Driving change: technology diffusion in the transport sector

June 2018

AR Wolken, MJ Smith, WH Kaye-Blake, KO Curry, MC Dickson, CE Drummond, AL Thomas
PricewaterhouseCoopers

NZ Transport Agency research report 647
Contracted research organisation – PricewaterhouseCoopers

ISBN 978-1-98-856112-7 (electronic)
ISSN 1173-3764 (electronic)

NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

Wolken, AR, MJ Smith, WH Kaye-Blake, KO Curry, MC Dickson, CE Drummond, and AL Thomas (2018) Driving change: Technology diffusion in the transport sector. *NZ Transport Agency research report 647*. 130pp.

PricewaterhouseCoopers was contracted by the NZ Transport Agency in 2016 to carry out this research.

Keywords: Bass model, consumer behaviour, electric vehicles, innovation, mobility-as-a-service, policy, technology

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Acknowledgements

We would like to acknowledge the members of the project steering group: Siobhan Bakker (NZ Transport Agency), Wayne Heerdegen (NZ Transport Agency), Peter King (Automobile Association), Glen Koorey (ViaStrada Ltd), John Macilree (Ministry of Transport), Simon Rae (Ministry of Business, Innovation and Employment), and Liz Yeaman (Energy Efficiency and Conservation Authority). We would also like to acknowledge the feedback from the peer reviewer, John Holt (Holt Data Science).

Abbreviations and acronyms

AFV	alternative fuel vehicle
AI	artificial intelligence
BMF	behavioural monitoring framework
EV	electric vehicle
GPS	global positioning system
HFCV	hydrogen fuel cell vehicle
ICE	internal combustion engine
MaaS	mobility as a service
pers comm	personal communication
NZHTS	New Zealand Household Travel Survey
PwC	PricewaterhouseCoopers
the Transport Agency	New Zealand Transport Agency
R&D	research and development
SUV	sport utility vehicle

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Executive summary

Overview

Technological advances are rapidly occurring in many industries, including the transport sector. From autonomous vehicles to e-bikes, the options available for travel are increasing. These changes can have a significant impact on the transport sector by disrupting the current patterns of behaviour. It is important to understand and take a clear view of the behavioural changes in the functioning of the transport system.

The NZ Transport Agency (the Transport Agency) engaged PricewaterhouseCoopers (PwC) to provide well-researched, practical solutions to understanding the technology diffusion rate and its subsequent impacts on the transport system. This report aims to guide policymakers in thinking about how technology could affect the transport sector, to be used in regulatory and investment decisions.

We used an innovative methodology that addresses the knowledge gap in technology diffusion in the transport sector. The project included the development of a technology diffusion model, a future technologies roadmap and a behavioural monitoring framework (BMF), and their application to two case studies. Outputs from these strands of work can be applied by the Transport Agency to make judgements about how technology diffusion will affect transport in New Zealand.

Technology is disrupting the transport system

Changes in technology are likely to have a significant impact on the transportation sector. Semi-autonomous and fully autonomous vehicles, e-bikes, electric cars, consumer devices, 3D printing, shared mobility and third-party software add-ons are all examples of the types of changes that can affect transport. These technologies have the potential to change the structure of the transport system, and in turn change the way people and goods move to their intended destinations. Technological changes can affect infrastructure or the modes available, or directly affect the behaviours of people and goods shipment.

Infrastructure is a critical part of the transport environment. Technology can enable more efficient use of the current infrastructure. The most visible parts of the infrastructure are the roads, bridges, ports and other structures that carry personal and commercial vehicles. Where technology is becoming increasingly integral is not to the existing structure of transport infrastructure, but to the ‘soft infrastructure’. Variable speed signs, electronic information boards and traffic lights are all examples of soft infrastructure with increasing use of technology, and with the aim of increasing the efficiency and safety of the transport system.

In recent history, the dominant mode of transport has been the internal combustion engine (ICE) car. The ease of use and convenience of the car in transporting people and goods led to widespread adoption. Technology has increased the range of transport modes currently and soon to be available. From e-bikes to autonomous and electric cars, the options available to move people and goods are greater now than in previous decades. These alternative modes have the potential to challenge the dominance of the ICE car. By reducing the cost of travel and increasing safety and efficiency, these modes have the potential to disrupt the way transport is delivered.

Technology, infrastructure and modes are elements of the transport system that all interact to ultimately transport people and goods to their destination. Technology is changing the interface between people and the transport system, affecting behaviours and the decision-making process by giving a more complete information set. Technology is also changing how services are ordered and paid for. No longer are printed timetables relied upon with cash the only payment method. Instead, real-time information on public transport service times allows users to make well informed decisions. Payment can be done through a number of non-cash methods. In the goods sector, technology has enabled greater tracking and monitoring of client orders as they move from the warehouse to the customer's door. This information is shared more widely with clients and customers online.

Diffusion models to describe technology uptake

New technologies follow a pattern of diffusion as they are adopted by the market. The process starts gradually, but accelerates as more people adopt the new technology and it becomes more visible. Once past the point of peak demand, the speed of adoption slows and the market becomes fully saturated. Some technologies diffuse from introduction to widespread use in a short period of time, while others take longer to reach widespread use. Both scenarios can be described using an S-shaped curve, which is a staple model of technology diffusion. With a wide range of applicability to new technologies, the S-curve and its related theory lend themselves well to the transport sector.

The speed and extent of technology adoption can affect the rate of disruption in the transport system. A fast and high level of adoption can cause disruption in the sector, whereas a slower or more gradual adoption profile can be managed in a more cohesive manner. One way of tracking and predicting the rate of diffusion is through the use of models, such as the Bass model. A Bass diffusion model was developed to describe the diffusion process of new technology in the New Zealand transport sector.

The Bass model describes how new technologies are adopted using an S-curve. It presents a rationale of how current adopters and potential adopters of a new technology interact. The basic premise is that adopters can be classified as innovators or imitators, and the speed of adoption is influenced by the degree of innovativeness and the degree of imitation among adopters. Bass (1969) presents the model with three main inputs: the coefficient of innovation (p), the coefficient of imitation (q) and the market potential (m). This simple modelling process has been applied to a number of new technologies, including hybrid, electric and autonomous vehicles in the transport sector.

Potential impacts from new technology

There are a number of different areas that could be affected by the diffusion of new technology. A future technologies roadmap was developed with transport sector representatives, to consider the possible impacts of different trends and how trends interact with each other. The roadmap considers trends in:

- technology
- behaviour
- demography
- adoption drivers.

The roadmap is intended to serve primarily as a focal point to initiate conversation and drive broader awareness of future planning challenges.

Monitoring response to technology adoption

To get a picture of the impacts on the transport system, it is important to monitor which technologies are being used and how they are being used. People, agencies and companies involved with the transport system need information about what to monitor and how to monitor it in order to get the best picture of the current state of technology diffusion and the likely future pathways. The BMF provides a systematic way for thinking about monitoring technology adoption and the behavioural responses to adoption.

The BMF contains three levels. At the first level, the boundary is the whole transport system. This level encourages users to describe the systemic impacts of technology. The second level focuses specifically on the technologies in the transport sector and how they are being used. This level provides some focus on existing and developing technologies. Finally, the third level draws a wide boundary around science and technology, broadly understood, to promote a scanning function that takes in a wide range of future potential changes. The goal of this third level is to keep thinking open and flexible rather than captured by a certain view of the future.

Case studies demonstrate the application of the framework

Two case studies were selected to demonstrate how the BMF can be applied to a new technology. The first technology selected was mobility as a service (MaaS). It brings together a wide range of transport modes into a single digital interface, providing users with tailored transport options based on their requirements and preferences, using both private and public transport options. Users of MaaS essentially substitute vehicle ownership for calling upon transport services as and when they are needed, leaning on the overall reliability of the system to provide them with transport. MaaS is a concept that is gaining a great deal of interest around the world even in the early stages of development.

