Greening Urban and Suburban Travel

Current situation, challenges, opportunities and emerging trends

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LOW CARBON LIVING CRC

Acknowledgements

Disclaimer

Peer Review Statement

The CRCLCL recognises the value of knowledge exchange and the importance of objective peer review. It is committed to encouraging and supporting its research teams in this regard.

The author(s) confirm(s) that this document has been reviewed and approved by the project's steering committee and by its program leader. These reviewers evaluated its:

- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2007),

and provided constructive feedback which was considered and addressed by the author(s).

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Acronyms

ABM   Agent Based Modelling

ASP   Adapted Stated Preference

AV   Autonomous Vehicle

BRT   Bus Rapid Transit

CBA   Cost Benefit Analysis

CBD   Central Business District

CO2   Carbon Dioxide

COE   Certificate of Entitlement

ETC   Electronic Toll Collection

GDP   Gross Domestic Product

GHG   Greenhouse Gas

GPS   Global Positioning System

IEA   International Energy Agency

ITS   Intelligent Transport Systems

LGA   Local Government Area

LCM   Low Carbon Mobility

MGI   McKinsey Global Institute

NEC   National Employment Cluster

RFID   Radio Frequency Identification

TDM   Travel Demand Management

TOD   Transit Oriented Development

VKT   Vehicle Kilometres Travelled

VPA   Victorian Planning Authority

Executive Summary

Prospects for the decarbonising of Australian cities will depend on opportunities for a reduction of transport energy use. This project focuses on the most significant challenge to Green House Gas reduction in urban transport -- specifically, that relating to provision of public transport and active travel options for low density suburban areas that are currently car dependent. As part of the interim deliverables for this project, the research team has undertaken an environmental scan of international best practices and trends in the provision of high-priority, transformative initiatives to tackle the mobility challenges facing both urban and suburban communities. The report gathers and collates information from a wide body of literature to assist the CRC partner organisations in responding to the impacts of this global challenge, and to inform their policy and advocacy positions.

This report starts by providing the background to this project, its aims and objectives which are focused on reducing greenhouse gas emissions from passenger car usage in urban and suburban areas. The report then details the current challenges facing urban mobility including rapid urbanisation, road crashes and injuries, traffic congestion, ageing assets and the infrastructure investment gap, and the limitation of the current approaches. The report then identifies the opportunities available today to set our cities on a path towards low carbon mobility, including investments in public transport and active travel solutions, travel demand management, transport and land-use integrations, and investments in dense, walkable and bicycle friendly cities. The report also identifies the role of transport technologies and digital innovations in improving access to jobs and opportunities and enhancing personal mobility, and promoting sustainable transport by providing travellers with information and better solutions to travel around our cities.

The next part of the report reviews the current global trends in sustainable transport solutions, and provides a reflection on how some of these trends can be applied to case studies relevant to this project. The review also covers some of the emerging technology-based trends including autonomous vehicles and how they can be used support public transport and first and last kilometre travel. The review also provides some background information on the modelling tools and other techniques that will be used in this project's future stages.

The report then details the policy principles for low carbon mobility which are based on the "Avoid, Shift, Share, Improve" policy instrument framework. The discussion includes the identification of key policy principles, their potential benefits, how they are applied in city context and urban/suburban needs, and how decision makers can match policy to a city's current and future needs and requirements. This section also emphasises the importance of stakeholder consultations and concludes with a number of case studies that demonstrate how cities around the world have applied these principles in the context of low carbon mobility. The report then also describes the role of digital innovations in creating sustainable urban mobility in the world's cities.

Finally, the report identifies the research needs and requirements for greening suburban travel in the Australian context, and how to adopt policies and strategies that accelerate their deployment and adoption.

This interim report concludes by providing an overview of the next stages of research required to achieve the aims and objectives of this research over the remaining duration of this project.

Introduction

This report provides an environmental scan and an objective review and analysis of the technological, social and economic impacts and trends surrounding urban mobility solutions, and how they are likely to influence the transport and mobility industries and marketplace now and into the future. Specifically, this report includes a review of the current and anticipated external factors that are of direct relevance to the environment in which the CRC partner organisations operate. The report gathers and collates information from a wide body of literature to assist the CRC partners in responding to the impacts of this global challenge, and inform their policy and advocacy positions when the needs arises.

Project Aims and Objectives

The overarching aim of this project is to reduce greenhouse gas emissions from passenger car usage in (sub)urban areas - which is the largest transport source of emissions contributing 8.5% of Australia's net emissions in 2010 and accounting for around 39.7 Mt CO2. The research explores the development and evaluation of new methods to provide suburban public transport and active travel options that offer efficient, affordable and flexible trips while reducing reliance on private vehicle use.

Specific project objectives include:

- Understand and assess the current situation and identify best practices and trends in (sub)urban public transport and active travel

- Understand the drivers for travel demand in suburban areas and determinants of shifts in travel behaviour from private vehicles to public transport and active transport

- Understand the land-use transport interactions and their influence on the demand for different travel modes under different scenarios of supply of public and active transport infrastructure and service patterns, especially as these relate to precinct planning and design

- Understand the impacts of different intervention measures and their benefits in reducing greenhouse gas emissions, reducing social and economic costs of current levels of car-dependence, and providing customers with alternative travel options

- Engage with the wider stakeholders and community and understand the barriers and opportunities to greening suburban travel

- Converge the research outcomes into a discrete set of transport interventions and applicable tools that will help end users to deploy and implement green transport initiatives in the nation's suburbs

Other wider objectives include:

- Accelerate development, evaluation and implementation of green mobility solutions in the suburbs

- Provide a meeting ground for researchers and practitioners to try new approaches to smart mobility, and evaluate prototype technologies using real-life data

- Promote local, national and international cooperation by encouraging participation of Australian and international researchers through exchange of data and expertise

- Provide researchers with access to high-end simulation and modelling tools for modelling transport networks and validating their performance using real-life data

- Train future generations of mobility professionals who are capable of ensuring sustainability of transport networks and human capital.

Background

Transport activity is one of the major sources of emissions related to the combustion of fossil fuels in Australia (National Greenhouse Gas Inventory - NGGI, 2011). As shown in Figure 1 (Taylor, 2014), transport contributed 83.2 Mt CO2 or 15.3% of Australia's net emissions in 2010. Road transport was the main source of transport emissions, accounting for 71.5 Mt CO2 or 86% of national transport emissions. Passenger car usage in urban areas was the largest transport source, contributing 8.5% of Australia's net emissions in 2010 and thus accounting for around 39.7 Mt CO2.
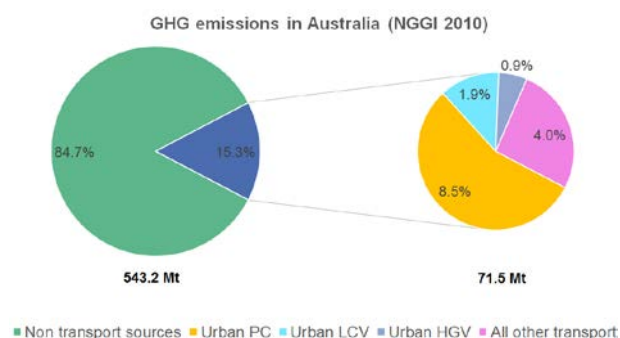
Figure 1 Transport contributions to national GHG emissions (Source: Taylor, 2014)

Transport emissions are also one of the strongest sources of emissions growth in Australia - emissions from this sector were 32% higher in 2010 than in 1990 and have increased by about 1.6% annually on average. According to the (Bureau of Infrastructure Transport and Regional Economics, 2010) emissions from the domestic transport sector in 2020 are projected to be around 70.3 per cent above 1990 levels (at 105.2 million tonnes of CO2 equivalent).

Low Carbon Urban Transition Theory

The shape and form of our built environment, along with lifestyle choices strongly influence the use of the private car in urban and suburban areas. (Newton and Newman, 2013) addressed this by developing a model framework for low carbon technology interventions in urban and suburban forms of the built environment (Figure 2), based on consideration of appropriate low carbon technologies applied to transport and housing in suburban and inner urban areas of our cities.
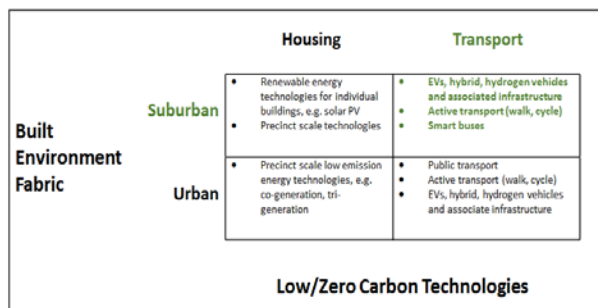
Figure 2 Modified Newton-Newman framework for low carbon technology interventions
Source: Adapted from Newton and Newman, 2013

The Newton-Newman framework identifies key differences in consideration between higher density urban regions and suburban developments. In terms of transport, for example, residents in the inner and middle suburbs of Australian cities are generally served more frequently by public transport systems with lower energy use and emissions, per capita.

Car dependency in the outer suburban areas, is arguably a more complex challenge, with reduced access to fewer modes of public transport. Electric vehicles (EV) could constitute a pathway to a lower carbon transport future where solar photovoltaics (PV) generated electricity in the outer suburbs can form a platform for recharging the cars that are housed in these areas. However, the uptake of EV's is not expected to be significant in near-medium term as a result of high prices, low competition and 'range anxiety' fears. Additionally EVs will not reduce traffic congestion which will continue to be a challenge until suitable public transport penetrates the outer suburbs more effectively. Further, a greater focus on land use-transport integration (LUTI) and planning and design decisions about more localised locations for services and facilities (thus enhancing opportunities for access to these by the active modes) is required to reduce the needs for private car usage. The Newton-Newman framework suggests a new theory of urban transition where different urban geographies can respond in different ways to reducing carbon as they have different physical constraints according to their form and infrastructure. The Newton-Newman approach also makes a distinction between relatively easy technological changes and more difficult structural changes for both the urban and suburban environments.

Automobile City/Outer Suburbs

This project focuses on what (Peter and K. Jeffrey, 2011) have described as the Automobile City (built around the

car, primarily since the Second World War), as opposed to the Transit City (built in the nineteenth and early twentieth century around trams and trains) and the Walking City (built earlier before motorised transport). According to (Newton and Newman, 2013), much of the research in the past few decades has been on how Transit City and Walking City urban areas have the best urban form to enable a pathway to reduce transport energy use. The research shows that these urban areas can effectively contribute to the carbon-constrained future by using cars less as distances are much shorter, destinations are more accessible through modes such as active transport, and potentially are better suited for deployment of electric vehicles. Therefore, there is a much clearer pathway for these urban areas to reduce dependence on fossil transport fuels.

The challenge remains, however, for the Automobile City/outer suburbs which will be the focus of this research. Although these suburbs are making the most of a built environment that lends itself to PVs, suggesting a pathway for such places to begin to decarbonise, these suburbs will need more than the household-based approaches that PV is positioned to provide. These suburbs still have a major sustainability challenge because of the significant carbon footprint of household travel that is largely dependent on fossil fuelled vehicles. Changes in vehicle technology will help to reduce this carbon footprint if there is an accelerated EV uptake in coming years and if this increased uptake is linked to renewable energy sources such as household and local-community solar. However, changes in vehicle technology, even if 'driverless' cars are part of the mix, will not achieve sufficient de-carbonising of household travel, nor will such changes reduce the high costs of road congestion or the social disadvantages of over-dependence on cars. Active transport and mode-sharing must still form an important part of the transition. (Newton and Newman, 2013) report there is now evidence to suggest that a transition is beginning to occur, and solar PV is part of that mainly in the Automobile City/outer suburbs where there are more opportunities and space for these technologies to be effectively introduced.

As (Newton and Newman, 2013) argue, the outer suburbs will need harder structural changes and redevelopment interventions supported by new urban policy and practices, to reduce trip lengths and trip numbers, and to replace some car trips with public and active modes. These practices and policies are more likely to enable better public transport and active transport modes such as walking and cycling. The international literature in transport and land-use planning provides a road-map for this transition. This includes a growing literature (Nielsen, G & Lange, 2005; Mees, 2010; Stone and Mees, 2010; Dodson, J, Mees, P, Stone, J & Burke, 2011; Stone, 2013; Petersen, 2014) that elaborates the theory and practice of changes to patterns of public transport supply that can be used to significantly improve patronage in the outer and middle suburbs of Australian cities at affordable costs.

Overcoming the access and mobility challenges in the middle and outer suburbs will not be easy or fast but will be needed to enable full transition to occur.

Challenges

As part of a more interconnected world, our cities are playing an increasingly active role in the global economy. According to the McKinsey Global Institute (Dobbs, R., Remes, J., Manyika, J., Roxburgh, C., Smit, S., Schaer, 2011), just 100 cities currently account for 30 percent of the world's economy. New York City and London, together, represent 40 percent of the global market capitalisation. In 2025, 600 cities are projected to generate 58 percent of the global Gross Domestic Product (GDP) and accommodate 25 percent of the world's population. The MGI also expects that 136 new cities, driven by faster growth in GDP per capita, will make it into the top 600 by 2025, all from the developing world, 100 of them from China alone (Dobbs, R., Remes, J., Manyika, J., Roxburgh, C., Smit, S., Schaer, 2011). The 21st century appears more likely to be dominated by these global cities, which will become the magnets of economy and engines of globalisation.

Whilst the forecast urban growth will be largely driven by economic development and the search for a better quality of life, the resulting success will dramatically change the scale and nature of our communities, and put a tremendous strain on the infrastructure that delivers vital services like transport, electricity, water, and communications (Dobbs, R., Remes, J., Manyika, J., Roxburgh, C., Smit, S., Schaer, 2011). Today, more than half the world's population lives in towns and cities and the percentage is growing. By 2050, two thirds of the world population will be living in cities and urban areas (Wilson, 2012). Already, ageing infrastructures in many cities around the world are at a breaking point with governments' budgets for major infrastructure projects under increasing pressure (Winston and Mannering, 2014).

The reform of urban and suburban mobility remains one of the biggest challenges confronting policy makers around the globe (Winston and Mannering, 2014; Neumann, 2015). According to the World Health Organisation (World Health Organisation, 2016a), it is estimated that 1.2 million people are killed on the world's roads each year. If left unchecked, this number is predicted to reach 1.9 million fatalities worldwide by 2020. The human cost is profound – unimaginable suffering and grief. The economic cost is also staggering, totalling $100 billion a year in developing countries alone (Foundation, 2016). The World Health Organisation (World Health Organisation, 2016a) has described road casualty figures as being of 'epidemic' proportions, with road-related trauma being the biggest single killer of those aged between 15 and 29.

In addition, it has also been estimated that the social, economic and environmental costs of avoidable congestion account for a large percentage of a country's GDP. At the international level, the avoidable cost of congestion is estimated to account for more than 1 percent of the GDP across the European Union, and currently cost the United States more than $115 billion each year (European Commission, 2011). In addition, road traffic continues to account for around 80 percent of all transport CO_2 emissions and is expected to reach 9,000 Megaton per year by 2030 if the current mobility trends are not curbed (International Transport Forum, 2010).

This section of the report covers the challenges faced by cities in providing adequate transport to meet current and growing demand. The section that follows explores the opportunities available for cities to develop in order to meet such challenges.

Rapid Urbanisation

The global urban population is increasing rapidly. Today, more people live in urban areas than in rural areas. Around 200 years ago, only 3% of the world's population lived in urban centres (Armstrong *et al.*, 2015). The urban population of the world grew from 746 million people in 1950 to 3.9 billion in 2014 (United Nations, 2014). Despite its lower level of urbanisation, Asia is estimated to accommodate around 53% of the world's urban population, followed by Europe with 14 percent and Latin America and the Caribbean with 13% (United Nations, 2014).

In 2007, for the first time in history, the global urban population exceeded the global rural population (Figure 3). Since then, the world population has predominantly remained urban (United Nations, 2014). In 2014, 54% of the world's population was urban and the trend is expected to continue so that by 2050, the world will be 66% urban and roughly one third rural (United Nations, 2014).
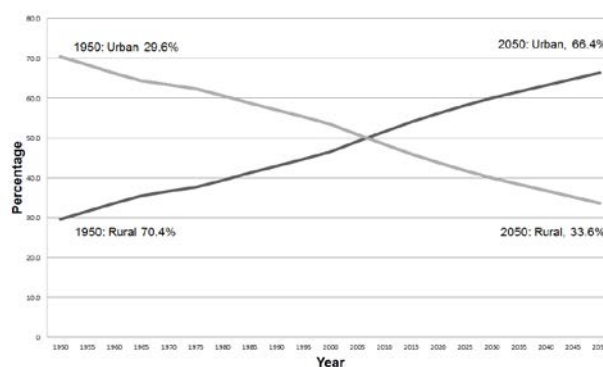
Figure 3 Percentage of world population living in urban and rural areas 1950-2050

Data source: (United Nations, 2014)

The levels of urbanisation vary greatly across the world's geographies. Although urbanisation has occurred in all major regions, Asia and Africa are still mostly rural but

are urbanising more quickly than other geographies. The proportion of urban population in Asia is increasing by 1.5% per annum, compared to 1.1% per annum in Africa (United Nations, 2014). The UN projections show that urbanisation combined with the growth of the world's population could add another 2.5 billion people to urban populations by 2050, with close to 90% of the increase concentrated in Asia and Africa (particular in India, China and Nigeria) (United Nations, 2014). These three countries will account for 37% of the projected growth of the world's urban population between 2014 and 2050. If the current trends continue, by 2050, India is expected to add 404 million urban dwellers, China 292 million and Nigeria 212 million.

The world's urban population is expected to exceed 6 billion people by 2045, with much of the growth taking place in the developing world. The countries in these emerging regions already face massive problems and it will become more challenging for them to meet the needs of their growing urban populations including housing, infrastructure, transportation, energy, employment and access to opportunities and basic services such as education and healthcare (United Nations, 2014).

Increasing number of mega-cities

In 1990, there were ten "mega-cities" with 10 million people or more. These cities accommodated around 153 million people or slightly less than 7% of the global urban population at that time (United Nations, 2014). In 2014, the number of mega-cities increased to 28 worldwide and accommodated around 453 million people or about 12% of the world's urban population. Of these 28 mega-cities, 16 were located in Asia, 4 in Latin America, 3 each in Africa and Europe, and 2 in Northern America (United Nations, 2014). By 2030, the world is expected to have 41 mega-cities with 10 million inhabitants or more. A number of selected current and future mega-cities are shown in Figure 4.
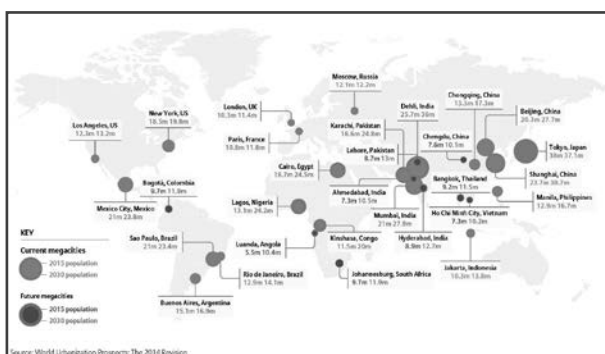
Figure 4 Selected current and future megacities 2015 to 2030 (Allianz, 2015)

(Royalty Free: Source
https://www.allianz.com/en/press/news/studies/151130_the-megacity-of-the-future-is-smart/

As of 2014, Tokyo was the world's largest city (38 million people), followed by Delhi (25 million), Shanghai (23 million), and Mexico City, Mumbai and São Paulo, each with around 21 million people. Osaka had just over 20 million, followed by Beijing with slightly less than 20 million. The New York-Newark area and Cairo complete the top ten most populous urban areas with around 18.5 million people each (United Nations, 2014).

In the future, Tokyo's population is expected to decline but it is projected to remain the world's largest city in 2030 with 37 million people, followed by Delhi (36 million in 2030). Osaka and New York-Newark were the world's second and third largest urban areas in 1990. By 2030, however, they are projected to fall in rank to the 13th and 14th positions, respectively, as mega-cities in developing nations become more prominent (United Nations, 2014).

Urban growth expected to concentrate in small and medium size cities

With the rapid rate of growth, the number of urban dwellers is expected to increase by three billion by the end of the century (International Geosphere-Biosphere Program (IGBP), 2012). Most of this urban growth is expected to take place in small- and medium-sized cities each with a million or fewer inhabitants. In 2014, nearly half of the world's 3.9 billion urban dwellers lived in relatively small areas with fewer than 500,000 inhabitants, with only one in eight living in the 28 mega-cities (10 million inhabitants or more). Many of the fastest growing cities in the world are relatively small urban settlements (United Nations, 2014). To meet the projected demand, it is estimated that approximately one new city of a million people each will have to be built every five days until 2050 (International Geosphere-Biosphere Program (IGBP), 2012). Furthermore, it is expected that the majority of people living in these cities will be in the developing world where the most rapid rates of urbanisation are expected to occur (Armstrong *et al.*, 2015). This process is already unfolding in some countries such as India where some urban centres today were only small villages one or two decades ago (International Geosphere-Biosphere Program (IGBP), 2012).

Impacts on Mobility and Transport Infrastructure

The economic consequences of urbanisation over the next 15 years will also lead to a shift in the concentration of wealth around the world. Today, only 600 urban centres generate about 60 percent of the global GDP (Dobbs, R., Remes, J., Manyika, J., Roxburgh, C., Smit, S., Schaer, 2011). While it is still expected that 600 cities

will continue to account for the same share of global GDP in 2025, the membership of this group of cities will be different. Over the next 10 years, the centre of gravity urbanisation is expected to move south and more decisively, east (Dobbs, R., Remes, J., Manyika, J., Roxburgh, C., Smit, S., Schaer, 2011). For example, it is expected that 136 cities will join the top 600 wealthiest cities by 2025. Around 100 of these cities will be within China and 13 within India. Those top 600 cities are estimated to be producing 60% of the globe's total GDP by 2025, with the top 100 cities alone contributing 35% of total GDP (Dobbs, R, Remes, J, Manyika, J, Roxburgh, C, Smit, S & Schaer, 2012). The increase in wealth as a result of this expansion will occur mainly in developing nations and will enable more than one billion people to have high enough incomes to become significant consumers of goods and services by 2025. These consumers are expected to stimulate the global economy by contributing an extra $20 trillion a year in spending (Dobbs, R, Remes, J, Manyika, J, Roxburgh, C, Smit, S & Schaer, 2012).

With this rapid growth in urban population and wealth, access to jobs, services and opportunities is also expected to grow. For example, between 2000 and 2010, the world's urban population increased by roughly 650 million people. The International Energy Agency (IEA) estimates that urban passenger travel increased by nearly 3 trillion annual passenger kilometres during that same period (International Energy Agency, 2013). The IEA expects that with the current trends, global urban passenger mobility will double by 2050 and increase as much as ten-fold between 2010 and 2050 in rapidly urbanising, fast-growing regions in Southeast Asia and the Middle East. This would have substantial implications for the global annual urban transport energy consumption which, by 2050, would increase by more than 80% over 2010 levels, despite improved vehicle technology and fuel-economy enhancements.

The rapid growth in urban population and wealth is also expected to increase the global car fleet which is estimated to reach around 1.7 billion vehicles by 2030 (Dobbs, R, Remes, J, Manyika, J, Roxburgh, C, Smit, S & Schaer, 2012). This will mainly occur in the developing world as there evidence to suggest that the total VKT per capita has plateaued and sometimes decreased in some of the developed countries. In the emerging economies, the areas where substantial increases are expected include China and India which are the world's two most populated countries. These two countries have not only experienced rapid population growth, but have also enjoyed strong economic development resulting in significant increases in the number of motor vehicles on their roads. Motor vehicle growth in both countries is heavily concentrated in urban areas, where 54% of China's population and 32% of India's currently live.

The flexible and comfortable personal mobility which private motor vehicles are seen to provide in these countries has led to a growth of individual, car-based transport which have resulted in negative impacts on an increasing scale - from congestion and traffic fatalities to greenhouse gas emissions that have consequences far beyond the cities themselves and contribute to global climate change.

Future directions to successful sustainable urbanisation

These urbanisation trends can lead to some significant benefits if they are well managed (United Nations, 2014). A successful urban planning agenda should include urban centres of all sizes. These urban centres will offer important opportunities for economic development and for providing access to basic services. Infrastructure provision in these cities (and similar dense urban population centres) would be cheaper and less environmentally damaging than providing similar level of services to a dispersed rural population. Access to the latest data on global urbanisation trends and city growth would be vital for setting policy priorities to promote inclusive, equitable and sustainable development for tomorrow's future cities.

Road Crashes and Injuries

Nearly 1.2 million people die in road traffic crashes worldwide annually with millions more sustaining serious injuries and living with long-term adverse health consequences (World Health Organisation, 2016a). The traffic fatalities worldwide translate into more than 3,000 deaths per day. This is the equivalent of 15 wide-body aircrafts, each with a capacity of 200 passengers, falling out of the sky every single day and killing everyone on board. This wouldn't be accepted in air travel and it is disturbing that it continues on our roads today. In addition to deaths on the roads, up to 50 million people incur nonfatal injuries each year as a result of road traffic crashes (World Health Organisation, 2016a).

Globally, road traffic crashes are the leading cause of death among young people, and the main cause of death among those aged 15–29 years (Figure 5). Road traffic injuries are also currently estimated to be the ninth leading cause of death across all age groups globally, and are predicted to become the seventh leading cause of death by 2030 if the current trends continue. This rise is driven by the escalating death toll on roads in low- and middle-income countries, particularly in emerging economies where urbanisation and motorisation accompany rapid economic growth (World Health Organisation., 2017).
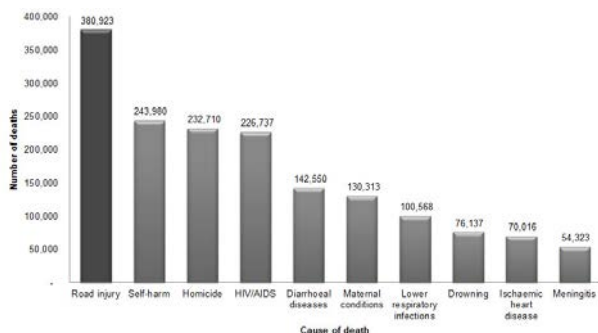
Figure 5 Top 10 causes of death among people aged 15-29 years old (2015)

Data Source: (WHO, 2017)

In many of these developing countries, the road infrastructure is not designed to international safety standards and the levels of enforcement have not kept pace with the increasing vehicle use. In contrast, many developed countries have managed to break the link between rising motorisation and road traffic deaths, with some managing to reduce such deaths by making infrastructure safer, improving the safety of vehicles, and implementing other interventions which are effective at reducing road traffic injuries. Figure 6, for example, shows the annual road crash fatalities for the period 2006-2015 in Australia (Bureau of Infrastructure Transport and Regional Economics, 2016). Available data suggests that the annual road deaths have declined during this period at an average trend rate of 3.7% per annum. Figure 7 also demonstrates that the annual road fatalities per 100,000 people over the same time period also declined but at a higher average trend rate of 5.3% per annum (Bureau of Infrastructure Transport and Regional Economics, 2016).

As vehicle ownership grows, particularly in developing nations, cities will face the combined problems of traffic congestion and rising vehicle emissions, resulting in higher rates of respiratory illness. There are also additional indirect health consequences that are associated with this. Rising car ownership in these countries will also result in reduced physical activities such as walking and cycling, with associated health consequences (World Health Organisation, 2016a).

In addition to the pain, suffering and unnecessary loss of life, road traffic crashes have associated econmic costs which strike hard at a national level, imposing a significant burden on health, insurance and legal systems. This is particularly true in developing countries which struggle with rapid urbanisation and other development needs, and where the quality of the road infrastructure does not meet safety standards. The consequence of such urbanisation leads to poor quality transport infrastructure that has a high risk of death. In these countries, the investment in road safety is also not commensurate with

the scale of the problem (World Health Organisation, 2016a). The available data suggests that road traffic deaths and injuries in low- and middle-income countries are estimated to cause economic losses of up 5% of these countries' Global Domestic Product (GDP) (World Health Organisation, 2016a). Globally, it is estimated that road traffic deaths and injuries cost countries between 1-3% of their gross domestic product - more than $500 billion each year globally (World Health Organisation, 2016a).

Road traffic deaths and injuries also impose a heavy burden on families and households. In low and middle income countries, road traffic crashes particularly affect the working-age groups, or those set to contribute the workforce (World Health Organisation, 2016a). This causes many families to slide deeper into poverty by the loss of a working family member, or by the expenses of medical care, or the added burden of caring for a family member who is disabled from a road traffic injury.
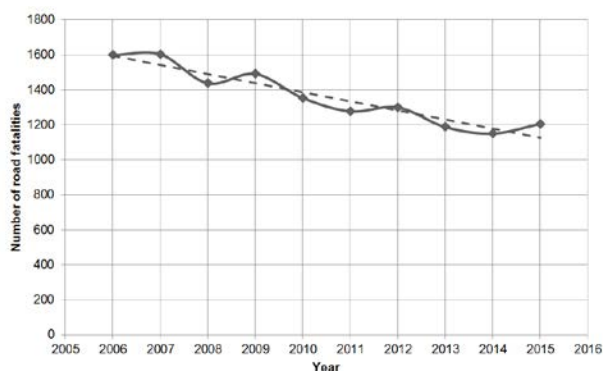
Figure 6: Annual road fatalities in Australia, 2006-2015

Data source: Bureau of Infrastructure, Transport and Regional Economics (2016)
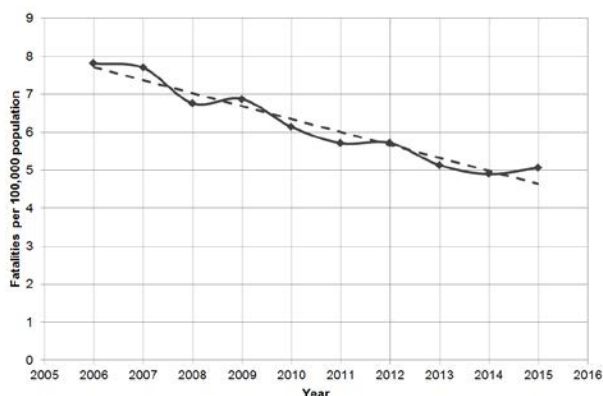
Figure 7: Annual road fatalities per 100,000 population in Australia, 2006-2015.

Data source: Bureau of Infrastructure, Transport and Regional Economics (2016)

Staggeringly, some 70-90% of motor vehicle crashes are caused at least in part by human error (National Highway Traffic Safety Administration (NHTSA), 2015). A large proportion of these crashes could be avoided by using semi-automated and automated vehicles and there are currently very rapid developments aimed at removing humans - the key source of distraction and collisions- from the driving equation by providing increasingly sophisticated technologies in vehicles. The biggest challenges across the globe remains for improving safety in low to middle-income countries that have rapidly urbanised while transport infrastructure has lagged behind.

