. (2014). 'Traffic Congestion's Economic Impacts: Evidence from US Metropolitan Regions'. *Urban Studies*, 51(10) 2088–2110.

[14] Denne, T., Irvine, R., Schiff, A. & Sweetman, C. (2013). *Blueprint for a best practice measurement indicator set and benchmarking*. NZ Transport Agency research report 522.

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suggested that throughput is a better indicator of the amount of economic activity supported by the transport network:

> *"Travel throughput measures the ability of the system to move people and freight per unit of time. Moving people and freight is what the transport system does, so throughput is a key measure of performance. […] In our view, throughput is a better measure of transport system performance than congestion or travel time-based measures."*

Empirical evidence suggests that minimising road congestion beyond a certain point will tend to reduce the amount of vehicles carried by the road, and hence the amount of economic activity supported by the road. Applying this approach to the simplified world represented by Figure 1, it is at the point where the capacity of the road is reached and flow begins to decrease (shown by point C) that a detrimental level of congestion starts.

Engineering measures

One of the ways that traffic engineering traditionally measures road network performance is using the concept of Level of Service (LoS). These qualitative levels, ranging from A to F, are used to categorise performance using measures such as vehicle speed, vehicle density, delay or volume to capacity (VC) ratio. Table 1 summarises LoS definitions for general road network performance using the relationship between measured traffic flow and maximum flow (the volume to capacity or VC ratio) as the measure. There are similar tables that use traffic speed, density or delay as the measure for LoS.

TABLE 1: ROAD NETWORK PERFORMANCE LEVELS OF SERVICE

LoS	Description	Motorway /Expressway VC ratio	Local/ Arterial Road VC ratio
A	Free-flow conditions with unimpeded manoeuvrability. Stopped delay at signalised intersection is minimal.	<0.30	<0.26
B	Reasonably unimpeded operations with slightly restricted manoeuvrability. Stopped delays are not bothersome.	0.30 < 0.48	0.26 < 0.43
C	Stable operations with somewhat more restrictions in making mid-block lane changes less than LoS B. Motorists will experience appreciable tension while driving.	0.48 < 0.70	0.43 < 0.62
D	Approaching unstable operations, where small increases in volume produce substantial increases in delay and decreases in speed.	0.70 < 0.90	0.62 < 0.82
E	Operations with significant intersection approach delays and low average speeds.	0.90 < 1	0.82 < 1
F	Extremely low speeds caused by intersection congestion, high delay and adverse signal progression	> =1	> =1

Source: Transportation Research Board. Highway capacity manual (TRB 1994)

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Due to the interactions of vehicles beyond a certain volume, once the volume to capacity ratio gets above about 0.85 (approaching LoS E), the flow of vehicles becomes unstable. This reduces the throughput, increases delays, and results in congestion. Therefore, to maximise the efficiency of the road network, the target LoS is typically LoS D – before severe congestion starts to occur.

2.5 The theory of congestion pricing

2.5.1 Early research

The basic economic theory of congestion was developed in 1920 by Arthur Pigou as part of his seminal work[15] to illustrate the economics of external effects and the ability of taxation to restore efficiency when goods are not optimally priced[16].

Presented below in Figure 2, the theory illustrates the relationship between the cost of travel and the flow of traffic along a particular route. In this situation as the cost of travel increases, fewer people are willing to travel (illustrated by the demand line). In calculating the cost of travelling along the route people will consider what is termed the 'marginal private cost' (MPC), that is the direct costs to them such as time, petrol and vehicle wear and tear; as such traffic volume will be 'y', that is the point where the MPC line meets demand. This MPC cost however is only part of the full cost of the trip; a person in making a trip will also impose other costs on society such as delays to other motorists (as shown in the speed-flow diagram in Figure 1).

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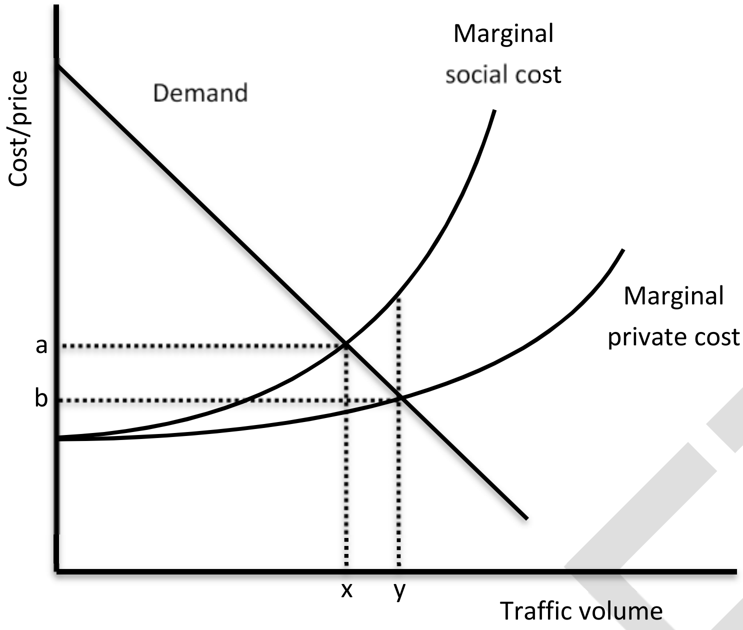
[15] Pigou, A. (1920). *The Economics of Welfare*. London, UK: MacMillan.

[16] Santos, G. & Verhoef, E. (2011). Road congestion pricing. In de Palma, A., Lindsey, R., Quinet, E., & Vickerman, R. (Eds), *A Handbook of Transport Economics* (pp561-585). Edward Elgar Publishing Limited.

FIGURE 2: RELATIONSHIP BETWEEN THE COST OF TRAVEL AND THE FLOW OF TRAFFIC



Source: Adapted from a diagram in A Handbook of Transport Economics (pg 562)

Without taking these costs into account an individual person may be better off by driving along a road but society as a whole will be worse off. The optimal use of the road for society overall lies therefore not at traffic volume 'y', but traffic volume 'x' where both the private and social costs are taken into account. Pigou found that imposing an optimal road price, equal in this case to the difference between 'a' and 'b' (or the marginal external congestion cost), achieves this optimal level.