MaaS has the ability to make the transport system operate more effectively through greater utilisation of resources. Through bundling of different modes together MaaS has the potential to offer competitive pricing relative to car ownership, while improving the travel experience. These changes will in turn have an impact on transport system behaviours – and potentially challenge the dominance of private vehicle ownership as the primary mode of transport.

However, development and diffusion of MaaS is in the early stages. Helsinki is one city where large resources have been dedicated to implementing MaaS for users. Through this development and pilot process in Helsinki, a number of barriers and issues have been identified to be resolved before widespread adoption is possible. Coordination issues, data quality and reliance on a charged smartphone are some of the barriers identified. These barriers are likely to result in a lag before the technology is ready for adoption in New Zealand's main centres.

The second technology selected was electric vehicles (EVs). EVs are alternative fuel technology vehicles that use electric motors and motor controllers for propulsion instead of ICEs. EV sales have started to gain traction in developed countries. At the same time, companies are spending large amounts on research and development on the technology, leading to an increase in the range of options available for users.

EVs function in a similar way to existing ICE cars, making them highly compatible with the current transport system. People can use EVs to get from one point to another, in a similar way to their current travel patterns. The cars can also use the existing transport network of roads and bridges, and operate under the same road rules as other vehicles. The main benefit from the adoption of the technology is through lower running costs. In New Zealand, fuelling an EV is equivalent to paying 30 cents per litre for petrol, a significant price differential to fuelling ICE cars. Users of EVs can also charge their vehicles at home making refuelling more convenient.

However, adoption of the technology has been limited to date, and is still in the early stages – both domestically and internationally. There is currently a significant initial price premium for purchasing an EV over an equivalent ICE vehicle, which is slowing adoption. The higher price is due to battery costs, which are currently an expensive component to manufacture. With greater adoption and manufacturing of batteries, the cost of EVs is expected to fall over time to be on par with, or lower than, ICE cars.

Abstract

Technology diffusion will have profound impacts on the transport system. This report does not attempt to predict the future, but instead aims to guide policymakers in thinking about how technology could affect the transport sector. The focus is on the behaviour of the transport user and how it translates into technology diffusion and then affects transport. As a guide, we developed a behavioural monitoring framework that incorporated several components. The components included a simplified model of the transport system to focus on important variables; a diffusion model based on the well-known Bass model; and advice for horizon scanning to identify and understand technologies with potential to affect transport. We applied the framework to two case studies: mobility as a service and electric vehicles. These technologies are seeing limited uptake in New Zealand and appear to face challenges. The research and framework in this report can be applied by the NZ Transport Agency to make judgements about how technology diffusion may affect transport in New Zealand.

1 Introduction

1.1 Context

Technological changes and advances are rapidly occurring in a number of different industries, including the transport sector. From autonomous vehicles[1] to e-bikes,[2] the options available for travel are increasing. It is important to understand the significant impact these changes can have on the transport sector, in disrupting the current patterns of behaviour and operation of the transport system.

1.2 Purpose of this report

The NZ Transport Agency (the Transport Agency) engaged PricewaterhouseCoopers (PwC) to provide well-researched, practical solutions to understanding technology diffusion and its subsequent impacts on the transport system.

This report aims to be a guide for policymakers in thinking about how technology could affect the transport sector, providing insight into how technology is changing the way people and goods move, some associated issues and potential solutions, to be used in regulatory and investment decisions.

1.3 Report structure

This report is divided into five sections:

- a review of the literature on technology diffusion
- a discussion of Bass type technology diffusion models
- a roadmap of future changes and challenges to the transport system
- a behavioural monitoring framework (BMF) to monitor the transport system
- two case studies demonstrating the application of the BMF.

[1] Autonomous vehicles refers to vehicles, typically cars, that can take passengers to a destination without requiring a driver.

[2] Electric bikes (e-bikes) are bicycles that support pedalling with an electric powered motor

2 Literature review

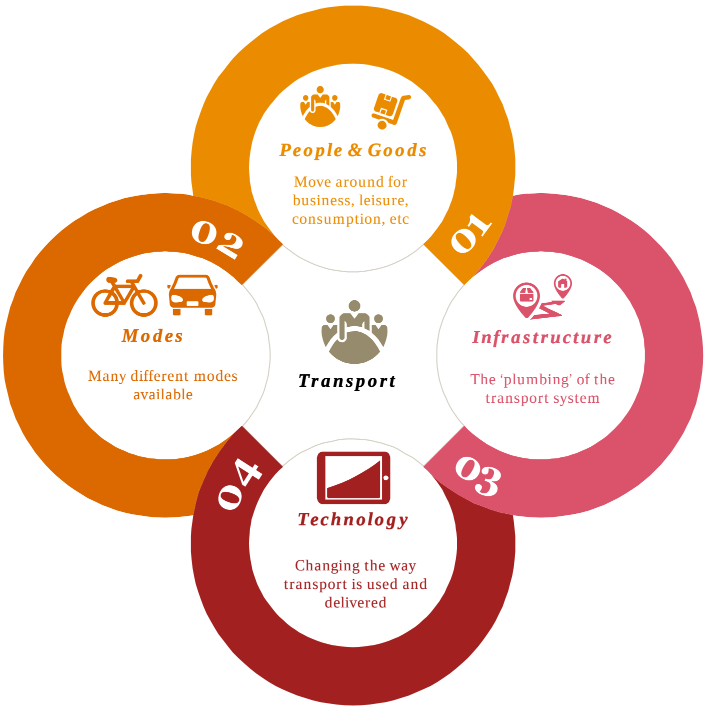
2.1 Introduction

For transport users, there is increasing diversity in technology and transport modes. For the individual traveller, there are early signs that MaaS could replace the traditional model of owning and using a car. Multi-modal services in which customers are able to request transport as they need and pay per use, are becoming viable options for households. From ridesharing to bike-sharing, the options available are increasing and able to compete with car ownership, particularly in highly populated urban areas. In the freight sector, technology is changing the way logistics are managed, with greater availability and quality data, and analytic tools to improve efficiency. In the future, autonomous vehicles could also have a major impact on the whole transport sector.

Already these changes are starting to disrupt the transport sector. For example, public transport providers and vehicle manufacturers are shifting their models away from managing a transport fleet, to a more customer-centric, service provision model (Lerner 2011). Increasingly, technology is changing the relative economics of vehicle ownership. There are already signs of significant shifts in relative costs away from private car ownership towards cheaper alternatives to achieve convenient personal mobility (Allison 2014).

Technology is beginning to disrupt all industries more generally (PwC 2016); however, each technology effect cannot be considered in isolation. In reviewing the literature on transport and technology, we identified four main elements that interact to make up the transport system: people and goods, modes, infrastructure and technology (figure 2.1). Changing one element can affect how the whole system operates. For example, new modes of transport, such as e-bikes, can move people faster and more efficiently, so greater use may result in prioritising the sort of infrastructure that supports and encourages e-bike use. As such, the whole system responds to relatively simple changes in the technology available.

Figure 2.1 Elements of the transport system



This chapter is broken into two sections:

- a review of the literature surrounding the impacts of technology on the other three elements of the transport sector
- a review of general work on the diffusion of technology.

2.2 Overview

Technology can act to complement other elements in the sector, such as GPS navigation systems that allow drivers to use their cars and the roads more efficiently. It can also act as a substitute for other elements: there are predictions that autonomous vehicles will remove the need for human drivers. If autonomous vehicles or a similarly disruptive transport technology, become widely adopted, the way transport services are delivered could change significantly from the current model.

A number of new transport sector technologies are on the horizon that will interact with infrastructure, modes and people and goods. Technology can help increase the efficiency of current infrastructure, by managing the routes vehicles take to control congestion and can change the modes we use for transport. More options allow different models for personal mobility to compete with the current main model of car ownership, changing the interface with which people and goods interact with the transport system. For example, information and connectivity are enabling people to make better transport decisions through real-time data and to allow people to track the delivery of goods.