Traffic Congestion

The past few years have seen remarkable improvements in the collection and analysis of international traffic congestion data. This data makes historical comparisons between different cities around the world more consistent and transparent. The main source of this data is provided from the detailed annual reports by the navigation and mapping company TomTom. The company's Traffic Index report (TomTom, 2016) provides analysis of congestion on the road networks of 295 cities around the world. The Traffic Index provides detailed information on the impact of congestion on travel times, and the findings are used by governments and road authorities to measure the performance of their networks and identify locations where improvements can be made. The Traffic Indices are calculated annually, allowing cities to track the yearly progression of travel conditions by observing the periodic change in congestion for an average day and in the morning and afternoon peak periods. Over the past few years, the company has compiled a database with more than 14 trillion historical travel time measurements with detailed actual traffic measurements for more than 50 countries.

The Traffic Index results are based on congestion level percentages which represent the measured amount of extra travel time experienced by drivers across the entire year, compared to measured travel times during uncongested conditions. The report calculates the overall congestion level (all day) in addition to the morning and evening peak hour congestion levels for each city where data is available. For example, an overall congestion level of 36% means that an average trip takes 36% longer than it would under uncongested conditions. The report takes into account local roads, arterials and highways. The sample size for each city is expressed in terms of total vehicle distance travelled for the period. All data is based on actual GPS measurements from historical traffic databases. Because the indices are calculated individually for cities, they take into account local conditions that could influence congestion, such as road hierarchy, population density and travel distances. Additionally, since the TomTom Traffic Index is

calculated as a ratio of local conditions per city, the individualised city congestion information is rendered comparable to other cities, thereby providing the opportunity to compare congestion levels between cities.

The annual Traffic Index results are based on analysis of field data from the previous year. The latest available results are based on data from 2015 (Tables 1-2). The findings show that congestion levels have increased globally by 13% compared to congestion levels in 2008. Interestingly, the data shows substantial differences between continents. While North America's traffic congestion has increased by 17%, Europe as has only increased by 2%. The smaller number for Europe could be heavily influenced by Southern European countries such as Italy (-7%) and Spain (-13%) where there has been a marked drop in traffic congestion in the past eight years.

The ten most congested cities (2015)

The 2015 results (Table 1) show that while congestion is a global problem, nine of the ten most congested cities were in developing countries (Andersen, J. and Bruwer, 2016). As described before, this may be attributed to the challenges that these cities face in addressing rapid urbanisation and the limited funding available for upgrading roads and public transport networks to deal with increased mobility in their urban centres.

Table 1: Congestion Levels in the Top 10 Congested Cities

City	Country	Overall Congestion Level#	Congestion Level Morning Peak	Congestion Level Evening Peak
Mexico City	Mexico*	59	97	94
Bangkok	Thailand*	57	85	114
Istanbul	Turkey*	50	62	94
Rio de Janeiro	Brazil*	47	66	79
Moscow	Russia*	44	71	91
Bucharest	Romania*	43	83	87
Recife	Brazil*	43	72	75
Salvador	Brazil*	43	67	74
Chengdu	China*	41	73	81
Los Angeles	United States	41	60	81

* Classified as developing countries (Andersen and Bruwer, 2016)

For example, an overall congestion level of 59% means that an average trip takes 59% longer than it would under uncongested conditions.

The data also provides some insights into regional rankings (Table 2). The results in Table 2 summarise the findings for regions with four or more urban areas with over 1 million population. The worst performance was in mainland China, with an average Traffic Index of 34. Eastern Europe and Brazil were close behind with traffic indices of 33 and 31, respectively. The lowest Traffic Indexes were in the United States (20) and Canada (26) where generally higher road capacities are available with lower population indices and greater dispersion of economic activity (Cox, 2016).

Table 2: Regional Rankings Based on Average Traffic Index

Region/Country	Average Traffic Index			Number of Urban Centres		
	Overall	Urban centres with population over 1 million	Urban centres with population over 5 million	Total	Urban centres with population over 1 million	Urban centres with population over 5 million
China (Mainland)	34	34	35	22	21	14
Brazil	31	31	38	9	9	2
Europe (Eastern)	31	33	42	20	7	2
Turkey	28	29	50	9	7	1
Australia	25	28		10	5	
Europe (Western)	25	28	32	122	39	4
Canada	23	26	28	12	6	1
South Africa	23	25	27	6	4	1
United States	18	20	27	71	46	9
Other*	32	37	42	14	9	5
Total				**295**	**153**	**39**

*Regions with fewer than 4 urban centres with population over 1 million

Cost of Congestion

Traffic congestion imposes a substantial cost to society when delays and environmental emissions are taken into consideration. Traffic congestion also dampens prosperity by slowing people and commercial vehicle movements resulting in lost productivity and wasted time.

The economic costs of congestion include the opportunity cost associated with the lost time spent in congestion and the financial costs associated with sitting in traffic, such as fuel consumption (Downs, 2004). In the United States, the cost of congestion in American cities is reported to have reached $160 billion in 2014 (David Schrank, Bill Eisele, Tim Lomax, 2015). The European Union estimates that congestion costs the community 1% of GDP (European Commission, 2011) while in Asia it is estimated to cost the Asian economies around 2-5% of GDP (Asian Development Bank, 2016). Traffic congestion in some of the world's mega cities like Egypt's Cairo is also estimated to cost the country 3.6% in GDP, with the annual cost of congestion estimated at $7,972 million USD in 2010 (Downs, 2004). In Australia, the cost of congestion is estimated to have climbed from $12.8 billion in 2010 to around $16.5 billion in 2015 (BITRE, 2015).

It is not clear whether these costs will continue to climb in the future given the growing momentum on provision of public transport and active transport, and the more recent evidence of peak-car phenomena which has seen the total kilometres of travel per capita decline in recent years, although it is not clear whether this trend will also continue in the future.

Congestion on a global scale has grown by 13% since 2008, with Australia being no exception to the trend (TomTom, 2016). Australia's population is projected to increase by 6.4 million people by 2031. The major four cities Perth, Melbourne, Sydney and Brisbane are expected to absorb 5.9 million people from this projected population growth (Infrastructure Australia, 2015). This will exacerbate current congestion costs which have been estimated around $16.5 billion in 2015, having climbed from $12.8 billion since 2010.

Emissions

Transport activity currently accounts for about half of the global oil consumption and is also a major source of atmospheric pollution (International Council on Clean Transportation, 2012). In 2010, 25% of GHG emissions were released by the energy sector, 24% (net emissions) from Agriculture, Forestry and Other Land Use (AFOLU), 21% by industry, 14% by transport and 6.4% by the building sector (Figure 8).

Emissions from transport have been shown to be growing more rapidly than those from other anthropogenic activities (Righi, M., Hendricks, J. and Sausen, 2015). In the time period 1990–2007, the EU-15 CO2-equivalent emissions from land transport increased by 24% (Righi, M., Hendricks, J. and Sausen, 2015). In the year 2000, emissions from land transport comprised 74% of the global CO_2 emissions from all transport activities (Eyring *et al.*, 2010; Uherek, E., Halenka, T., Borken-Kleefeld, J., Balkanski, Y., Berntsen, T., Borrego, C., Gauss, M., Hoor, P., Juda-Rezler, K., and Lelieveld, 2010) related mobility (Righi, M., Hendricks, J. and Sausen, 2015). In the year 2000, there were roughly 625 million passenger light-duty vehicles (PLDVs) around the world (International Energy Agency, 2013). By 2010, that number had reached nearly 850 million PLDVs. Modelling by the International Council on Clean Transportation (International Council on Clean Transportation, 2012) predicts a doubling of the world's motor vehicle population over the next twenty years. Modelling by the International Transport Forum, using Carbon Dioxide Equivalent (CDE) measures, projects that transport emissions would grow by 9 GtCO2eq by 2030 and increase by a further 110% above 2010 emissions levels by the year 2050 (International Transport Forum, 2010). These forecasts underscore the importance of current and future policies that target reductions in oil consumption and GHG emissions from the transport sector.

The effects of growing travel demand and increasing shifts to private motorisation are particularly evident in urban areas in developing countries. Motorised vehicle traffic has significant adverse effects on environmental quality and health. The IEA expects global travel (in terms of passenger and freight-tonne km) to double by 2050 and corresponding transport energy use and emissions to increase 70% between 2010 and 2050, despite expected vehicle technology improvements. Global motorised vehicle stock is expected to double, and subsequent roadway occupancy levels are projected to increase as much as six-fold in some countries (International Energy Agency, 2013).
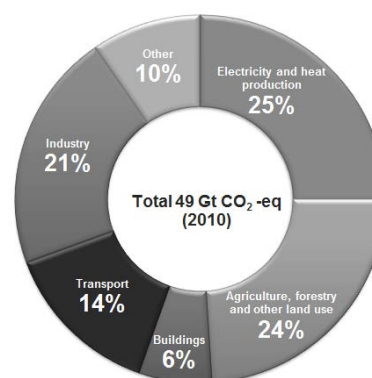
Figure 8: Total global anthropegenic greenhouse gas emissions in 2010.

Data source: (Intergovernmental Panel on Climate Change (IPCC), 2014)

Globally, modelling forecasts a three-fold increase in both fuel demand and CO2 emissions for the period between the years 2000 and 2030 (Uherek, E., Halenka, T., Borken-Kleefeld, J., Balkanski, Y., Berntsen, T., Borrego, C., Gauss, M., Hoor, P., Juda-Rezler, K., and Lelieveld, 2010). The modelling also showed that emissions of CO2 from land transport and shipping accounted for 13% of the total anthropogenic CO2 warming (year 2005).

In addition to long-lived greenhouse gases, ground-based vehicles also emit aerosol particles as well as a wide range of short-lived gases, including also aerosol precursor species (Forster et al, 2007). Atmospheric aerosol particles have significant impacts on climate, through their interaction with solar radiation. In populated areas, they also affect air quality and human health (Chow, 2006; Pope and Dockery, 2006; Forster et al, 2007).

Transport also accounts for half of the global oil consumption and nearly 20% of world energy use, of which approximately 40% is used in urban transport alone (International Energy Agency, 2013). The IEA expects that increased mobility will impose new challenges and anticipates urban transport energy consumption to double by 2050, despite on-going vehicle technology and fuel-economy improvements. Attention to urgent energy-efficiency policies will be required to mitigate associated negative noise, air pollution, congestion, climate and economic impacts, all of which can cost countries billions of dollars per year.

The situation across the geographies of the word differs widely. Examples of the situation in Australia, India and China are provided below.

Australia

In Australia, transport activity is one of the major sources of emissions related to the combustion of fossil fuels (National Greenhouse Gas Inventory - NGGI, 2011). Transport contributed 83.2 Mt CO2 or 15.3% of Australia's net emissions in 2010. Road transport was the main source of transport emissions, accounting for 71.5 Mt CO2 or 86% of national transport emissions. Passenger car usage in urban areas was the largest transport source, contributing 8.5% of Australia's net emissions in 2010 and thus accounting for around 39.7 Mt CO2. Transport emissions are also one of the strongest sources of emissions growth in Australia. Emissions from this sector were 32% higher in 2010 than in 1990 and have increased by about 1.6% annually on average. The Bureau of Infrastructure, Transport and Regional Economics (Bureau of Infrastructure Transport and Regional Economics, 2010) estimates that emissions from the domestic transport sector in 2020 are projected to be around 70.3 per cent above 1990 levels (at 105.2 million tonnes of CO2 equivalent).

India and China

Urban transport emissions forecasts for China and India also pose some challenges. The current level of carbon dioxide (CO2) emissions from the transport sector in China is estimated at about 7% of its total CO2 emissions. Like Australia, around 86% of transport emissions comes from road transport. Between 1994 and 2007, emissions from transport increased by 160% across China's cities. This is expected to continue to increase due to the growing number of vehicles (International Transport Forum, 2015a).

Despite its low ownership rate of 39 light-duty vehicles per 1,000 persons (compared to the United States' 680 vehicles per 1 000 persons) in 2010, China is already the world's largest CO2 emitter and has recently become the top global importer of crude oil. With the transport sector over 90% dependent on oil due to the dominance of internal combustion engines, China's demand for oil will only increase as its transport sector grows, which it inevitably will. Increased CO2 emissions will follow, unless a comprehensive range of policies and measures is implemented to alter the course of development.

In India, increasing household incomes, a growing urban population and surging vehicle sales are also leading to a more motorised society. India's urban population increased from 62 million in 1951 to 285 million in 2001, and as cities grow and new urban agglomerations develop, the demand for transport and total distance travelled by Indians will grow as well, with cars and motorised two-wheelers increasingly becoming the preferred mode choice. The number of passenger vehicles on India's roads grew from 16 million in 1990 to almost 40 million in 2000 and reached 131 million in 2014.

Going forward, the focus will increasingly shift to mitigation measures for road transport. During the period 1970-2010, the road sector was the largest contributor to the growth in GHG emissions, and is still the largest polluting sector within the transport sector. The share of road transport in the overall transport GHG emissions has increased from 59.85% to 72.06% during the same period, making it historically the largest polluting sub-sector in transport. By comparison, all of the other transport sectors have grown from approximately 1-2 GtCO2eq for the same time period, with each sector growing only slightly in the amount they emit. Therefore, the road sector has to be the focus of any future plans to curb pollution if any meaningful reduction in GHG emissions from the transport sector is to occur (Intergovernmental Panel on Climate Change (IPCC), 2014).

Ageing assets and the Infrastructure investment gap

Today, the world's ever-expanding infrastructure consists of 64 million kilometres of roads and four million kilometres of railways (Khanna, 2016).

Inadequate or poorly performing infrastructure impedes economic growth and presents major challenges for governments around the world. Without well-maintained and resilient transport infrastructure – roads, rail and public transport – cities cannot meet their full growth potential and economic targets. At the same time, investment in new infrastructure and urgent maintenance of existing assets comes at a time when many governments operate in constrained budgetary environments and have competing demands on their scarce resources.

This issue affects developing countries and also many nations in the developed world. From the US through Europe to the emerging world, the backlog of projects includes upgrade of existing assets and proposals for new projects to drive economic growth. One of the pressing issues in both developed and emerging markets is the need to invest in transport infrastructure that provides connectivity and ease of access to jobs and opportunities. Although technology has a big role to play in asset optimisation and making better use of existing assets, many cities still suffer from a lack of integrated and connected networks of transport systems.

Although governments and industry bodies agree that an infrastructure deficit exists in many cities, there is less agreement about the size of the global infrastructure gap. The World Economic Forum estimates a global need for $3.7 trillion in infrastructure investment each year, while only $2.7 trillion is annually invested, mostly by governments, around the world (World Economic Forum, 2016). The McKinsey Global Institute (Dobbs, R, 2013) estimates the infrastructure gap at around $57 trillion over the next 14 years (up to 2030). This includes transport (roads, rail, ports and airports), power, water and telecommunications with transport collectively accounting for around 23.8 trillion (Figure 9). This comes at a time when governments have only planned to invest around $37 trillion in all infrastructure assets over the same time period (Dobbs, R, 2013). The same study, however, suggests ways to reduce the required investment but and details a number of approaches to achieve an improvement in infrastructure productivity delivering savings of 40 percent (e.g. optimising project portfolios, delivering projects more efficiently, and getting more out of existing assets as an alternative to building new ones). PwC estimates the gap at around $78 trillion in infrastructure needs and forecasts a need for capital project and infrastructure spending more than $9 trillion per year by 2025, up from $4 trillion per year in 2012 (PwC, 2014). It is widely estimated that the deficit sits around $20 trillion to 2030 (PwC, 2014).
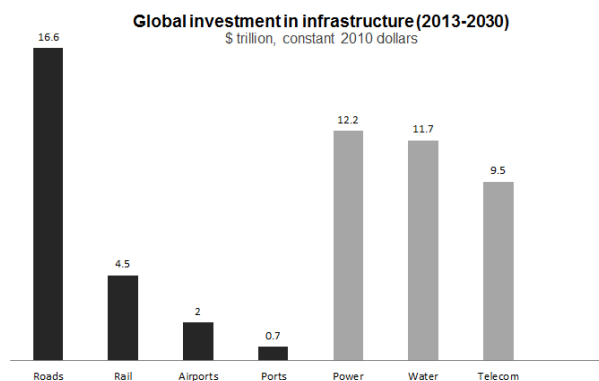
Figure 9: Demand for global infrastructure (2013-2030)

Data source: (Dobbs et al, 2013)

The barriers to investment vary between the developed and emerging markets. In developed markets, the barriers are primarily public discomfort with privatised or partly privatised models, and governments taking measures to reduce debt amid fiscal constraints. This is likely to become more challenging in the future as government revenues from transport activities becomes under more pressure. For example, a number of peak bodies in Australia, including the Productivity Commission, have argued that there has been a steady decline in the real net revenue from the fuel excise in recent years. One of the reasons for this decline in revenue is based on the increased credits and grants that are given to heavy vehicles. The other major factor that is contributing to this shortfall is the increasing fuel efficiency of new vehicles. With more fuel-efficient and electric vehicles coming into the market in future years, it appears that the fuel excise will become increasingly less effective as a mechanism to raise revenue.

In emerging markets, the barriers are more about skills and economic capability. Countries that lack developed capital markets find it challenging to provide long-term finance and currency-exchange protections that investors require.

The global need for infrastructure is significant, particularly in emerging markets where the levels of service are not adequate and connectivity is largely missing. Going forward, more emphasis needs to be given to maintenance of existing assets and also more deployment of technological solutions to enhance the performance of existing infrastructure, while reducing reliance on building new assets.

Resilient infrastructure

The resilience of a city's critical infrastructure, such as transport networks, affects its liveability and economic growth. For the purposes of this report, resilience is defined as the ability of a transport system (exposed to hazards) to resist, absorb, adjust to and recover from the effects of a hazard in a timely and efficient manner,

including initiatives to preserve and restore essential structures and functions (Deloitte Access Economics, 2016).

There are two types of disruptions that affect transport infrastructure in cities. Chronic stresses are long-term problems such as population growth, increasing pressures on infrastructure assets and the gradual effects of climate change. Acute stresses or 'shocks' are immediate short-term incidents such as natural disasters or human-induced stresses such as road crashes (City of Melbourne, 2016). Both types of disruptions impact the reliability of a city's transport system and its ability to meet travellers' needs.

A city's critical infrastructure is highly vulnerable to, and a major casualty of, short-terms incidents. Repairing or replacing infrastructure assets after an incident or disaster is often difficult and costly, which can exacerbate the suffering of affected communities. For example, between 2002-03 and 2010-11, more than $450 million was spent each year by Australian governments to restore critical infrastructure after extreme weather events (Deloitte Access Economics, 2016). This equates to about 1.6% of total public infrastructure spending. In addition, it is estimated that $17 billion (in net present value terms) will be needed to directly replace critical infrastructure between 2015 and 2050 due to the impact of natural disasters (Deloitte Access Economics, 2016).

In many countries around the world, there is growing national awareness of these issues. For example, the Productivity Commission in Australia undertook a public inquiry into the effectiveness of natural disaster spending (Deloitte Access Economics, 2016). The inquiry found that governments in Australia have overinvested in post-disaster reconstruction and underinvested in mitigation measures and interventions that would limit the impact of natural disasters in the first place. As such, natural disaster costs have become a growing, unfunded liability for governments.

More specifically for transport operations, travel time reliability is a good measure of the resilience of a city's transport system. Travel time reliability measures the consistency of trip times within expected time ranges and service levels. Consistent trip times can be achieved by minimising total travel time variability. Travel time variation is caused either by short-term or long-term stresses within the transport network.

There are three categories of events that have influence on travel time variability (Downs, 2004; Bhoite, S., Braulio, S., Birtill, K., Gillespie, S., Morera, B., Silva, J., Stratton-Short, 2013). These include: (1) Traffic influencing events (e.g. traffic incidents and crashes, work zone activity and weather and environmental conditions); (2) Traffic demand (e.g. fluctuations in temporal travel demand and special events); (3) Physical road features (e.g. at-grade railway crossings and geometric bottlenecks).

Some of the intervention measures that can improve the resilience of transport systems include investment in smart infrastructure technologies that enable operators to respond quickly to short-term stresses, and also long-term infrastructure investments to increase the system's capacity and connectivity to prevent disruptions and make the system more robust.

There is a strong case that can be made for greater consideration of, and investment in, resilience. Mitigating disruptions and disaster risks is a priority for both existing and future assets. Some guidance and principles for infrastructure planners and decision makers to embed resilience in their projects is available (Deloitte Access Economics, 2016). These include: (1) identifying disaster risks; (2) applying robust methodologies for Cost-Benefit-Analysis; (3) coordinating, centralising and making available critical data and information; (4) strengthening approval processes; and (5) embedding on-going monitoring of resilience.

Limitations of traditional approach – 'Predict and Provide'

The traditional approach to providing transport infrastructure - through expansion of capacity to meet travel demand - has met with limited success over the past few decades. In this approach, forecasts of economic growth are translated into projections for increased demand for transport, and therefore the need for investment in increasing the capacity of the transport network. The rationale behind this approach ('predict and provide') is that the lack of investment in infrastructure would result in more congestion which would impede economic growth (Banister, 2008; Giovani, M and Banister, 2013).

One of the main limitations of this approach, where demand is predicted and then the infrastructure is provided, is the generation of induced demand (Goodwin, 1996). The theory of induced demand is now well understood and accepted. Road improvements which reduce travel times attract more trips from other routes and also encourage new more frequent travel which would have not occurred if the road has not been improved. This additional vehicle traffic consists in part of induced travel, which refers to increased total vehicle kilometres (VKT) compared with what would otherwise occur (Todd Litman, 2016). If road capacity is increased, peak-period trips also increase until congestion delays discourage additional traffic growth (Todd Litman, 2016). Research shows that the additional traffic generated would often fill a significant proportion of the capacity added (Todd Litman, 2016).

Opportunities

There is increasing wide recognition and acceptance that addressing transport issues through building additional road capacity is not sustainable, and that it does not solve traffic congestion or improve mobility in cities.

Sustainable transport policies and intervention measures provide opportunities to meet the needs and demands of citizens and businesses in urban environments. Setting a city on a course towards sustainable transport requires a roadmap and a holistic vision, which incorporates different strategies to meet the demand for travel, including public transport and active transport policies. In recent years, technology has also been playing a big part in enhancing the performance of existing assets and thereby reducing the need for building additional infrastructure.

A sustainable transport system is one that meets the mobility and accessibility needs of people while supporting the community's long-term social, environmental and economic goals and aspirations.

The Centre for Sustainable Transportation at the University of Winnipeg in Canada offers a comprehensive definition: A sustainable transportation system is one that accomplishes the following (The Centre for Sustainable Transportation, 2016).

- Allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations.

- Is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy.

- Limits emissions and waste within the planet's ability to absorb them, minimises consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise.

Sustainable transport and low carbon mobility are closely related and linked. Mobility is the total amount of travel that is undertaken on all modes of transport, and relates to the physical movement from an origin to a destination (Federal Ministry for Economic Cooperation and Development, 2014). When mobility is undertaken using motorised forms of transport, it results in harmful emission of carbon and other pollutants. Transport, on the other hand, is broader than mobility and includes all modes of transport in addition to the supply of transport. For physical movement to take place, transport infrastructure needs to be supplied. Without the physical infrastructure, travel cannot happen. Infrastructure supply does not generate movement, but allows it to take

place. In This context, mobility can be seen as being situated between the demand for transport and the infrastructure that allows this demand to be realised (Federal Ministry for Economic Cooperation and Development, 2014).

Low carbon mobility

Low carbon mobility is defined as 'mobility that results in substantially lower levels of carbon' (Federal Ministry for Economic Cooperation and Development, 2014). There are four key strategies to achieve this, which will be the focus of this report. The first one is the 'Avoid' strategy which implies the need to change the social norms and travel behaviour to ones that require less mobility (e.g. telecommuting and living nearer to shops and services). The second is to 'Shift' travel from energy-intensive modes to different forms of transport (e.g. from car to train or cycling or walking). The third is to 'Share' transport and mobility resources (e.g. ride-sharing or car-sharing). The fourth is the 'Improve' strategy which calls for improving the fuel efficiency and emission of vehicles (e.g. the use of hybrids and electric vehicles) and also maximising the efficiency of the physical infrastructure that is required for the movement of people and goods.

The topic of low carbon mobility is not new. Researchers and policy think tanks have tried to advance this agenda before but progress has been slow. The renewed interest and opportunity today stems from the new interpretations that have begun to focus on both the supply and demand sides of travel, and a better understanding for traveller behaviour. This has also been facilitated through the convergence of a number of forces such as shared mobility, digital innovations and disruptive mobility models which are introducing new options for travellers through ride-sharing and car-sharing through easy to use and reliable technology platforms. The proliferation of Intelligent Transport Systems throughout transport infrastructure also means that disruptions and incidents are detected quickly. This information is then provided to travellers with more ease and speed than ever before, providing them with options to change mode of travel or time of departure.

Planning for sustainable transport solutions

Traditional transport planning approaches focused on the provision of vehicular traffic without equal attention to other modes of transport. Today, transport professionals increasingly recognise that the infrastructure decisions that a city makes today will have a profound impact on the shaping of that city and people's travel behaviours in

the future. In many cities around the world, greater emphasis is being given to integrated transport planning and sustainable modes of mobility such as public transport, cycling, and walking. Such policies play a key role in reducing greenhouse gas emissions and pollution. They also have a wide range of benefits to the community, and have been shown to enhance the fabric of urban environments and make cities more liveable. Well-planned mobility solutions for tomorrow's cities also improve accessibility to jobs and opportunities, which are preconditions for sound economic development and musts for mitigating emissions and pollution in urban centres.

Conventional approaches versus sustainable mobility solutions

Cities that have been successful in implementing sustainable transport solutions have adopted simple but radical approaches to meeting the travel needs of their citizens. Rather than focusing on the infrastructure required to facilitate the movement of private vehicles, the emphasis was shifted towards the movement of people and goods, regardless of the mode of transport. And instead of focusing on operational strategies that promote longer travel and through movements of traffic, the focus was shifted towards providing access and accessibility to all groups of society (The Centre for Sustainable Transportation, 2016).

Table 3 compares the basic premises between sustainable mobility solutions and the traditional approaches which focused on the dominance of motorised transport.

Table 3: Shifting urban transport towards low carbon mobility

Source: Low Carbon Mobility for Future Cities (Dia, 2017).

Conventional approaches (transport planning and engineering)	Sustainable and emerging low carbon mobility approaches
Focus on supply and building additional infrastructure and capacity	Focus on demand management, maximising efficiency, reliability and resilience of transport systems
Physical dimensions	Social dimensions (mobility benefits are equally and fairly distributed; fair access to transport infrastructure and services for all income groups)
Focus on mobility or physical movement from an origin to a destination	Accessibility*: Focus on the mobility required for access to employment, opportunity, goods and services
Large in scale	Local scale - precinct level
Street as road for vehicles	Street as space to be shared between all modes
Vehicle-oriented	People-oriented and customer-focused. Balanced development of all transport modes and shifting towards cleaner and more sustainable modes such as public transport and active transport
Motorised transport	All modes of transport in a hierarchy with priorities for walking and cycling
Transport modelling approaches	Scenario development and modelling
Traffic forecasting	Visioning on cities
Focus on reacting to congestion and disruptions	Focus on positive business and operational outcomes
Travel as a derived demand	Travel as a valued activity as well as a derived demand
Minimisation of travel times	Reliability of travel times
Key performance indicators: Traffic throughput and speeds	Key performance indicators: Accessibility, sustainability, social equity, environmental quality, health and well-being and quality of life
Planning by experts	Planning through transparent and comprehensive stakeholder consultations
Segregation of people and traffic	Integration of people and traffic
Economic evaluation driven by transport efficiency gains	Multi-criteria analysis to take into account environmental and social concerns
Funds raised through petrol taxes, vehicle registration and licensing fees	Congestion and road pricing, and user-pay models
Private car ownership	New business models that challenge car ownership, promote public and active transport and a shift to car-sharing and ride-sharing solutions enabled by technology platforms
Spending on physical infrastructure	Spending on information technology solutions, data fusion, predictive analytics, integration, decision support systems and adaptive tools
Emphasis on "knowing and seeing", and measuring past performance against key performance indicators	Emphasis on "predicting and anticipating" in order to improve resilience and avoid disruptions

*The terms *access* and *accessibility* offer distinct meanings. Accessibility is "the potential for reaching locations where services, goods and opportunities are available". Access is "the realisation of this potential" (Sclar, E.; Lonnroth, M.; and Wolmar, 2016).

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Summary

This section of the report highlighted how the dominance of motorised transport has resulted in high levels of mobility and urban sprawl which translated into high volumes and distances needed for travel to access economic opportunities and services, leading to high carbon mobility. Traditionally, transport investment has been based on the lack of capacity in the system, and a misconception that congestion can be solved by building additional infrastructure capacity. Infrastructure investments were based on travel time savings resulting in interventions that led to longer journeys using more energy and more dependence on motorised transport.

Addressing the challenges facing our cities in the 21st Century requires new approaches. Efforts to reduce carbon emission from transport fall under four categories: Avoid, shift, share and improve. These strategies, if well planned and communicated to the public, have strong potential to produce the desired outcomes. There is now sufficient evidence from cities around the world that low carbon mobility measures under these strategies have helped to reduce motor vehicle traffic and promote more efficient and environmentally friendly travel. The policy measures implemented in these cities have also resulted in increases in transport efficiency, improved passenger mobility, safer roads, reduced congestion, improved health and better air quality.

These strategies are addressed in more detail in the next section.

Current trends in urban and suburban transport

Sustainability of suburban transport

Suburban growth in countries like United States and Australia has been characterised by low density development, which has been enabled by the mobility provided by private cars and highway network (Zhang, Guhathakurta and Ross, 2016). However, this car dependent urban sprawl has been implicated in increasing the environmental impact of cities through pollutant emissions, such as carbon dioxide (Mann and Abraham, 2006; Abrahamse *et al.*, 2009). The reliance on cars-based transportation is a major contributor to global warming (Balsas, 2003). Greenhouse gas emissions related to private transport contribute significantly to the overall carbon footprint of Australian cities. In 2014, road transport accounted for 15% of Australia's total Greenhouse Gas (GHG) emissions (Department of Energy and Environment., 2017). Cars were responsible for approximately 80% of these road transport emissions. There is the need to reduce the contribution of suburban travel to global emissions, and reducing these emissions requires improvements in not only transport technology and planning, but also in better understanding the factors that influence people's transport behaviour (Klöckner and Matthies, 2004; Natalini and Bravo, 2014) identified two issues in developing polices to reduce transport related emissions, which are: new modelling approaches to assess the likely performance of different polices, and based on modelling insights, the design of more effective policies.