This is a simplified representation of this theory and many in the years since have expanded on its concepts[17]; however, its main point remains valid and sits at the centre of understanding the reason traffic congestion arises on Auckland's roads. If a charge is applied to use the road at congested times to reflect the overall societal cost component, society will be better off (as use of the road network is optimised), even if some individuals are worse off (by having to pay a charge).

2.5.2 Optimal pricing in relation to network performance

The primary aim of a congestion charge is to allow an area of the road network to operate more efficiently. Some drivers will choose to pay the charge and maintain the same driving behaviours. Other drivers will choose an alternative travel method/time, rather than pay the charge, and this will have the positive effect of reducing the number of vehicles in the congested area and improving traffic flow. As the relationship between congestion and demand is non-linear, even small reductions in the number of vehicles in a congested area can have a noticeable effect on the stability of the traffic flow, allowing speeds to improve and travel times to become more reliable.

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[17] Small, K., & Verhoef, E. (2007). *The Economics of Urban Transportation*.

The level at which the charge is set will determine how many drivers change their behaviour. If the charge is set too high, there will likely be a significant reduction in the number of vehicles on the roads in the charging area. However, there will also be large resistance from society in terms of whether the charge is fair and equitable. If the charge is set too low, too many drivers will continue with their usual driving patterns, having negligible impacts on traffic flow.

From a network performance perspective, the optimal charge would be set at a level to allow the network to perform at optimal capacity. In reality, the level of charge will additionally need to consider social impacts and practicality, when being set.

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3 Auckland situation

Regional context:

Since 2010, Auckland's population has increased by over 250,000 people. The current population of Auckland is approaching 1.7 million and projections from Statistics NZ suggest that over the next 30 years, up to a million more people will call Auckland home. Historically, Auckland's urban footprint has been made up of low-density suburbs, connected by a motorway network with widespread vehicle ownership by residents. As Auckland's population grows, the urban footprint and the way we move around the city will need to change.

Growth will be accommodated by increasing density and investing in infrastructure:

The city centre will continue to be an important area for business, tourism, civic, educational and cultural activities. However, it is not the only main centre in Auckland. Housing and economic activity will increase in density in other key locations including Albany, Westgate, Manukau and the airport industrial area. While public transport options are available to access these locations today, further capacity and choice will need to be provided to allow the city and its residents to prosper.

Recent years have seen record growth in public transport use in Auckland. Annual public transport boardings have increased by 37 percent, from 69.7 million in December 2013 to 95.6 million in November 2018. Fast, reliable and convenient public transport solutions, such as the rapid transit lanes on the Northern Corridor through to the city centre, now enable more people to commute to the city centre via bus, than via private car. However, residents own more cars on a per capita basis than ever before. There were over 700 additional cars registered in Auckland every week in the twelve months to September 2017 and peak period congestion has increased significantly. Compared to 2014:

- 33% more of the arterial network is now congested during the morning peak hour, and
- average weekday motorway trips now take almost 10% longer (The Congestion Question Phase I report).

With the predicted rate of population growth in Auckland coupled with private vehicle being the preferred mode of transport, the demand on the road network will continue to increase, further worsening congestion in the absence of any interventions.

The Auckland Transport Alignment Project (ATAP) recently developed an aligned strategic approach for transport investment priorities in Auckland in order to accommodate the anticipated growth in the region. The ATAP package contains $28 billion of investment in Auckland's transport infrastructure and services over the period 2018-2028. The majority of the ATAP package focusses on capital improvements, primarily in the modes of public transport, walking and cycling. There is also in excess of $5 billion allocated to maintaining and improving the quality of Auckland's roads.

ATAP concluded that while investment in transport infrastructure (and services) is an essential part of achieving transformational change, they need to be complemented by a series of other interventions.

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These include "**implementing road pricing to manage travel demand**, make better use of existing infrastructure and encouraging a modal shift to public transport, walking and cycling"[18].

3.1 Where is congestion experienced today?

Data from Auckland Transport (June 2018) shows the areas of Auckland that are affected by congestion in the AM peak, interpeak and PM peak periods; congestion is widespread. The LoS highlighted in Figure 3, Figure 4 and Figure 5 (following) use proportion of the posted speed limit as the measure, with the different levels defined as follows:

TABLE 2: ROAD NETWORK PERFORMANCE LEVELS OF SERVICE USED BY AUCKLAND TRANSPORT

LoS	Colour coding	% of speed limit
A		90% and greater
B		70-90%
C		50-70%
D		40-49%
E		30-39%
F		Less than 30%

Source: Auckland Transport

The proxy for 'congested conditions' is when the average speed travelled on a section of road is less than 50% of the posted speed limit (i.e. Levels of Service D – F, coloured red, crimson and black on the maps).

The most widespread congestion occurs during the PM peak when the average speed on several sections of the road network is at 30% or less than the speed limit (black colour coding). This can be seen in sections of the North-Shore; around East Tamaki and Botany, the North-Western motorway and arterial routes in close proximity; the Southern and South-Western motorways and surrounding arterial routes. It is worth noting that on some sections of the motorway – e.g. the North-Western near Lincoln Road and the Southern near Takanini, ongoing roadworks are in progress to widen the motorway in these sections. The reduced speed limits and temporary traffic management force traffic to slow down below the usual speed limit and thus further contribute to the congestion in these areas.