Diffusion theory attempts to explain how new technologies diffuse through a system, shown using an S-shaped curve to illustrate cumulative uptake (figure 2.3). The rate of diffusion can be modelled to produce forecasts of uptake and we discuss the Bass model of technology diffusion in this chapter, and later develop a specific Bass model for uptake of technology in the New Zealand transport sector.

2.3 Technology and the transport sector

This chapter discusses the potential impacts of technology, with the sections organised around the sector framework introduced in figure 2.1.

2.3.1 Technology and infrastructure

Infrastructure is a critical part of the transport environment. Infrastructure refers both to 'built-infrastructure' – the most visible parts of the built transport system – roads, bridges, ports and other structures that carry personal and commercial vehicles. Infrastructure also refers to 'support-infrastructure' – systems and processes for managing transport such as routing software, electronic signage and other information systems.

Technology can enable more efficient use of the current infrastructure. New communications technology and the widespread collection of data about users' movements provide opportunities for individuals, companies and public agencies to make better use of existing systems. For example, transport users value quality information about traffic conditions and the opportunity to make informed decisions about their own routes. With the rise of smartphones, there are more opportunities for users to access transport information while planning and making trips. Transport agencies are releasing their data for others to adapt and integrate into other products, such as Google Maps, in the hope of changing people's travel behaviour to make the overall system more efficient.

This chapter reviews the way technology interacts with infrastructure. It starts by considering the built urban environment and then moves to soft-infrastructure and public policy, closing with a consideration of technology use within logistics and freight.

2.3.1.1 Urban form

Urban form is the process of designing and shaping cities, of which infrastructure plays a significant role. Both built and support infrastructure affect the uptake of new transport technology. One important consideration is the potential disconnect in time scales between how quickly the two components of infrastructure can respond: built infrastructure tends to respond slowly, whereas support infrastructure can change and be adopted more quickly. As a result, it is easier to change support infrastructure to increase the efficiency of built infrastructure and potentially delay the need for additional road or bridge construction.

For urban form, an additional concern is path dependence. This is the idea that historical and current decisions tend to dictate future outcomes and in particular can make significant change very difficult. Previous investment decisions in infrastructure are now fixed and will affect which technologies are used in the future and their rate of diffusion. Transport can have a very high degree of path dependence due to the cost and inflexibility of built infrastructure. Existing infrastructure tends to be adapted to match the needs of the currently dominant technologies (or even earlier technologies), limiting opportunities for new innovations. For example, the dominance of individual car use tends to reduce innovation that is not dependent on the existing car-centric infrastructure (Wiesenthal et al 2011).

As a result, in many cities around the Western world, it is difficult to move the transport system away from dependence on the personal car. The previous goal of infrastructure has been to increase the size of the transport network to alleviate congestion for car users. However, the ability to keep increasing capacity is becoming more expensive with long delays in design and construction. Other options and solutions are needed to deal with congestion of the network, although some technologies can enable more efficient use of existing infrastructure, reducing or delaying the need for additional construction of roads.

Urban areas with the greatest transportation crises may be expected to innovate the most rapidly because they have the biggest incentive to change. Policymakers at the same time will have greater opportunity and political capital to undertake action to design urban infrastructure that accommodates other transport technologies. However, urban areas built with vehicle ownership as the primary mobility option may struggle to adopt the range of non-vehicle options (Bouton et al 2015).

2.3.1.2 Policy and regulation

In the past, poor linkages between urban mobility strategy and other urban strategies have held back innovation (Arthur D Little 2014). These have been characterised by a separation of different components of transport and urban design:

- Urban planners were responsible for zoning and location of people and activities.
- Transport agencies were responsible for the provision of infrastructure.
- Environmental agencies focused on regulating pollution.
- Social agencies were concerned with supporting the mobility of the transport-poor.

It is now recognised that effective mobility outcomes require collaboration and integration across the urban environment (Litman 2013). The overarching goal is to improve the quality of the urban environment for residents and businesses, not just to achieve transport efficiency (Lerner 2011).

In many leading urban areas, policies are in place to actively reduce the use of private vehicles. A recent trend has been away from private vehicles towards public transport and active transit[3] (Rode et al 2015). Congestion charging, investment in public transport, pedestrianisation and investment in cycling infrastructure are notable trends. Some of these policies are giving cars lower priority in highly built-up areas and instead giving priority to pedestrians and other active transport modes. Specific policy settings work in combination with the infrastructure in place and new and emerging technologies to change transport outcomes.

In New Zealand, transport agencies are viewing technology as a possible solution to a number of the transport issues under their jurisdiction, including safety (National Road Safety Committee 2016) and improving mobility on their existing infrastructure (Ministry of Transport 2016a). However in many cases, enabling policies will also be part of the mix. Achieving the benefits from some technologies may require a substantial uptake to reach the economy of scale required. Agencies may need to provide encouragement through funding and regulation to reach transport and mobility objectives. Policymakers can also mandate technology uptake to meet transport goals and increase innovation. Such an approach could allow new technologies to be tested and deployed faster than would be the case without intervention.

In addition, there are risks associated with some technologies. The increasing role of data in the transport system will require careful monitoring and security requirements. Testing the resilience of software and network communications that are required for many technologies to function effectively will need to be robust. Less obvious is the possible detrimental impact if new transport modes reduce the profitability of publicly provided services (Allison 2014). Better coordination between the private and public sectors will be important to manage these risks moving forward (Bouton et al 2015), which may require a policy response to achieve.

2.3.1.3 Logistics and freight

Logistics and freight form an integral part of the infrastructure of the economy, with changing technology impacting on their business models and activities. Some of the main drivers include the rise of internet shopping, expanding use of data and information systems that are increasing tracking and efficiency, as well as the more common use of rail services due to environmental concerns (Evangelista 2002).

McKinnon (2009) classifies freight-related innovations into five categories:

- On-vehicle: relating to the design and equipping of the truck
- Fleet management: more efficient external planning and control of fleet trucks
- Network-based: relating to the management of road infrastructure
- Materials handling operations: affecting the loading and unloading of vehicles and nature of handling equipment used
- Logistics systems: the interface between the road transport operation and other logistical activities such as warehousing and inventory management.

[3] Active transit refers to human powered transport such as walking or cycling.

Future innovations are expected to follow along similar lines. There are still areas in which there are substantial amounts of waste, opportunities to innovate and interest groups are advocating for greater integration and collaboration across the supply chain (Punte 2016).

Research into the adoption of innovation in the logistic sector has been limited (Grawe 2009), as the sector is highly fragmented with low profit margins (Brauer 2011). Consequentially, investment into research and development (R&D) intensity is estimated to be 3.5% in the European Union (compared with approximately 6% [4] in the private vehicle market) (Wiesenthal et al 2011).

There is a notable difference in adoption of new technologies between small and large firms. This can be largely attributed to the cultural and financial capabilities of the respective organisations (Evangelista and Sweeney 2006). Early adopters of technology are usually larger logistic groups who have access to back office resources, and are willing and able to differentiate themselves from the rest of the market by adopting new technologies (Grawe 2009; McKinnon 2009). The fragmented market for small firms results in them having a survival/make-ends-meet culture, which limits their ability to invest in untried technology (Grawe 2009). Furthermore, these small firms may not have staff with the capability to implement and analyse more technical solutions.

The overall trend in the freight sector is for incremental adoption. Users are primarily motivated by cost reduction goals or driven by policy requirements (Wiesenthal et al 2011). A sudden increase in the cost of an input, such as fuel or labour, may temporarily increase the rate of technology adoption. In addition, the regulatory environment is an important catalyst, driving innovation and its uptake through environmental and health and safety standards (McKinnon 2009).

When firms are adopting technology, they may not be using it to the maximum benefit of their business or the wider economy; instead, in some cases technology is being adopted for very narrow purposes. For example, telematics may be installed with the purpose of tracking the physical location of vehicles, but the collected data is not being used to improve driver habits or influence routing, which provide further opportunities for fuel savings and emission reductions (Yeaman, pers comm 2016; McKinnon 2009).