(Szyliowicz, Gudmundsson and Banister, 2003) noted that while sustainability can be defined in many different ways, policies should be based on three general principles:

1. Renewable resources should not be used faster than their regeneration rates.
2. Non-renewable resources should not be used faster than substitutes become available.
3. Pollution emissions should not exceed the assimilative capacity of the environment.

The suburban transportation sector, however, universally violates all of these criteria. Passenger transportation is subject to pressures, as people demand ever faster, reliable, and convenient travel service. While, also ensuring that transport systems contribute to environmental and social objectives. (Szyliowicz, Gudmundsson and Banister, 2003) highlights that a transport system of unintegrated and uncoordinated modes can no longer meet the economic needs of cities,

let alone the other dimensions of sustainability. Therefore, there is an urgent need to develop mobility solutions that utilise each mode's benefits so as to create an intermodal system that minimises negative impacts and enhances the productivity and functioning of urban systems. The characteristics of a high performing urban transport system would be efficient connections, viable choices for passengers, coordination between modes, and cooperation between government agencies at all levels and the private sector. It would benefit young and old alike, stimulate the economy, and promote sustainable development by enhancing efficiency, safety, mobility, and equity (Szyliowicz, Gudmundsson and Banister, 2003).

There is also the need to reduce the greenhouse gas emissions associated with suburban transport, which are contributing to climate change (Gardner and Abraham, 2008). (Kemp and Van Lente, 2011) highlight that transition to more sustainable transport and lower emissions may be a difficult as the mobility offered by cars and the affordability of fossil fuels are deeply embedded in modern society as basic rights. (Bristow *et al.*, 2008) explored a range of possible strategies that could be applied in Great Britain to reduce carbon emissions associated with passenger transport, which included: technological development, pricing, public transport improvements and soft measures (e.g. ride-sharing, providing public transport information, and encouraging tele-commuting). This found the most promising combinations of measures included: price signals to reduce private car use, development of more efficient vehicles, improving public transit access while also reducing its carbon intensity, and reducing the need to for travel by car (Bristow *et al.*, 2008).

Suburban areas often lack access to high quality transit and active transport infrastructure that connects them to required destinations, which results in increased car dependence and associated GHG emissions (Vandeweghe and Kennedy, 2007). In addition to the environmental impacts, a lack of access to high quality transit and active transport infrastructure in suburban location has a number of other impacts. The benefits of increased investment in sustainable transport modes, in addition to reduced traffic congestion and greenhouse gas emissions, are discussed in the following section.

Co-benefits of sustainable transport modes

The use of active transport modes is often promoted as one measure to improve declining levels of physical activity that is associated with the rise obesity and other adverse health outcomes from sedentary lifestyles (Bull et al., 2005; Kornas et al., 2017). (Woodcock et al., 2009)

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evaluated the public health outcomes of different policies targeted at reducing GHG emissions of urban transport. This study found that important health gains and reductions in emissions can be achieved through greater investment in active transport infrastructure.

Previous studies have identified that the suburban fringe of Australian cities is disadvantaged in terms of transport accessibility, which can compound social exclusion in vulnerable members of the community (Currie, 2010). (Currie, 2010) undertook a spatial assessment of the quality of public transport supply with transport needs (based on social disadvantage) in Metropolitan Melbourne. This study showed that outer suburban areas had very high transport needs (social disadvantage) with little or no public transport supply. (Newton *et al.*, 2012) also highlighted that residents living in car-dependent suburbia are vulnerable to rising fuel prices, which can compound existing socio-economic disadvantage.

Transportation strategies that encourage mode shift can also address disadvantage and social inequality. (Lucas *et al.*, 2016) modelled the travel behaviour of socially disadvantaged population segments in the United Kingdom. This modelling revealed significant differences in travel behaviour according to household income, with low income groups undertaking less trips per week, particularly for trips taken for social and leisure reasons (Lucas *et al.*, 2016). Policies that improve the accessibility and quality of public transit services may help to address social disadvantage. (Roorda *et al.*, 2010) analysed mobility, on the basis of number of trips per week, in vulnerable population groups in three Canadian cities. The analysis highlighted that the factors affecting mobility differed among the vulnerable populations groups. For the elderly, mobility was mostly affected by car ownership and to a lesser extent transit proximity. While for single parents vehicle ownership and employment had a more effect than the reference population on mobility, but not proximity to transit (Roorda *et al.*, 2010). This underscores the importance of considering the implications of strategies to encourage mode shift on vulnerable population groups.

Review structure and objectives

This review has the purpose of informing the development of a decision support tool that can be used in selecting the most effective and efficient interventions for reducing the carbon footprint of suburban travel.

This literature review will address the following:

- Highlight the trends in urban form and transport planning that have influenced current mode share in suburban areas, which is dominated by private cars;

- Review policy responses that have been implemented in attempts to reduce car use, and associated emissions;

- Analyse travel patterns for a suburban case study, the Monash National Employment Cluster, and opportunities to shift to sustainable transport modes;

- Summarise the variables that have been used to explain how people select transport mode; and,

- Explore theoretical frameworks that can be used to model the impact of different transport supply and demand interventions on mode share.

Trends in urban form and travel behaviour

Growth and decentralisation of Australian cities

Since 1945 the population of Australian cities have grown rapidly. The majority of this population growth has occurred in new growth areas, rather than the densification of existing urban areas (Troy, 1995). Prior to the 1950s areas of new urban growth were influenced by proximity of hard-rail infrastructure. However, the rise in private car ownership decoupled urban growth from public transit, which saw the rise of car-dependent suburbs (Newton *et al.*, 2012).

In addition to population growth outside of the city core there has been decentralisation of employment. In Melbourne the majority of employment is located 5 kilometres or more from the City centre. Figure 10 shows the distribution of employment across Greater Melbourne. This shows that while the greatest density of employment occurs within the core of the City, the majority of jobs (66%) are located 5 kilometres or more from the CBD. This is a marked shift from 1961 when 55% of job in Melbourne were located in the inner city (Department of Infrastructure and Transport, 2011).

(Coffee, Lange and Baker, 2016) analysed changes in population density in Australian cities over a 30 year period (1981 to 2011). In Melbourne, in the period to 1981 to 1991 the growth of the city predominately occurred on the outer fringe with the inner core declining in population. However, in the final period of the analysis (2001 to 2011) it was found that while growth was still occurring on the outer fringe there was a marked shift to increased population density in the City's core and middle ring suburb. This shift was attributed to the impact of policies that encouraged increased density around transport corridors, and attempts to limit urban sprawl through urban growth boundaries (Coffee, Lange and Baker, 2016). These polices for urban consolidation were motivated by concerns around the environmental and social impacts of continued urban sprawl (Coffee,

Lange and Baker, 2016). Transit-orientated developments, one of the policy approaches to encourage urban consolidation is explored in a subsequent section.

The focus of this review is the travel patterns and mode share in the suburban context. It can be difficult to define what constitutes a suburb as distinct to other areas of the city (Forsyth, 2012) Suburbia has been described as existing outside of the core of a city, with land use dominated by low density residential development, and households having to commute to the city core for employment opportunities (O'Connor and Healy, 2004). However, the density of residents and jobs outside of the Melbourne's core are not evenly distributed, with high density hot spots emerging around transport corridors and employment clusters. The shift from monocentric cities to polycentric cities creates a more complex urban form when considering travel patterns, and how to encourage a greater uptake of public transit and active transport modes in the suburban context.

Understanding decentralisation of employment and the development of polycentric cities is complex (Alpkokin *et al.*, 2008). There is the need to understand the patterns for different types of jobs and workers. For example, in some dispersed sectors, such as retail, there may be a stronger connection between location of housing and jobs. While, workers who provide services to businesses and governments, which are concentrated in the city's core, may be limited in their ability to shift their house close to their place of employment due to house prices (O'Connor and Healy, 2004). This means to understand the potential for a shift to sustainable transport modes for commuting, there is a need to consider spatial patterns of workers' residences and places of work, their transport needs and other factors that may influence their mode choice.

A study by (Zhang, Guhathakurta and Ross, 2016) compared trends in vehicle energy use and GHG emissions between suburban and inner city neighbourhoods in Phoenix. This study found that as the suburban neighbourhood developed and diversified, with increased employment density and retail services that the difference in vehicle-kilometres-travelled and GHG emissions between households in inner city and suburban neighbourhoods decreased. This suggests that as suburban areas mature and diversify it can reduce the need for people to travel long distances to access services and jobs.

(David A, 1998) identified some of the key elements that are shaping the travel patterns in suburban areas, which included: changing composition of the workforce and working hours, the suburbanisation of employment and the associated loss of high-density mobility corridors

(however there is an increase in the number of low density corridors suitable for rapid bus transit).
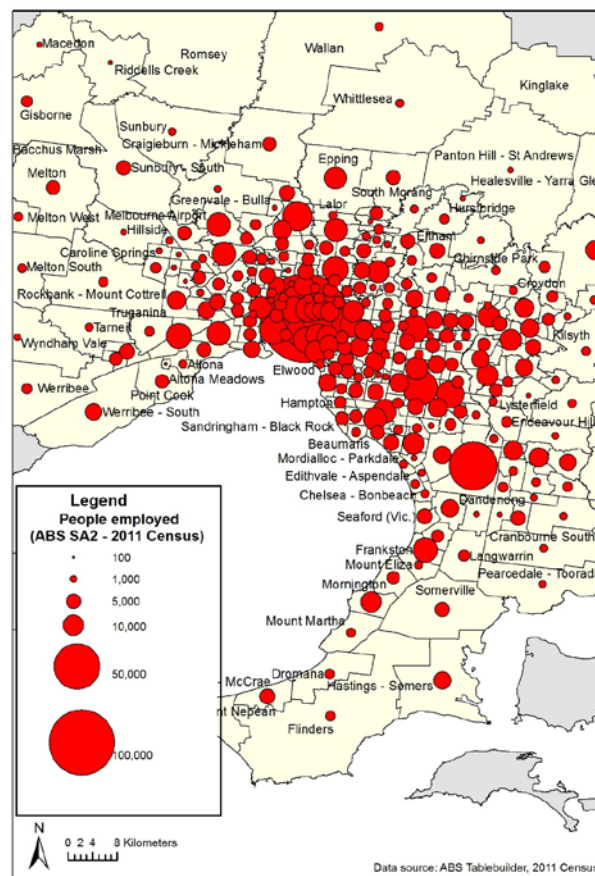
Figure 10 Distribution of employment in Greater Melbourne

Trends in transport mode share in Greater Melbourne

In the period following the Second World War, Australian cities experienced a considerable decline in the proportion of passenger kilometres travelled by public transport (Australian Bureau of Statistics, 2008). The rapid decline was associated with the increased registration of private vehicles. In the year 1955 there were 153 passenger vehicles per 1,000 people in Australia. By 2013, the number of passenger vehicles per 1,000 people had reached 568 (Australian Bureau of Statistics, 2013). This high rate of car ownership is indicative of the car dependence of Australian cities. (Mees and Groenhart, 2014) analysed travel to work trends over the period 1976 to 2011. This analysis, which was based on census data from the Australian Bureau of Statistics, found that cars are the main transport mode for commuting to work in all cities. However, there has been a recent resurgence in the use of public transit in recent

years for many Australian cities (Mees and Groenhart, 2014). Trends in mode share are explored in more detail for Greater Melbourne.

Melbourne is a car dependant city (Wyatt, 2006), with data from 2006 ABS Census showing 77 % of people used a private vehicle to get to work, while 13 % used public transport, 4% walked and only 1% cycled (Department of Infrastructure and Transport, 2011). There is however considerable spatial variation. Figure 11 shows the current trends in mode share for commuting to work by destination Local Government Areas (LGA) across Greater Melbourne. This shows that public transport and active transport modes are only popular where the employment destination is located close to City's core, which is relatively accessible by sustainable transport modes.

The low mode share for public transit in the outer suburban areas of Melbourne has been attributed to the following (Department of Infrastructure and Transport, 2011):

- Limited cross-town connectivity by public transport;
- Poor integration of transport modes;
- Outer suburban employees are more likely to working in trades and other sectors that often require a car to transport tools and equipment to workplaces; and,
- Significant investment in road infrastructure.

(Zeibots, 2009) confronted the commonly stated view that the car dependence of Australian cities is due to an inherent preference for cars in Australian society. Instead (Zeibots, 2009) argued that high-levels of car use are due to the limited feasible transport options that are available to most of the population. The investment in highways and arterial road infrastructure induces greater demand for car trips, as people are most likely to select the quickest transport mode (Zeibots, 2009). An analysis of travel patterns in Melbourne showed that trips by active transport modes are concentrated in inner City zones (Stone and Mees, 2011), which indicates people will adopt sustainable transport modes where they are practicable. These inner city areas have conditions that favour active transport modes when compared to suburban locations, with often shorter trip distances and greater connectivity of cycle paths and footpaths.

An (Australian Bureau of Statistics, 2008) survey found that people who did use public transport for the work commute, did so because it was more convenient and comfortable, and less stressful than other transport modes. The converse was the main reason by people who didn't use public transport, as these people reported that there was no public transport service available at a convenient time, and that their car offered greater convenience and comfort (Australian Bureau of Statistics, 2008). Only a small proportion (2%) of Australians cycle to work, with the main reason given for not cycling being that the distance between home and place of work was too great (Australian Bureau of Statistics, 2008).

In Melbourne the growth of public transport patronage during the period 2004 to 2008 was much stronger than projected by Department of Transport modelling (Gaymer, 2010). The growth was particularly pronounced for the metropolitan train network, where patronage increased 47% between 2004/05 and 2008/09. There was also rapid growth in metropolitan trams and uses, where the annual growth rates peaked in 2008/09 as the growth in train patronage started to moderate (Gaymer, 2010). A survey of travellers found that the top stated reasons for reduced car use were increased petrol prices, followed by increased awareness of health & wellbeing benefits of alternative modes, and concern for the environment (Gaymer, 2010). The rapid growth in patronage caused capacity issues as the system struggled to cope with the increased demand for services. This led to issues of crowding during peak periods and declining customer satisfaction. A number of measures were enacted to ease the pressure on the system, such as free travel before 7AM, however fundamentally improving the service through new rolling stock and improved infrastructure has a long lead time, which makes it difficult to catch up with the higher than anticipated growth in patronage (Gaymer, 2010).

The shift in Melbourne to increased public transit patronage due, in part, to increased petrol prices provides an indication of the cross-elasticities between transport modes, where a change in the demand for a transport mode results from a cost change in another mode. For example, increased driving constraints (parking fees or petrol prices) may drive in increased demand for transit (T. Litman, 2016).
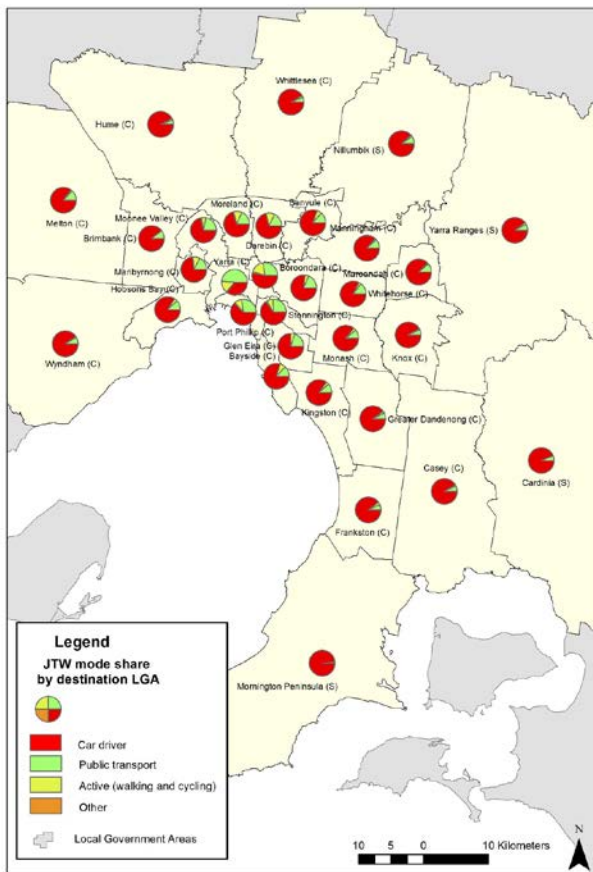
Figure 11 Journey to work mode share by destination Local Government

Data Source: Victoria Integrated Survey of Travel and Activity (VISTA)

Urban form and mode share

The relationship between urban form and transport mode share is an important area to address in considering opportunities to reduce car dependence in suburban areas. In particular, urban form and transport dynamics are important to understanding if the relationship between low density suburban areas and car dependence is causal or merely correlated. Governments often promote polices for urban consolidation on the basis that urban sprawl is associated with car dependence and associated GHG emissions (Handy, Cao and Mokhtarian, 2005; Cao, Mokhtarian and Handy, 2009). There have been a number of studies that have linked urban form to transport related emissions (Vandeweghe and Kennedy, 2007; Zhang, Guhathakurta and Ross, 2016). The US EPA have recognised the relationship between land and transport related emissions, as they allow jurisdictions to account for the air quality benefits of land use polices as part of the voluntary Mobile Source Emission Reduction Program (Cao, Mokhtarian and Handy, 2009).

(Cao, Mokhtarian and Handy, 2009) noted that many studies demonstrate that residents in low density, suburban areas drive more and walk less than those in denser urban areas. However, often the underlying causality of this association between urban form and transport choice has not been established. For example, there is the potential for an aspect of self-selection, where residents choose to live in areas that support their preferred travel model. However, after accounting for the influences of residential preferences and attitudes to different travel modes it was still found that the built environment influenced the use of active and public transit modes. The relationship between policies that encourage densification and impact on reducing car use was also explored by (Williams, 2000) in the United Kingdom through three case studies. This found that each case study demonstrated a different relationship between urban densification and reduced car use, which the authors argued demonstrated that the relationship between urban form and travel patterns implied by many policies may be overly simplistic (Williams, 2000).

The age of an urban subdivision has often been used a proxy measure of urban form, and therefore the walkability of an area (Badland and Schofield, 2005). Pre-World War II cites were highly localised as car ownership was low, therefore people's daily needs had to be within walking distance, or accessible by public transit. Following the War cities became more distributed as car ownership and disposable income grew. This enabled the rise of lower density development and single land uses, where the residential areas became separated from commercial and industrial areas (Badland and Schofield, 2005). This means these pre-war neighbourhoods are more amenable to active transport modes due to higher density, greater diversity of land uses, gridded street layout and connected network of footpaths. The rise of car dependent suburbs with poor connectivity and lack of access to high-quality transit has spawned a range of problems that include: traffic congestion, pollution, rising infrastructure costs and degeneration of community (Badland and Schofield, 2005).

(Kenworthy and Laube, 1999) presented an analysis of cities from around the world, in both developed and developing countries, which showed a high correlation between decreasing urban density and increasing car use. This apparent correlation has been used as the basis for the argument that urban density is the main determinant of public transit use (Newman and Kenworthy, 1996) However, (Mees, 2011) undertook an in-depth re-examination of the data used to develop this correlation. This found that the strength of the correlation was in large part an artefact of the method used to calculate urban density, which used administrative urban boundaries that

in many cases did not reflect actual urban density (Mees, 2011). Re-calculation of the correlation between density and car dependence within these cities, using a consistent approach to calculating density, demonstrated that public transit and car use were only weakly correlated with density, while active transport modes showed no correlation (Mees, 2011). (Stone and Mees, 2010) highlight examples of low-density, semi-rural settings where public transit has significant mode share, which is attributed to effective transport planning that balances providing adequate service levels and economic efficiency.

This section has found that the association between the built environment and levels of sustainable transport are complex, which means that increasing use of sustainable transport modes in suburban contexts requires more than policies for increased urban density. There is the need for improved provision of integrated, multi-modal transit systems that efficiently connect trip origins and destinations. The effectiveness of transit-orientated developments in reducing car dependence are explored in a following section.

Approaches and policies for encouraging low-carbon transport modes

This section reviews some of the approaches and policy responses to increase the trips taken by sustainable transport modes. The section also identifies the barriers for realising a more sustainable transport mix in the suburban milieu.

(Vergragt and Brown, 2007) argues there is a need to urgently address the societal dilemma, where individuals choose to travel by car to maximise personal utility at the expense of global sustainability. (Mees, O'Connell and Stone, 2008) highlight that current policy settings at state and federal government levels are supporting growth in car travel and associated GHG emissions. In particular, the authors maintain that there is a need to shift transport investment priorities away from building road infrastructure to investing in sustainable transport modes.

Market instruments

The shift to more sustainable transport modes requires an integrated response, which should include technological innovation, changes in the physical infrastructure and land use, and social, cultural, and institutional changes (Vergragt and Brown, 2007). These changes need to consider the regulations, incentives and subsidies that may present market failures and barriers that impede the adoption of more sustainable transport modes. (Brown, 2001) highlighted market failures and barriers that can impede clean energy polices, which can be adapted to the

sustainable transport context. The examples provided by (Brown, 2001) are included below, with the examples adapted to the transport context:

- *Misplaced incentives* – this is often called the "principal agent problem" in economics, and refers to when an agent has the authority to act on behalf of users, but does not always reflect the user's best-interests. For example, transport planning engineers may first seek to minimise upfront costs, which determines the transport infrastructure available to the broader community. The dominant influence of these planning decisions may not be representative of the needs of the travelling public.

- *Distortionary fiscal and regulatory policies* - An example of a distortionary fiscal policy could be the government funding available for highway infrastructure relative to public transit, which may prevent markets from operating efficiently and subdue incentives for investing in sustainable transport modes.

- *Unpriced costs and public goods* – A range of negative impacts are associated with the use of fossil fuels for private vehicles. It could be argued the cost of fossil fuels for transport do not take full account of the social costs associated with their use, such as impacts on air quality and traffic congestion. Policy interventions can help ensure market choices reflect full costs and benefits of options.

- *Insufficient and incorrect information* – the effective operation of markets, such as transport mode choice, assumes free and perfect information. If a person is not knowledgeable on the features and economics of different transport modes it may present a barrier to considering a shift to more sustainable modes.

Service improvement and demand management

Interventions to improve the uptake of sustainable transport modes can focus on supply or demand measures, or usually a combination of both. Supply side intervention can include improving the quality and connectivity of transit and active transport infrastructure. While, transport demand management can refer to any action that attempts to influence people's travel behaviour that will encourage adoption of sustainable transport modes and/or reduce congestion (Meyer, 1999).

(Meyer, 1999) presented the following categories for demand management actions:

a) Offering travellers alternative transport modes or services that increases vehicle occupancy;

b) Providing incentives/disincentives to reduce travel or push outside of peak periods; and,

c) Accomplishing trip purpose without transportation (e.g. shopping online or working from home).

(Miralles-Guasch and Domene, 2010) based on survey analysis found that at a suburban university there was unsatisfied demand for bicycle commuting due to inadequate infrastructure, while public transport demand was impeded by long commute time, poor infrastructure and low service frequency.

(Bull *et al.*, 2005) demonstrated the importance of improvements in perceived and actual travel time in encouraging modal shift to public transit and active transport in a university setting. This study found that around 20% of staff and 47% of students at the University already used active (cycling and walking) and public transit modes in accessing the university. However, addressing some of the barriers identified could improve the uptake of these low carbon transport modes by 30%. Key strategies identified included:

- Increasing and improving public transport services to university;

- Improve the pedestrian and bicycle network to the University;

- Provide additional student housing close to the campus;

- Increase cost of campus parking relative to public transport;

- Provide subsidised public transit card; and,

- Improved information on timetabling, as it was found that students often over-estimated public transport journey times.

A range of Transport Demand Management (TDM) approaches have been employed to reduce car dependence on university campuses in the United States. These TDM measures have included: parking prices, expanded transit access, park and ride lots integrated with shuttle buses, rideshare programs, bicycle and pedestrian facilities and traffic calming features (Balsas, 2003). TDM is a suite of measures that include planning strategies, incentives and disincentives to reduce the use of single occupant vehicles (Balsas, 2003).

Table 4 Demand management approaches to reduce car commuting in the context of a suburban university

Adapted from: (Miralles-Guasch and Domene, 2010)

Transport demand management type	Description and Examples
Modal substitution	Investments to improve public transport service quality, or improvements in cycling and walking infrastructure that improve safety.
Pricing incentives/disincentives	Providing subsidies for public transit modes, or increasing parking costs.
Land-use transport strategies	Higher density and mixed use development that reduce the need to travel to access services and employment/education opportunities, and are attractive for walking and cycling.
Tele-commuting	Use of telecommunications to reduce the need to travel, such as distance learning, tele-conferencing and use of technology to work remotely.
Technology and efficiency improvement	Adoption of technologies that reduce environmental impact of commuting such as the uptake of electric vehicles using renewable energy.
Information	Provide information, such as intelligent transportation systems and scheduling information, which increase efficiency.
Education	Encourage mode shift by educating people on costs and benefits of different modes.

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Transit Orientated Developments (TODs) and Bus Rapid Transport (BRT)

Strategies and policies for Transit Orientated Developments (TODs) have been a common response by governments both in Australia and overseas to better coordinate land use and transportation planning in order to reduce car dependence, and associated traffic congestion and greenhouse gas emissions. TOD refers to focussing urban growth in areas that are serviced by high-capacity public transit services (Higgins and Kanaroglou, 2016). TODs are an integrated land-use transportation strategy to reduce traffic congestion and emissions through increasing trips made by active transport modes and public transit.

A justification for encouraging TODs is that areas with greater population density and mixed land use have greater trip-end concentrations, which should reduce the need to travel outside of the area. It is also postulated that it makes public transit more feasible and possibly reduces car ownership (Badland, Schofield and Garrett, 2008). Areas that have co-located residential and commercial areas will have increased localised job-housing balance, which can reduce commute distance.

Often TODs have been focussed around high capacity metropolitan railway lines. However, Bus Rapid Transit (BRT) TODs have increased in prominence due their lower cost structure than investment in urban rail systems (Cervero and Dai, 2014; Sengers and Raven, 2015).

BRT has been viewed as less important than rail infrastructure in shaping land use patterns, where often there is an intensification of land use along rail corridors (Cervero and Dai, 2014). However, an analysis by (Cervero and Dai, 2014) found that when the implementation of BRT is well integrated with other modes, such as high-quality connections with foot paths and cycle paths, that commercial development is attracted to BRT nodes. (David A, 1998) noted that there are many approaches to providing public transport into suburbia – including heavy and light rail, rapid and local buses, and on-demand buses. (Currie and Wallis, 2008) reviewed effective ways to increase the mode share of urban buses. This review found that the largest growth in bus patronage were related to increased frequencies and service levels, which includes the use of BRT and bus priority lanes to improve reliability.

(Mees, 2014) evaluated the implementation of TODs, and their influence in reducing car use. The case studies reviewed showed that in some cases the planning of TODs ignores the broader spatial and planning context, which means when not planned well their impact on reducing car can be negligible. For example, strategies for TODs sometimes focus only on increasing housing density around major transit nodes, while not considering

functional connectivity to transit. (Hale, 2014) described this as Transit Adjacent Development (TAD), which can be applied to some of the less successful examples of TODs. (Mees, 2014) highlights that the successful implementation of TODs requires a truly multi-modal approach, where the approach is more than just locating residents near major transit nodes to enable commuting to the CBD. TODs need to support the complexity of travel patterns in modern cities with a diversity of destinations, and both peak and off-peak travel. There is need to manage the demand for park-and-ride by providing efficient feeder and connecting bus and light rail services (Mees, 2014).

Case Study - Monash National Employment Cluster

Background

The Monash National Employment Cluster (NEC) is located around 20 kilometres from the Melbourne CBD, and with around 83,000 jobs has the highest employment density outside of the CBD. The Monash NEC is one of six National Employment Clusters that have been identified as areas that have significant potential to provide for future growth in employment and housing densities associated with good transport connections (Victorian Planning Authority, 2016).

The Monash NEC was historically an area that specialised in manufacturing and logistics employment. However, the Monash NEC is now a hub for growth of job in the health, education, technology and research sectors. Anchor tenants include: Monash University, CSIRO, Monash Medical Centre and the Australian Synchrotron. These anchor tenants are providing the environment to attract a range of commercial and advanced manufacturing businesses (Victorian Planning Authority, 2016).

The Victorian Planning Authority (VPA) is developing a Framework Plan to guide future land use, development and infrastructure planning to support job growth in the Monash NEC over the next 30 years. This growth is being planned around 11 precincts, which are depicted in Figure 12. The projected growth of jobs and residential population by 2051 by precinct is shown in Figure 13. This shows that growth in jobs will be most concentrated in the precincts around Monash Medical Centre and Monash University. To accommodate a tripling of the residential and working population is some precincts there is a significant emphasis on planning for improved transportation connections both within and outside the Monash NEC. A survey of Monash NEC stakeholders identified that improved local access and transport connections was the most important component of

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planning for the future of the Monash NEC (Victorian Planning Authority, 2016).
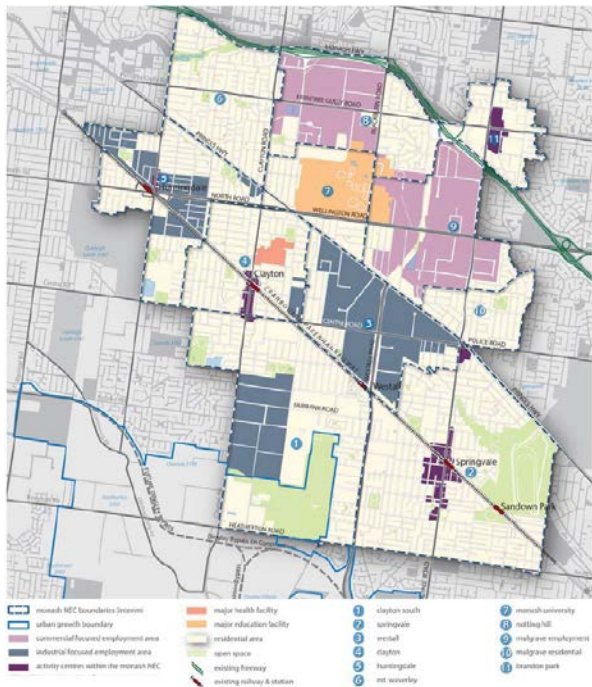
Figure 12 Monash NEC context and planning precincts

Source: Victorian Planning Authority
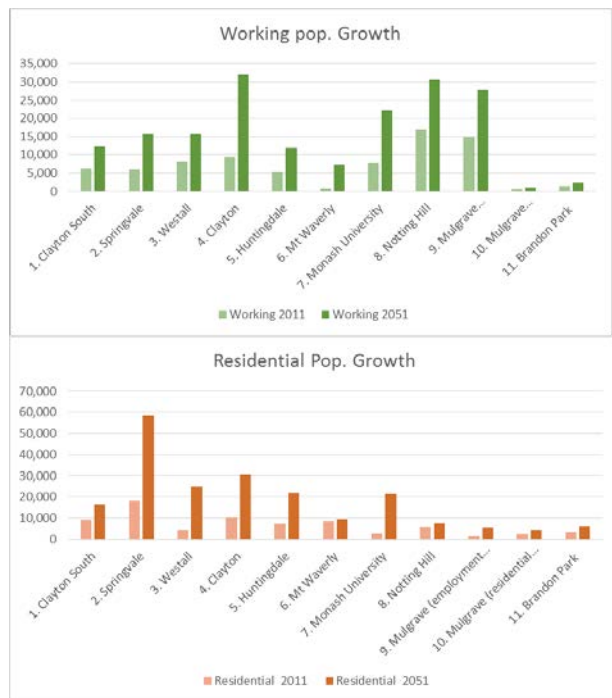
Figure 13 Monash NEC - Projected growth in jobs and residential population by 2051 by precinct

Source: (Phillip Boyle and Associates, 2014)

Current Transport Infrastructure and Travel Patterns

The Monash NEC is serviced by a number of major roads. This includes the Monash Freeway and Princes Highway, as well as the following major arterial roads: Westall Road/Blackburn Road, Huntingdale Road, Clayton Road, Centre Road Wellington Road, Ferntree Gully Road and Springvale Road. The Monash NEC has 3 stations on the Dandenong railway line, which operate 15 services in the AM peak (in-bound to city) and 15 services in the PM peak (out-bound) (Phillip Boyle and Associates, 2014). There are 25 bus routes servicing areas with the Monash NEC, with many of these services routed through Monash University interchange. Bus services include a shuttle bus between Huntingdale station and Monash University, which runs every 4 minutes during peak times and carries 6,000 passengers per day (Monash University., 2017). This makes it the busiest bus route in Victoria. The pedestrian and bicycle network has limited connectivity and integration with other modes across the Monash NEC. Specific issues with active transport include: gaps in network, missing connections, lack of signage and route information and safety concerns (Phillip Boyle and Associates, 2014).