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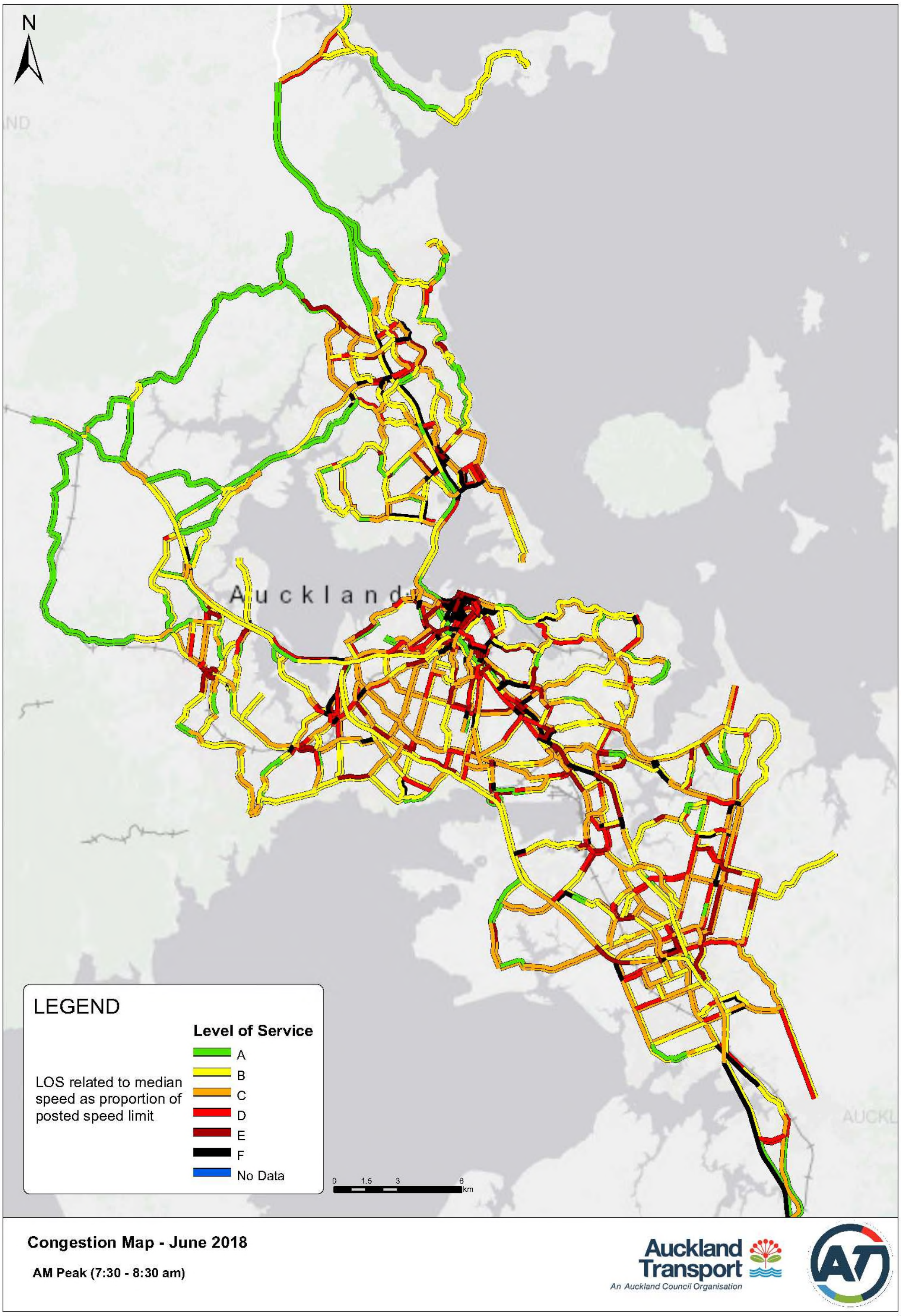
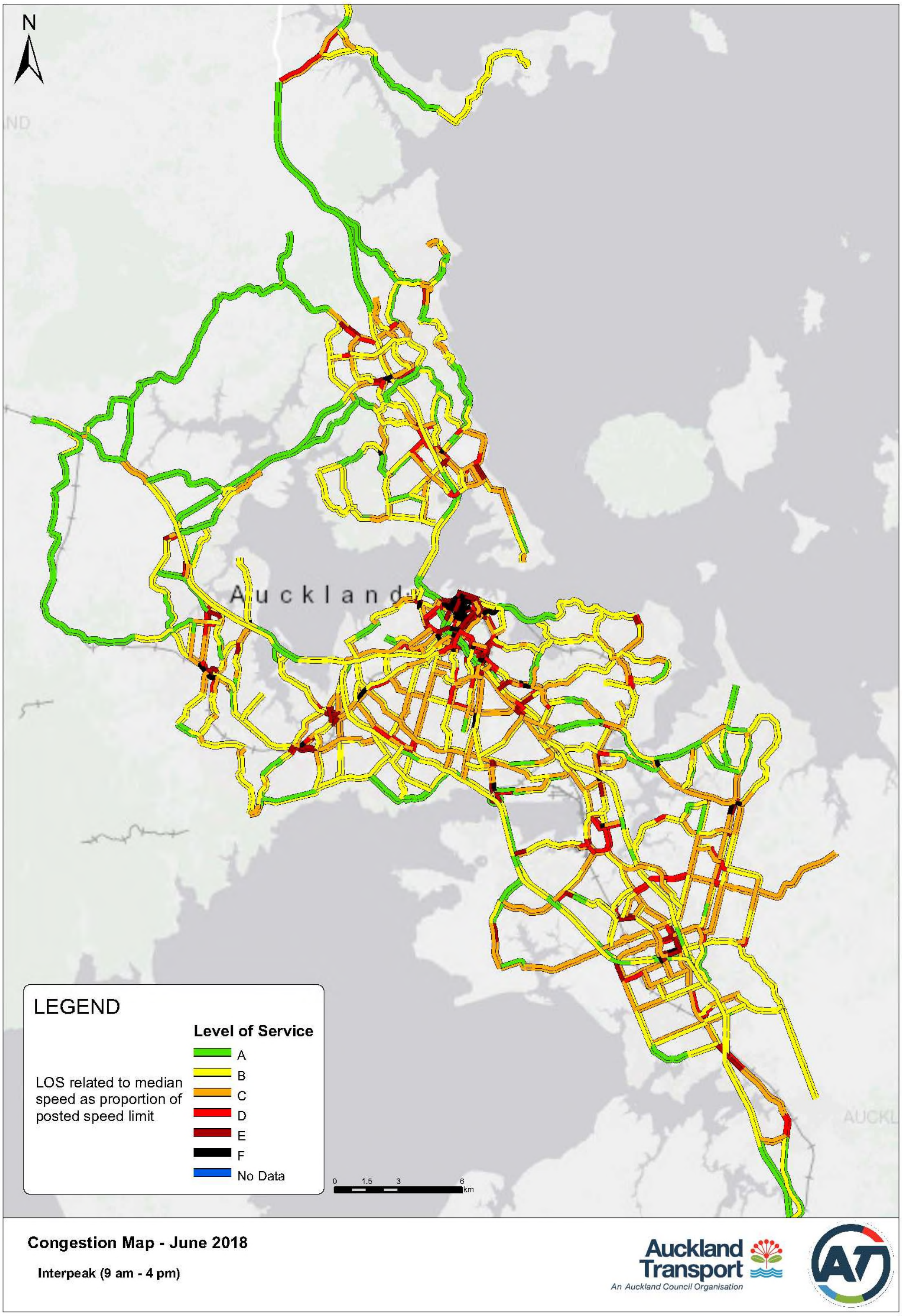
[18] Auckland Transport Alignment Project, April 2018, pp 13