While a number of years off, Costello and Suarez (2015) suggest that driverless trucks could be part of the logistics industry. These vehicles are likely to be first used on line-haul portion of truck movements, while local pick-up and delivery routes are completed by drivers. However, a number of limiting factors are slowing the adoption of the technology at this stage (such as safety, the stage of development of the technology and regulations in different parts of the world).

Overall, technology adoption with respect to infrastructure has been gradual due to the large inertia of the system and the fragmented market of commercial operators. Targeted policy changes may, however, be able to push the sector towards more desirable outcomes, helping speed the rate of adoption.

2.3.2 Technology and modes

Technology has increased the range of transport modes that are currently and soon to be available to consumers, and which are greater now than in previous decades. New modes of transport can disrupt the way transport is currently delivered.

[4] R&D intensity is the ratio of R&D investment to net sales.

In recent history, the dominant mode of transport has been the internal combustion engine (ICE) car. The ease of use and convenience of the car in transporting people and goods has resulted in widespread adoption. In New Zealand more than 70% of commuting for work is by private vehicles (Statistics New Zealand 2015). The infrastructure (roads and highways) and support services in New Zealand both reflect and encourage the use of private vehicles in a self-reinforcing feedback loop.

Car manufacturers have invested heavily in research and development (Wiesenthal et al 2011), with new technologies having been released and adopted in a gradual manner, resulting in an improvement in comfort and safety (Bahpai 2016). However, the fundamental model of a driver controlling an ICE-powered car has not changed. New technologies now challenge the current dominance of the ICE car and the way vehicles are used, having the potential to replace ICE vehicles – all the while increasing the safety and efficiency of the transport system.

This section looks at the increased number of transport modes available. Four relatively new modes of transport in the early stages of uptake are examined: connected vehicles, electric vehicles (EVs), autonomous vehicles and e-bikes. Each of these modes is in the early stages of uptake. The impact of policy settings on the uptake of alternative modes of transport is examined in section 2.3.2.5.

2.3.2.1 Connected vehicles

One new technology altering the range of transport options is connected vehicles. Connected vehicles are equipped with internet access and usually with a wireless local area network. This allows the car to share internet access with other devices inside and outside the vehicle. Furthermore, connected vehicles allow vehicles and infrastructure to communicate directly with each other, warning drivers of situational dangers. There are a number of motivations for the development and adoption of connected vehicles:

- improving traffic flow as vehicles can travel closer together
- decreasing fuel consumption
- improving safety.

Connected vehicles' capabilities are likely to be bundled into new vehicle purchases. As adoption increases, the wider benefits to society will increase in a non-linear fashion as more vehicles are able to connect with each other. It is estimated that connected vehicles could significantly increase road capacity by at least 43% and these benefits will rise with adoption (Allison, 2014). However, there are some barriers to adoption in New Zealand. Connected vehicles built in different countries currently use different standards. This means that vehicles built in different countries cannot communicate with each other (Ministry of Transport 2016b) and as a result New Zealand will likely only benefit significantly from connected vehicles after compatibility issues are addressed.

2.3.2.2 Electric vehicles

Electric vehicles (EVs) have the potential to replace fossil-fuelled vehicles. Although the technology has been around for some time, recent technological breakthroughs now mean that EVs are a viable alternative to ICE vehicles, which has seen greater competitiveness and higher uptake. Earlier iterations of electric vehicles had a much slower uptake, as poor range, slow charging and expensive batteries made ICE cars more convenient by comparison (Bouton et al 2015).

The purchase of alternative fuel vehicles (AFVs) has required a more conscious decision on the part of early adopters. Research has found that an individual's choice of new passenger vehicles is dependent on purchase price, operating costs, maximum speed, fuel availability, emissions, range and refuel locations (Shepherd et al 2012). Customer research found that initial reluctance towards purchasing alternative fuel vehicles was attributed to perceptions they were inferior, as well as misinformation and consumer judgements about range and charging time (Brook Lyndhurst Ltd 2015; Gardner et al 2011). Similarly, in New Zealand, an AA survey (King 2016) found that negative views of EVs were about battery technology (perceived range, recharging requirements and replacement cost) and uncertainty surrounding maintenance.

Along with the technical features of EVs, several buyer characteristics predict positive attitudes towards uptake. These include people with higher levels of education and who have demonstrated a willingness to change their behaviour to reduce greenhouse gas emissions (Gardner et al 2011). In addition, research into the status of early EV adopters has found the group to be affluent, middle-aged, well-educated males who live in urban areas in households that have two or more cars and the ability to charge at home (Brook Lyndhurst Ltd 2015). Neighbourhood type has also been used to understand uptake, as neighbourhoods measured at small spatial scale are often homogenous in terms of age, income and education (Higgins et al 2012). Using neighbourhoods as an explanatory variable indicates the demonstration effect for those who are in contact with early adopters. Urban areas had the greatest uptake in a study of spatial uptake in Australia and the geographic differences were largely explained by driving distance, income and employment status (Higgins et al 2012).

The second stage of adoption is uncertain at this stage. The experience in Norway, which has very strong promotional policies for EVs, has been that every vehicle bought influences three others to purchase (Bu 2016). However, in a review of the literature, the demographics of imitators were not substantially different from the early adopters and overall there is very little understanding of how new alternative fuel vehicles will diffuse through the rest of the new vehicle market at this early stage (Brook Lyndhurst Ltd, 2015).

2.3.2.3 Autonomous vehicles

The increased level of technology within vehicles has enabled a greater number of functions to be controlled by the vehicle, rather than the driver. Autonomous vehicles take the functionality one step further by removing the need for a driver to control the car. This can range from full autonomy, where no human intervention is required, to semi-autonomous vehicles where human intervention may be required under certain conditions. This change is perhaps the most disruptive new technology to affect the transport sector (Morgan Stanley 2013; Strategy& 2016).

A number of possible impacts could result from adoption of autonomous vehicles, depending on how driving habits are altered (PwC 2015). At this stage the impacts on the transport system are uncertain and will only become apparent following greater adoption. However, potential impacts that have been suggested include (Corwin et al 2015):

- The same mobility can potentially be provided with fewer vehicles through greater efficiency.
- Trip cost will be greatly reduced by removing labour costs and increasing utilisation.
- Overall the volume of vehicle miles travelled is likely to increase.
- Less parking space may be needed as cars move out of the area.
- Crashes and need for law enforcement on traffic issues may decline, possibly to zero.

As well as altering the way transport is delivered, autonomous vehicles could affect the vehicle ownership model. Currently, drivers predominantly own and use their own car – a model used in many western countries. If autonomous vehicles make using personal cars cheaper and easier, they may increase the demand for car ownership and have little impact on the vehicle ownership model. However, with the expected cost per trip to decline with autonomous vehicles, alternative models of service delivery become viable – negating the need to own a car personally. Instead a shared fleet of autonomous vehicles could be available on demand to meet any travel requirements (International Transport Forum 2015; Deloitte 2014).

Technology optimists have forecast that autonomous vehicles in combination with EV technology will revolutionise the transport market in a relatively short space of time. Arbib and Seba (2017) have argued that autonomous vehicles, alongside other technological changes, will allow vastly fewer vehicles to provide a far superior service at a greatly reduced cost to that of a private vehicle – that transport as a service (referred to in this report as mobility as a service (MaaS) will provide 95% of passenger miles travelled by 2030.

We are rather more conservative in our estimations of future change. In particular, autonomous vehicles have several barriers to overcome before widespread adoption. These range from cultural barriers to practical issues around liability and insurance, that could slow the rate of adoption (Ben-Shahar 2016; Crawford 2016). In one survey of New Zealand households, the AA found that households are cautious of technologies which ‘contradict the autonomy and authority of the vehicle owner’. In contrast, younger generations report being more comfortable with possible automation (Deloitte 2014) and may be more likely to be early adopters.