Analysis of journey to work data shows that Monash NEC is car dependent, with 87% of all trips to work that are located in the Monash NEC Local governments (Monash, Kingston and Greater Dandenong local governments) occurring by private vehicle. Figure 14 shows that only 10% of trips to work places in the NEC use public transport, compared to 18% across Greater Melbourne. Active transport is only used on 3% of trips to work. A third of all work trips to the Monash NEC originate from the 3 LGAs (Monash, Kingston and Greater Dandenong) that intersect the cluster.

Major transport issues for the Monash NEC include (Phillip Boyle and Associates, 2014):

- Increasing traffic congestion on arterial road network;

- Lack of viable public transport alternatives to access employment across cluster;

- Poor connectivity of active transport modes within the cluster; and,

- Current reliance on cars.
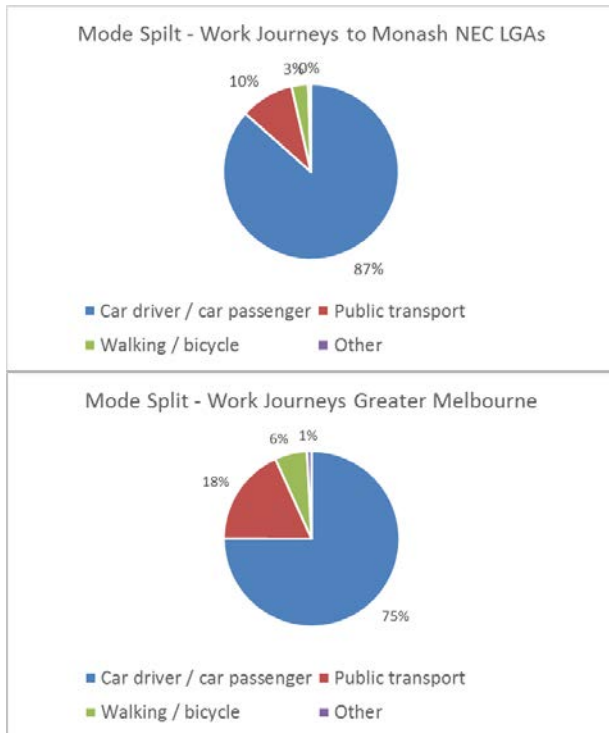
Figure 14 Modal split: Monash NEC LGAs and Greater Melbourne

Source: Victorian Integrated Survey of Travel and Activity

Monash University - shift in travel mode choice

Monash University's Clayton campus is the main campus for Australia's biggest university, with more than 33,000 students. The campus is an anchor tenant for the Monash NEC, which helps to support the science and technology specialisation of the employment cluster. (Holland, 2015) highlighted the importance of suburban universities in supporting specialist employment clusters, which can help drive jobs growth outside of the CBDs.

The Monash University Clayton campus is set on over 100 hectares of land, and was built in the late 1950s in a suburban setting (Tomaney and Wray, 2011), which was not serviced by rail. The location and size of the campus meant that in the early days of the campus there was more than enough land to cater for all students driving to the campus and parking. In 1987, (Bennett, D. W., 1988) noted that most car spaces were not time restricted and that the supply of parking spaces was not limiting for driving to the campus. (Bennett, D. W., 1988) analysed travel patterns for Monash University students in 1972 and 1987. This analysis showed that in 1972 nearly 75% students arrived by car (48% driving, 26% as car passengers), with less than 8% arriving by public transit. By 1987, more than 70% of students were still arriving by car, but the proportion of students using public transit

as the main mode of transport to the campus doubled to16% (Bennett, D. W., 1988).

There has been a significant change in this split between modes at Monash University. In 2016, a survey found that 41% of students and staff arrive at the campus by car (single occupant and car-pooling), while 41% arrive by public transport and 18% by active transport (Monash University., 2016).

The following initiatives have influenced the increased use of sustainable transport modes to travel to Monash University (Monash University., 2016):

- Public Transport Victoria commissioning a dedicated shuttle bus that links Huntingdale Station with the Monash campus. This services runs every 4 minutes during peak periods and is the busiest bus route in Victoria, carrying 6,000 people per day (Monash University., 2017);

- Parking demand has been managed through more limited space available due to building of university facilities and permit system;

- Incentives for car-pooling, such as dedicated parking spots;

- Free intercampus shuttle bus, which links Clayton campus with the Caulfield campus every 17 minutes;

- Increased accommodation on-campus and in surrounding area, which has made active transport more attractive; and,

- Construction of bike arrival station and initiation of on-campus bike share scheme.

Figure 15 Monash University bike share scheme and inter-campus shuttle bus

Source: https://www.monash.edu/environmental-sustainability/campus-initiative/transport

Options for improving access and connectivity in Monash NEC

The options have been identified to improve access and connectivity across the Monash NEC, and encourage the shift to sustainable transport modes (Phillip Boyle and Associates, 2014):

- Improve pedestrian link between Clayton Station and Monash Medical Centre;

- Develop integrated strategy to manage parking across the three local government areas;

- Encourage mixed use development in all precincts, to provide daily needs (e.g. lunch) within walking distance of workers;

- Improve transit interchanges at all train stations;

- Improve bus network, including increased services;

- Improve interchange between Smart bus routes (key cross-city routes);

- Ensure that program to remove railway crossings includes design elements that improve amenity of major transit stations;

- Westall Road extension, which will provide a divided arterial road to service north-south movements through Monash NEC.

Modelling transport mode choice

There is the need for tools that can help evaluate and prioritise investment in strategies to reduce GHG emission of suburban transport. (Handy, van Wee and Kroesen, 2014) highlight that the biggest challenge to increase adoption of cycling for transport is to identify the most effective ways to spend the limited resources available, while demonstrating the need for greater allocation of funding for active transport modes.

Travel demand modelling

Traditional approaches to modelling transport demand have focussed on identifying the most efficient mode on the basis of 'rational behaviour theory' (Walker, 2011; Kohoutkova, A., G. Wets, A. Yasar, T. A. Trinh, A. Jayasinghe, K. Sano, 2016). This approach assumes that a traveller selects the best route and mode based on a utility function that assesses costs of different options, and minimises these costs while maximising expected utility. However, stochastic choice models to simulate travel behaviour such as Expected Utility Theory or Random Utility Theory may neglect that a traveller's behaviour is shaped by previous experiences, cognition and attitudes (Kohoutkova, A., G. Wets, A. Yasar, T. A. Trinh, A. Jayasinghe, K. Sano, 2016). Also, (Zeibots, 2004) argues that a limitation of assessing transport options based on traditional economic theories is that they are often a-spatial, and therefore do not explain the consequences of transport plans such as induced demand from a new highway.

(Walker, 2011) found there were two main problems is using a utility function to model the decision process associated with mode choice. Firstly, the utility function is based how travellers should make a mode choice rather than how they do. This assumes not only a completely rational travel behaviour, but also that the travellers has complete knowledge of all travel options available in order to make an optimal decision (Walker, 2011). The second problem is that the utility model might not be the best approach to explain modal choice. For example, would two people faced with exactly the same choice make the same decision? This highlights the potential for an approach that incorporates learning theory and habit formation (Walker, 2011).

Choice modelling

Choice modelling have been widely used for understanding demand for transport modes (Greene and Hensher, 2003; Hensher, 2006; Shen, Sakata and Hashimoto, 2008; Rose and Bliemer, 2009; Shen, 2009; Wiley and Timmermans, 2009). Choice models uses stated or revealed preferences in an attempt model the decision-making process of a traveller when selecting mode. (Gaymer, 2010) explored the factors that drove the more rapid than expected growth in public transport use in Melbourne over the period 2004 – 2008 based on a stated preference survey of 3,000 people, with the sample segmented into six groups according to their preference for car or public transit. This found that stated preferences did influence actual travel behaviour.

A well-constructed choice experiment is able to determine the independent influence of different variables that influence travel mode choice (Rose and Bliemer, 2009). The objective is to estimate preferences or utility functions that can be used to determine market shares of different transport modes (Wiley and Timmermans, 2009). (Hensher, 2006) identified two challenges to developing useful choice based experiments for exploring travel choice, which were: incorporating uncertainty into the experiment, and introducing dynamics that accounts for correlation between random components of the stated preference utility functions. Another limitation of choice models is that a participant may be asked to state preferences across a large range of attributes, which can challenge the human cognitive capacities to make meaningful judgements (Herrmann, A., D. Schmidt-Gallas, 2001). Adaptive-stated preference surveys are one approach that can address some of the limitations of conventional stated preference surveys. (Richardson, 2002) highlighted that Adaptive-Stated Preference (ASP) surveys differ from conventional stated preference surveys in four main ways:

1. The options available to the respondent in a ASP survey depend upon the responses given in a previous question;

2. The respondent is presented with less options and fewer attributes in ASP;

3. The targeting of information means that in a ASP survey a respondent may evaluate more scenarios; and,

4. The ASP approach immediately estimates parameters of interest (e.g. value of time) for each individual.

This approach allows a respondent to exclude attribute levels they deem completely unacceptable, no matter the utility levels in the remaining attributes (Herrmann, A., D. Schmidt-Gallas, 2001). This allows a user to reflect at what level they wouldn't accept trade-offs, and then refine choices once these thresholds have been established. For example, a traveller may consider if 10% of transit services are cancelled or delayed by 10 minutes or more that this level of reliability is unacceptable, regardless of performance of other attributes. This non-compensatory approach to attribute levels deemed unacceptable provides a more realistic representation of the way that people actually make decisions, and reduces the survey complexity for participants by removing redundant choices. This can enable better segmentation of the travelling population, and focus more on realistic trade-offs that people might make in selecting a transport mode.

Variables for modelling travel mode choice

The following identifies variables that may be used to simulate travel mode choice, and the likely factors that may influence a shift to low carbon transport modes. While there are many factors that drive the potential for an individual to change travel behaviour the primary drivers of travel behaviour are structural variables such as: trip distance, time, cost, urban density, road network quality and availability of public transit (Miralles-Guasch and Domene, 2010). However, travel behaviour is also influenced by individual variables such as: purpose of trip, time constraints, environmental ethics, age, income, gender, attitudes and lifestyle (Miralles-Guasch and Domene, 2010). (Gardner and Abraham, 2007) applied grounded theory analysis to understand the main motives that sustain high-levels of car use. The top motives for car use were: minimising journey time, minimising physical and psychological effort of trip, minimising cost, creating personal space and maintaining control over the travel experience (Gardner and Abraham, 2007).

Key factors that influence the demand for different transport modes are discussed in the following sections.

Journey time and distance

(Clark, Huang and Withers, 2003) used a longitudinal dataset to explore the relationship between changes in residential location and employment location. This demonstrated how sensitive households were to length of commute. The study showed when commute distance was greater than 13 kilometres a household is more likely to try to reduce commute time when relocating homes. The study indicated that commute distance does matter to households, and households are aware of the trade-offs between commute distance and residential location. This spatial complexities increase for dual-income households.

(Ahmed and Stopher, 2014) reviewed studies of Travel Time Budget (TTB). TTB differs from Travel-Time Expenditure (TTE), as the latter can be measured based on actual travel time while the former refers to the maximum amount of time a person would be willing to travel per day, and therefore is not directly observable (Ahmed and Stopher, 2014). This review found that at the aggregate level TTB are remarkably stable despite the highly variable nature of individual travel. The margin between TTB and TTE indicates the additional time that might be spent on travelling. This has implications when considering mode shift, as people will try to stay within their TTB. (Morris, 2015) found that when controlling for relevant demographic, socio-economic and temporal covariates that travel time per day is significantly and positively correlated with life satisfaction.

(Kingham, Dickinson and Copsey, 2001) surveyed workers at two large companies in England, where more than 85% employees travelled to work by car, to understand what factors might influence a shift to sustainable transport modes. This study found that even if cycling infrastructure and end-of-ride facilities were improved there would likely be little increase in cycling to work due to the distance that most employees need to travel to work. Therefore, policies to improve cycling infrastructure are likely to only have an impact where a significant number of employees live close to work (Kingham, Dickinson and Copsey, 2001). (Badland, Schofield and Garrett, 2008) found that for people who lived 5 kilometres or less from their place of work there was a disconnect between their intent to travel by active modes and their actual behaviour. The World Health Organisation (WHO) advocates distances of up to 5 kilometres are realistic for active based transport. It has been demonstrated that people who live 5 kilometres or less from their place of work are more likely to ride or walk to work, with this likelihood decreasing as the commute distance increases (Badland, Schofield and Garrett, 2008).

Trip complexity and purpose

The purpose and complexity of a planned trip can influence mode selection. Trip purpose can be broadly categorised as commuting or non-commuting travel (David and April, 2000). Commuting covers travel to work or education, and is generally much more predictable in terms of destination and behaviour than non-commuting travel. Studies have often focused on travel behaviour associated with commuting in part due the fact that better data is available to characterise these trips (Handy, van Wee and Kroesen, 2014).

Trips can also be categorised as simple or complex, where a simple trip is defined as a trip to a destination and then returning to home.

Mode quality and accessibility

(Balcombe *et al.*, 2006) noted that mode quality can be defined by a wide-range of attributes, which include those that can be easily observed and included in models, such as: access and egress time, service intervals and in-vehicle time. There are also a range of other mode quality factors, such as: quality and comfort of rolling stock, interchange between modes, availability of information. The valuations of these attributes are often derived from stated preference models (Balcombe *et al.*, 2006).

(Kingham, Dickinson and Copsey, 2001) reported on a survey that asked respondents what factors would encourage them to shift from the car to public transit. The main factors identified were: frequency, reliability, better connections and discounted fares. Frequency, accessibility and connectivity can be used to assess the quality of public transit (Asensio, 2002). However, (Gaymer, 2010) found that commute choice by car can be extremely resilient to significant changes in mode quality. For example, (Gaymer, 2010) found that travel times for car drivers could get 40% worse and there would be minimal defection to other modes, with the exception of those travellers who had stated a preference for public transit use. (Gaymer, 2010) also found improved train service reliability (less chance of delay) substantially increases demand for train services, even from segments of the travelling population that who preferred car use. However, this did not hold for bus travel – as those people who preferred car use will continue to reject bus travel despite any improvements in service quality (Gaymer, 2010). This suggests a problem with the perceptions of bus travel.

Actual and perceived safety of transport modes can influence the adoption of active and public transport. (Woodcock *et al.*, 2009) found that for some cities as rates of cycling increased there was a decrease in the rate of fatalities and serious injuries for cyclists. While, this might indicate there is some effect from safety in numbers, it is also likely to be a result of improved cycling infrastructure that encouraged the increase in cycling for transport.

Economic factors

The selection of modes requires a traveller to consider trade-offs across different levels of attributes—time, monetary cost, reliability, comfort, convenience, safety, and so forth— for each travel mode (Walker, 2011). A traveller has to consider the relative importance and value of each attribute and based on that select the mode that provides the greatest utility. (Walker, 2011) notes that the most important behavioural trade-off in transportation is between the time cost and monetary cost, where the value of a traveller's value of time can be based on traveller's hourly wage rate and it represents the amount of money that one is willing to spend to save a certain amount of time.

(Wardman, 2004) describes the value of travel time as the ratio of the marginal utilities of time and money, while the marginal utility of time is the opportunity cost (wage rate) of time spent travelling and disutility of that time. The value of time will vary across modes, due in part to the comfort and conditions of different modes will impact on the marginal utility of time (Wardman, 2004). This study suggests that time spent walking or waiting as part of a commute is around twice the value of in-car time. (Wardman, 2004) suggests this justifies investment in providing high service frequency bus services that connect core areas.

An analysis by (T. Litman, 2016) found that transit elasticities are influenced by the trip type and user type. Elasticities for off-peak and leisure travel were found to be double those of trips taken during peak and for commuting purposes. It was also found that transit price elasticities are lower for transit dependent riders (those without access to car) than for discretionary riders, who can chose to drive a car. This analysis showed that commonly used elasticity values often understate the potential for transit fare reductions and service improvements to address issues such as traffic congestion and GHG emissions (T. Litman, 2016).

(Gaymer, 2010) explores the factors that drove the more rapid than expected growth in public transport use. The analysis found that three factors had the greatest influence on higher than modelled growth in public transit patronage, which were: population growth, CBD jobs growth and petrol price increases. The actual elasticities of the Melbourne market higher than those used in the demand model, which meant increased petrol prices had a larger impact than anticipated. The

interactive effect of these factors (petrol price increase, improved public transit service services and increased travel congestion) were greater than the sum of the parts.

Built environment

Previously, this review has discussed the relationship between urban density and mode share, which suggested a complex relationship between urban density and increased proportion of trip by sustainable transport modes. Particularly, unless increased urban density is supported by integrated and efficient multi-model transport system it may not have a significant influence of reducing car use. There are many examples in the literature that argue urban form is an important component of reducing transport related emissions (Williams, 2000; Schwanen and Mokhtarian, 2005; Vandeweghe and Kennedy, 2007; Cao, Mokhtarian and Handy, 2009; Tiwari, Cervero and Schipper, 2011; Combs and Rodríguez, 2014; Kerr *et al.*, 2016). (Cervero, 2002) points out that while the literature contains numerous empirical observations that link more compact and diverse developments with increased share of sustainable transport modes, often the relationship between urban form and mode share is not adequately specified.

There is an association between older neighbourhoods that have more granular, gridded networks with smaller lot sizes. While newer developments have cul-de-sacs and curvilinear road networks, which can impede connectivity for active transport modes (Badland, Schofield and Garrett, 2008).

(Randall, 2001) argued that to reduce the energy consumption and sustainability of suburban areas there is the need for retrofitting that will enable people to walk to meet some of their needs and connect to regional transit system. Pedestrian connectivity in suburban location is impeded by circuitous street layouts, lack of footpaths and long travel distance to intended destinations.

(Badland, Schofield and Garrett, 2008) found that the disconnect between intention to use active modes and actual active commuting was seven times greater for those residents who lived in neighbourhoods with poor street connectivity compared to those living in neighbourhoods with good street connectivity. The relationships between active commuting and other urban design variables, population density and mix of land uses, were not as strong as for street connectivity (Badland, Schofield and Garrett, 2008). However, one possible explanation for this lack of a relationship was that this study focussed on commuting only, where many of the active transport for short trips may for purposes other than accessing employment or school.

Mixed land use, residential density, street connectivity and commute distance have been found to influence levels of physical-based commuting (Badland, Schofield and Garrett, 2008). Badlands et al. (Badland, Schofield and Garrett, 2008) suggest that increased adoption of physical-based transport can reduce traffic congestion, CO_2 emissions and traffic pollution, as well as providing health benefits. Low-density, single land use and car-centric neighbourhoods have reduced the opportunities for active transport (Badland, Schofield and Garrett, 2008). Although commute distance may be the dominant driver for the adoption of low carbon transport, other urban features also influence active commuting, which are residential density, mixed land use and street connectivity (Badland, Schofield and Garrett, 2008). The survey undertaken by

Behavioural and social factors

A range of studies have demonstrated the strong habitual nature of daily travel mode choice (Aarts and Dijksterhuis, 2000; Matthies, E., 2002; Bamberg, Hunecke and Blöbaum, 2007; Domarchi, Tudela and González, 2008; Verplanken *et al.*, 2008). (Bamberg, Hunecke and Blöbaum, 2007) pose the following question: is the reported habitual nature of mode choice based on causal relationships or more likely deliberative justifications based on strongly established behavioural habits. The results showed that including past behaviour strongly improves the predictive power of the model. With the exception of two constructs (feelings of guilt and awareness of consequences) all other constructs listed above are significantly associated with past behaviour. (Bamberg, Hunecke and Blöbaum, 2007) compared two case studies with differing population segments. The study showed that socio-normative factors had a significant impact on people's intention to use PT, which justifies the importance of public awareness campaigns that aim to create a receptive public may be an important pre-requisite for the effectiveness of measures targeting individual mode shift (Bamberg, Hunecke and Blöbaum, 2007). (Gardner and Abraham, 2008) undertook a meta-analysis into potentially modifiable correlates of car use and intentions to drive. Programs that target behavioural change are typically more acceptable to the community and less expensive than infrastructure modifications. The importance of attitudinal data has long been established in transportation research, where it has been suggested that it can improve prediction of mode choice (Beck and Rose, 2016).

(Klöckner and Matthies, 2004) explored how habits can be integrated into a model of normative decision-making. Understanding individual decisions to use a car is

important as it provides a starting point to consider the possible interventions that will reduce private car use and associated emissions. The choice of travel mode is a repeated daily actions, particularly for habitual travel such as commuting. Therefore, the potential for habit to influence travel mode choice is significant (Klöckner and Matthies, 2004). Possible habit indicators could include: the number of public transit trips in a given time period; distance to the regularly chosen location; the most frequent occurring departure time; past use and vehicle ownership; and past and current ownership of 'season tickets' for public transport (Cooper, 2009). Event such as moving house or changing jobs may prompt re-evaluation of travel habits.

(Carrus, Passafaro and Bonnes, 2008) examined the role that anticipated emotions and past behaviour have in influencing intentions for use of public transport, which found that past behaviour is the best indicator of future intentions. Also, (Rasouli and Timmermans, 2014) argue that most models of transport behaviour assume individuals choose between alternatives under conditions of certainty. However, in reality there can be considerable uncertainty in the likely performance of a chosen transit mode.

(Anable, 2005) argues that studies have also shown that habit influences mode choice, as a trip is not always preceded by a deliberation of alternatives. There are broadly two approaches to segmenting a population of travellers, which are: groups are defined based on known characteristic (e.g. socio-demographic characteristics), or groupings can be identified using multivariate statistical analysis. Therefore, in the latter the segments are determined by the data and not the researcher (beyond selection of the variables). Often socio-demographic characteristics are used to segment populations for travel behaviour and intention to shift mode. However, (Anable, 2005) demonstrated that socio-economic variables did not influence behaviour but was related more to attitudes and beliefs around benefits and impediments to mode shift.

Summary

The uptake of sustainable transport modes is influenced by a range of observable and latent variables. Latent variables refer to unobservable factors that influence mode choice, such as preferences and values that drive travel behaviour. (Vredin Johansson, Heldt and Johansson, 2006) explored the influence of latent variables on mode choice, where they found that in addition to modal time and cost that attitudes to flexibility and comfort, as well as being environmentally included influenced commuters' mode choice. (Beirão and Sarsfield Cabral, 2007) undertook a qualitative study to better understand attributes to public transit attitudes

towards transport and to explore perceptions of public transport service quality. The key finding was that to increase public transport patronage the services should be planned to meet the levels of services required by the customer, but that in addition mode choice is influenced by a number of other factors, which include:

"Individual characteristics and lifestyle, the type of journey, the perceived service performance of each transport mode and situational variables (Beirão and Sarsfield Cabral, 2007)."

This suggests that when designing policies and strategies to increase the use of sustainable transport modes there for softer interventions, such as education or awareness programs, should be targeted at segments of the travelling population most likely to be receptive.

Figure 16 depicts both the observable and latent variables that influence utility and mode choice. This section has highlighted that while the utility (time and cost) function of relative modes is the main influence on travel mode choice, there are a range of behavioural aspects that can influence the decision to shift to sustainable transport modes. Therefore, it is proposed to identify modelling approaches that can simulate the mode choice of different segments of the travelling population given constraints and changes in the supply of sustainable transport services and infrastructure.

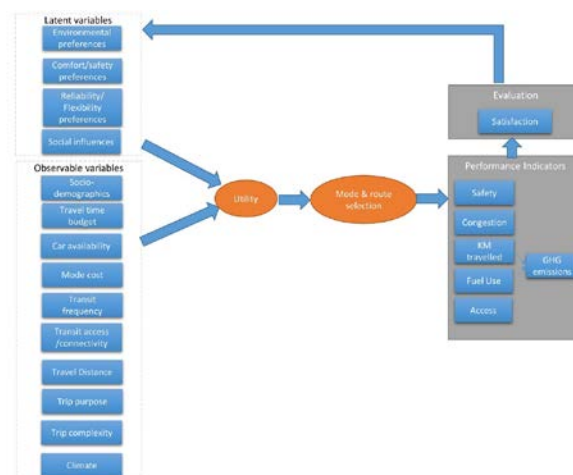Figure 16 Latent and observable values that influence utility and mode choice

Agent-based Modelling

Agent-Based Models (ABMs) as an approach to modelling transport mode choice is explored in this section. (Ziemke, Nagel and Moeckel, 2016) argues that traditional integrated land-use and transportation models are not able to represent the complexity and dynamic nature of modern cities, and how individuals make

transport decisions. ABM is an approach that has emerged out of Artificial Intelligence and Cellular Automatons, and allow for software representations of agents' behaviours and decision making in interaction with each other and with their environment (Gilbert, 2000). ABM has been used in a diverse number of areas, including archaeology, biological sciences, economics, ecology, electricity market analysis, financial analysis, social science, transport systems and water management, among others (Dia, 2002; Zhang, L., 2004; Davidsson *et al.*, 2005; Macal, C. M., 2005; Moglia, Perez and Burn, 2010; Macal, 2016). ABM is well suited to modelling situations where the interaction between agents results in behaviour that is complex and non-linear due to being shaped by learning and adaption (Zheng, H., Y. J. Son, Y. C. Chin, L. Head, Y. Feng, X. Hui, 2013). ABM provides a flexible, bottom-up approach for simulating emergent phenomenon Figure 17. Simple rules that govern behaviour agents at a local level can result in the emergence of complex system behaviours (Zheng, H., Y. J. Son, Y. C. Chin, L. Head, Y. Feng, X. Hui, 2013).
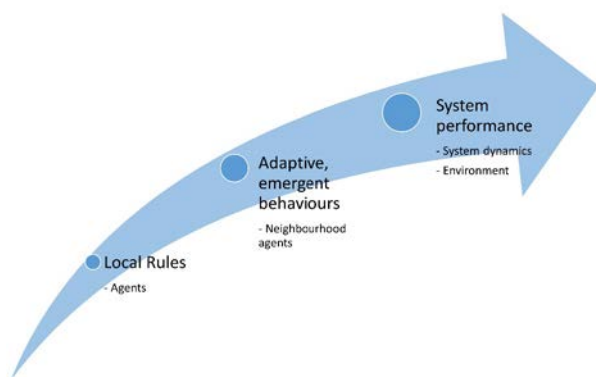
Figure 17 ABM - A bottom-up approach

Source: Adapted from (Zheng, H., Y. J. Son, Y. C. Chin, L. Head, Y. Feng, X. Hui, 2013)

There are two main approaches to modelling travellers' behaviour: equation-based modelling and ABM. Equation-based modelling uses approaches such as the Logit model, which applies a utility function to aggregate and evaluate system variables (Mao, C., M. Zou, Y. Liu, 2015). (Mao, C., M. Zou, Y. Liu, 2015) compared equation-based modelling and ABM in simulating travellers' behaviour, using data from a joint stated preference survey and web-based travel behaviour survey. This showed that when access to data is adequate, ABM has a similar predictive capacity for modelling transport behaviour as equation-based diffusion modelling but with a greater flexibility in assumptions and issues that are explored (Mao, C., M. Zou, Y. Liu, 2015). Ultimately, ABM has the same limitations as any model in that any prediction is subject to conditional

prediction, i.e. prediction only under the circumstances set out in the model (Boschetti, Grigg and Enting, 2011). A challenge in implementing ABM is that the patterns of emergent behaviour are inherently unpredictable, and that ABM with human agents may need to account for irrational behaviour, subjective choices and complex psychology (Zheng, H., Y. J. Son, Y. C. Chin, L. Head, Y. Feng, X. Hui, 2013). This can make validation of ABM problematic as it can be difficult to measure, quantify, calibrate and justify all factors.

(Natalini and Bravo, 2014) described the development of an ABM that was designed to simulate the mode choice of travellers in the United States and the associated GHG emissions, in order to investigate commuting behaviours and the ex-ante consequences of policies to reduce transport related emissions. This study found that ABM is a rigorous and cost-effective method to evaluate the likely effectiveness of different policies. In particular, the ABM approach enabled the evaluation of policies in combination, which allowed for identifying best mix of measures for encouraging sustainable commuting. Therefore, it is suggested that ABM is explored as an alternative to equation-based diffusion modelling of transport mode choice in order to support policy assessment of approaches to encourage the adoption of sustainable transport modes.

(Sarmiento *et al.*, 2016) developed an ABM to assess the effect of improved infrastructure for Bus Rapid Transit (BRT) on walking. In the AMB agents were assigned a home location, work location and socioeconomic status. The mode decision of agents was based on a utility function that accounted for monetary cost and time relative to available resources (Sarmiento *et al.*, 2016). The ABM was able to replicate empirical evidence that increasing BRT access increases the time spent walking for transportation. The ABM was considered to be useful to explore potential policies for improving access to BRT, as it can demonstrate the effect of different interventions in BRT in increasing walking for transportation.