FIGURE 3: AM PEAK CONGESTION (7.30AM-8.30AM)



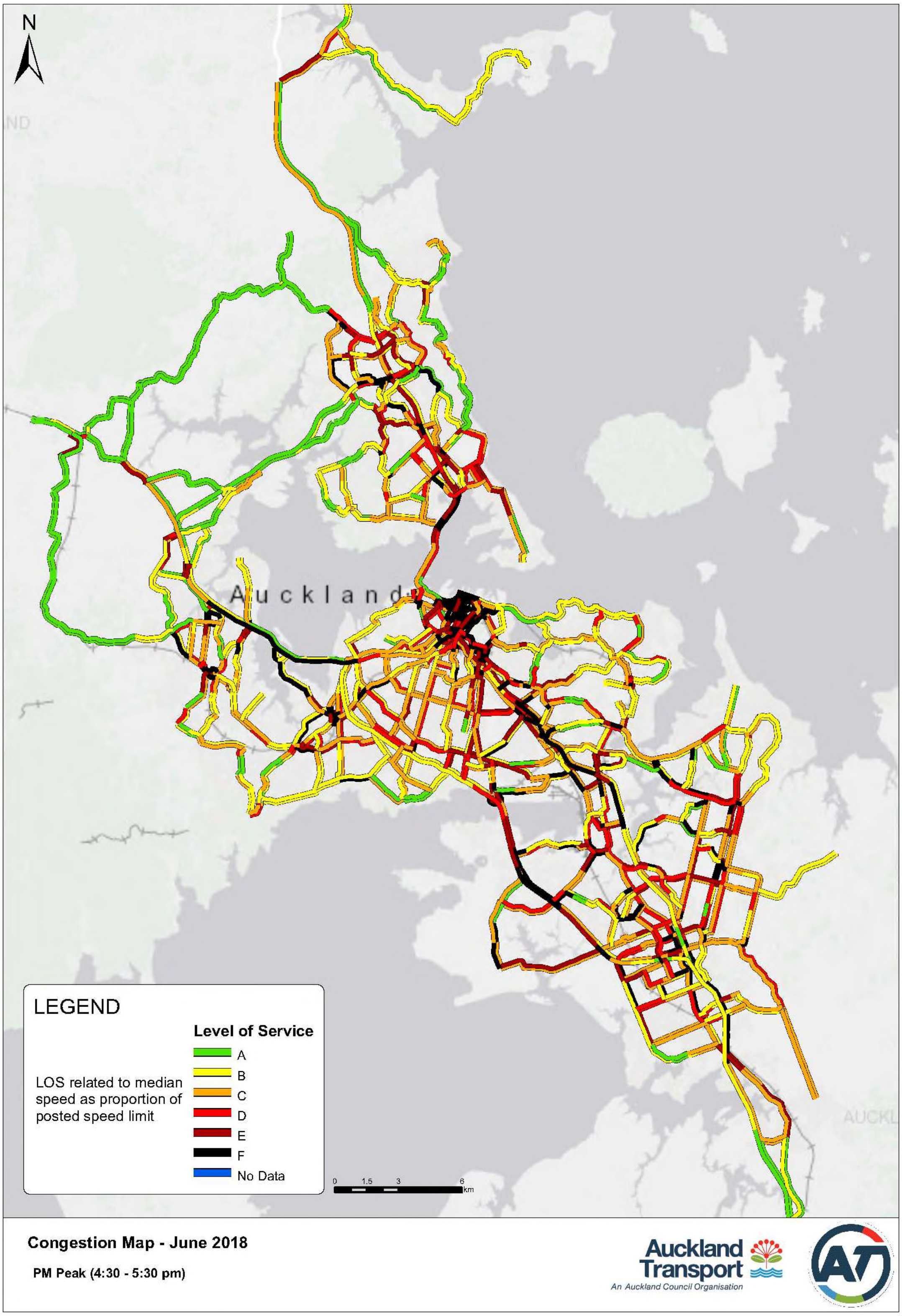
Source: Auckland Transport traffic monitoring data

FIGURE 4: INTERPEAK CONGESTION (9AM-4PM)



Source: Auckland Transport traffic monitoring data

FIGURE 5 : PM PEAK CONGESTION (4.30PM-5.30PM)



Source: Auckland Transport traffic monitoring data

3.2 Different causes of congestion in Auckland

Different locations and sections of the road network experience different levels of congestion due to their layout and constraints. Auckland examples for different types of congestion (as discussed in section 2.2.1) are outlined below.

1. Simple interaction on homogeneous roads, for example:
    - When a car slows to turn into a driveway, the cars following have to also slow down.

2. Multiple interaction on homogeneous roads, for example:
    - When vehicles are merging lanes on a busy stretch of motorway or changing lanes where the vehicle speeds are different.
    - Great South Road (or other busy four lane roads), where people are pulling into and out of parallel carparks, driveways, side streets and also changing lanes.

3. Bottlenecks are experienced in several locations, for example:
    - Northbound on SH1 at Mt Wellington where three lanes reduce down to two lanes.
    - At a set of traffic signals where two lanes at the intersection merge to one lane after the intersection.