Regulatory barriers in some jurisdictions could affect the speed of diffusion. Policymakers now must decide how to regulate autonomous vehicles in the near future as they become ready for consumer purchase. The technology is complicated and being developed in different ways, making it difficult to understand how to make it work safely. Furthermore, it is unclear as to how the technology will be used in the future, making it difficult for legislation to cover all future possibilities (Davies 2015). There could be a divide between those jurisdictions that support autonomous vehicle use and those that attempt to slow its adoption.

Autonomous vehicles will create and record large amounts of data which will require extensive management and protection, as they are connected to the internet (KPMG 2015). While this data will be beneficial to car manufacturers and users alike, there is an increased risk (even higher for autonomous vehicles) that hackers are able to manipulate vehicles. This is because the connectivity and complexity requirements of autonomous cars are much greater, offering multiple potential points of entry to hackers (Simonite 2016). This risk may be exacerbated if autonomous vehicles rely on others in the network or connectivity to infrastructure, as disruption in one component may affect the whole network.

Another barrier to adoption is to determine how autonomous vehicles respond to a situation of possible injury or death. Crash algorithms will have to explicitly determine how to value the vehicle user’s own life, those around them, the risk of damage or death, and whether some groups should be valued over others (Lin 2013). In a recent announcement, Mercedes have stated they will save the car’s driver and passengers, even if that means sacrificing the lives of pedestrians, in a situation where those are the only two options. Furthermore, in the event of a crash where an autonomous vehicle is involved, liability is yet to be determined – as autonomous vehicles are expected to be more responsive, the ‘reasonable person’ legal standard will no longer be accepted in crashes (Goodall 2016). Determining legal responsibility will initially be on case-by-case basis until the realities of autonomous driving are known (KPMG 2015).

2.3.2.4 E-bikes

Outside of car-based technologies, e-bikes are increasingly gaining traction as a replacement for traditional pedal powered bikes, offering the normal benefits of a bicycle with added range and reduced effort on the part of the rider.

E-bikes are an interesting case study of a new technology diffusing through the cycling community. Early analysis of the market expected e-bikes to appeal to those who were more likely to ride a bike and younger groups; however, the early adopters of the technology were older riders, as it reduced the barrier of physical effort (Seebauer 2015; Peine et al 2016). The initial reluctance of younger audiences was attributed to the visual design of the bikes, as a bike with an obvious motor created connotations of disability. With improvements in technology and design, the motor in newer models is less prominent. Accordingly, uptake amongst younger generations has improved (Peine et al 2016).

2.3.2.5 Policy and regulation

Policy enforcement is one driver that affects the speed of technology adoption. Some policies can speed up the rate of technology uptake, while others can slow it down. Policy that expedites the removal of vehicles (eg Australia's rust regulations) from the fleet can in turn increase uptake of new vehicles with new technology (Ministry of Transport 2009). Policy can also 'mandate social acceptance' of a technology, such as the requirement for all vehicles to have safety belts (Gargett et al 2011). Conversely, environmental policies can slow the uptake of vehicles that have negative or socially undesirable impacts.

Mandated changes for vehicle technology can take some time before they filter fully through the system, as vehicles are in operation across a number of years. New technology enters the system through the purchase of new vehicles, with the standards met at the time of manufacturing. As older vehicles are replaced by the purchase of new vehicles the technology uptake will filter through the system. In New Zealand, the old age of the vehicle fleet (average age of light vehicles was 14.08 years in 2013) makes complete diffusion of a new technology slower compared with countries that renew vehicles on a more regular basis.

Because New Zealand is a small market and does not have local automobile manufacturing, policymakers' control is somewhat reduced. New Zealand can set standards for imports and does have vehicle standards, such as warrants of fitness. Nevertheless, New Zealand imports vehicles from countries that have their own rules, which might not be consistent across all countries. This makes it difficult to set standard policies for the vehicle fleet. Instead, policy and standards are set by the country where the vehicle is produced, importing the technology and standards with them. Because New Zealand is too small to have vehicles made just to New Zealand specific standards, these cannot be set entirely independently of the manufacturing countries – otherwise manufacturers will simply not export to New Zealand.

2.3.3 Technology, people and goods

In the previous two sections technology, infrastructure and modes are discussed. These elements all interact to ultimately transport people and goods to their destination. The movement of people and goods is at the heart of the transport system. Technology is changing the interface between people and the transport system, by enabling them to make decisions with more complete information. For example, in the past, printed timetables for public transport could not reflect delays or other on-the-day factors. Today real-time traffic information gives updates to users to help them make well informed decisions. In the goods sector, technology has enabled greater tracking and monitoring of client orders as they move from the warehouse to the customer's door, while being shared more widely with clients and customers online.

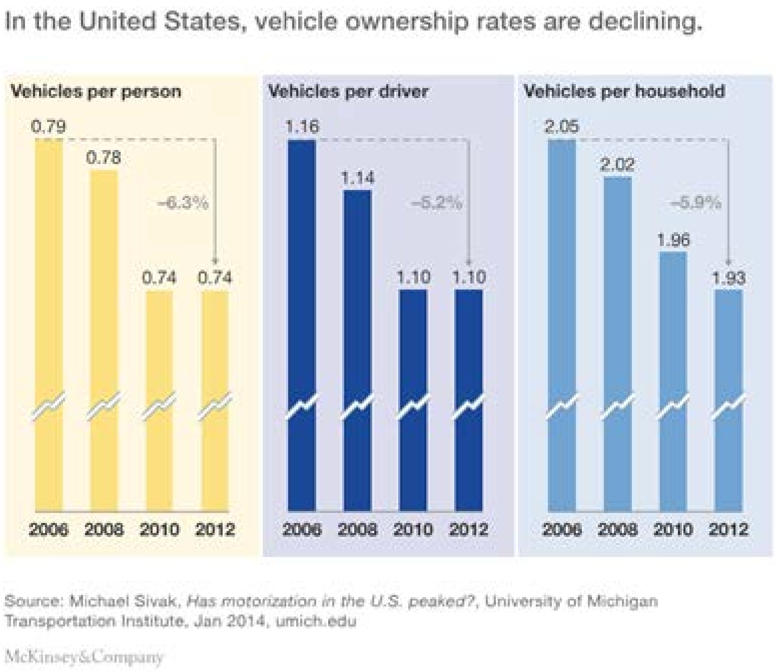
Technology has enabled alternative transport options to become viable business models, such as shared mobility (transport services that are shared among users). Wireless connectivity has made the sharing process more efficient and user friendly, allowing easy booking and payment of shared mobility services. These options are starting to challenge the current model of car ownership, by offering greater choices and flexibility by:

- bridging the first and last mile gap to connect with public transport

- providing independence for those who cannot own a vehicle
- reducing the costs of transport
- increasing efficiency and convenience by linking modes together
- offering opportunities for individuals to earn additional income.

As sharing becomes a viable option, car ownership rates have started to decline in the US. Historically owning one or more cars per household has been the norm, with 2.05 vehicles on average per household in 2006 (figure 2.2). In 2012 this had fallen to 1.93 vehicles on average per household. Interestingly, car ownership in millennial generation (born after 1980) is a large driver behind the decline. Surveys have found that American millennials are 16% less likely to commute by car to work, use public transport almost three times more often and are 23% less interested in owning a car than the previous generations (Bouton et al 2015). They are also more likely to use shared transport services like car sharing and e-hailing[5] (Deloitte 2014). However, more research is needed to determine whether this group is choosing to just delay ownership or this trend represents a new phase in urban mobility, especially as surveys report high levels of interest in buying cars (Deloitte 2014).

Figure 2.2 Car ownership rates in the US



Sections 2.3.3.1 to 2.3.3.3 focus on car, ride and bike-sharing respectively; followed by an examination of how transport data is affecting the movement of people and goods.

[5] Car-sharing typically refers to schemes where a small fleet of vehicles are shared among a large group of users for a regular fee and can be booked for short periods. E-hailing refers to hailing a taxi or other transport services using a computer or smartphone.