(Sunitiyoso and Matsumoto, 2009) applied an ABM to simulate the social dilemma of travel mode choice that accounted for social and psychological influences. (Sunitiyoso and Matsumoto, 2009) gave an example of this social dilemma based on a bi-modal transit system (car and bus) sharing the same highway. If all commuter travelled by car there would be severe congestion, while if some commuters switched to a bus this would alleviate congestion but those switching may gain less payoff than those who continue to drive. This means the rational choice of users is to keep driving, and try to benefit from others who use bus, while the best outcome (reduced cost and time of travel) would come from all users switching to bus transit. The ABM explored conditions that would

enable greater cooperation through social learning mechanisms.

Consumat Framework

The Consumat framework is a generic conceptual framework that can be used to guide the development of ABMs as it provides an approach to simulate different human needs and decision strategies (Schaat, S., W. Jager, 2017). The Consumat framework has been applied to simulate the decision process associated with the adoption of more sustainable behaviours, including how travellers make a choice to adopt a sustainable transport mode or persist with their existing transport mode (Societies and Simulation, 1999; Jager, W., 2012; Jager, W., M. Janssen, 2014).

The fundamental drivers of behaviour in the Consumat framework are related to needs, and if these needs are fulfilled (Schaat, S., W. Jager, 2017). A distinction is made between the types of human needs: existential needs and social needs. Existential need relates to criteria that guide transport mode choice which can be observed or revealed, such as trip time, cost, reliability, comfort, safety, and trip purpose. Social needs relates to how decisions are influenced by interactions with others (Schaat, S., W. Jager, 2017). These social needs can relate to the need to conform or be different when comparing behaviour to those who might influence the agent, such as friends, family, peer groups, etc. The Consumat framework also considers the 'uncertainty' in the existential and social needs being satisfied. Figure 18 outlines the decision modes that are used in the Consumat approach based on needs fulfilment and uncertainty. The decision modes are as follows:

Repetition: High level of needs satisfaction and certain. The repetition decision mode involves repeating the behaviour of the past.

Imitation: High level of needs satisfaction, as well as uncertain. The imitation decision process is normative and involves copying the behaviour of a connection in the agent's the social network.

Optimisation: Low levels of needs satisfaction and certain, will mean an agent is motivated to invest effort in improving their level of satisfaction.

Inquiry: Low level of needs satisfaction, but uncertain. The inquiry decision mode involves evaluating the behaviour of others, and copying when expected satisfaction increases.
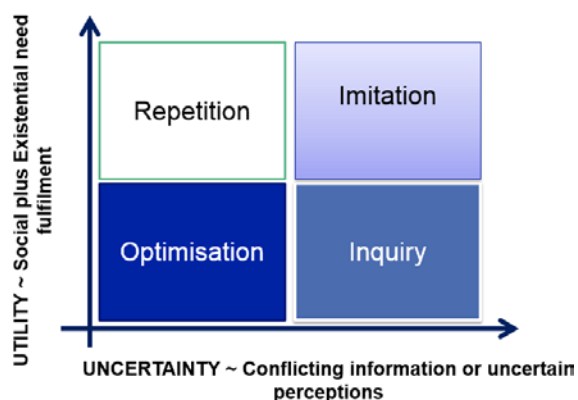
Figure 18 Decision modes in Consumat framework

Theory of Planned Behaviour and Norm Activation Model

Reducing fossil fuel use associated with car travel is seen as a central prerequisite of mitigating climate change impacts. However reducing car use for pro-environmental objectives is associated with significant individual cost (Bamberg, Hunecke and Blöbaum, 2007), as car use can provides convenience, speed, comfort and individual freedom (Anable, 2005). Therefore, it can be argued that measures designed to reduce car use should consider the influence of psychological factors including perceptions, identity, social norms and habits (Anable, 2005). The Theory of Planned Behaviour (TPB) framework assumes mode choice is a rational decision influenced by attitudes and perceptions of barriers to behavioural change (Figure 19). Intention is taking as a summary of all the pros and cons that a person takes into consideration when deliberating. Intention is itself seen to by causally determined by three independent psychological variables (Bamberg, Hunecke and Blöbaum, 2007):

1. Attitude – reflects the beliefs that a person holds about the positive and negative consequences of a behaviour (behavioural beliefs) and the values this person ascribes to their consequences (outcome evaluation).

2. Subjective or social norm – Expectation that important reference persons thinks she/he should carry out the option being considered.

3. Perceived behavioural control – determined by the specific control beliefs as well as their expected power to prevent or promote the performance of a behavioural option.
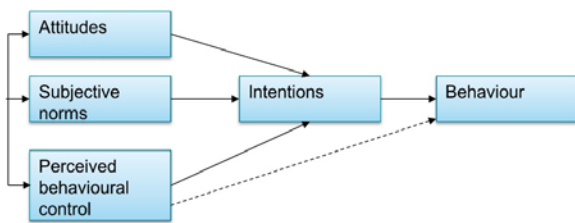
Figure 19 Theory of Planned Behaviour

The evidence linking personal norm and intention, or personal norm and actual travel mode choice is mixed, which might be explained by the different theoretical frameworks that have been applied (Bamberg, Hunecke and Blöbaum, 2007). A study in two German cities showed that perceived expectations of an important reference person as well as feelings of guilt showed a strong association with the reported personal obligation to use public transport (Bamberg, Hunecke and Blöbaum, 2007). This result indicates that for an everyday behaviour like travel mode choice that the influence of social norms may not rely so much on feared social sanctions but more on the informational function of social norms.

Summary of Agent Based Modelling

Suburban transport is a significant contributor to greenhouse gas emissions in Australian cities. Therefore, in transitioning to a low carbon future that mitigates the potential impacts of human-induced climate change there is the need to increase the adoption of low carbon transport modes, such as public transit and active transport modes, in the suburban context. Suburban transport is currently heavily car dependent which, in addition to greenhouse gas emissions, contributes to: traffic congestion, poor local air quality, social inequity, and health impacts due to lack of physical activity. Suburban development was partially enabled by increased car ownership, which allowed for mobility in areas not serviced by transit and/or distant from employment locations. The ongoing predominance of car use in suburban areas can be attributed to lack of planning and investment in transit systems that meet service levels required by the travelling population, and induced demand for car travel from extensive development of highways and arterial roads. In order to reduce car dependence, and associated carbon emissions, in Australian cities there is the need to identify effective interventions that will enable a greater proportion of trips to be taken by sustainable transport modes.

The suburbs are often envisaged as sprawling areas of low-density residential development around the city core. However, analysis of employment locations in Australian

cities, such as Melbourne, shows that while the greatest density of jobs occur in the core of the city that the vast majority of jobs are located in the suburbs. This decentralisation of jobs is not supported by current transit infrastructure, especially rail, which is designed around getting people in and out of the city core. A response to reduce car dependence in suburbia has been to encourage increased urban density (housing and jobs) around transit infrastructure, on the assumption that this will encourage use of transit and active transport modes. However, a review of the implementation of transit orientated developments showed that their impact on reducing car dependence can be less than anticipated. This was due to the transit services available not being sufficient to meet the complexity of trip patterns and travellers' service requirements. Furthermore, while it has often been stated as density of development decreases that car dependence increases it was found that this relationship was not as strong as it first appears. There are a number of examples from around the world where low-density areas where a significant share of trips are taken by sustainable transport modes, which highlights the importance of economic and efficient transit services in suburban locations in order to reduce car dependence.

The Monash National Employment Cluster is situated in the suburban heartland of south eastern Melbourne. This area was developed in the 1950s and historically an area that specialised in manufacturing and logistics employment. However, the Monash cluster is now a hub for growth of job in the health, education, technology and research sectors. Overall travel patterns for the employment cluster are typical of post-war suburbia, with the majority of trips being in private vehicles. However, Monash University, which is the hub of this employment cluster demonstrates an example where there has been significant increase in the share of trips taken by sustainable transport modes due to a range of measures that have improved transit and active transport services, and also measures to moderate demand for car travel such as parking fees. A planning framework is currently being developed for the Monash National Employment Cluster in order to plan for the services and infrastructure required to accommodate future growth. It has been identified that a major constraint to the growth of this employment cluster is car dependence and associated traffic congestion. The cluster provides an opportunity to model and evaluate interventions in suburban context that will increase the uptake of sustainable transport modes.

Transport mode choice is mostly driven by a traveller selecting the mode that maximises their utility in terms of travel cost and time. The most effective intervention to improve adoption of sustainable transport modes was found to be in improvements in infrastructure and service

levels that meet the needs of the travelling population. However, it has also been shown that an individual's attitudes influence their receptivity to changing transport modes. Therefore, when developing a tool to evaluate the effectiveness of different interventions in increasing the adoption of sustainable transport modes there is the need to consider different segments of the travelling population, and how they might react to transport supply and demand interventions. Adaptive–conjoint analysis has been identified as an approach that will enable the segmentation of the travelling population, and an understanding of how they value relative travel attributes and what conditions would need to be achieved for them to change modes. Agent-based modelling provides a framework that can represent transport mode choices in a complex and dynamic environment, where the interaction between agents can result in the emergence of non-linear behaviour. Agent-based modelling provides a flexible, bottom-up approach for simulating how simple rules that govern transport mode choice at a local level can result in the emergence of complex system behaviours at a regional scale.

Autonomous vehicles in green suburban travel

Autonomous vehicles (AVs) may improve road safety, reduce vehicle emissions, reduce car ownership by increasing car sharing, and enable efficient use of urban space by reducing the need for parking. Conversely, AVs also have the potential to reproduce car dependency and encourage sprawl, and shift investment away from public transport systems that our cities will still require (Hall P, 2012; Thomopoulos and Givoni, 2015). In any case, they "will have a dramatic impact on urban life", particularly as they begin to "blur the distinction between private and public modes of transportation" (Claudel M, 2015).

The evolution of the 'driverless city' will be shaped by complex interplay between the competing visions for AV technology:

- The IT industry wants declining private-vehicle ownership and the emergence of urban 'mobility as a service' with shared vehicles operated under as-yet-undefined ownership, licencing and regulatory arrangements.
- The existing automobile industry is pursuing a vision of growing private vehicle ownership.
- For public transport, AVs could threaten some network segments and strengthen others meaning that public transport agencies could both rationalise existing operations and expand their market through collaboration with AV providers.

Research questions relevant to AVs and green suburban travel

Most credible modelling of the impacts of AVs on traffic volumes and congestion recognises that mass transit, in some form, will remain a central requirement for improving the sustainability of urban travel. Therefore, it is necessary to consider how the deployment of AVs can be achieved in ways which complement and strengthen existing transit networks, rather than allow the fulfillment of the apparent corporate ambitions of some 'disruptive' global IT companies to ultimately replace state-funded transit systems.

(Stone J, 2017) set out principles and recent practice examples for the conditions under which current public transport systems can be organised into strong networks that can provide effective and affordable competition with the car in dispersed suburban environments.

(Lindsay G, 2016) is a good example of the emerging literature setting out the ways in which public transport agencies can and should engage with the new AV technologies to strengthen the potential for achieving sustainable transport objectives.

From this work, it is clear that, as identified by (Isaac, 2016), the actions of public land-use and transport planning and operations agencies will be crucial in managing the deployment of AV technologies.

To support the Greening Suburban Travel objectives of the LCL CRC, the following research questions have been identified:

1. What is the preparedness of state transport and land-use planning agencies for AV deployment in the light of the strong neo-liberal and corporatist turn in regional governance in Australasia?
2. What would the dominance of different visions for AV futures mean for urban form and structure?
3. How should possible ownership, regulatory and licencing arrangements be designed to strengthen the complementarity between existing transit networks and new forms of AV technology?

Emerging projects to meet this agenda

The 'Planning the Driverless City' project, based at the University of Melbourne and Curtin University in Perth, began in late 2016.

Pilot work in this project is now underway through interviews with State and Commonwealth transport agencies. This work is modelled on research by (Guerra E, 2016) who found a paralysis of un certainty among US metropolitan planning agencies

This work will be presented as an invited paper at the WCTRS Research Day 'Governing the Smart Mobilities Transition at the International Transport Forum in Leipzig in May http://2017.itf-oecd.org/governing-smart-mobility-transition, and at AESOP in Lisbon in July.

As part of the pilot project, John Stone is also planning in June 2017 to conduct research interviews with planners from European urban transit agencies to understand how they are positioning their organisations to benefit from deployment of AV technologies (see (Verband Deutscher Verkehrsunternehmen [VDV], 2015) for indications of the directions German agencies are taking)

The project team has also submitted a Discovery Project proposal to the Australian Research Council for a three-year project to:

1. Analyse the competing visions for AVs in the city.
2. Develop conceptually focused scenarios that convey the scope, scale and impact of AVs on urban space.
3. Produce a socio-institutional analysis of the policy, regulatory and planning interventions available in Australian cities to mediate competing AV visions in public interest.
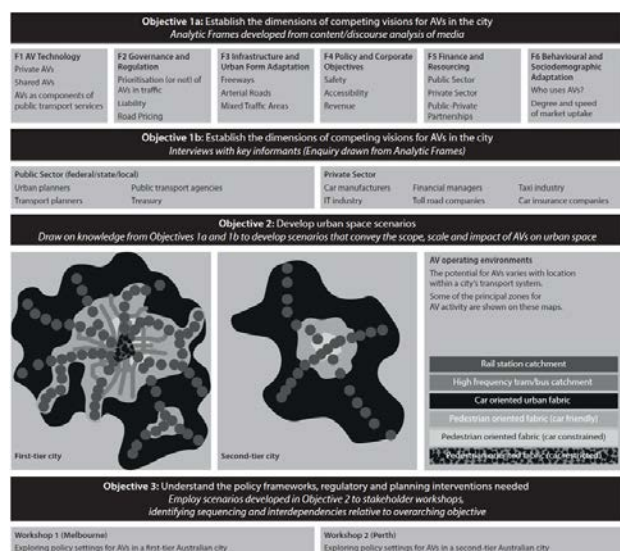

Figure 20 The proposed work program for this project

The outputs of these projects will be used to inform the 'Greening Suburban Travel' project by allowing us to articulate a range of transport supply scenarios in which AVs play both complementary and competitive roles in relation to existing or improved 'conventional' mass transit and fixed-route feeder bus service networks.

Policy principles for low carbon mobility

The efficiency, productivity and environmental sustainability of urban transport systems continue to present big challenges for city leaders and decision makers around the world. These challenges, however, are not insurmountable. Despite the enormous difficulties, from growing urban populations to congestion and through to fiscal policy constraints, many cities have successfully achieved energy efficiency improvements in urban transport and have demonstrated how substantial gains can be achieved through well-planned policies and stakeholder consultations (International Energy Agency, 2013). Although the urban form and transport characteristics of each city are different, and policy responses vary, there are a number of policy pathways available to help decision makers in charting a path for sustainable mobility in their cities. To realise the desired outcomes of sustainable mobility, policy makers must consider a holistic and long-term planning to deal with urban transport challenges. Governments should also move beyond isolated projects and consider strategies to build and retrofit the world's cities which will accommodate nearly 6.3 billion people by 2050 (International Energy Agency, 2013).

The development of low carbon urban transport systems requires a conceptual leap (UN-Habitat, 2012) and a reframing of the objectives of transport policies. At the centre of this shift is a recognition that the purpose of transport is to provide consumers with access to destinations, services, activities, goods and opportunities. Therefore, "access" becomes the core objectives that should be pursued by policy instruments. As a result, urban design should consider how to bring people and places together, by developing transport and mobility solutions that focus on access and accessibility, rather than reliance on increasing the capacity of transport infrastructure. Urban form and integrated land-use and transport planning therefore become a major focus of any policies that aim to achieve sustainable and low-carbon urban mobility.

Today, transport planners increasingly recognise that the infrastructure decisions that a city makes will have a profound impact on shaping its future and people's travel behaviours.

Traditional transport planning approaches in most cities have been mainly driven by the economic dimensions of the challenges described before. The traffic gridlocks experienced on roads and motorways have been the basis for the development of most urban transport strategies and policies. The solutions prescribed in most of these strategies has been to build more infrastructure for vehicles, with a limited number of cities paying equal attention to managing the demand for travel or improving

other modes of urban mobility (e.g. public transport) in a sustainable manner. But this has changed in the recent past (although progress is slow) and continues to unfold in many cities around the world, where greater emphasis is being given to sustainable modes of mobility such as public transport, cycling, walking and in more recent years also to disruptive mobility solutions that rely on car-sharing and ride-sharing enabled by technology platforms.

The policy instruments that promote this transition play a key role in reducing greenhouse gas emissions and pollution. They also have a wide range of benefits to the community, and have been shown to enhance the fabric of urban environments and make cities more liveable. Well-planned mobility solutions for tomorrow's cities also improve accessibility to jobs and opportunities which are preconditions for sound economic development and for mitigating emissions and pollution in urban centres.

This section presents these policy instruments and describes some case studies which demonstrate how the policies have been effective and successful in unlocking low carbon mobility benefits in cities around the world.

Urban transport system energy efficiency

An efficient transport system is what makes urban centres competitive (GIZ, 2013). It produces access to jobs, services, healthcare, education and other activities. It also favours the movement of people over the movement of a particular form or mode of transport.

The policy pathways presented in this section aim to help policy makers improve their cities' "transport system energy efficiency". The International Energy Agency (International Energy Agency, 2013), defines transport system energy efficiency as "the maximisation of travel activity with minimal energy consumption through combinations of land-use planning, transport modal share, energy intensity and fuel type."

The transport energy efficiency can be improved in a number of ways. Cities with high dependence on motorised transport can promote shifts to cycling, walking and public transport. They can also adopt higher vehicle fuel-economy standards and establish regulations to govern land-use transport interactions. In practice, however, realising energy efficiency improvements in transport is much more complex. Transport activity and mobility are highly dependent on travel demand, which is very challenging to improve in the short term and needs longer term policies that focus on behavioural changes. The use of more efficient modes of transport also depends on the choices available to consumers and the ease of reaching those modes (accessibility). They also depend on people's travel choices and preferences as

influenced by culture, values and socio-economics factors (Figure 21).

The energy efficiency policies can therefore be generally defined as a combination of (a) shaping the development of land-use and the physical transport network; (b) providing travellers with easy access to travel mode options and improve their travel choices; and (c) application of travel demand management strategies which in the long-term can influence travel behaviour and mode choice preferences. Under this framework, energy efficiency in transport can be achieved through influencing transport activity and travel decisions from an energy and context-based perspective. This in turn can lead to a broader definition of urban transport system energy efficiency which can be articulated as the "maximisation of the urban geography-transport network interface so as to provide optimal access and choice and maximise the efficiency of travel activity through combinations of modal share, energy intensity and fuel type" (Banister, 2008; International Energy Agency, 2013). Under this definition, energy efficiency in transport systems can be achieved through prioritising land-use transport integration such that it reduces the need for energy-intensive travel options (Banister, 2008; International Energy Agency, 2013).
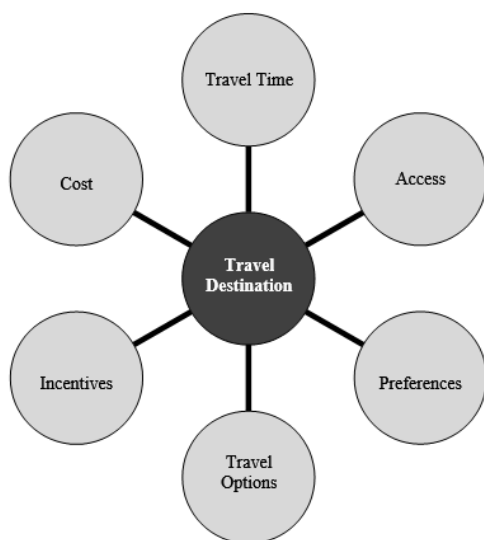
Figure 21: Transport activity decision matrix

Source: Adapted from (International Energy Agency, 2013)

Policy instruments

Rigorous yet flexible policy instruments play a key role in shaping low carbon mobility strategies. In the absence of such policies, provision of transport and mobility will continue to favour motorised transport modes which are not energy efficient (Banister, 2008; International Energy

Agency, 2013). This would result in poor prioritisation of investments, which would encourage private vehicle usage while giving less weight to more efficient modes of travel.

The International Energy Agency (IEA) has done substantial work on this and recommends several policy instruments to address low carbon mobility. These policies include demand management (e.g. congestion and road pricing), regulatory policies (e.g. parking restrictions) and supply-side strategies (e.g. introducing on-demand public transport). The IEA also suggests that incentives for private motorised travel are eliminated and replaced with taxation regimes to reflect the full range of external costs of fuels and vehicles (Banister, 2008).

Weak regulatory frameworks can also result in inadequate transport provisions. The most recent example of this is demonstrated by the wide range of policy responses to the ride-sharing services such as Uber and Lyft. Policy and decision makers in many cities around the world are still struggling to regulate the new business models and markets that are emerging, and which are increasingly playing a crucial role in people's mobility in cities. Yet, these services are still considered illegal in many cities and blunt policy instruments are used to discourage rather than support disruptive modes of transport that have potential to curb private vehicle use. By improving or introducing regulatory policies that support innovations in transport provision, policy makers can increase transport system efficiency, improve the quality of transport services while influencing the shift to more efficient travel modes.

The "Avoid, Shift, Share and Improve" Framework

A package of measures, collectively known as the "avoid, shift and improve" approach, have been proposed over the past 12 years as necessary policy instruments to achieve sustainable transport improvements (Banister, 2008; International Energy Agency, 2013). This framework was proposed with the aim of (1) avoiding motorised travel when possible; (2) shift travel to more efficient modes; and increase the energy efficiency of vehicles, fuel technologies and maximising the utilisation of existing infrastructure (IEA, 2012).

In this section, the framework is extended to include the recent developments in car-sharing and ride-sharing services (Figure 22). Recent evidence suggests that these collaborative mobility-on-demand services have started to influence car ownership models and are reducing the total number of vehicles required to meet people's demand for travel. In the case of ridesharing, there is also increasing evidence that 'car-pooling' types of ridesharing services are increasingly being introduced in cities around the world and resulting in substantial

benefits in terms of reductions in the total number of vehicle-kilometres of travel and reducing emissions and pollutions (Dia, 2016a).
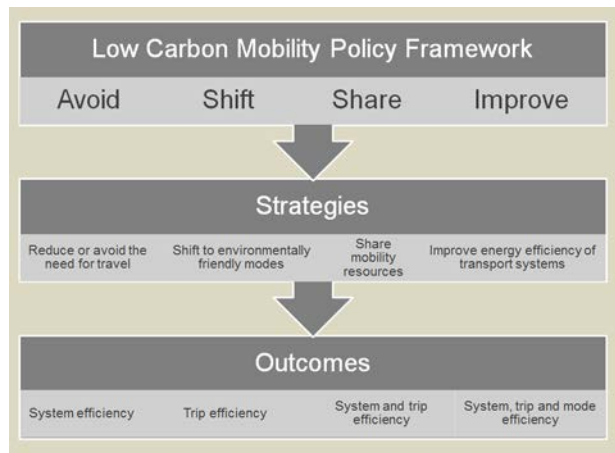
Figure 22: The Avoid, Shift, Share, Improve Framework

Source: Adapted from (International Energy Agency, 2013).

Together, these policies can help to achieve significant reductions in emissions, while also addressing urban transport issues such as congestion and access to services and employment. The key characteristics of these policies are outlined next.

Avoid

Avoid policies aim to slow travel growth through integrated land-use transport planning and travel demand management (Banister, 2008; International Energy Agency, 2013). These policies include: (1) virtual mobility programs (e.g. tele-working); (2) initiatives to reduce trip length (high density and mixed land use developments); (3) initiatives to reduce the need or desire for travel (congestion pricing, promotion of car-sharing and ride-sharing schemes). Other examples include on-line purchasing and similar business models which help consumers to avoid shopping trips altogether.

Shift

These policies encourage travellers to shift their travel from private motorised vehicles to more efficient modes such as public transport, walking and cycling. Policies under this category include integrated public transport and land-use planning, improved bus routes and services, pricing strategies (road use pricing, congestion charging, vehicle quotas or bidding systems for license plates such as the Certificate of Entitlement (COE) in Singapore), road space allocation (dedicated lanes for cycling or bus lanes). Increasing the reliability and affordability of public transport, for example, can also promote their use

over private vehicles which improves access to destinations. The same applies for incentives which make electric vehicles (EVs) more affordable.

Share

Share policies enable and promote a shift from car ownership models and private vehicle use towards car-sharing, ride-sharing, bike-sharing (and even vehicle parking space sharing in resource restrained urban centres). Consumers today, especially younger generations, are no longer interested in the vehicle as a 'status symbol' nor owning an expensive asset that stays parked for 90% of the time. Consumers are also increasingly demanding a higher level of service, more efficient and less polluting mobility options that suit their modern-day lifestyles. Disruptive mobility trends, enabled by increasingly sophisticated app-based technology platforms, have the potential to fundamentally change the relationship between the consumer and automobile. The rise of the collaborative or sharing economy, popularised by the companies such as Airbnb, Zipcar and Uber, has enjoyed remarkable rapid growth over the last few years and looks set to expand over the next decade (Kaas, 2016). Access to mobility rather than to car ownership will enable customers to be more selective in choosing from the door-to-door mobility services offered by 'mobility operators' for intercity, suburban as well as 'last kilometre' travel solutions. The transport sharing economy is therefore an opportunity to move people, goods and services collectively by sharing the transport mode. This will in the long-run help improve congestion, reduce emissions and air pollution and enable a new form of crowd-sourced on-demand mobility. With mobility offered as a service and on-demand (regardless of fixed bus routes or public transport schedules), consumers in the future will have the flexibility to choose the best solution for a specific trip purpose during any time of the day using their smart phones.

Improve

The "improve" policies include initiatives which promote efficient fuels and more efficient combustion engine vehicles. They also include policy responses such the application of transport and urban information technologies, introduction of electric vehicles, and adoption of Intelligent Transport Systems, eco-driving, low-carbon electricity generation and smart grids for electric vehicle charging stations. This policy principle has been well embraced in recent years with the shift in the thinking on how to provide the infrastructure required to support our mobility needs. Instead of building additional road capacity, there is more reliance nowadays on using technologies to optimise the performance of

existing infrastructure and sweating of assets, in addition to improving vehicle performance and energy efficiency.

Ten key principles from the "Avoid, Shift, Share, Improve" Framework

The following principles summarise the practical approaches for the application of the "Avoid, Shift, Share, and Improve" framework (Bongardt, 2016):

1. **Planning dense cities.** In 1989 an influential study by (Kenworthy, 1989) compared the density of 32 cities across the world. They found that denser cities have lower car use than sprawling cities. This is largely accepted today. Planning dense, walkable cities is now the new paradigm in city planning. Central to this concept is the integration of urban and transport development. This approach supports the creation of small urban fabrics, mixed-use city quarters, and car-free housing.

2. **Develop transit-oriented cities**. Transit oriented developments (TOD) is a successful strategy that addresses a range of issues including traffic congestion, increased urban sprawl, air pollution and increased energy use (Cervero, R., Ferrell, C. and Murphy, 2002; Nahlik, MJ, Chester, 2014). It is a strategy aimed at the grouping of high density and mixed use commercial and residential developments near or around public transport hubs or corridors (rail, light rail, bus). It is characterised by designs that encourage the use of alternate modes of transport such as walking, cycling or public transport, with lower parking supply, shopping malls and pedestrian amenities being prominent design features (Chatman, 2013).

3. **Optimising the road network and its use.** This strategy enhances urban connectivity and reduces the distances and times of travel between origins and destinations. It also uses transport technologies and Intelligent Transport Systems solutions to optimise performance through network management systems, incident management and traveller information systems to keep travellers informed of traffic conditions especially in the case of delays due to incidents and other unexpected events.

4. **Implementing public transport improvements.** This strategy looks at enhancing existing public transport to ensure high quality of services for public transport users. It can include examples such as introduction of bus rapid transit and other high performance public transport services, integration of interchanges to make it easier for travellers to switch between modes, and integration car sharing, taxis, and ride-sharing services into the mix of public transport options especially at interchanges.

5. **Encouraging walking and cycling**. This strategy includes creation of complete urban cycling networks, high quality design standards for sidewalks and cycle paths, ensuring safe facilities for cyclists and pedestrians, enhancement of traffic signal control strategies and intersection designs to improve mobility and safety for pedestrians and cyclists at road junctions.

6. **Controlling vehicle use.** This includes strategies such as congestion charging and user-pays road pricing based on charge per kilometre or time of day, incentives to commute by bike or public transport, and teleworking. Some cities around the world are also experimenting with total car bans in city centres.

7. **Parking management.** This includes strategies to establish parking fees, limit parking duration, better enforcement of parking rules, parking information systems including mobile-based apps that show parking availability or shared parking spaces, and providing incentives to property developers to replace in-development car parks with fewer parking spaces dedicated to car-sharing.

8. **Promoting clean vehicles.** This includes promoting low emission zones in city centres and introducing incentives and rewards for electric vehicles and clean-fuel vehicles. It also includes rolling out electric vehicle charging infrastructure and improved methods for taxing transport fuels.

9. **Stakeholder consultations and communication of results.** This includes stronger engagement with the public and decision makers, marketing campaigns for better public transport, car-sharing and ride-sharing.

10. **Pathways to comprehensive deployment.** This includes creating agencies that are responsible for overseeing low carbon mobility initiatives, integrating transport into climate change action plans, developing low carbon urban mobility plans, and monitoring implementation and performance.

The Benefits

A number of cities around the world have already taken successful measures to reduce motorised transport and promote more efficient forms of travel. This resulted in increases in transport efficiency, improved passenger mobility and access to opportunity, safer roads, reduced congestion, and improved health and air quality. According to the International Energy Agency (IEA), improving the energy efficiency of transport systems is estimated to save the world economy $70 trillion by 2050 (International Energy Agency, 2013). The IEA estimates that the combined "avoid" and "shift" policies have the potential to reduce the global transport sector expenditure (to year 2050) by nearly USD 30 trillion. When further combined with "improve" policies, an "avoid, shift and improve" approach could lower expenditure by nearly USD 70 trillion by 2050 (International Energy Agency, 2013). The IEA study is based on examples from more than 30 cities around the world, and shows how improvements in transport efficiency and energy use can be achieved through better land-use transport integration planning, travel demand management and infrastructure technologies.

City contexts and urban needs

Different cities will require different policy responses. The interventions will depend on the type of urban centre, existing base conditions, immediate transport challenges, and the population's drivers of travel demand. The IEA identifies four city contexts which describe general travel characteristics and challenges facing cities across the globe (International Energy Agency, 2013).