4. 'Trigger neck' congestion, for example:
    - Someone travelling from Devonport to Takapuna in the morning peak on Lake Road, will get caught in the congestion flowing back from vehicles joining the motorway at Esmonde Road.
    - Access to a right turning bay at a set of traffic signals is blocked by the queue going straight ahead (or vice versa).

5. Network control congestion, where traffic signals or roundabouts which are necessary to allow safe travel for conflicting vehicle movements, create queues of traffic. For example:
    - North-South traffic on Dominion Rd vs East-West traffic on Balmoral Rd.

6. Congestion due to network changes, where road/motorway widening effectively "moves the bottleneck" downstream. For example:
    - Prior to the opening of the Northern Gateway tunnel, there was significant congestion at the Grand Drive interchange (Orewa), especially on holiday weekends. The extension of the Northern Gateway moved the congestion from this point to further downstream at the Johnstones Hill tunnel.

7. Congestion due to roadworks and incidents which cause a temporary reduction in supply/capacity. For example:
    - Takanini motorway expansion. Road agencies are very concerned about managing the impact of congestion in these scenarios. They do this through scheduling of maintenance works, temporary speed limit reductions and rapid response teams.

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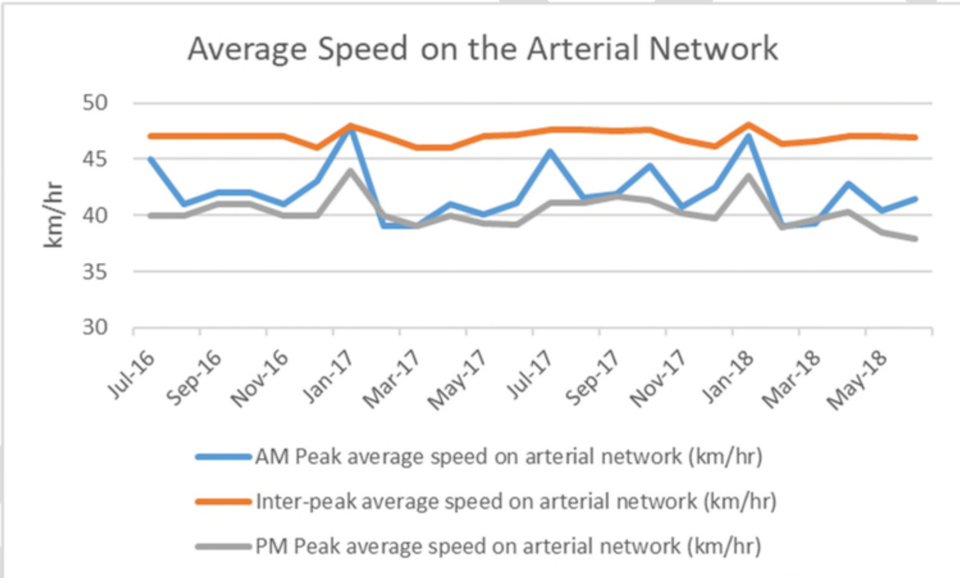
- When incidents occur, generally any resulting congestion is localised. Significant incidents on the motorway network, eg bridge strikes (over height vehicles hitting an overbridge) or multi-vehicle pile ups, can result in severe congestion. However, these large-scale incidents do not occur very often.

3.3 Variances in congestion levels

Congestion varies depending on the time of day, the day of the week and the time of the year. The worst congestion generally occurs at times when most people want to travel, i.e. the morning peak and the afternoon peak, Monday to Friday. This can be seen in Figure 6which shows average speeds on the Auckland arterial network by month, for the AM peak, interpeak and PM peak periods. The AM peak has the most variability in average speed, and the PM peak generally experiences the lowest average speeds. Growth in the city is also contributing to increased congestion throughout the interpeak period and at weekends, though it is not as widespread as typical 'commuter peak' congestion.

FIGURE 6 : ARTERIAL MONTHLY AVERAGE SPEEDS AT THE AM PEAK, INTERPEAK AND PM PEAK PERIODS



Source: Auckland Transport traffic monitoring data

Seasonality

Seasonality effects have a noticeable impact on congestion levels in Auckland. During school and university holidays, congestion levels in most locations ease (increases in average speeds can be seen in Figure 6 in January, April, July and October). The change to travel patterns during the holiday periods illustrates that only a minor reduction in traffic volumes results in a noticeable increase in average speeds, which are a proxy for congestion.

At the beginning and end of public holiday weekends, periods of congestion are prolonged and more intense, particularly on the major state highways, as more people try to exit and then return to the region. Public information campaigns are often utilised to encourage travellers to make their journeys outside peak times.

Disrupting factors

Adverse weather conditions can negatively impact congestion with heavy rain forcing motorists to slow their travel speeds, and king tides disrupting travel routes for Auckland motorists. Crashes and roadworks can also exacerbate congestion, however these factors are not considered to contribute to recurring congestion.

3.4 What do Aucklanders think about congestion in the region?

The Auckland Transport road user satisfaction study conducted in the first half of 2018 states that only one in every three Aucklanders are satisfied with travel by road. Traffic flow accounts for half the impact on overall satisfaction levels.

On the arterial routes, the lowest levels of satisfaction with both the flow of traffic and the consistency of time taken to travel are seen within the North, City and Newmarket, West, Otahuhu, Onehunga/South – showing dissatisfaction levels are widespread across the city.

According to the June 2018 survey, half of Auckland residents in full or part time employment are affected by congestion on most days of the week. Approximately 60% of drivers agree with the sentiment they are "battling the traffic everyday".

Aucklanders are already using a range of strategies to manage peak time travel, including: travelling before or after the peak; using public transport, active modes or choosing to work from home rather than travel to their place of work. This shows that congestion is an existing problem and Aucklanders are changing their travel behaviours to work around it.

3.5 Costs

Traffic congestion affects users of the road network in that it delays journeys, limiting access to economic, educational and social opportunities. Direct costs of traffic congestion to individuals are increased fuel and maintenance costs, loss of time (due to sitting in traffic) and schedule delay costs (having to change time of travel to avoid delay).