2.3.3.1 Car sharing

Car sharing is a model of car rental in which people rent cars for short periods of time, often by the hour. It is attractive to customers who make occasional use of a vehicle, as well as others who would like occasional access to a vehicle outside typical day-to-day activities. Other drivers of the shift towards car sharing are inner city congestion, shifting mind sets about car ownership and increasing cost of vehicle ownership. The new model of transport mobility can be seen as a challenge to the existing car ownership model by changing the way mobility is delivered. According to The Economist (2012) one rental car can take the place of 15 owned vehicles.

Car sharing has spread across many European and North American cities since the 1990s (Metro Vancouver, 2014). Companies generally focus their business in high-density urban areas or highly walkable neighbourhoods (Metro Vancouver 2014). As the distance required to walk to the nearest available car share vehicle is an important factor in usage, urban density is a critical component to allow firms to be profitable (Celsor and Millard-Ball 2007). Therefore firms are investing in areas of the city that are increasing in density (Baalsraud Hauge et al 2014; Metro Vancouver 2014). These areas have a high number of potential customers in a small area, where the costs of parking a vehicle can be prohibitive. Over time, car sharing can be extended to less dense areas as the network expands.

Users are generally between 20 and 44 years of age and are less likely to own their own vehicle. Providers have also traditionally targeted middle income neighbourhoods (Metro Vancouver 2014). As the network expands and the system becomes more established, other demographics are also likely to join. However, at this stage car sharing is under-represented in low-income communities, as these user groups have a number of barriers to use, including unfeasible pricing structure and lack of internet access, bank accounts and valid driver licences (Kodransky and Lewenstein 2014).

2.3.3.2 Ridesharing

Ridesharing services are those that arrange one-time shared rides on very short notice. Taxis are the original ridesharing service that facilitated short distance trips on demand. Technology has enabled a new generation of ridesharing services where drivers provide mobility services using their personal vehicles for a fee, often facilitated by an app platform that connects drivers and customers, as well as processing the payments (Johnson and Walker 2016). Drivers in this situation may be providing services as they wish, rather than having scheduled working hours. The model makes use of three recent technological advances that have been included in smartphone technology:

- GPS navigation devices to determine a driver's route and arrange the shared ride
- smartphone connectivity to request a ride from wherever the user is
- social networks to establish trust and accountability between drivers and passengers.

Perhaps the biggest companies providing ridesharing services are Uber and Lyft. These services are similar to taxi services and as a result have had regulatory difficulties in some jurisdictions (Bouton et al 2015). But despite teething problems, Uber has expanded its service globally, currently in over 500 cities, and these services are priming populations for the possibility of increased car sharing serviced by autonomous vehicles (Corwin et al 2015).

Many transport agencies, including New Zealand, view increased vehicle occupancy as a mobility solution (Ministry of Transport 2016a). Greater vehicle occupancy can reduce the number of vehicle trips while transporting the same number of people. The increased uptake of smartphones has broadened the appeal of ridesharing, as the technology is being driven by applications and the algorithms that power them. For example, Helsinki’s transport authority initiated a ridesharing scheme in 2012 that matched riders and routes to provide added mobility where the subway reach was limited. The pilot was considered a success; however, it was disestablished before it reached a level where the economies of scale made it effective (Sulopuisto 2016). Other firms have found an alternative to the economy of scale problem; for example, Chariot, a San Franciscan start up ‘crowd sourced’ their routes, ensuring profitability and high ridership (Cutler 2015).

2.3.3.3 Bike sharing

Bike sharing originated in the Netherlands in the 1960s with the provision of a number of free bikes placed around Amsterdam. The model is similar to car sharing, where bicycles are made available for shared use to individuals on a short-term basis, and technology has advanced it into a viable and convenient model through the development and integration of apps, electronic locking and payment systems (DeMaio 2009). There is a wide variety in models of bike-sharing provision, with governments, transport agencies, non-profit and for-profit organisations and advertising companies all involved (DeMaio 2009). Since 2007 there have been substantial increases in bike-sharing provision, and as of 2012 there were an estimated 400,000 bikes across 450 locations (Fishman 2013).

Users of bike share schemes are primarily people who currently cycle (Buck et al 2013). In Australia, riders are likely to have higher incomes and for members between the ages of 18 and 34, there is a relationship between their location of work and distance to docking stations (Fishman et al 2015). Predictions of future growth of bike-share schemes include future development to business models, better tracking of bikes across the network to provide users with information on access to bikes and the electrification of the bike fleet (DeMaio 2009). Electrification of the fleet would encourage older users to join and participate in bike-share schemes.

Success of bike-share schemes can be affected by perceptions of safety and provision of effective cycling infrastructure (Fishman et al 2013; Shaheen 2010). Effects of regulations, such as requiring cyclists to wear helmets in New Zealand, have been detrimental to past bike-sharing schemes success (Koorey, pers comm 2016). It is also important to users to have integration with public transit and provide an extensive network of docks (Fishman et al 2013).

2.3.3.4 Transport data

Transport data and information has played an increasing role in moving people and goods around more efficiently. One way of doing this is linking up different transport modes to create a seamless journey across the network. For example, users can take a bus, followed by a train and then walk to their final destination, which is useful as often different transport modes service different areas. At a basic level, having one system for payment across multiple platforms is the first step for accessibility across multiple modes. The next step is integrating planning across multiple mobility providers, which is currently being done at a city level in a few selected locations, such as Hong Kong (Lerner 2011). Apps in the private sector are looking to provide journey planning across multiple modes, as with Finland’s MaaS platform (The Economist 2016). As mobility options and sophistication increase, these solutions offer a continuation of the trends of increased flexibility and improved mobility for consumers.

Other technology platforms can provide real-time information and updates on the status of a journey. Perhaps the most widely used platform is Google maps. Via the use of apps on mobile phones Google is able to locate and aggregate user movements, giving real-time updates about congestion and travel times (Google 2015). Users can also comment on traffic conditions through social media platforms, such as Twitter. These updates can be combined with aggregated data on traffic conditions to give a rich array of information for the user (Data61 2015). Based on this information, people are able to adjust their decisions to reach their destination efficiently.

Technology can adjust traffic management systems to control and mitigate congestion by altering signals and providing warnings on signage, which can greatly reduce the effect that congestion related to traffic incidents can have (MATOC 2010). For example, the smart motorway in Wellington improves safety and removes congestion by altering the speed limit, which reduces the sudden braking that can cause a domino effect on following traffic (NZ Transport Agency 2016). Another example is the retiming of traffic signals. In one case in Portland USA, changing the traffic signals reduced public transport delays by 30–40% and saved over 300 tonnes of CO_2 annually (US Department of Transportation 2013).

Technology has also replaced inefficient methods for collecting revenue from toll roads and road user charges. Better tracking and monitoring technology has made payment in advance feasible. The EU has launched a satellite-based augmentation system developed by the European Space Agency, the European Commission and EUROCONTROL, enabling them to implement road user charges, use information to reduce congestion and offer smart pricing opportunities such as pay as you go congestion charges (European GSA (nd)). New Zealand is investigating similar systems to reduce costs of transport network regulation related to compliance, network planning and payment systems (NZ Transport Agency 2014). These lower administration costs for users allow a more efficient process when moving people and goods around.

The literature reviewed rarely mentions the effect that new technologies may have on the transport-poor. When transport services are unreliable (for example, regular car breakdowns) or lacking in options (for example, those living in a rural location), these people are considered to be transport-poor. Individuals who have limited access to reliable transport options are likely to be disadvantaged in their ability to access resources and services (Gutierrez 2009). Currently, low socio-economic groups and those living in rural areas are the most affected by the lack of transportation options in New Zealand (Fitzgerald 2012). We have identified a number of possible impacts on those with low accessibility to transport in New Zealand:

- Rural groups are unlikely to be able to access sharing schemes which require economies of scale and are not efficient for widely dispersed populations.
- Older technologies become more expensive to run but may be the only viable solution for rural groups if the infrastructure to support newer technologies or economies of scale to support newer technologies does not exist.
- The increase in sharing technologies and service models may improve transport outcomes for current transport-poor in urban areas, by expanding on the public transport provisions at a reasonable cost. For example, private companies can collaborate with public transport to provide 'last-mile' or 'last-leg' connections to transport hubs.
- If private modes of transport continue to dominate to the detriment of public transport options, lower socio-economic groups may suffer.