Developing cities

These cities are characterised by high demand for transport services, and rapid growth in private vehicles. They often have inadequate transport infrastructure, especially for walking and bicycling, and weak public transport services. The urban sprawl in these cities encourages growth in motorised private vehicles leading to increasing roadway congestion, rising road-induced crashes and injuries, and harmful emissions. These cities are also characterised by inequities in access to transport, employment and social services.

Sprawling cities

These cities generally have low densities with their urban cores poorly defined. Commercial and business hubs spread throughout the metropolitan areas. The share of travellers using public transport, cycling and walking is generally low, while private motorised transport dominates as the primary mode of travel. Long distances between destinations make it difficult to provide efficient public transport services. Peak hour congestion is high, and road infrastructure requires heavy investments and maintenance due to ageing assets. Emissions and road-induced crashes are major concerns (Benfield, 2012).

Congested cities

These cities experience high volumes of traffic especially during peak hours. They have medium to high densities and strong urban cores. They generally have good public transport systems and high public transport modal shares. The cities are characterised by daily gridlock due to heavy traffic and dependence on private vehicles. Emissions and road crashes and injuries are also major concerns (IEA, 2012; UTIP (International Association of Public Transport), 2012).

Multi-modal cities

These cities are characterised by high public transport, cycling and walking mode shares. They also have strong urban cores and high densities. Their transport networks are interconnected and well-developed which encourages more efficient travel. Their mixed land-use developments and high quality public transport services provide travellers with good access to different mode choices. Their non-motorised infrastructure is also well-developed and includes cycling lanes and adequate pedestrian spaces. These cities feature public transport terminals, including train stations and bus interchanges. Some of these cities would also have implemented demand management strategies which discourage driving (e.g. road pricing, congestion charging and parking restrictions) (Wien (Stadtentwicklung Wien), 2006; Winkler, A., Hausler, 2009).

Matching policies to city needs

The "Avoid, Shift, Share, Improve" policies are applicable in numerous contexts but the degree or intensity of response may vary to suite the specific local needs and challenges (International Energy Agency, 2013).

Developing cities

In these cities, some of the potential policies include regulations that limit sprawling developments and land-use strategies that prioritise dense urban cores, such as transit-oriented development. Transport infrastructure upgrades, such as spaces for pedestrians and public transport networks, can also help to improve access to destinations. To maximise benefits, the infrastructure and land-use policies should be co-ordinated with travel demand management to ensure that improvements are competitive with private vehicles. Other actions include better regulation of public transport operations and increasing service quality and frequency of public transport.

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Sprawling cities

The long-term objective of policy interventions in sprawling cities is to transition them to denser urban centres that support more efficient transport. Medium and long-term goals include travel demand management and land-use policies that favour denser developments. Shorter terms policies include improving existing systems and prioritising strategies that shift travellers away from private motorised travel. These policies include parking reform, road pricing and traffic management tools that help to maximise efficiency of existing assets such as adaptive traffic signal control.

Congested cities

A range of policies apply to these cities. These include travel demand management to influence a shift to more energy efficient travel modes, in addition to policies that discourage vehicle ownership (e.g. Singapore's vehicle quota and Certificate of Entitlement). Intelligent Transport Systems solutions including real-time travel information can also help to improve mobility, while car-sharing and ride-sharing incentives can encourage additional shifts to more efficient travel modes. Shorter-term policies could address the gaps in network connectivity which also helps to encourage shifts away from private vehicles. These interventions would be more effective when they are paired with travel demand management measures.

Multi-modal cities

These cities can benefit from policies that improve traffic flows and access to more travel options. This includes dedicated facilities for energy efficient modes (e.g. bus and cycling lanes), and investments in vehicle technology improvements. Multi-modal cities can also benefit from travel demand management policies. The wide-spread use of ITS can also improve urban mobility including real-time information on road conditions and public transport arrival and departure times.

Can policy measures be combined to increase impact?

Improvements which focus on transport efficiency can have increased impacts when they are planned using a co-benefits approach (Ang, G., 2013), which addresses the relationship between transport and other urban issues, such as health and well-being. By developing such interactions between transport and other urban policies, decision makers can influence changes in the transport sector, which can help to secure broader support for transport initiatives (Table 5).

Table 5: Example benefits of sustainable urban transport policies

Source: (Chatman, 2013)

Policy Options	Benefits				
	Reduction in GHG emissions	Improved air quality and health	Reduced congestions	Increased accessibility	Improved road safety
Bus rapid transit (BRT) or Busways	Medium	Medium	High	High	Medium
Light rail or metro rapid transit	Medium	Medium	High	Medium/High	Medium
Rail	Medium	Low	Medium/High	Medium	Low
Low-carbon vehicles	Medium/High	High	Low or Negative	Low or Negative	None
Non-motorised transport	Low	Medium	Medium/High	Medium/High	Medium
Land-use planning	Medium	Medium/High	High	High	Medium

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Stakeholder Consultations

The success of urban transport policies relies to a large extent on the support it receives from the public and the wider stakeholders impacted by the policies. Soliciting the input and agreement of the stakeholders ensures the long-term success and support for these policies into the future. The stakeholders involved include city and regional elected officials, civil servants and national governments (if they are involved in the planning, financing and implementation of projects that extend beyond municipal jurisdictions). The stakeholders also include non-governmental bodies, professional organisations, consumer groups and private companies. Local government officials, particularly mayors, are very important in urban transport improvements. Cities often have direct ownership of city roads and have the capacity to set and enforce policies related to urban transport systems. This control enables mayors to introduce cycling lanes, congestion charging and road pricing, Bus Rapid Transit (Busways) and EV charging infrastructure. Often mayors also exert control over the major public transport services through regulation and policy setting (ARUP, 2011).

Case Studies

Low carbon mobility has many social and economic impacts that can transform cities around the world. In this section, a number of case studies are presented to demonstrate the use of some of the policy instruments described in this report. These case studies demonstrate how city investments in low carbon transport strategies result in more affordable, efficient, and safe travel connecting people to more employment and social opportunities. They also demonstrate how cities can accelerate the provision of social and economic benefits for city residents by choosing low-carbon transport policies and projects.

Congestion charging in London, Stockholm, Gothenburg, Singapore and Milan

Congestion charging has long been proposed by planners, economists, policy makers and peak bodies as a likely solution to improve mobility particularly in congested urban centres (Crawford, 2015). In some countries like Australia, road pricing and congestion charging are also the focus of an ignited debate on tax reform and the need to rethink how city dwellers pay for the transport infrastructure that supports their mobility needs. The current transport funding models, which are largely based on collecting revenue from fuel excise, vehicle registrations and license fees, is inequitable and is unlikely to generate enough funds to meet future

infrastructure expenditure requirements. These models will be under more stress in the future when revenue from fuel excise declines as consumers move towards electric vehicles and more fuel-efficient cars.

Congestion pricing is also the most likely solution to curb transport emissions in congested urban areas (Crawford, 2015). Through this approach, drivers would pay directly, through a user charge, for travel into congested areas (a road user driving in a regional area and not contributing to congestion in the city would not pay). The charge can be dynamic and would change to reflect the current congestion levels (higher charges would apply during peak hours). This would be part of an overall tax reform that would remove or reduce other transport taxes (e.g. vehicle registration which is essentially a 'property' tax as it is not a charge related to the amount of travel).

The scheme would also provide incentives for carpooling, car sharing and other strategies to encourage people not to drive into congested areas. Measures would also be put in place to provide more public transport and improve services. The revenue generated from the user charges would go towards maintaining and operating roads and transport services, and improving the travel options available for travellers.

Overseas, a recent report by the Royal Academy of Engineers in the UK (H. Dia, 2015) identified congestion pricing as the single best option to tackle road congestion. In Australia, road pricing has been paraded as a key approach to fix transport problems over the past few years. The Henry tax review in 2009 (Department of Treasury and Finance, 2010), the Productivity Commission review of public infrastructure in 2014 (Productivity Commission, 2014), and the Harper Review in 2014 (Commonwealth of Australia, 2014) all urged governments to consider road pricing as a matter of priority. These studies also recommended that governments conduct pilot studies to demonstrate the benefits to road users.

A number of cities overseas have already implemented congestion pricing. These include London, Stockholm and Gothenburg in Sweden, Singapore and Milan.

The benefits reported for these cities are compelling. In the 12 years since London started the scheme, traffic congestion was reduced by around 10% in the central city area (Davies, 2015). This included a 34% drop in private cars entering the area, and 28% increase in cyclists. The scheme also resulted in a 16% reduction in emissions within the charging zone, amounting to 30,000 tonnes annually. A recent study has also found that the program resulted in reducing traffic collisions by 40% between 2000 and 2010. In addition to saving money and lives, congestion pricing is also reported to raise more than

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$300 million every year which would go towards improving the city's transport services.

In Stockholm, the congestion pricing scheme removed 20% of peak hour vehicles and stimulated around 9% increase in public transport ridership (Jaffe, 2012). In the densely populated city centre, emissions decreased by around 10-14%. The system is also reported to have cut down particulate matter by 9 percent and mono-nitrogen oxides by 7 percent. It has also been generating daily revenues of $500,000 to $2.7 million for the city. These funds are then reinvested for expanding bike lanes and new bus lines.

Sweden's lesser-known congestion charging program in Gothenburg is also reported as a big success (Börjesson, M., Kristoffersson, 2015). The scheme was effective in reducing traffic by 12% during the peak hours, with many travellers switching to public transport.

Singapore's experience with congestion pricing dates back to 1975. This was in the form of an Area License System (ALS) which was based on a flat rate charge. The ALS reduced traffic by 45% and vehicle crashes by 25%. The ALS was replaced by an electronic road pricing system in 1998 resulting in a further 15% decrease in traffic (DAC & Cities, 2014).

These overseas success stories provide a unique insight into those cities' remarkable journeys in implementing congestion charging. Although the schemes initially proved to be decisive and controversial, more people have gradually become accepting of the approach particularly as the benefits became more visible.

Bus rapid transit in Guangzhou, Ahmedabad and Lagos

Bus rapid transit (BRT) or Busway projects can help reduce costs, make journeys more efficient, and cut GHG emissions.

The city of Guangzhou launched its BRT in 2010. The system carries 850,000 passengers every day and has succeeded in shifting 10-15 percent of trips away from private vehicles. In addition to generating annual savings of US $14 million and reducing 86,000 tons of CO_2 every year, passengers are reported to personally save $103 million in out-of-pocket travel costs and 30 million hours of travel (Yadav, N., Lefevre, 2016).

In Ahmedabad, the BRT has carried over 140,000 daily passengers since its establishment in 2009, and is expected to reduce the city's CO_2 emissions by 30% before 2040 (Yadav, N., Lefevre, 2016). A number of cost-effective projects such as designated entry and exit points to the system have led to 79 percent positive safety ratings for the system.

Nigeria's Lagos BRT system is also reported as a success story. It provides an efficient and affordable service to the local population where it has helped reduce the income spent by poor households on public transport from 17 to 11 percent. The BRT fares are structured such that they are 30 percent lower than those for traditional public transport (Yadav, N., Lefevre, 2016).

Bike share system: Paris

Paris' bike share program has about 20,600 bikes at 1,451 stations spread throughout the city. The municipal government is supporting the program through road safety campaigns, speed restriction zones and about 125 miles of new bike lanes to improve connectivity. This has helped increase ridership by 70 percent since the introduction of the program, cutting emissions down by 32,330 tons of CO_2 per year (Yadav, N., Lefevre, 2016).

Car-Free urban centres: Plans for Oslo, Milan, Dublin, Paris, Madrid and Brussels

Plans to ban private cars in parts of central business districts are being considered by some European cities (Jaffe, 2015). These plans are very controversial and are seen by many people as an intrusion on their freedom of choice. Nevertheless, some cities are using them as a last resort to curb vehicular traffic from central business areas. Since the start of 2014, at least six cities have announced ambitions to convert parts of their central districts into pedestrian-only spaces.

Oslo

The Norwegian capital plans to ban private cars in the central district by 2019. The city plans to enhance its bike infrastructure and improve its public transport services (Jaffe, 2015).

Milan

Milan has an existing congestion charging scheme in the city's centre. In July 2016, the city announced plans to restrict cars from its historical centre. The plan proposes for Piazza della Scala to join two other downtown pedestrian zones and gradually stretch outward to other parts of the city (Jaffe, 2015).

Dublin

In 2016, the Irish capital proposed a €150 million plan to ban cars from parts of the city centre as early as 2017. The city hopes to reach a point where 25 percent of people would commute into the central business district using private cars. The city is targeting increasing the mode share of public transport to (55 percent),

cycling (15 percent) and walking (10 percent) (Jaffe, 2015).

Paris

The French capital trialled a one-day ban on odd-numbered cars in the spring of 2014. The trial resulted in a substantial decrease in traffic congestion and pollution. This was followed by another temporary car-free day in 2016. The city is reported to be considering more trials and studies in future years (Jaffe, 2015).

Madrid

One of the world's most ambitious plans to ban cars from the city centre can be found in Madrid. In 2015 the Spanish capital began issuing tickets to drivers who either don't live in the central areas or don't have a guaranteed parking space in an official parking space. The city is hoping to make more areas of the city strictly for pedestrian use (Jaffe, 2015).

Policy Pathways

Policy pathways are intended to provide a practical guide to help national and local policy makers improve their response to urban transport system energy efficiency. Achieving energy efficiency improvements in urban mobility is not always easy, but many cities around the world have used the policy instruments described in this report and achieved substantial gains in energy efficiency as was discussed previously.

 The policy pathways include detailed steps for supporting the development, financing, implementation and evaluation of the described policies. These have been identified by the IEA based on the findings from a study (International Energy Agency, 2013) they conducted which documented success stories in more than 30 cities around the world. These pathways include four stages (Figure 23): Plan, implement, monitor and evaluate, with ten critical steps which have been developed based on lessons learnt from successful policy implementations from cities around the world.
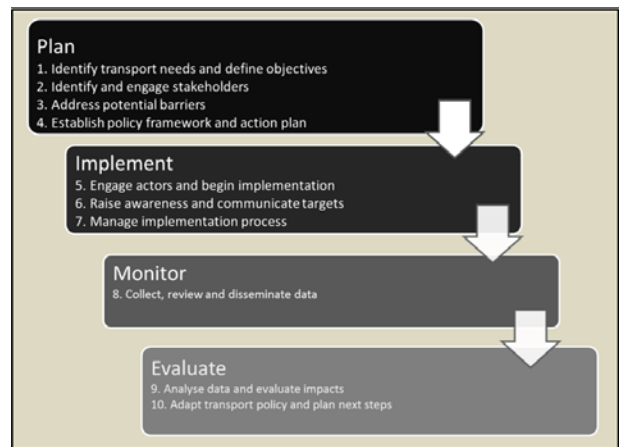
Figure 23: Policy pathways to low carbon mobility

Source: Author, adapted from (International Energy Agency, 2013)

The four stages in the policy pathway and the detailed ten steps identified by the IEA (International Energy Agency, 2013) are summarised below:

Plan

The planning stage includes administrative, technical and financial preparation to set the stage for implementation of the proposed policies. Stakeholder consultations and engagement with the public and decision makers are an important characteristic of this stage. This helps to ensure that the policy addresses the wider views of the community including other aspects such as transport accessibility, economic, social and environmental needs which also helps to ensure acceptance of the policies once they are introduced.

This stage includes steps 1-4 of the ten critical steps (International Energy Agency, 2013):

1. Identify the transport needs and the aims and objectives of the policy. This includes identifying the issues and needs of the community where the policy is being proposed; define the vision, aims and objectives, and clarify the policy responses most adequate to meet these needs. When identifying the user needs, data and information is collected/collated about the mobility needs of households; relationships that may exist between soci-economic status and access to services and opportunities; limitations of existing transport provisions; future needs; existing and desired modal shares; the status of the transport infrastructure; availability of public transport services; security and reliability of services; land-use plans for the area; the nature of the urban economic structure; governance; and population and demographics trends. Once the user needs and issues are identified, policy makers need to articulate a vision

and define the aims and objectives to address these issues. At this stage, both short-term and long-term objectives can be identified under the single vision. The projected improvements in the levels of service which the public can expect to see as a result of the policies are also articulated and expressed to the community. When identifying the policy responses, more than one specific policy can be implemented based on experience and lessons learnt from other implementations. This includes consideration of co-benefits and complementary measures by implementing a multiple-benefits approach that capitalises on common threads between multiple urban issues (International Energy Agency, 2013). For example, the pairing of road safety programs and travel demand policies could lead to improvements in the safe movement of people and goods, while also addressing congestion and energy efficiency.

2. Identify and engage stakeholders. Stakeholders provide support and feedback that can have valuable impact on the project. The number of engaged stakeholders varies but would generally include road and transport agencies, local city councils, public transport operators, and professional organisations representing their members. This step includes identifying the stakeholders who are likely to contribute to the decision making; who has authority and power to support interventions; who is affected by the policies; and what motivates their decisions. Genuine engagement and incorporating feedback from the stakeholders is key to the success of any new policy interventions.

3. Address potential barriers. Regardless of the policy instruments, barriers will exist to effective policy implementation. Identifying the potential barriers from the start, e.g. financial constraints, legal restrictions or inadequate regulatory frameworks, can help to manage their impacts if they are anticipated and planned for in advance. The steps involved include identifying the potential barriers; preparing to respond to the barriers; and engaging with the stakeholders to respond within specific time frames. For example, initiating legislative approvals and outreach to disfranchised or opposition groups can be pre-emptively taken before barriers hinder progress (International Energy Agency, 2013). It is also important in this step to identify the technical, institutional and financial resources required for successful implementation

4. Establish policy framework and action plan. This includes identifying the tasks that need to be completed; roles and responsibilities; time frames; and expected outcomes (International Energy

Agency, 2013). This helps to create a step-by-step framework to implementing and achieving the policy goals. The action plan should have direct input from the implementing bodies and stakeholders to ensure that the steps and timeframes are feasible. This step also includes preparation of a robust analysis of economic impacts; contingency plans and a framework for how progress will be measured and the key performance indicators that will be used to judge the efficacy of the policy. This could include measurement of impacts on energy use, car ownership and public transport ridership, parking spaces and requirements, population density, emissions, exposure to noise and accidents, and government revenues.

Implement

This stage includes steps 5-7 of the ten critical steps:

1. Engage actors and begin implementation. This includes defining the contracting and project management procedures that need to be put in place to allow for measuring performance and setting clear lines of communications, roles and responsibilities. This helps to ensure an implementation process that is smooth and successful. Once the planning process is complete, the policy is then launched through official announcements, press conferences and other ceremonies. The policy launches are important events to inform the public of changes and can also be used to raise awareness of policy objectives.

2. Raise awareness and communicate targets. This is a vital step to ensuring public acceptance of policy changes and initiatives. By communicating the goals and objectives of the policy measures, policy makers can raise awareness and encourage people to support the policy initiatives. Campaigns can also help to dispel any misconceptions and promote the real benefits of the proposed policies through effective communication. Examples of effective communication includes advertisements on billboards and buses, online information videos and outreach to target audiences. This step is also an opportunity for policy makers to communicate to the public the true cost of their mobility choices thereby encouraging behavioural shifts to more energy-efficient modes of transport.

3. Manage implementation process. This is a project management task that ensures the parties responsible for project execution are adhering to their roles on the project, and that progress is being made. Poorly managed projects can undermine confidence in a government's capacity to implement change (International Energy Agency, 2013), and such projects can potentially derail the policy goals. This step also includes verification of

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progress and ensuring compliance and timely delivery of project deliverables. Finally, this step is also an opportunity to provide technical training and build capacity to provide all relevant stakeholders with the support they need to execute the policy changes and disseminate information to the public.

Monitor

This stage includes step 8 of the ten critical steps:

1. Collect, review and disseminate data. To establish the impacts of the policy initiatives, data is collected before and after the policy initiation to measure the impacts. Effective and meaningful data is necessary to evaluate not only the benefits, but also any negative impacts that were not initially foreseen during the planning stage. The data collection process and goals should also reflect institutional needs and resource limitations, including budgetary concerns and financing. Data collection and analysis can be costly and therefore considerable planning needs to be undertaken to ensure the right types and amounts of data are being collected to measure performance. Once the data is collected, it needs to be reviewed, 'cleaned' and analysed according to established key performance indicators by which the project is going to be judged a success. All analyses should be verified and the results should be reproducible. There is an increasing expectation nowadays that the data collected should be open to the public and other interested parties.

Evaluate

This final stage includes steps 9-10. This step is aimed at establishing the effectiveness of the program of works in meeting the objectives of the policy. This in turn helps to determine how the policy can be improved for future implementations; what were the success/failure factors; and how can they be mitigated:

1. Analyse data and evaluate impacts. Once the data has been collected and 'cleaned', it can then be analysed and used to assess the effectiveness of the policy. There are a number of key performance measures against which the policy can be evaluated. These include (International Energy Agency, 2013): relevance (i.e. whether the project has met the policy objectives); effectiveness (the degree to which the objectives were met); impact (improvements that have been achieved); efficiency (cost-effectiveness); and sustainability (benefits can be maintained in the long-term). The evaluation also identifies the success or failure factors; the strengths of the project which should be replicated; and the weaknesses that should be avoided. Another important element of this step is communication of results and information dissemination, which are

vital to raising awareness of the benefits and increasing public support.

2. Revise policy and plan future directions. This step includes regular reviews of the policy to ensure that it continues to meet the desired objectives even as the system changes and evolves. This helps to provide insights into the inter-play between the demand for travel and the policy initiatives. It also helps to understand the public's willingness to change with respect to these initiatives. Planning the next steps also helps to continue development of existing programs.

Summary

This section provided policy guidance for developing low carbon mobility solutions. It identified the emerging trends and policy instruments that can be used to steer our cities on a sustainable course of urban mobility. These solutions are grouped into four broad categories using the 'avoid, shift, share, improve' dimensions. This section also examined the strategic pathways to low carbon mobility, and presented the policy principles that can help achieve efficiency improvements. These include planning dense cities; developing transit-oriented and pedestrian-oriented cities; optimising the road network and its use; public transport improvements; and planning for walking and cycling.

Central to these strategies is a recognition of the crucial role of integrated land-use transport planning, which involves the optimal distribution of facilities and services to allow residents in urban areas to access services and economic opportunity while minimising the use of private vehicles. This helps to ensure effective integration of transport and urban development policies. In order to become more sustainable, cities need to be more compact, encourage mixed land-use and prioritise sustainable modes of mobility (e.g. walking, cycling, and public transport, car-sharing and ride-sharing).

The case studies presented in this section demonstrate the benefits that can be achieved, not only in reduction of emissions and pollution, but also in reducing congestion and improving access to jobs and opportunities. This section argued that accessibility should be the central focus of any policies for achieving an urban form that is environmentally sustainable and socially equitable.

Finally, this section included steps for practitioners - based on lessons learnt from successful cities around the world - to support them in the development, financing, implementation and evaluation of low carbon mobility policies and practices.

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Digital innovations: Harnessing disruptive technologies for low carbon mobility outcomes

As was discussed before, our cities are playing an increasingly active role in the global economy (Dobbs, R, Remes, J, Manyika, J, Roxburgh, C, Smit, S & Schaer, 2012). Today, just 100 cities account for 30 percent of the world's economy. New York City and London, together, represent 40 percent of the global market capitalisation. In 2025, 600 cities are projected to generate 58 percent of the global Gross Domestic Product (GDP) and accommodate 25 percent of the world's population. It is also expected that 136 new cities, driven by faster growth in GDP per capita, will make it into the top 600 by 2025, all from the developing world, 100 of them from China alone (Dobbs, R., Remes, J., Manyika, J., Roxburgh, C., Smit, S., Schaer, 2011). The 21st century appears more likely to be dominated by these global cities, which will become the magnets of economy and engines of globalisation (Dobbs, R., Remes, J., Manyika, J., Roxburgh, C., Smit, S., Schaer, 2011; Dobbs, R, Remes, J, Manyika, J, Roxburgh, C, Smit, S & Schaer, 2012; Kaas, 2016).

The multitude of challenges facing our cities including congestion, emissions, ageing infrastructure and limited budgets to maintain and upgrade urban transport systems have also been described before (International Transport Forum, 2010; America, 2011; European Commission, 2011; Wilson, 2012; United Nations, 2014; Winston and Mannering, 2014; BITRE, 2015; Neumann, 2015; World Health Organisation, 2016a; Foundation, 2016; World Health Organisation, 2016b). Digital innovations are expected to have a role in addressing these challenges. Already, substantial progress has been achieved using Intelligent Transport Systems over the past 20 years. This includes a range of technologies that allowed operators to maximise the efficiency of the infrastructure.

Cities of the future will also include systems that utilise field sensors to detect and respond quickly to operational disruptions. Vital infrastructure downtimes will be cut using sensors that monitor the health of critical infrastructure, collect data on system functioning, alert operators inside an integrated urban control centre to the need for predictive maintenance, and identify potential breakdowns before they occur. Smarter vehicles, trains and public transport systems are increasingly sensing their surrounding environments and enhancing safety in situations where driver error is most common. Technology will also gradually influence car ownerships models, promote more ride-sharing and car-sharing in our cities and increasingly start to blur the line between on-road private and public transport systems.

The opportunities

The convergence of physical and digital worlds is creating unprecedented opportunities to enhance the travel experience for millions of people and businesses every day. Disruptive and emerging forces - including on-demand shared mobility, big data analytics and autonomous vehicles are expected to change the mobility landscape and provide travellers with more choices to meet their travel needs while reducing reliance on building additional infrastructure. The coming together of these trends is providing new opportunities to 'sense the city' and unlock operational innovations and access to high-quality urban mobility. Through data mining, artificial intelligence and predictive analytics, smart mobility systems can help city managers monitor the performance of vital infrastructure, identify key areas where city services are lagging, and inform decision makers on how to manage city growth.

Decision makers and leaders who run our complex cities are increasingly recognising the role of smart technologies in improving the efficiency of existing infrastructure and sweating of assets through better utilisation of available infrastructure (Hobbs, A, Hanley, 2014). These systems can significantly improve operations, reliability, safety, and meet consumer demand for better services with relatively small levels of investment (Batty, 2013).

Cities are essentially made up of a complex network of systems that are increasingly being instrumented and interconnected, providing an opportunity for better infrastructure management (Batty, 2013; Kitchin, 2013). An "Internet of Things" comprising sensors, monitors, video surveillance, and radio frequency identification (RFID) tags, all communicating with each other to enhance infrastructure capability and resilience, and capturing volumes of data (Kitchin, 2013). Through data mining, artificial intelligence and predictive analytics tools, smart infrastructure systems can help city managers to monitor the performance of vital infrastructure, identify key areas where city services are lagging, and inform decision makers on how to manage city growth and make our cities more liveable (Neumann, 2015).

Smart Cities: Technology-driven Urban Infrastructure

The infrastructure marketplace is rapidly changing and is becoming more dependent on technology to manage assets, collect and analyse data, generate and collect revenue, and provide decision makers with real-time information on system performance and operational problems. Cities around the world are increasingly recognising the role of smart technologies in improving

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the efficiency of existing infrastructure and sweating of assets through better utilisation of available infrastructure. These systems can significantly improve operations, reliability, safety, and meet consumer demand for better services with relatively small levels of investment.

The smart infrastructure paradigm includes applications of information technology, data mining, sensors, smart algorithms and predictive analytics to improve the performance of infrastructure systems and asset management in the buildings, energy, health, water, and communications fields as shown in Figure 24. Smart cities of the future will therefore include advanced network operations management and control systems that utilise field sensors to detect and respond quickly to equipment and infrastructure faults. This will reduce down time in vital city services by using these sensors to monitor the health of critical infrastructure, collect data on system function, identify potential breakdowns before they occur and when necessary alert operators inside an integrated urban control centre to the need for predictive maintenance (Batty, 2013).
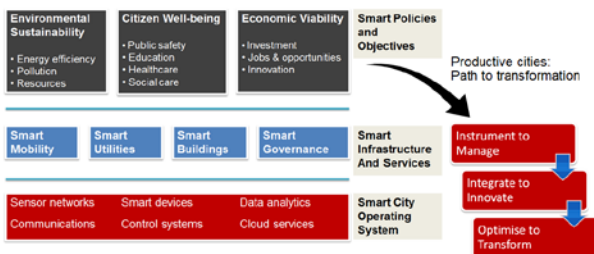
Figure 24 Smart cities model

Source: Author (Hussein Dia, 2015b)

Figure 24 illustrates that technology should be viewed and used only as an enabler to achieve a city's desired objectives. These objectives include, but not limited to, environmental sustainability (energy efficiency and improved air quality), citizen well-being (public safety, education, social care) and economic viability through providing access to jobs, services and opportunities. To achieve the desired transformation, cities would need to harness the increasingly available amounts of data from infrastructure and crowd-sourced information. To develop insights into this information, the data needs to be integrated, fused and mined to establish patterns and trends which can be used to optimise city services and transform cities to meet the desired policies and objectives.

Smart Mobility

The impacts of digital innovation have already started to be felt in cities around the world. Technology has brought with it smart phones, connected devices and infrastructure, highly automated vehicles and access to large amounts of real-time traffic data. For the first time in decades, road users have access to increasingly more sophisticated applications to help them plan their journeys and meet the demands of their travel. This fundamental shift offers consumers a real choice based on real-time and in some cases predictive information that allows users to plan ahead and anticipate delays and disruptions to their commute. New technologies also offer consumers mode choices based on comparative pricing and current network status. As transport operators change their business models, and new start-ups and technology providers enter the urban mobility landscape, new business models will continue to transform the use of information, payment, integration and automation (Deloitte, 2015).

Providing access to high-quality urban mobility services requires a variety of planning and operational innovations, as well as better understanding of travel behaviour, operational processes, and the factors which affect these issues. The last five years, in particular, have seen rapid developments in technology and a marked shift in the thinking towards the provision of mobility solutions to meet people's demand for travel in urban areas.