The aggregate cost of congestion to Auckland has been recently calculated in two separate research publications:

a) Ian Wallis and David Lupton, in their NZ Transport Agency research report 489, published in February 2013 and,
b) The New Zealand Institute of Economic Research (NZIER), in their report: Benefits from Auckland road decongestion, published in July 2017.

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Wallis and Lupton

The Wallis and Lupton report defines congestion based on the engineering definition, as "occurring when the demand for the road exceeds its capacity – i.e. the maximum sustainable flow." The report goes on to define the cost of congestion as "the difference between the observed travel time and the travel time when the road is operating at capacity – plus schedule delay costs, reliability costs and other applicable social and environmental costs."

The report used the Auckland Regional Transport Model (ART3) for data inputs, and adjusted prices to 2010. It estimates that the annual cost of congestion to Auckland is $1,250 million per year when compared with free-flow conditions and $250 million per year when compared with the network operating at capacity.

NZIER

When calculating the benefits of decongestion, NZIER considers the impacts beyond the direct time-savings to freight operators and commuters. The calculation considers the benefits that also accrue to all businesses that use transport and employ workers who commute, and to households who waste their scarce time in traffic jams. The estimate of benefits includes the flow-on impacts across the economy plus social benefits such as reduced carbon emissions.

NZIER estimates the benefits of decongestion in Auckland would be between $0.9 billion and $1.3 billion per annum (approximately 1% to 1.5% of Auckland's GDP, based on 2016 prices). These estimates represent the economic and social benefits[19] to Auckland if the road transport network was operating within its capacity Monday to Friday. The estimates do not include the benefits of decongestion in the weekends, which if included, would increase the value of the estimated benefits.

NZIER note that their estimate is likely to be conservative as there are several other potential benefits from decongestion that have not been included due to data, time and resource constraints. These include:

- Auckland's overall liveability
- Greater choice in work location (better skill matching around the Auckland region)
- Greater choice in household location (increased accessibility to jobs, services and leisure)
- Greater freedom for business to locate around Auckland (trading off labour market access and rental costs)

[19] These benefits accrue across three sectors: government, business and household. The benefits to households are estimated to be between $233 million and $382 million per year. This represents an economic benefit of approximately $500 - $750 per household.

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3.6 Future state

3.6.1 Regional Land Transport Plan

Recommendations from ATAP have been used to guide statutory planning processes, including the Regional Land Transport Plan (RLTP). The RLTP outlines the investment program for the next 10 years, for transport in Auckland. The RLTP aims to deliver a safe, reliable and accessible transport system that supports and shapes Auckland's development.

Under the investment program, improvements are expected to support a modal shift away from single occupant vehicles as the dominant mode of travel, towards public transport use and active modes. The RLTP aims to increase total annual public transport boardings to almost 150 million by 2028 (compared with 95.6 million annual boardings in the year to November 2018), without congestion pricing.

Delivery of the projects outlined in the RLTP will enable the transport system to keep up with the predicted growth of the region. However, while this significant programme of investment will deliver good outcomes at a localised level, congestion is <u>not</u> expected to improve from current levels. The Auckland Forecasting Centre's (AFC) Macro Strategic Model (MSM) forecasts future road network performance, taking into account:

- the most recent population and employment projections and,
- the investments planned in the RLTP.

The impact of the RLTP projects on congestion levels in Auckland, is that in ten years' time, the city will experience similar levels of congestion to those which it experiences today (see Figure 7).

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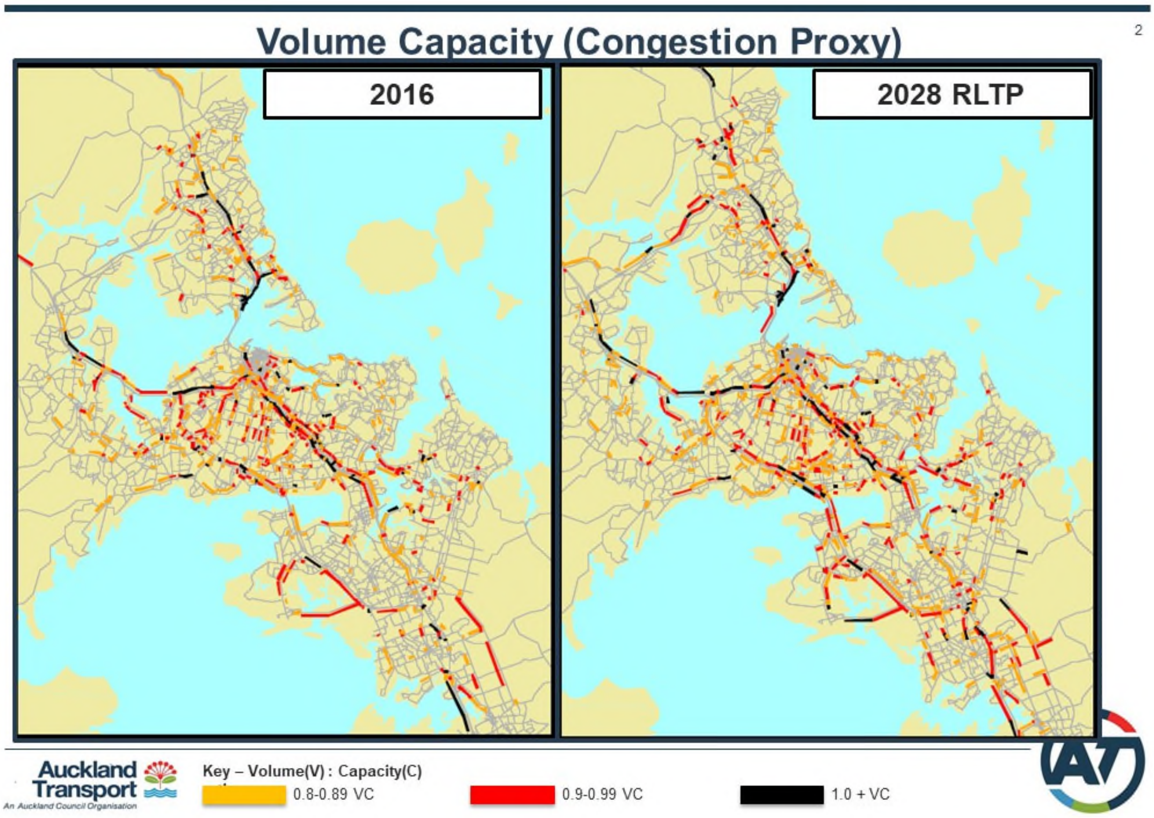
Figure 7: Congestion in Auckland (2016 and 2028)