2.3.4 Technology and transport conclusion

Technology plays an important role within the transport system, from autonomous vehicles to shared mobility services. These alternative services could challenge the current model of car ownership. In addition, new technologies have the potential to reduce costs for users and improve safety by lowering the number of crashes. These changes could see an evolution in the transport system as to how transport is thought of and delivered:

- Technology has the potential to make better use of the existing transport infrastructure. More efficient use of infrastructure can reduce or delay the need for construction of new roads to deal with congestion issues. Previously construction of new roads to increase capacity was the solution to alleviate congestion.

- New transport modes are expected to offer greater flexibility while reducing travel costs. As a result, the number of kilometres travelled across all modes is expected to rise, increasing demand for transport. Urban design policy and transport policy will need to carefully consider competing forces and may need to consider additional regulation to ensure other social outcomes are not harmed.
- Vehicle ownership could be displaced by a pay-per-service model of transport delivery. In this situation, vehicles are likely to be used more intensely through car and ridesharing schemes. Greater utilisation will lead to a faster turnover of vehicles and offer greater flexibility for users.
- There are risks that private, on-demand transport sources may remove passengers from public transport as the costs of private transport fall below that of public transport (Bouton et al 2015; Allison 2014). This can make public transport less economical or result in reduced services.
- The land use of the transport sector could be different under different models of transport service. With autonomous vehicles, parking requirements could be reduced as after the car is not needed for a while it can move itself to another area. Ridesharing also reduces the need for parking spaces, as users use a pick up and drop off service.

We identified four main elements that make up the transport system: people and goods, modes, infrastructure and technology (figure 2.1). Each of these elements interacts with the others to deliver transport services, and the interaction of each element with technology has been the catalyst for alternative options to move people and goods more efficiently.

2.4 Diffusion theory

2.4.1 Introduction

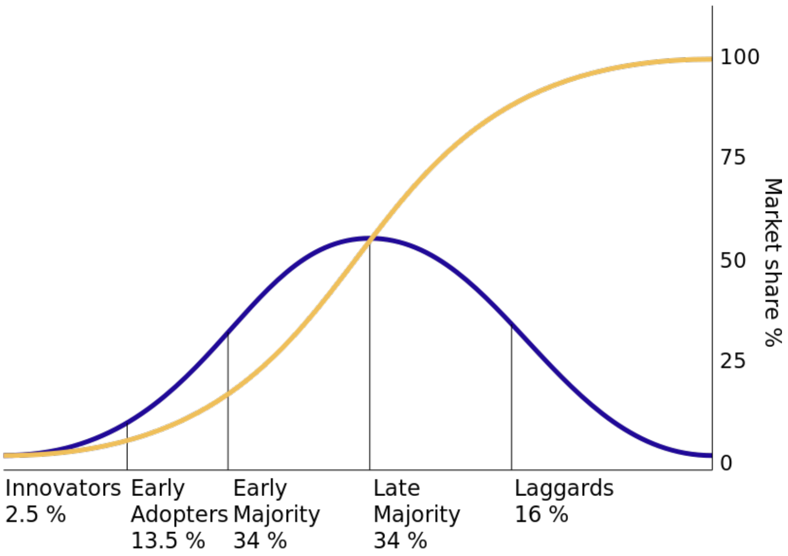
Diffusion theory explains the process of how a new technology diffuses through a system. The study of diffusion of innovations was developed in the field of agricultural technology. Technology was advancing quickly and researchers were looking to understand how individual farmers were adopting hybrid seeds and other techniques. Griliches (1957) was one of the seminal studies that investigated the adoption of hybrid corn seeds in the Midwestern United States using an S-shaped-curve (described in section 2.4.2). This study and S-curve modelling are relevant today as the results are applicable to new technology diffusion outside the agricultural sector. Further, the process is robust to other variables which are not explicitly accounted for, such as income. With the wide range of applicability, researchers are still using the S-curve for modelling and explaining technology diffusion. This chapter discusses diffusion theory and the factors that influence the diffusion process.

2.4.2 The S-curve

The literature on diffusion of innovations seeks to explain the rate of adoption of a new technology by the number of members of a social system adopting within a specified period, such as each year.

The literature uses an S-shaped curve (referred to in this report as an S-curve) to describe the cumulative share of adoption – the process starts gradually, but as more people adopt the new technology the slope of the curve steepens. Once past the point of peak demand, the speed of adoption slows as the market nears full market potential. Figure 2.3 shows the basis of the S-curve.

Figure 2.3 S-curve



Within the S-curve, successive groups of consumers adopt the new technology. Rogers (1962) breaks down the new adopter process into five categories: innovators, early adopters, early majority, late majority and laggards. Each stage is shown in figure 2.3 above. Each phase attracts a different type of consumer with distinct behavioural characteristics and these consumers make the decision to adopt at different points in time. Rogers (1962) describes the behavioural characteristics for each group as follows:

- Innovators are willing to take risks and have the highest social status, financial liquidity, contact with scientific sources and interaction with other innovators. Their risk tolerance allows them to adopt technologies that may ultimately fail, but their financial resources help absorb these failures.
- Early adopters have the highest degree of opinion leadership among the adopter categories. Early adopters have a higher social status, financial liquidity and advanced education and are more socially forward than late adopters. They are more discerning in adoption choices than innovators and they use choice of adoption to help them maintain a central communication position.
- Early majority individuals adopt new technology after a varying degree of time that is significantly longer than the innovators and early adopters. They have above average social status, contact with early adopters and seldom hold positions of opinion leadership in a system.
- Late majority individuals adopt new technology after the average participant. These individuals approach an innovation with a high degree of scepticism and after the majority of society has adopted the new technology. They typically have below average social status, have little financial liquidity, are in contact with others in the late majority and early majority but have little opinion leadership.
- Laggards are the last to adopt new technology. Unlike some of the previous categories, individuals in this category show little to no opinion leadership. These individuals typically have an aversion to change. They tend to be focused on ‘traditions’, have the lowest social status and financial liquidity, are the oldest among adopters and tend to be in contact with only family and close friends.

2.4.3 Diffusion of new technology

Some technologies diffuse from introduction to widespread use in a short period of time. For example, it took the telephone 75 years to reach 50 million users, whereas it took radio 38 years and TV 13 years

(Aeppel 2016). The literature (Rogers 1962) highlighted four main elements in affecting the rate of diffusion of new ideas.

2.4.3.1 The innovation

Each innovation has unique characteristics that affect the diffusion process. These characteristics can be broken into five factors:

1 Relative advantage is the degree to which an innovation is perceived as being better than the idea it supersedes, usually expressed as profitability, social prestige or other benefits. A high level of relative advantage will lead to a steeper S-curve. Status motivations for adoption seem to be more important for those in the early stages of adoption and less important for laggards. Relative advantage is one of the best predictors of an innovation’s rate of adoption.

2 Compatibility as perceived by members of society is positively related to the rate of adoption and affects the way consumers behave towards innovations. If the behaviour is similar to the way the potential adopter currently behaves or similar to products they already use, then uptake is more likely – and the shape of the S-curve is likely to be steeper. Full adoption is more likely with higher compatibility, whereas innovations that require bundling or other expensive purchases are often slower to diffuse (eg technology within a car, as the purchase is expensive and technology is bundled together).