Smart mobility essentially includes systems that are used to provide seamless, efficient and flexible travel across all modes of transport. This is illustrated in Figure 25 which shows a number of elements which make up smart mobility including instrumented smart infrastructure, Intelligent Transport Systems (ITS), operational and strategic modelling. In addition, it also includes some of the emerging disruptive mobility solutions including mobility-as-a-service and the anticipated autonomous shared mobility-on-demand services.
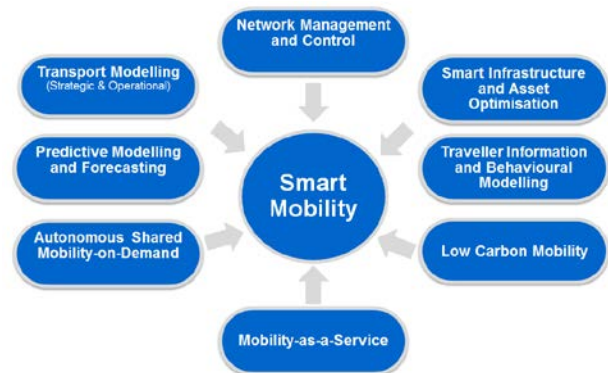
Figure 25: **Smart mobility model** (Hussein Dia, 2015b)

In practice, this would translate into smarter connected vehicles, trains and public transport systems which would increasingly sense their surrounding environments and enhance safety in situations where driver error is most common (Winston and Mannering, 2014). For example, on-board public transport, a range of GPS, position fixing, video surveillance, and communications equipment are increasingly providing more accurate and reliable multi-modal real-time passenger information, resulting in better informed travellers and ensuring a smoother, safer and more reliable experience for customers (Neumann, 2015). Back-office systems that leverage sensors, web, mobile, and GPS technologies are increasingly utilising smarter algorithms, data mining and predictive modelling tools to reduce delays to passengers by optimising schedules and capacities in real time (Neumann, 2015). Near railroad level crossings, a range of train-to-infrastructure and train-to-vehicle technologies are improving passenger safety by better detection of fast approaching vehicles and providing warnings to avoid collisions (Rail Level Crossing Group, 2010). Electric vehicle charging infrastructure will also increasingly being integrated into smart grid networks, providing consumers with access to sustainable and equitable forms of connected mobility (Yi, P, Kandukuri, 2012). A combination of technologies and sensors will also improve safety and security by permitting operators to remotely disable or enable a public transport service in the event of a security threat (e.g. an unauthorised driver).

Disruptive technologies

Disruptive forces are increasingly changing the mobility landscape and providing consumers with more choices to meet their travel needs while reducing reliance on building additional infrastructure. Although some of these technologies are still a few years away (e.g. driverless vehicles), they have already started to shape a vision for a mobility transformation driven by a number of converging forces including vehicle electrification, automated self-driving, mobile computing, on-demand shared mobility services (Burt, M, Cuddy, M & Razo, 2014), mapping and predictive analytics. The coming together of these powerful trends, and the ability to monitor and control things in the physical world electronically, have inspired a surge of innovation and enthusiasm about the future of urban mobility. Some of the most notable disruptions that are either being introduced or planned for cities include the collaborative on-demand shared mobility services and autonomous vehicles. These are aimed at improving the passenger experience, access to jobs, services and opportunities, reducing both capital and operations costs and enhancing the resilience and efficiency of city services.

Autonomous vehicles

Vehicle automation is part of a much larger disruption in automation and connectivity. A number of studies provide a comprehensive coverage of the technologies and the anticipated impacts on mobility (Burt, M, Cuddy, M & Razo, 2014; International Transport Forum, 2015b; Cunningham, 2016; Dia, 2016b; Nvidia, 2016). Vehicle autonomy will increasingly play a bigger role in the mix of travel options available to travellers in the future, although their benefits won't be fully realised until the opportunities are well-developed for fully autonomous vehicles. Only then, when the human driver is no longer included in the costing of trips, will they reap their potential benefits. As was discussed before, their advent may also bring some negative impacts if they are not planned for as part of a holistic approach towards low carbon mobility.

Collaborative Shared Mobility

To date, the transport sector is the most funded industry in the Collaborative Economy (Owyang, 2015). This is manifested by one of the most promising trends within the disruptive mobility space, known as 'Mobility-as-a-Service' or (MaaS) as shown in Table 6 (Bouton, 2015). The key concept behind MaaS is to place the road users at the core of transport services, offering them mobility solutions based on their individual needs.

This means that easy access to the most appropriate transport mode or service will be included in a bundle of flexible travel service options for end users. MaaS has the potential to fundamentally change the behaviour of people and reduce reliance on car ownership by providing easy on-demand access to the mobility services they need (Kamargiani, M, Matyas, M, Li, W, Schafer, 2015). The trend is therefore gradually shifting, particularly in the context of smart cities, from the provision of urban transport networks i.e. buses, trams and trains, to a focus on what people require, and how a more considered and integrated approach could produce far better outcomes (Burrows, 2015). The key advantages to these new services include reliability, predictability, convenience and ease of accessibility. Most services also offer easy and secure payment options using cashless mobile transactions. For a given trip, consumers can select from different types of services based on trip distance, waiting and travel times and levels of service (Center for Automated Research, 2016).

Self-driving vehicles will have a dramatic impact on urban life especially when they begin to blur the distinction between private and public modes of transport. By combining ride sharing with car sharing, it may be possible to meet people's need for travel with much fewer vehicles. As more sensors and intelligence saturates our cities, it will become possible to collect

more accurate real-time information, seamlessly, on every dimension of urban life. Consider HubCab, for example, which is a web-based interactive visualisation tool that looks at how New York's 170 million annual taxi trips connect the city (Santi, P, Resta G, Szell, M, Sobosevsky, S, Strogatz, S, Ratti, 2013). Gradually, it is becoming easier to see precisely where, how, and at what times different parts of a city become stitched together as hubs of mobility. By using these technologies, decision makers can begin to unravel the complexity of travel patterns and identify how to reduce the social and environmental costs embedded in transport systems. HubCab, as an example, was developed to target taxi services as a way to understand the linkages between travel habits and the places people travel to and from most often. The same principles can be applied to optimise the performance of autonomous on-demand mobility systems.

Table 6 New urban mobility services

	Traditional mobility solutions	New mobility Services	
Individual-based mobility	Private car ownership	Car sharing: peer to peer	A peer-to-peer platform where individuals can rent out their private vehicles when not in use (e.g. Turo)
	Taxi	E-hailing	Process of ordering a car or taxi via on-demand app. App matches rider with driver and handles payment (e.g. Uber, Lyft)
	Rental cars	Car sharing: fleet operator	On-demand short-term car rentals with the vehicle owned and managed by a fleet operator (e.g. GoGet, Car2Go, ZipCar, Getaround)
Group-based mobility	Car pooling	Shared e-hailing	Allows riders going in the same direction to share the car, thereby splitting the fare and lowering the cost (e.g. UberPool, LyftLine)
	Public transport	On-demand private shuttles	App and technology enabled shuttle service. Cheaper than a taxi but more convenient than public transit (e.g. Bridj)

Source: Adapted from (Bouton, 2015)

Access versus Ownership and the Collaborative Economy

The disruptive mobility trends have the potential to fundamentally change the relationship between the consumer and automobile. The rise of the collaborative or sharing economy, popularised by the companies such as Airbnb, Zipcar and Uber, has enjoyed remarkable rapid growth over the last few years and looks set to scale new heights over the next decade (Kaas, 2016). Access to mobility rather than to car ownership will enable customers to be more selective in choosing from the door-to-door mobility services offered by 'mobility operators' for intercity, suburban as well as 'last kilometre' travel solutions. Today, consumers use their cars as "all purpose" vehicles regardless of whether they are commuting alone to work or enjoying a leisurely drive with the family to the beach. There are already significant early signs that the importance of private car ownership is declining, and shared/collaborative

mobility is increasing. With mobility offered as a service, consumers in the future will have the flexibility to choose the best solution for a specific trip purpose, on demand using their smart phones. According to a recent report (Kaas, 2016), the shift to diverse mobility solutions is likely to result in 10% of new cars sold in 2030 to be a shared vehicle. This will reduce private-use vehicle sales but at the same time increase utilisation of shared vehicles. This will lead to a faster replacement rate of shared vehicles which may offset some of the reduction in private-use vehicles. The report also estimates that more than 30% of kilometres driven in new cars sold could be from shared mobility.

Opportunities through Technologies

The shift towards embracing collaborative mobility is driven by the recognition of the potential opportunities, and risks, generated as a result of the interaction between existing and emerging disruptive technologies (Kaas, 2016). The use of collaborative mobility has been seen as a way of harnessing new developments, like big data analytics and the Internet of Things, to mitigate against the effects of potentially negative trends, like increased congestion and pollution resulting from continued urbanisation (Doherty, M.J., Sparrow, F.T., Sinha, 1987; Hu, 2015).

With population growth expected to add an additional billion people to the world's inhabitants within the next decade, and with 60% of these people expected to live in cities, transport operators are faced with a situation where traditional methods will no longer be sufficient to restrain congestion (World Resources Institute, 1994; Bouton, 2015). Under these conditions, increasingly large amounts of effort are being diverted into alternate means of providing mobility (Hietanen, 2015). In addition to the efforts by transport authorities, who are already struggling to keep pace with existing congestion levels, the predicted migration of the earth's population towards its cities will cause congestion to spread to regions that have never before experienced traffic issues (Bouton, 2015; Kaufman, 2016). The following section reviews some of the opportunities and trends, and identifies ways that they have potential to influence the drive towards collaborative mobility.

Digitalisation and the Internet of Things

Since the conception of collaborative mobility, attempts to organise large scale programs have been hampered by the difficulty of establishing an effective central administration (Doherty, M.J., Sparrow, F.T., Sinha, 1987). The underlying premise behind any collaborative mobility enterprise is to increase transportation

efficiency by increasing vehicle utilisation. This cannot be easily achieved without strong centralised control of the vehicle fleet (Burrows, 2015). Early examples of failed attempts included the Procotip (Montpelier, France, 1971) and Witkar (Amsterdam, 1973) shared car schemes. Both of these schemes made compact small vehicles available for use in and around the congested inner city areas using a payment token system. Both of these schemes failed because of inefficiencies in vehicle distribution caused by a lack of control over the vehicle fleet, resulting in poor asset utilisation and excessive downtime between each trip (Doherty, M.J., Sparrow, F.T., Sinha, 1987).

At the same time, the advent of the 'Internet of Things' - whereby people and physical objects are constantly interconnected to the Internet - has also exacerbated effective control of such undertaking (Burrows, 2015). Operators are now provided with unprecedented levels of data, including real time analysis on everything from vehicle positions to weather patterns. With this data available, the challenge facing transport decision makers is no longer about gathering information, but how to use the information available for decision making in a meaningful and timely manner (Liu, J., Lin, D., Li, 2010). In Finland, the Kutsuplus bus network received constant updates on traffic conditions, allowing drivers to provide updated estimates of arrival times to their passengers, often accurate to within 30 seconds (Finger, M, Bert, N & Kupfer, 2015). Around the world software developers have developed tools to combine information on every transport option available in a given city. Users simply enter their origin and destination, and the software would provide them with a route optimised for cost, travel time, comfort or environmental efficiency (Hussein Dia, 2015a).

The MaaS and shared mobility trends are breaking down the boundaries between different transport modes. This is largely due to the fact that technology is creating an intermediate level between the different means of transport and their users, which is made possible by the fusion of data into a new data layer. This is introducing new challenges to the regulatory and policy frameworks of transport. For the users, the focus will no longer be on the transport mode, but rather on mobility which will increasingly become an information service with physical transportation products, rather than a transportation product with services (Karl, 2015). In addition to ensuring public safety and access to services, regulators and policy makers must also oversee other aspects such as interconnection, interoperability, capacity management, standards, and security. To achieve this, regulators must focus on the establishment of new comprehensive regulatory frameworks which would enable the use of information technology

especially across the different transport modes. In particular, this will imply the need to develop an outcome-focused regulatory framework which (1) puts the users at the centre of the new mobility system, (2) encourages innovation and promotes safety, security, social equity and environmental sustainability. In the short-term, MaaS will also provide public agencies with the opportunity to bring innovation to their own transport services. In the long term, public agencies may need to rethink their role and consider opportunities for public-private-partnerships and service agreements with private mobility providers (Center for Automated Research, 2016). This new perspective will allow policy maker to focus on the regulation of the new data layers as well as the interface between the data layers and the physical transportation services.

In many cities in the U.S., public agencies are increasingly considering MaaS as an opportunity to provide more mobility options and also address the first-and-last-kilometre problem, particularly during late hours of the night and in low density areas. Few cities are already collaborating with mobility providers such as Bridj and Uber to supplement and strengthen their existing public transport offerings and are viewing the technology and mobility providers as partners rather than competitors. Some examples from Tampa, Dallas, Atlanta, Memphis and San Francisco demonstrate how this can be achievable and cost-effective (Center for Automated Research, 2016).

Another challenge to policy makers is protection of privacy. Those who have access to the data (and especially to the way the data is conveyed to the end-users) control the information and have immense power. The abuse of such data and information can result in market distortions, security risks, and diminished privacy protection (Karl, 2015).

The arrival of shared autonomous mobility-on-demand systems is also likely to introduce major challenges to policy makers. Regulations will in the future play a key role in the emergence and development of autonomous vehicles and the new business models around them such autonomous MaaS. They are also likely to be the biggest hurdle for the deployment and public acceptance of these services. The regulators are already adapting and rethinking their approaches on this issue to avoid stifling the innovative uses of these technologies. Effective responses require an early and on-going dialogue between regulators, developers and the public in which regulators would create legal frameworks that are flexible but robust. An important role for the regulators will be to limit physical risks especially those that might be posed during interim years when legacy fleets of cars

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would interact with the autonomous vehicles that are offering the MaaS solutions.

The benefits: More for less

Adoption of technology-based customer-centric approaches have the potential to introduce substantial improvements in customer satisfaction, and create a shift in attitude to cost and value. A smarter city will mean better access to sustainable forms of transport; electricity and drinking water that can be counted on; and energy-efficient buildings resulting in enhanced standards and quality of life for today's increasingly empowered citizens and consumers. In addition to improving asset utilisation, these systems will also improve safety and security, enhance business and operational outcomes, boost productivity and economic growth, and deliver environmental benefits.

Given the maturity levels and affordability of smart technologies, these benefits can be achieved at a fraction of the cost of investment in new infrastructure. In a study for the Australian Market (Wollschlaer, D, Foden, M, Cave, R, Stent, 2015) reviewed the potential economic benefits from the adoption of smart technologies in transport, electricity, irrigation, health, and broadband communications. The report examined how smart systems will allow the use of vast amounts of data collected in all areas of city activity far more effectively, providing the potential to radically alter our economy and society for the better. Their research demonstrated that smart technologies would have significant benefits including a 1.5 percent increase in GDP, and increase in the net present value (NPV) of GDP by $35-80 billion over the first ten years. In another report prepared by the Climate Group (Ford, 2015) on behalf of the Global e-Sustainability Initiative, it was estimated that a 15 percent reduction in emissions can be realised in 2020 through smart technologies that achieve energy and resource efficiency using adaptive and proactive technologies.

Globally, the benefits of investment in smart infrastructure is highlighted by research from the McKinsey Global Institute (MGI) which looked at how modernising our infrastructure to drive economic growth will require costly future investment in new projects (Titcomb, 2016). The MGI study, which looked at the projected global infrastructure investment over the next 17 years, estimated that just keeping pace with projected global GDP growth will require $57 trillion in infrastructure investment between now and 2030. Nearly 60 percent more than the $36 trillion spent over the past 18 years, and more than the estimated value of today's infrastructure.

Given widespread fiscal constraints, even assembling the minimum investment required to meet growth predictions is going to be a challenge. So rather than investment in new projects, governments should look to address some of their infrastructure needs by getting more out of existing capacity by adoption of smart infrastructure technologies. Boosting asset utilisation and expanding the use of demand-management measures can produce a decisive difference if scaled up globally, and can result in savings of up to $400 billion a year according to the MGI research.

The literature on smart transport technologies is abundant with case studies which demonstrate the benefits of Intelligent Transport Systems (Titcomb, 2016). In addition to reducing reliance on building additional capacity, smart infrastructure technologies also offer a much lower capital and investment cost. For example, the cost of the transport technology solution on the UK's M42 motorway was $150 million and took two years to implement; widening the road to produce the same outcome would have taken 10 years and cost $800 million (Titcomb, 2016). Other studies have also suggested that using smart transport technologies for roads, rail, airports and ports can double or triple asset utilisation. The average cost benefit ratios for each category of road improvement project are displayed in Figure 26.
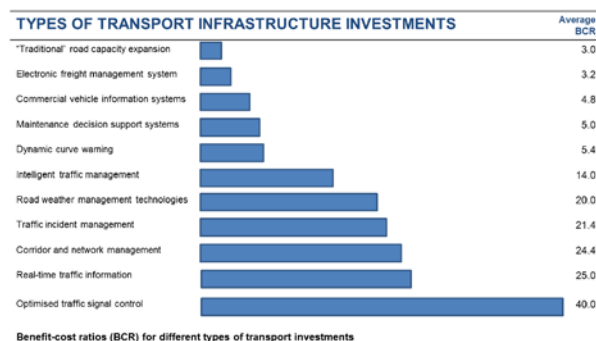
Figure 26: Comparison of cost-benefit-ratios for different road investment strategies

Source: Author (Adapted from (Titcomb, 2016))

Case Studies - Mapping the Value beyond the Hype

The ability to reduce congestion, cut travel times, improve trip efficiency, save petrol and reduce pollution through the use of collaborative mobility has long been understood (Doherty, M.J., Sparrow, F.T., Sinha, 1987). The addition of high funding levels and the potential to create an entire new consumer market within the

transport sector offers a tempting reward for anyone who can unlock the potential of collaborative mobility (Kaas, 2016). With the capacity for profit, combined with environmental and social benefits, a wide range of international initiatives have been launched, with varying degrees of success, in an attempt to harness its potential (Barber, 2016). The following section will analyse some of the key collaborative mobility projects that have been undertaken around the world. It will focus on identifying success and failure factors, and will try to identify lessons that may be learnt from each case.

Early Beginnings

While recent advances and breakthroughs in technology have helped the push towards 'mobility as a service', the benefits have long been recognised (Doherty, M.J., Sparrow, F.T., Sinha, 1987). Two examples of early experiments of collaborative mobility are presented next.

Purdue University – Mobility Enterprise (1983)

In January 1983, Purdue University began its Mobility Enterprise, which provided families who joined the scheme with a MAV (Minimum Attribute Vehicle or 'small car') and access to a shared pool of larger vehicles. The aim of the project was to use the availability of shared cars to enable drivers to choose a fit-for-purpose vehicle for each trip, rather than having to use an all-purpose vehicle for every occasion. It was expected that this would increase the efficiency of the vehicle kilometres travelled and reduce fuel consumption. The experiment ran for two and a half years and incorporated an average of 12 households. To encourage people to join their experiment, the Mobility Enterprise had to be competitive when compared with private car ownership. The results from this initiative showed a significant reduction in fuel consumption, but no change in the driving habits of those involved. The researchers found that they were not able to significantly influence the driving behaviour of those involved. However, the project was able to demonstrate that fuel consumption could be reduced through use of fit-for-purpose mobility and that a tangible monetary saving can be used to motivate change (Doherty, M.J., Sparrow, F.T., Sinha, 1987).

San Francisco – STAR Project (1983-1985)

The STAR (Short Term Auto Rental) project was undertaken in the San Francisco area between 1983 and 1985. The project identified an apartment complex of 9,000 residents that was well serviced by public transport, and established a car rental dealership within the precinct which provided competitively-priced short-term rental agreements. The aim of the project was to demonstrate that it was possible to live in an American City without owning a motor vehicle. The study found that since the public transport services were well utilised during the commute to and from work, many of the trips made by private vehicle were discretionary in nature. For these discretionary trips, the presence of a rental dealership would allow drivers the choice of a fit-for-purpose vehicle, providing fuel savings and increased vehicle utilisation. The project was a partial success, with those who made infrequent trips electing to forgo private vehicle ownership (and in some cases saving as much as $1,000 a year). But the project was limited in that it was only utilised for discretionary, non-work related trips. The project concluded that the scheme was well-suited to provide fit-for-purpose mobility in support of high quality public transport (Doherty, M.J., Sparrow, F.T., Sinha, 1987).

New Beginnings

In recent years, the convergence of technology and infrastructure has renewed interest in shared mobility. Some of the emerging trends in this space are covered next.

Car sharing services

As most private vehicles are only utilised less that 10% of the time, shared car services aim to increase vehicle utilisation and efficiency by maintain a fleet of vehicles that can be accessed on either a subscription or hire basis (Bouton, 2015). Global car sharing provider Zip Car estimates that due to the increased utilisation of the vehicles, each of the shared vehicles can replace as many as 15 ordinary vehicles, though it should be noted that most Zip Car users drive between 60% to 80% less than the average motorist and this allows each shared car to provide for a greater number of people than would otherwise be the case (Burrows, 2015). Surveys of the users of Autolib, the French car sharing operator revealed that of those who did not own a private vehicle, 70% listed Autolib as the reason that they had been able to move beyond private car ownership (Burrows, 2015). In recent years some shared car providers have been developing new additions to their services and forming new partnerships to further realise the potential of collaborative mobility (Crist, P, Greer, E and Ratti, C, 2015). In an attempt to increase the attractiveness of car sharing in inner-city environments, companies are attempting to provide services that facilitate short-term, impulse use of shared cars. BMW's Drive now program uses flexible hire services to accommodate short distance trips. Proving initially to be successful, the scheme has now been established in 5 German cities as well as London and San Francisco (Doherty, M.J., Sparrow, F.T., Sinha, 1987). Ford's City Driving on-demand

scheme follows a similar approach and utilises a pay-by-the-minute hire scheme with the option for one way trips (Benjamin, 2015). In Germany, the car-sharing operator Flinkster reached an agreement with Ford to have access to Ford's existing network of car dealerships as depots for the car-share scheme. In doing so, Ford and Flinkster have created a nation-wide car-share network without the capital for purchasing land and storage facilities (Benjamin, 2015).

Two other schemes currently being trialled by Ford are for non-corporately controlled car sharing. The "Car Swap" register is an internal experiment where a registry has been compiled of Fords employees in the Dearborn area in the USA. The register includes people who are interested in car sharing their vehicles. If someone who is part of the scheme needs a vehicle with some particular feature, a search of the registry would provide a list of people who they can contact to acquire the use of that vehicle. Ford's second user-managed scheme 'Share Car' is currently in the development stage, with a team in Bangalore partnering with Zoomcar to establish the legal framework that would allow a group of people to jointly share ownership of a private vehicle (Benjamin, 2015). A final scheme from the Ford motor group is the Remote Positioning project being undertaken in Atlanta, USA. The project is aiming to perfect the use of drone vehicles that can be controlled from a centralised facility, as shared vehicles. The use of these vehicles would allow a shared car operator to both deliver a vehicle to the customer's door and retrieve used vehicles from any point without the cost and time involved in physically ferrying valet drivers backwards and forth between jobs (Benjamin, 2015).

E-hailing

The largest, most heavily-funded and most well-known on-demand mobility providers are the e-hailing services such as Uber, Lyft and Didi (Burrows, 2015; Hietanen, 2015). Using private drivers who supply their own vehicles (to minimise the capital cost associated with traditional fleet operations), these companies operate an on-demand taxi-like service in most major cities around the world (Bouton, 2015; Burrows, 2015). In particular, Uber is rapidly destabilising the traditional taxi industry (Burrows, 2015; Hietanen, 2015) with recent reports showing that together with competitor ridesharing companies, they have captured more than 50% of the taxi market share for trips. Uber also has a ridesharing variant of its service known as UberPool (Titcomb, 2016) which operates in a number of cities including London. Statistics released by Uber claimed that, after six months of UberPool being introduced to London, the system has saved 700,000 vehicle miles (1,120,000 km) or 52,000 litres of fuel [59]. This saving translates to savings of 124 tons of CO2 (Katal A, Wazid, M, Goudar, 2013). Uber also claimed that in some cities, over half of the trips are now being made using UberPool (Mims, 2013).

Public transport innovations

While most cities are continuing to push ahead with the expansion of existing conventional public transport networks (Beijing alone constructed over 230 miles (380 km) of subway between 2008 and 2015), the world is increasing seeking ways to diversify the current transport options (Bouton, 2015). Active transport (walking or cycling) has recently been gaining acknowledgement as a legitimate transport option, with bikeshare schemes flourishing around the world (Bouton, 2015). In Paris, these two trends have been combined, with the city including its bikeshare service under the umbrella of its public transport network (Bouton, 2015). Probably the most innovative approach to public transport in recent times is the on-demand buses such as Kutsuplus and Bridj described next.

Kutsuplus - On demand public transport

The city of Helsinki in Finland has been praised for its 'ambitious' plans and target to overcome the need for private car ownership by 2025. The Kutsuplus mobility experiment initiated is seen by many as the flagship project leading this attempt (Hussein Dia, 2015a). Hailed as the first true on-demand public transport service, the Helsinki Regional Transport Service ran a technology-driven minibus service which utilised advanced algorithms to assign vehicles based on passenger demand on a real time basis (Barber, 2016). The initiative entered active service in 2012 with a fleet of three dedicated minibuses. Kutsuplus allowed commuters to specify an origin and a destination point (within a defined service area), and the algorithm then identified a minibus travelling in that direction and instructed its driver to pick up the new passenger (Finger, M, Bert, N & Kupfer, 2015).

The Kutsuplus experiment was launched with two initial goals: (1) Test the technological feasibility of using computer-based routing algorithms to overcome the difficulty of maintaining effective control over mobility; and (2) Measure public support and willingness to pay for on-demand public transport (Barber, 2016). The service received strong public support with positive feedback and continual growth in ridership figures (Barber, 2016). A survey of user satisfaction recorded an overall satisfaction rating of 4.7 out of 5, 10% higher than the satisfaction rating received by Helsinki's conventional public transport networks (Rissanen, 2016). An important finding from this experiment, which is

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relevant to other collaborative mobility operators, is that people were willing to accept longer travel times during a journey more readily than they would accept longer waiting times at the start of a journey. This finding helped the operators to revise the algorithm used for bus routing to minimise waiting times on pickup which resulted in an considerable increase in the number of users (Finger, M, Bert, N & Kupfer, 2015).

Although the cost per trip was reported to be lower than that seen in conventional bus services (Finger, M, Bert, N & Kupfer, 2015), the Kutsuplus bus service was deemed a financial strain on the public purse and was discontinued at the end of 2015 (Kaufman, 2016). This was contrary to public expectations of seeing the service expanded into the future (Barber, 2016). To increase ridership, the system needed to provide a more attractive service covering a larger service area, longer operating hours and shorter waiting times at pick-up. While some improvements in service quality were achieved, larger-scale increases in the services required the purchase of extra vehicles (Finger, M, Bert, N & Kupfer, 2015). Data collected during the trial showed that every time the service was expanded, the increase in passenger numbers improved the efficiency of the entire system because a higher density of users allowed the computer algorithm to plot a more optimised route with less meandering to pick up lone passengers (Finger, M, Bert, N & Kupfer, 2015). To that end, it was reported that a 31% increase in the system's capacity would result in an average of a 60% increase in income (Kaufman, 2016).

Other examples of on-demand public transport

The almost success story of Helsinki's on-demand minibus service has drawn interest from around the world (Kaufman, 2016). Kutsuplus demonstrated to both governments and individuals that on-demand collaborative mobility was challenging but feasible from a technology perspective (Finger, M, Bert, N & Kupfer, 2015). Since Kutsuplus' launch, cities around the world have begun to adopt similar on-demand shared mobility solutions. Many of these schemes are directly modelled after Kutsuplus, like the Via Transportation and Chariot systems (Bouton, 2015). Other initiatives, however, have used Kutsuplus as a base framework but have then tailored the system to overcome identified weaknesses and meet the needs of the operator (Kaufman, 2016). An example is the Bridj service which includes a number of cities and project in the U.S. including Kansas City (Missouri) where Bridj partnered with the city to provide a partial on-demand service. The city-owned Bridj busses follow a rough route in accordance with an established timetable (like in a traditional bus service) but will respond to customer request for pick up along that route (Kaufman, 2016).

In both London and New York, Ford has launched Dynamic Social Shuttle, its own on-demand minibus scheme with a focus on minimising response time. Ford aims to use this project to gain data on shared mobility patterns and better understand the social dynamics that are driving shared mobility (Benjamin, 2015).

The Split project in Washington DC uses the same software as the Kutsuplus mini busses to optimise vehicle routes and travel times. However, it has succeeded in overcoming the growth difficulties that crippled its predecessor by using private vehicles for its fleet. This Uber-style approach where drivers provide their own vehicles reduces the financial barrier to growth which prevented Kutsuplus from achieving the scale of operations that would have allowed it to function effectively (Benjamin, 2015).

In Bangalore, rather than using dynamic pricing to affect the cost of bus fares throughout the day, the bus operators issue a raffle ticket to every person who travels on a bus outside peak hours, with cash prizes for the lucky winners. The scheme doubled the pre-peak ridership, and reduced peak hour travel times by 24% at little cost to the bus operator (Burrows, 2015). As a point of comparison, Singapore's attempt to influence pre-peak ridership on their rail lines achieved a 7% shift in passenger numbers by making all travel before 8 am free (Burrows, 2015).

Crowd-sourcing and data fusion

One of the key challenges facing mobility providers and data analysts is how to combine and fuse data streams from separate, often incompatible sources and combine them into a meaningful, user-friendly and cohesive set of information [60]. The computer algorithm used to direct the Kutsuplus busses was one of the first to combine user requests with spatial positioning and real time traffic reports to control route planning and predict accurate estimates of arrival times (Finger, M, Bert, N & Kupfer, 2015). The success of this computer algorithm has paved the way for a new era of informed journey planning (Kaufman, 2016). By combining multiple information sources into one interface, tools like London's "CityMapper" application (now expanded to cover 10 EU cities) can increase the efficiency of people's mobility by allowing them to view all of their options in real time, and optimise their journeys (Burrows, 2015). Other initiatives such as Moovit and Moovel are also being used around the world with each system offering some unique features (Burrows, 2015). For example, the Moovit App augments its data collection by utilising

customer feedback to increase the accuracy of its route recommendations (Burrows, 2015). The WAZE App, while not a journey planning app, advises drivers of traffic congestion and disruption in real time, guiding their vehicles around hotspots to reduce travel time and save fuel (Bouton, 2015).

The concerns

Although there is considerable support for the benefits of embracing the possibilities that smart mobility has opened through the availability of big data and the internet of things, international governments and service providers have proved slow to adopt these changes (Neumann, 2015). While some of this delay has undoubtedly been caused by conservative decision makers reluctant to to trial new technologies, this pragmatic view can in the long term hinder rather than help with adoption and uptake (Winston and Mannering, 2014). As with all new emerging technologies, there also exist community concerns that must be addressed in order to accelerate the wide scale acceptance of the technology into society (Hobbs, A, Hanley, 2014).

Research into the application of smart mobility has identified three main areas of concern that need to be addressed. These include legislative support, software resilience and personal privacy (Kitchin, 2013).

Legislative support

It is often argued that the current legislative frameworks provide insufficient guidance and constraints in dealing with the potential of where smart mobility and smart cities could lead (Neumann, 2015). This lack of legislative support is understandable as the rapid advancements in technology that have been made in recent years have left the traditional legal policies out of date and insufficient to deal with the realities of big data and the interconnectedness of things at a city-wide level While some law-making bodies are beginning to investigate and legislate (for or against) smart mobility (for example, Europe is considering laws making communications software with inbuilt automatic distress functions mandatory in all new vehicles), the issue is still largely in limbo (Hobbs, A, Hanley, 2014). While the uncertainty regarding the legality of new policies and technologies remains, it will be difficult to formulate an effective plan for the future (Kaas, 2016). For example, this uncertainty is highlighted by the development of legislative governance surrounding self-driving cars in America. Out of fifteen states to debate laws allowing the trial of AV's, nine states (60%) rejected the proposal.