Source: Auckland Forecasting Centre, Macro Strategic Model outputs

Accommodating another 300,000 people in Auckland (i.e. accommodating approximately twice the current population of Hamilton) without adding to congestion would be a significant achievement in its own right. However, we know that people aren't happy with the current situation – every day Aucklanders spend hours sitting in traffic when they could otherwise be at home with their families, or doing something more productive. An average weekday motorway trip now takes 10% more time than four years ago, and motorists now need to allow an additional 40-55% longer for trips to be assured of arriving on time[20]. Congestion is also becoming increasingly worse throughout the day and at weekends. If congestion does not improve, access to jobs, education and other opportunities will become more difficult, negatively impacting both productivity and liveability.

Analysis undertaken as part of Phase I indicates that road network performance will continue to decline, even with major investment in transport infrastructure and services and by 2046:

[20] The Congestion Question – Phase I report

- The proportion of car travel in severe congestion (modelled as any road link >0.8 volume/capacity ratio – ie orange, red and black shading in Figure 7) is projected to increase by 29% in the morning and afternoon peaks and by 38% in the interpeak
- Severe congestion on the freight network during both the morning peak and interpeak is projected to increase by 50%.

This project builds on findings from ATAP, that influencing travel demand should be considered alongside increasing investment in order to get better use of the transport network. Congestion pricing is a mechanism that can be used to manage demand on the road network, encourage users to change their travel behaviour - the time, route or mode by which they travel - and has been successfully implemented in several cities around the world.

3.6.2 Technological changes

Technology advances in, or affecting, the transport sector are already having noticeable impacts on congestion and are not always for the better.

- For example, there is evidence that the increase in popularity of ride-sharing/ride-hailing services (e.g. Uber/Lyft) is increasing congestion by providing a more convenient, but less efficient alternative to public transport. This also increases the numbers of vehicles circulating on the road network without purpose (e.g. in between customer rides), further adding to congestion.
- A survey released in October of over 4,000 adults in Boston, Chicago, Los Angeles, New York, the San Francisco Bay Area, Seattle and Washington, D.C., concluded that 49 to 61 percent of ride-hailing trips would not have been made at all – or would have been made instead by public transport, walking or biking – if ride-sharing apps were not available.
- A study on the rise of online shopping conducted by researchers at the University of Delaware found that an increase in the number of home shopping purchases is likely to increase travel time, traffic delays, and vehicle emissions of the transportation network as a whole. Simulation results indicate the additional burden on the transport system is primarily due to the increased number of delivery trucks required, even though personal shopping trips may decrease.

The introduction of autonomous, connected vehicles and people's access to more data such as digital services that provide real-time information (e.g. congestion levels and parking availability) also have the ability to impact congestion. These advances are still in development and the longer-term impacts are challenging to forecast:

- Autonomous and connected vehicles – these vehicles are expected to play an important role in the future of transport. They have the ability to communicate with each other and their surroundings, hence they are able to theoretically identify the optimal route and spread the demand for road space. They are also able to travel closer together, increasing the capacity of existing roads. Enhanced ride-sharing capabilities are a potential feature of driverless cars (e.g. through mobility as a service (MaaS)), further optimising use of the road network by increasing individual vehicle occupancy. While the potential benefits of autonomous and connected vehicles are significant in theory, there is considerable uncertainty of these benefits and associated timeframes, and there is the risk that demand may in fact result in increased congestion.

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- Data and information services – the provision of real time information (e.g. via mobile apps) allows road users to optimise their route by providing information on, for example, congestion levels on particular roads, parking availability at a destination or ride-sharing options. This can assist people in managing their travel choices (e.g. time and mode of travel) which has the potential to contribute to the goals of congestion pricing, being better network performance.

Overall, although there are some potentially promising aspects to new technologies enabling more efficient use of the road network, uncertainty around their timing and impact means that we cannot wait to take action.

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4 What are we trying to achieve with congestion pricing?

The primary aim of introducing congestion pricing is to change people's behaviour and subsequently allow an area of the road network to operate more efficiently.

4.1 What would this mean for people?

For congestion pricing to work, it requires a behavioural change for some people to change the way they travel. In the short term, this could be:

- Do nothing – people continue with their previous routes and pay the higher price.
- Shift routes – people find an alternative route with no charge or a lower charge.
- Shift modes – people take an alternative form of transport – public transport, walking/cycling, carpooling to share costs, etc.
- Shift travel time – people shift their travel to a different time of day when the charge may be lower, potentially smoothing congestion away from the peaks.
- Avoid trips – people decrease the number of trips they make to avoid the charge, for example by online shopping. This is especially relevant for discretionary trips, which are probably the lowest value trips.

Longer term behavioural changes might be:

- Choose a different destination – people opt to travel to a different location to avoid or minimise the charge – this may include changing place of work/school/shopping etc.
- Choose a different origin – people opt to move their home/business location to avoid or minimise the charge.

International evidence shows that the vast majority of people tend to pay the charge and continue driving[21]. However, because the relationship between traffic speeds and flow is non-linear (as per the speed-flow curve in Figure 1), it only takes a small reduction in vehicle volumes to have a big impact on congestion. The idea of congestion pricing is to target the lowest value trips that could be deferred or re-timed, freeing up the roads for those who need to travel.

4.2 What would people perceive?

What would this look like to people using the transport network? How would they perceive the changes to traffic flow if a congestion charge were imposed on drivers?

[21] Social and Distributional Impacts of Time and Space-based Road Pricing (final draft report), MRCagney, 12/5/2018

- People should experience faster journey times and generally more consistent travel speeds, i.e. less stop-start traffic.
- There would also be an improvement in journey time reliability. People should be able to plan their journeys with more confidence knowing that it is unlikely they will be stuck in slow moving traffic and consequently, there will be a reduction in scheduling costs. People will not need to allow as much buffer time for trips, and tradespeople and freight operators will be able to schedule more jobs with the confidence that they can make them on time.

One important outcome that evidence suggests people will not perceive, or at least will not perceive fully, is the extent of behavioural change that they have actually made. A 2006 study undertaken in Stockholm following the introduction of the scheme questioned people on the changes they had made to their travel. The researchers were surprised to find that a significant portion of the trips that were no longer occurring were unaccounted for. In fact:

> "*Most drivers were unaware that they had reduced their trips across the cordon. A comparison of drivers' stated change in behaviour and objective traffic measurements showed that around three-quarters of the decrease in trips had apparently gone unnoticed by drivers*"[22]

It is likely that people will for at least some of the time not realise they have made the choice to change their time or mode of travel, or to not make the trip at all. These decisions around the edges are the primary targets of any pricing scheme, and demonstrate the potential of even a relatively small charge – making people question the need to make that trip, potentially subconsciously, in the first place.

4.3 What does success look like?

In 2010, the International Transport Forum held a roundtable forum looking at the lessons learned from the successful implementation of congestion charging schemes. The summary report of proceedings has many interesting lessons for the project but perhaps none more so than that included in the opening paragraph of the report "Implementing Congestion Charges":

> *""Success" means (a) that a policy is implemented, (b) that it works, (c) that it is accepted by actual and potential users, and (d) that it generates benefits for society overall."*

Success first and foremost then, is an implementable scheme that results in network performance improvements, the merits of which are accepted by the public.

[22] The Stockholm congestion charges: an overview, Jonas Eliasson, KTH Royal Institute of Technology CTS Working Paper 2014:7

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A new charge, as with any new fee or tax, is likely to be met with some opposition both on principle from those who object to new or increased taxes and from those who will be personally worse off. Nevertheless, it must be acceptable in that it:

a) is well founded/justified;
b) is easy to understand and use; and
c) once implemented demonstrates noticeable benefits.

Over time, the level of acceptance of a charging scheme is likely to increase, as has been observed in European cities where congestion charging has been introduced (see Table 3).

TABLE 3: ACCEPTANCE OF CHARGING BEFORE AND AFTER IMPLEMENTATION IN FIVE EUROPEAN CITIES

City	Before	After
Stockholm	21%	67%
Bergen	19%	58%
Oslo	30%	41%
Trondheim	9%	47%
London	39%	54%

Source: Congestion Charging: Policy and Global Lessons Learned / CURACAO Deliverable D3: Case Study Results Report, 2009

Congestion charging schemes that have been delivered around the world have shown significant improvements to road network efficiency. In Singapore, traffic in the restricted zone reduced by about 13% and average travel speeds increased by 20%. Singapore has a flexible tariff policy that is reviewed every three months and adjusted to manage speeds. In Stockholm, during the congestion pricing cordon trial and the subsequent scheme implementation, congestion levels reduced to a stable level of 22% below the 2005 pre-charging conditions. Interestingly, between the end of the trial period and the reintroduction of the charges in Stockholm, traffic volumes rebounded to levels from before the trial – almost. There was a residual effect of 5-10% lower traffic volumes that remained even after the charges had been abolished, which most likely indicates that some car users adapted alternative travel habits that remained after the charge was removed[23].

In addition to reducing congestion, further positive outcomes from congestion charging schemes are improved health benefits (from modal switches to walking and cycling); cleaner air from lower vehicle emissions and safer roads.

[23] The Stockholm congestion charges: an overview, Jonas Eliasson, KTH Royal Institute of Technology CTS Working Paper 2014:7

4.4 Congestion charging in the real world

If a congestion charging scheme were to be implemented in Auckland, it will need to balance:

- **Network performance -** A scheme must meet the primary objective of the project; that is to improve congestion results. It must also be a positive thing to do, in that it should generate net benefits for society compared to the current situation. However, to *optimise* network performance, a high charge might be required and this may conflict with the other considerations below – hence the need for trade-offs to be made.
- **Social and equity impacts -** A scheme needs to consider principles of equity and fairness in its design; these might include:
    - Whether or not charging is perceived to deny individual basic rights such as freedom of movement
    - Whether people on lower incomes are more adversely impacted - a congestion charging scheme should not disproportionately affect less well-off and more vulnerable members of society
    - Whether different members of society have the opportunity to adopt alternatives, based on, for example, their geography, access to services and access to other travel choices.
- **Practical considerations -** A scheme needs to be implementable in practical terms, considering:
    - technical feasibility
    - capital and operational costs
    - clear communication around the use of revenue
    - ease of use for customers
    - privacy concerns (linked to the technology that is utilised)
    - provision of alternatives (e.g. increasing public transport and active mode offerings)

A rules-based tariff policy will provide flexibility to adjust parameters (e.g. time of day, location and even the charge itself) to manage some of these trade-offs. A suitable tariff policy enables a scheme to remain flexible to allow changes to be made over time, based on the results achieved and the scheme's impact on social, environmental and safety outcomes.

4.5 We need to consider a range of options

A review of international pricing initiatives and lessons for Auckland, commissioned in Phase I of the project, recommended to begin with an achievable scheme that targets a widely accepted problem, and then evolve[24] (the scheme). An initial scheme must be easy for the public to understand, so that they know how to pay the charge, what the charge will be and so they also understand how to avoid it (i.e. what the alternative options are).

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[24] Review of international pricing schemes, previous reports and technologies for demand management purposes, D'Artagnan Consulting, August 2018

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Therefore, when considering the design of potential congestion charging schemes for Auckland, a wide range of options (e.g. location, style, size) need to be considered in this phase of TCQ, so that we can understand and take into account the trade-offs between network performance, social impacts and practicality, as discussed above.

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