Software resilience

While smart mobility is designed to improve the resilience of transport infrastructure by responding to disruptions in real time, it's success (or in fact its entire operation) is based upon the quality decision making software and the quality of the digital network that supports that software (Batty, 2013). Some researchers have expressed some valid concerns that the concept of smart mobility is based upon brittle foundations and that as more and more items are added to the existing internet of things (from which all smart mobility initiatives draw their decision making data), the likelihood of a software malfunction or incompatibility error compromising some or all of this web is growing (Kitchin, 2013). They argue that such service failures (power blackouts, loss of mobile networks, poorly handled version updates) have been a traditional part of life, but the interconnectedness of the modern world means that failure of one point could (if the system has not been properly designed) have flow-on considerations for the rest of the smart cities structure (Kitchin, 2013). While the obvious remedy for this concern is the careful, methodical, construction of a city's data collection web, the prohibitive cost of establishing duplicate infrastructure will mean that software developers will be working with the existing systems of dispersed data collection methodologies and all of the data compatibility issues that it implies.

Added to the concerns of unnoticed errors is the problem of cyber-attack, where an external party chooses to cause the software to fail. In an age of growing tension and mistrust, this is a very real and present danger (Kitchin, 2013). The issue that must be resolved with any smart system is simply: When this system fails, how much of the smart city will it take with it (Kitchin, 2013).

Privacy

In the age of the internet of things, personal data is being created, transmitted, tracked and recorded at an unprecedented rate. Take mobile phone data as an example. Even without the benefit of triangulation, a single tower can place the location of an individual's mobile phone to within a few kilometres. With triangulation, this radius can be decreased to as little as 50 metres. If the individual's phone is GPS equipped, then the bearer's position can be accurately identified to within less than five meters. On its own, this would only be a mild concern. But in an interconnected world, everything from credit cards, public transport tickets, Wi-Fi strength from a passing café etc., leaves a recordable trace. It is this level of detailed, real time, location based data that is both the greatest strength and greatest cause for concern of a smart mobility system (Kitchin, 2013). The main reason is that it is very hard to collect location-based data in an anonymous fashion. If a data set contains

an individual's movement patterns for the last three years (where they live and work, which road they use, their times of departure), will it really matter if the data set doesn't use their name

In the past this information, whilst still recorded, was difficult to accumulate as it was obtained by different parties for different purposes, often using incompatible methods of data collection and storage (Kitchin, 2013). However, this has begun to change with many governments recognising that to access the full benefits of smart mobility in a smart city requires a previously unknown level of data interconnectedness (Hobbs, A, Hanley, 2014). This level of interconnectedness, many now believe, can only be realised by the creation of a single decision making entity with direct access to all of the data in and around its area of responsibility e.g. Rio's City Control Centre in Brazil (Kitchin, 2013). It is the creation of these urban intelligence centres that allows for the greatest real time, big data benefits and the greatest potential loss of individual privacy (Kitchin, 2013). For this reason, it is the responsibility of the operators and decision makers to operate them with transparency (Neumann, 2015). For people to receive the full benefits of what a smart city has to offer, they need to be able to feel that their data is safe.

Policy lessons

A number of studies which examined the promise of smart mobility have repeatedly identified three nations as global leaders: South Korea, Japan and Singapore (Information Technology and Innovation Foundation, 2010). One of the most notable aspects of mobility in these countries is how widespread their smart technologies were, and the impact they had on the quality of life of people in terms of ease of travel, reduced congestion, and improved safety and reliability of transport services. These studies provide a unique insight into these countries' remarkable journeys in smart mobility and the factors which contributed to their success (Figure 27). Although non-policy factors such as geographical constraints, cultural and political issues played some role, it was ultimately their national ITS policies which made them successful in smart mobility innovations. The recurring policy themes in these leading nations summarised below. These policy principles apply both to nations embarking on new smart infrastructure projects, as well as developed economies looking to make the most of existing assets.

National Vision. South Korea, Japan and Singapore have all demonstrated a national level commitment to smart mobility. From the outset, their governments articulated and owned a clear vision for ITS and linked it to national Information Technology policies and long-term strategies for improving road safety and the quality of life for their citizens. Governments in these countries also demonstrated strong leadership in convening relevant stakeholders and spearheading implementation.

Commitment to Funding. As a percentage of GDP, South Korea and Japan each invested more than twice as much in smart mobility than the United States. Not surprisingly, this level of annual spending (around 0.016 percent of GDP) allowed South Korea to provide 100 percent coverage of ITS on all expressways (around 4,000 km), and 20 percent ITS coverage on national roads (2,500 km out of 13,000 km).

Partnership and Collaboration. The public and private sectors in these leading nations played an important role in co-developing platforms that enabled government, industry, academic and professional associations to collaborate on developments at both local and national levels.

Private Investment. The three leading countries were all successful at forging public private partnerships within their nations, and viewed their investments as creating a platform through which the private sector can develop value-added products and services.

Standardisation. Leading countries developed national ITS architectures which provided the basis for interoperable ITS applications and assisted in the delivery of consistent, cohesive and cost-efficient services to citizens. For example, establishing common standards for electronic toll collection (ETC) in Japan encouraged high market penetration and uptake of on-board devices in more than 70 percent of vehicles. In Singapore, the single national standard of ETC also facilitated the implementation of a city-wide congestion charging scheme from early 1998

R&D and Education. The three leading nations recognised from early stages that ITS will not reach critical mass unless they commit to funding large-scale research and demonstration projects. For example, the 2025 ITS vision, announced by the Japanese Cabinet in June 2007, articulated policies on R&D and set a goal that: "By 2025, ITS will have been constructed that integrate vehicles, pedestrians, roads, and communities; and that have made traffic smoother, and almost eliminated all fatal traffic accidents"

Innovation and Competition. This policy principle recognises the role of the private sector in developing and making available to governments and citizens innovations and technologies to improve their lives. Examples include alignment between the transport and telecommunications industries, where ITS was recognised as being inseparable from wireless technologies (for cooperative mobility applications) and high speed networks (for video transmission).

Planning for Deployment. A big portion of the funding available to these countries was allocated to supporting

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ITS technology development, test-beds and proof of concept demonstrations as a precursor to wide-spread deployment. This approach also helped to inform and educate their citizens about the tangible benefits of smart technologies in transport

Performance Based Mobility Systems. Nations leading in ITS recognised the need to move from a political or jurisdiction-based system of allocating transport investment to one that uses performance and cost-benefit analysis as the basis for investment decisions. ITS promotes this principle by providing quality data needed to make sound performance-based investment decisions. This data can also be used by the private sector to provide value-added services. These nations also recognised smart mobility and ITS as a 'force multiplier'. Decision makers in these nations were informed to recognise the importance and high benefit-cost ratios provided by ITS.

consumers and enhanced connectivity between vital infrastructure systems. Whilst decision makers and leaders who run the world's cities are increasingly recognising the role of smart technologies in 'sweating of assets', deployment at a global scale is still in its infancy.

The benefits of investing in smart systems are compelling, particularly given the improvements that could be made in terms of providing innovative solutions to lift our economic efficiency and living standards. To spur change programs and capture potential savings, cities must move beyond a project-by-project view and upgrade systems for planning, operating, and delivering smart infrastructure. This sort of investment will give our cities an opportunity to modernise their infrastructure and help drive economic growth and create jobs for the 21st century.
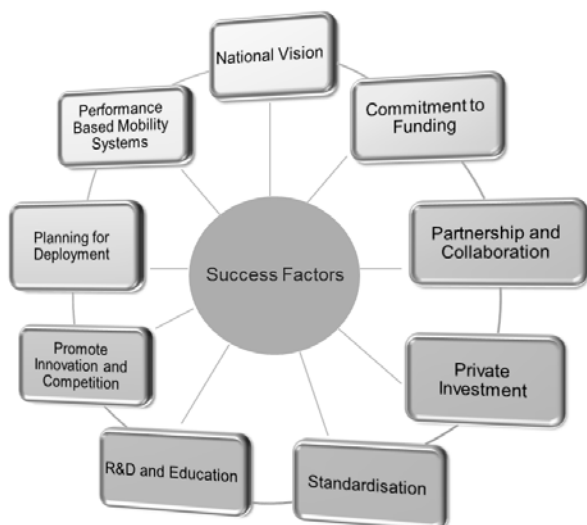
Figure 27: Policy principles for deployment of smart mobility

Source: (Dia, 2017) Low Carbon Mobility for Future Cities: Principles and Applications

Summary

The influence of digital innovations is changing the road user and traveller experience, and setting high expectations that will shape the future demand for transport services.

Cities around the world are anticipated to benefit from the use of smart technologies, but they must first overcome a number of challenges to improve infrastructure resilience and reliability. The deployment of these technologies, complemented by appropriate governance and regulatory changes, will deliver substantial benefits through improved city management systems, better informed

Prospects for Greening Urban and Suburban Travel

This project will include contributions from a number of multi-disciplinary research fields including urban planning, transport planning and strategy, traffic management and transport technology. Together, they will represent a cohesive investigation into the landscape of urban mobility and the policy principles and practical solutions that will drive the development of sustainable urban mobility and improve accessibility to jobs and opportunities in our cities.

This project also analyses the relationships between urban form and mobility, and calls for a future with more integration of land-use and transport in compact cities. Although each city is different and policy responses vary, case studies are presented to show how engagement with a broad range of stakeholders, development of clear objectives and policy responses, on-going monitoring and evaluation, and communication of progress helps to achieve the outcomes of sustainable transport and reduce greenhouse gas emissions.

The previous sections of this report discussed the breadth and depth of a large number of contemporary challenges and best practices in the provision of sustainable urban transport. This report started by providing a comprehensive picture of the challenges facing urban mobility, and identified a framework for transitioning the conventional "predict-and-provide" approaches towards a framework for planning sustainable transport solutions. It then detailed the policy pathways available to decision makers and reinforced these through case studies which demonstrated a range of benefits that accrued to communities which adopted and implemented these policies. By providing this background, this report laid the foundations for understanding the existing situation, emerging trends and the potential pathways for triggering change. The remainder of this report includes contributions for tackling the specific challenges facing urban transport and provides solutions, pathways and best practices to address them. These include reducing automobile dependence; integrated land-use and transport planning; prospects for decarbonising suburban mobility; public transport provisions; policy direction for creating built environments which support active transport; mobility through the sharing economy; future vision for shared autonomous mobility-on-demand solutions; gamification as a tool to trigger sustainable behaviours in urban mobility; and digital innovations and disruptive mobility solutions - current and future.

Overall, this report acknowledges that urban mobility and accessibility are key for promoting sustainable urban development. It also acknowledges their importance for enhancing the economies of urbanisation. This report also analyses how the urban function is improved through sustainable mobility solutions. However, the report also acknowledges that gaps exist towards achieving this vision, and that these gaps exists today largely due to the separation of land-use and transport, as well as the inadequate integration among transport modes. This report emphasises the urgent need to reframe urban mobility policies and practices in order to address these shortcomings.

This closing section of the report ties the analysis together, emphasises the key messages advocated in the report, and summarises the policies and pathways that can be implemented to bring about the desired outcomes of sustainable urban mobility.

A framework for rethinking urban mobility

This report calls for a conceptual leap and renewed thinking in addressing urban mobility. A summary of the key elements for reframing how urban transport is planned and designed in cities, and how best to provide sustainable urban transport services is provided next. These elements have been recognised in previous studies which also explored similar pathways to reducing dependence on motorised transport (Banister, 2013; Bishop, 2013; Giovani, M and Banister, 2013; Givoni, 2013; Hickman, 2013). Here, they are updated and reinforced.

A systems approach

Cities are a complex network of interconnected systems. The challenges facing transport in our cities – rapid urban growth, dependence on motorised transport, reduced access to services and activities etc. – are structural in nature and must be framed as part of a holistic approach to improve urban form in cities. Solutions and interventions which recognise this complexity will have a strong potential for charting a course towards sustainable urban mobility

Transport as a 'derived demand' and 'valued activity'

In planning and designing urban mobility solutions, it is essential to recognise travel as a 'derived demand' but also a 'valued activity'. Travel originates from the need for people to access places, jobs, opportunities, services, and activities. The purpose of most travel is to earn income, purchase goods, attend schools etc. The transport infrastructure and the vehicles, cars, trains, buses and bikes that move on it are simply the means to achieve these ends (UN-Habitat, 2012). Making this distinction shifts the focus to 'people' and 'places' and away from 'movement'. From a practical perspective, this implies planning and designing compact, mixed-use communities that reduces the need for travel and improves pedestrian and bicycling infrastructure. This in turn would lead to less reliance on private cars.

Accessibility over transport

Reframing the primary objective of urban transport as one for improving access to jobs and opportunities gives priority to policies and strategies which promote transit-oriented developments, improved public transport services, active transport infrastructure and less reliance on policies that encourage private vehicle usage. The concept of accessibility should apply to all segments of society to ensure that the poor and disadvantaged have good access goods and services within the city.

Policies and strategies

Ten key principles from the "Avoid, Shift, Share, Improve" framework were identified in previous sections (Bongardt, 2016). These included (1) Planning dense and human scale cities; (2) Developing transit-oriented cities; (3) Optimising the road network and its use; (4) Improving public transport; (5) Encouraging walking and cycling; (6) Controlling vehicle use; (7) Parking management; (8) Promoting clean vehicles; (9) Stakeholder consultation and engagement; and (10) Creating pathways and adapting regulations to comprehensive deployment.

In this section, the broad policies and strategies are grouped into six categories to demonstrate their strategic linkage and their cumulative potential for triggering policy and operational change (Giovani, M and Banister, 2013).

Strengthening the linkage between land use and transport

The connection between land-use and transport needs to be re-built and strengthened to achieve sustainable urban mobility. An integrated approach to land use and transport shifts the focus of planning from placement of structures and designation of land use to that of enabling the realisation of people's needs and everyday functions in the most efficient and sustainable manner. Within this approach, the key challenge is therefore not merely to overcome the separate handling of transport and land-use planning. Rather, it is to foster an integration of multi-modal mobility within a holistic and sustainable land-use system.

Rethinking urban planning and transport engineering designs

As was discussed before, a strong link exists between transport supply and demand, and urban form. Mixed-land use developments reduce the need for travel and promote active transport. Quality transport connections between functional places and facilities improve access and increases functionality of each place, leading to a reduction in the distances and number of trips between origins and destinations. This can be achieved through creative planning and urban designs, combined with innovative infrastructure and transport engineering designs. For example, compact configurations complemented with transport-oriented developments reduce private cars while still making it viable for cities to invest in different modes of public transport.

Realigning transport infrastructure investment

Achieving low carbon mobility requires prioritisation in the choices of infrastructure investments. The current imbalance in funding and investments between private and public modes of transport needs to be corrected. This applies equally to developed and emerging countries. It is not sufficient to pursue policies that 'balance' investments between different modes of transport. More initial funding should be allocated to developing and expanding non-motorised and high-capacity public transport infrastructure. The option of value capture to complement public funding should be examined to generate sustainable funding streams. Besides being a politically appealing option, this funding model also reinforces the link between land use and transport.

Integrating urban transport facilities and service operations

Efficient land-use patterns (e.g. compact, mixed and walkable) allow for less reliance on expensive mobility systems in general. Properly designed transport systems also contribute to business expansion, increased economic output and employment generation. Efficiency must underpin management, operational and system design practices throughout the urban transport sector. In the case of high-capacity public transport systems, this can take the form of redeploying buses and equipment to high-ridership markets that produce the highest fare-box returns. Integrated transport and land-use planning development must also be emphasized in national urban development policies and plans.

Urban governance frameworks

The development of a fully integrated and sustainable multi-modal urban mobility system requires a robust urban governance structure. Innovations and policies geared towards sustainable mobility require strong institutional and governance structures to oversee their successful implementation. Political will, sound leadership, transparency and accountability are essential in building public trust. Also vital to the entire process are the planning institutions, as these are capable of creating compelling visions of urban futures. There is also a need to inject efficiencies, accountability and transparency into

the urban transport decision-making process. This requires the development and institutionalization of planning processes and evaluation approaches that are based on objective measures of performance and tied to well-articulated goals and hoped-for outcomes. This promotes both transparency and accountability.

Regulatory frameworks

The current regulatory frameworks for management of road space and urban form have perpetuated urban transport design that favoured motorised transport. Transforming our cities towards sustainable urban mobility requires major reforms in the legal and regulatory framework relating to urban transport management. The interventions highlighted in the book call for changes in the management of space, the urban form, the engineering of transport, as well as in the institutional and financing arrangements related to urban development.

Research Agenda to inform low carbon mobility policies – Australian Perspective

Central to the success of these low carbon mobility solutions is rigorous research that meets the twenty-first-century global challenges including energy provision, climate change and health. Cities and urban areas are expected to achieve big gains through well-planned policy implementations and smart thinking on urban transport. To deliver substantial improvements in mobility and reductions in emissions, major policy, behavioural and technological changes would be required to achieve desired outcomes and targets for low carbon living.

The establishment of a research agenda on low carbon mobility presents an opportunity to enhance support for research and innovation by building on existing success in transport research and intellectual capital. A thriving research agenda represents a major investment in the future of low carbon mobility and sustainable transport, and would also provide a distinctive trajectory and direction for students, researchers and industry practitioners. This section provides a research framework that identifies high level research needs to enable successful deployment and integration of low carbon mobility solutions in our cities. The framework articulates a vision for low carbon mobility, maps the landscape of research themes and identifies the research gaps that need to be bridged to enable successful deployment. The framework draws on an environmental scan of the current status of low carbon mobility research and discussions and engagement with academics and industry stakeholders.

The research framework presented in this section draws on the current status of low carbon mobility research, and discussions with academics, researchers and industry stakeholders. This approach allowed for an objective analysis of the current challenges and opportunities, areas where there is general agreement that fundamental research is lacking, and highlighted new research opportunities available through new technologies. Soliciting the insights and judgements of researchers and industry specialists also allowed for more insights. It also helped to map the areas where the stakeholders believed insufficient work has been done, and where more focused research is needed. It also allowed for identifying those areas that are likely to become important in the future and where research is needed to support their development.

In compiling these priorities, the insights of researchers and specialists were solicited during workshops that were held in Adelaide and Melbourne, Australia, as part of the involvement of a few universities in low carbon mobility research (Dia, 2014; Philp, M. and Taylor, 2014). The workshops included participants from academia and industry who presented on a range of wide topics which covered demand modelling and urban planning studies, through to new methodologies for urban mobility data collection, modelling, to establishment of living laboratories to evaluate impacts of new interventions. The workshops resulted in the mapping of a broad research framework that included inputs from the stakeholders who attended and participated in the workshops. The context of this framework was suburban travel, but the high level research needs are equally applicable to low carbon mobility in urban environments (Figure 28).

The overarching vision for the low carbon mobility research framework is to reduce greenhouse gas emissions from passenger car usage. The proposed framework includes research programs which would investigate travel demand in the age of connected mobility; new methods to provide travel supply including autonomous shared mobility and on-demand car and ride-sharing; and investigations of long-term impacts on mobility, energy, urban form, sustainability and quality of life. The research agenda also includes strategic research programs in urban governance and opportunities for improving urban transport in the developing world. The mapping in Figure 28 demonstrates the wide range of ideas that have potential to improve mobility, including options for electrification of road travel, teleworking and smart work centres. The key common theme in this mapping is the need to provide reliable and cost-effective alternative mobility options that reduce reliance on private vehicle travel. The research framework includes studies which aim to understand:

Current situation and trends. This includes an assessment of the current situation and best practices in deployment of urban mobility and the new options for reducing the carbon footprint of urban transport with a particular focus

on the opportunities available through disruptive technologies, shared car ownership and on-demand access to public transport and new mobility options. It also includes identification of emerging or anticipated future trends in urban mobility with a particular focus on the role of autonomous on-demand shared mobility solutions. While it is important that comprehensive environmental scans are conducted, and a synthesis of published research is undertaken to identify gaps, it is also recognised that using the literature reviews as an extrapolation method has some limitations and will provide a limited insight into the trajectory of research in smart mobility. In these studies, it becomes important to solicit the insights of stakeholders through interviews, workshops, surveys and questionnaires on issues affecting their short to long-term transport operations and planning.

Policy and institutional analyses. This includes assessment of the barriers and opportunities arising from smart mobility solutions. The analyses should include an evaluation of the current regulatory frameworks, pathways to developing outcome-focused research, regulations under uncertainty, public expectations and acceptance of technology-driven mobility solutions, the future role of government agencies in managing the transport network under scenarios of shared autonomous mobility, and enhancing engagement with the community, local governments and other stakeholders. An important focus under these category of studies is also development of new urban governance systems to guide the creation of urban mobility innovations, corporate social responsibility, internet-enabled multi-stakeholder communication, and new modes of community engagement to plan pathways for deployment of ubiquitous smart mobility solutions. These efforts would be directed towards developing and evaluating new models and processes by which social, design and technological innovation can be more effectively delivered into the planning of smart mobility.

Travel demand analysis. This includes analysis of existing household travel surveys to define travel behaviour (e.g. trip generation, destination choice and mode choice for households), the conduct of new studies to understand the drivers for travel demand in urban areas in the age of shared and connected mobility, and surveys to establish the determinants of shifts in travel behaviour from private vehicles to new mobility solutions. It also includes Stated Preference experiments to explore opportunities for changes in travel behaviour (trip frequency, destination and mode choices), focussing on areas of high car dependency/forced car usage/ areas to explore determinants of shifts in travel behaviour. Other studies that would need to be completed under this framework include travel demand estimation and analysis using predictive analytics, machine learning tools, and data mining of new sources of information from mobile use, smartcard automated fare collection and crowd-sourced

data to uncover behavioural patterns using sophisticated modelling and analytics tools. Travel demand studies would also need to include projects that examine the land-use transport interactions and their influence on the demand for travel modes under variable scenarios of supply of and service patterns, especially those related to shared mobility and future autonomous vehicle applications such as first-and-last-kilometre travel solutions.
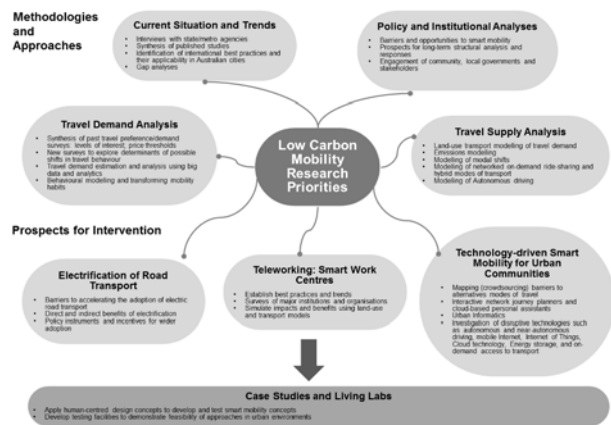
Figure 28: A research framework for low carbon mobility.

Travel supply analysis. This should include studies into the modelling of land-use transport interaction, demand for travel and mode splits under different scenarios of infrastructure supply, including walking and cycling infrastructure, electric vehicle charging networks and networked public transport service patterns. The modelling tools should allow for evaluating the impacts at a regional level (macro models); precinct level (meso models) and operational level (e.g. micro and increasingly sophisticated nano behavioural models). The application of these tools will allow for investigations of modal shifts, and the impacts of smart mobility intervention measures including their benefits in reducing greenhouse gas emissions, reducing social and economic costs of current levels of car-dependence, and their efficiency and cost-effectiveness in providing customers with alternative travel options. The travel supply analysis research should also look into transport planning and modelling studies focusing on pathways to increasing customer usage of different modes of travel. The modelling tools can also serve as decision support systems for investment in smart mobility and would be valuable for assessment of the feasibility and cost-effectiveness of the proposed interventions; assess a portfolio of investment options to encourage greater adoption of new mobility solutions that optimise the reduction in cities' carbon footprint and high areas and social cohorts that might be most receptive to adopting smart mobility solutions.

Prospects for intervention. A large number of interventions are potentially available for decision makers including smart transport interventions, teleworking and electrification of road transport. There is already considerable research and momentum around network management, teleworking (Aguiléra, A., Guillot, C. & Rallet, 2012) and ITS interventions, but probably the area where important research is needed going forward is in disruptive mobility which includes collaborative shared mobility, autonomous vehicles, and digital innovations. In these areas, more research is needed to address the following issues particularly about autonomous vehicles:

• Will they reduce or increase congestion?
• How will they impact total vehicle-kilometres of travel?
• Will they increase or decrease urban sprawl?
• How will they impact urban form?
• Will they induce more demand for travel?
• What impact will they have on parking?
• Will they reduce or increase emissions?
• How will they impact car ownership?

Case studies and living laboratories. Research into low carbon mobility solutions and interventions should also include opportunities for creation of case studies and pilots in living labs. For example, a number of universities in the U.S. have established off-road test-beds for testing autonomous driving. These are especially relevant to assessment of road safety impacts. Equally important are trials on public roads to provide travellers and consumers with opportunities to witness the new mobility solutions, evaluate their experiences, and get a better understanding of the potential impacts and opportunities while also helping the public authorities to learn more about the solution and work towards its deployment.

Practical research routes to inform urban mobility policies

The high level research framework described in this paper is aimed at identifying some practical routes that can be used to steer transport policy on low carbon mobility. As the list of "next big things" grows longer with the fast pace of breakthroughs and scientific advances, it is important that policy making provides a guiding vision to ensure that technology interventions, in particular, are well applied and focused on user needs, and that they address genuine and practical problems that promote sustainable cities.

Some of the key research routes that have been identified in previous research (Bruun and Givoni., 2015) are relevant and valid for low carbon mobility policies. These include:

Looking beyond the immediate benefits and establish long-term impacts of new technologies

The sweeping changes anticipated by disruptive mobility have at times inspired visions of a very different future, as well as a good deal of hype. To distinguish between the hype and reality, rigorous and extensive research must go beyond the immediate obvious impacts. An example is autonomous vehicles which seem to have captured people's imaginations over the past few years. While they are very likely to introduce some big benefits such as reducing traffic injuries and fatalities and free up people's time from the driving task, it is still not well understood how they will impact congestion and the total vehicle-kilometre-travelled per capita, and whether they are likely to replace or augment public transport, and their potential impacts on health and wellbeing. There are also concerns about over-extensive urban sprawl and also impacts on energy and land use. Recent research (Dia, Javanshour and Hill, 2016) suggests that the current vehicle fleet could be reduced by up to 90 percent in urban areas when a shared network of driverless vehicles are introduced. It is not clear, though, whether they will induce new demand for travel given that travel time will become shorter because of fewer vehicles on the road, and because people would feel that travel time is no longer unproductive because they are free from the task of driving. It is therefore important to undertake research that looks past the immediate benefits and investigate how these technologies are likely to impact urban living, demand for travel, and social cohesion in the long term.

Develop rigorous but flexible evaluation frameworks and tools

Given that some of the disruptive mobility solutions have not been tested and deployed yet, their impacts are probably best evaluated on test-beds or in simulations. The key advantage of using test-beds is that the ease of replicating reality and how consumers and drivers engage with and and react to the technology. The limitation, however, is that they are usually small scale and can't capture wider long-term impacts on larger city networks. Agent-based simulations, properly calibrated and validated, provide a cost-effective solution to complement the test-bed evaluations, but these also have some limitation particularly in replicating behavioural issues. Further developments are also needed for decision making tools. The most commonly used method to evaluate transport projects today is the cost-benefit analysis (CBA). While this is effective in determining monetary value over a period of time, CBA does not consider other important factors in terms of how it will affect other facets of people's lives. This includes who exactly will benefit from the project, as well as who does not. Multi-criteria analysis (MCA) is an improved evaluation tool compared to CBA as it analyses a broader set of criteria or policy objectives. However, this method

is subjective and inconsistencies may arise (Cristobal and Ramon, 2012). Other methods that offer improved evaluation techniques must be developed. These techniques should complement the CBA with risk assessment, as well as consideration of qualitative impacts on the general public.

Adapt governance systems and develop agile and outcome-focused regulations

Regulations will play a key role in the emergence and development of disruptive mobility solutions. They are also likely to be the biggest hurdle for their deployment. The regulators must adapt and rethink their approaches to avoid stifling the innovative uses of these technologies. Effective responses require an early and on-going dialogue between regulators, developers and the public in which regulators would create legal frameworks that are flexible but robust. For example, with driverless vehicles, an important role for the regulators will be to limit physical risks especially those that might be posed during interim years when legacy fleets of cars would interact with autonomous vehicles. Given the fast pace of technological developments, regulators would need to re-think their roles and focus on achieving agreed outcomes rather than enforcement of codes and standards.

A good example is the regulation of ride-sharing services such as Uber and Lyft which have become very popular among commuters. Governments are finding it challenging whether to fully legalise or impose regulations on these services (Tomazin, 2016).

Facilitate and encourage active transport and public transport innovations

Some of the current mobility disruptions are already impacting the taxi industry and there is some concern that it may in the long run impact public transport, particularly bus services. There are a number of innovative public transport initiatives around the world such as the Bridji bus service in the U.S. which so far has been deployed in a successful way. Adopting innovative solutions for bus transport, in particular, is crucial for moving towards a more sustainable future and will play an important role in bridging the gaps for first-and-last kilometre travel. Public transport must be efficient, attractive and of good quality to appeal to the general public, and its development must be part of a holistic solution that integrates public and active transport modes. Bike-sharing has become popular in many cities around the world and has become 'trendy' rather than simply 'sustainable' (European Commission, 2013). Smart technologies and strategies that can support and increase the attractiveness and appeal of this mode of

travel would also contribute to more sustainable mobility solutions in our cities.

Concluding Remarks

The need and urgency for steering our cities on a course towards low carbon mobility is important not only for reducing the costs associated with urban transport, but also for increasing the overall benefits to society (Banister, 2013). Widespread deployment of sustainable mobility systems would cut across the intersection of the most urgent challenges confronting the global community today (Giovani, M and Banister, 2013). Measures that seek to reduce greenhouse gas emissions or improve the quality of life for urban dwellers cannot succeed without addressing the challenges of sustainable mobility, nor without redressing the prevailing distortions in accessibility to our urban centres.

The contributions in this report demonstrate that sustainable urban mobility is an essential ingredient to many of the indicators by which we measure our quality of life: our health, happiness, prosperity, connectedness and security. They also suggest that it is possible promote interventions that can effectively enhance the mobility and accessibility of our cities by providing policy makers with the instruments and strategies to positively influence the well-being of city populations.

The next stages of this work will include a number of modelling tasks to extend the work reported in this document and provide results that can be used to inform low carbon mobility policies.

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