3 Complexity is the degree to which an innovation is perceived as relatively difficult to understand and use. Some innovations are clear, while others are not. In general, there is a negative relationship between complexity and the rate of adoption: simple technology or innovations diffuse faster than complicated ones.

4 Trialability is the degree to which an innovation may be experimented with on a limited basis. The trialability of an innovation is positively related to the rate of adoption. Trialability is more important to early adopters as they have no precedent to observe the innovation in use. These peers act as a vicarious trial for late adopters and laggards.

5 Observability is the degree to which results are observable to the user and to others. At times it can be hard to observe the impact or result from the innovation. Observability is positively related to adoption. Some impacts or results take longer to observe and users are more likely to give up due to the longer time taken to observe results.

2.4.3.2 Communication

Communication is the process by which users create and share information with one another in order to reach a mutual understanding, using channels as the means by which messages get from one individual to another. Mass media channels are more effective in creating knowledge of innovations, whereas interpersonal channels are more effective in forming and changing attitudes toward a new technology and thus in influencing the decision to adopt or reject. Most individuals evaluate an innovation, not on the basis of scientific research by experts, but through the subjective evaluations of near-peers who have adopted the innovation. So, increased levels of communication may lead to a steeper S-curve and faster adoption.

2.4.3.3 Time

The time dimension is involved in diffusion process in three ways: the decision to adopt new technology, how early the individual adopts the technology and the rate of adoption by members of a social system:

1 The first time step involves the process by which an individual goes from learning about a new technology to the decision on whether to accept or reject it – broken into another five-step process: knowledge, persuasion, decision, implementation and confirmation.

2 The second way in which time is involved is the stage of uptake the individual falls into. The five different categories (discussed above) or classifications of members of a social system on the basis of their innovativeness are: innovators (2.5%), early adopters (13.5%), early majority (34%), late majority (34%) and laggards (16%).

3 The third way in which time is involved in the diffusion process is in the rate of adoption – the relative speed at which an innovation is adopted by all members of a social system.

2.4.3.4 The social system

The fourth element is the social system in which technology is diffused. Social systems are defined as a set of inter-related units that are engaged in joint problem solving to accomplish a common goal. It is a boundary for the technology to diffuse within and can be based on demographics or geographic location. Social norms and leadership can affect an individual's attitude towards a specific technology.

2.4.4 The generation of innovations

The diffusion process starts with the first adopter of a technology, that is, with the left-hand tail of the S-curve (figure 2.3). A great deal of activity and process is involved before the new technology is ready to be diffused through the system – from innovation and design of the new technology to the communication to an audience of potential adopters. At the end of the innovation process the first adoption occurs, so events and decisions prior to this can have a considerable impact on the diffusion process.

The innovation and design process is an important part of the pre-diffusion process. There are four key steps in the innovation and design process:

1 Recognising a problem or need: one of the ways the innovation and design process begins is from the identification of an issue or need.

2 Basic and applied research: finding the best solution to address the need or problem is normally based on an existing set of research. For example, electrically powered vehicles are reliant on pre-existing research on batteries and electrical engineering. Applied research on the other hand, is research directly applied to solving an identified need. Hence, an invention may result from a sequence of basic research, then applied research leading to development.

3 Development: development is the process of putting a new idea in a form that is expected to meet the needs of an audience of potential adopters. This normally occurs after, but is sometimes difficult to separate from, the research phase.

4 Diffusion and adoption: the decision to begin the diffusion process is a key stage of the entire process. Here, timing is crucial: release the product too early and product flaws could spread negative perceptions about the new technology; release the product too late and competitors could have taken market share already. Financial considerations can affect the timing of diffusion decisions.

2.4.5 Centralised vs decentralised diffusion

The diffusion process can occur through two different models: centralised or decentralised. In a centralised model the new technology is diffused from an expert source, as a uniform package to potential adopters who either accept or reject the new technology. The key decisions about which innovations to diffuse, how to diffuse them and to whom are made by a small number of technically expert officials near the top of a diffusion system. One failure of this model is that it fails to capture the complexity involved in decentralised diffusion systems, where innovations originate from many sources and evolve as they diffuse via horizontal networks.

Decentralised diffusion systems follow a convergence model of communication in which participants create and share information with one another, in order to reach a mutual understanding (Rogers and Kincaid 1981). A fundamental assumption of the processes is that members of the user system have the ability to make decisions about how the diffusion process is managed. This model works for new technologies where the users are technically competent or when the new technology is user friendly.

Table 2.1 Difference between centralised and decentralised diffusion models

Characteristics of diffusion	Centralised diffusion model	Decentralised diffusion model
The degree of centralisation in decision making and power	Overall control of decisions by national government administrators and technical subject matter experts	Wide sharing of power and control among the members of the diffusion system; client control by local officials/leaders
Direction of diffusion	Top-down diffusion from experts to local users of innovations	Peer diffusion of innovations through horizontal networks
Sources of innovations	Innovations come from formal R&D conducted by technical experts	Innovations come from local experimentation by non-experts, who often are users
Who decides which innovations to diffuse?	Decisions about which innovations should be diffused are made by top administrators and technical subject-matter specialists	Local units decide innovations should the basis of their evaluations of the innovations
How important are clients' needs in driving the diffusion process?	An innovation-centred approach; technology-push, emphasising needs created by the availability of the innovation	A problem-centred approach; technology pull, created by locally perceived needs and problems
Amount of re-invention?	A low degree of local adaptation and re-invention of the innovations as they diffuse among adopters	A high degree of local adaptation and re-invention of the innovations as they diffuse among adopters

Source: Hoffmann et al 2007.

2.4.6 Consequences of new technology

The diffusion process can create winners and losers in a social system. Although important to understand and analyse, consequences often receive inadequate attention as they are difficult to measure and understand fully. It must be noted that many innovations cause both negative and positive consequences and both sides need to be accounted for when evaluating the impact of an innovation.

Certain technologies can have a larger impact on the economy than others. These are known as general purpose technologies and have the potential to drastically alter societies through their impact on pre-existing economic and social structures. In New Zealand, the telegraph experienced elements of general purpose technology (Grimes 2008). As a network industry, its usefulness increases as the number of people able to access the network increases. Rosenberg and Trajtenberg (2001) examine the role of the steam engine as a general purpose technology. In the early 19th century, waterpower offered abundant and cheap energy, but restricted the location of manufacturing to areas with favourable topography and climate. Steam engines offered the opportunity to relax this severe constraint, allowing industry to locate where other key considerations dictated, such as markets for inputs and outputs. This change induced the movement of widespread, more efficient relocation of economic activity and long-term growth.

2.4.7 Bias in models

Practitioners need to be aware of biases when conducting research on the diffusion process. Although difficult to identify at times, the main bias is a pro-innovation bias. This is a tendency to suggest that an innovation should be adopted by all members of a social system simply because it is new, that is should be diffused more rapidly and that the innovation should be neither re-invented nor rejected. It biases attention away from negative and destructive components of technology diffusion, leading to higher estimates of benefits for a particular technology than is actually experienced (Komlos 2014).

It also leads researchers and practitioners to overlook re-invention, underemphasise the rejection or discontinuance of innovations and fail to study anti-diffusion programmes that are designed to prevent 'bad' innovations from spreading. As a result, the diffusion literature contains more information on rapidly diffusing new technologies' adoption and continued use, rather than rejection and discontinuance.

2.5 Discussion

The transport sector appears to be on the cusp of a major change. For a number of years, conditions have been rather stable in the way transport services were provided, following traditional models of car ownership and increasing infrastructure to allow more capacity. Companies have relied on this model, where technology has improved the comfort and safety of cars and infrastructure, but largely left the modes of transport and the kind of infrastructure required unchanged. Now, new technologies are emerging that are changing the way transport is delivered and thought about.

Technology is interacting with infrastructure, modes and people and goods, to affect change in the transport system. Changes in one element can affect other areas. For example, shared mobility can increase the occupancy rate of each vehicle, reducing the load or congestion on infrastructure. In turn, this could delay the need for additional infrastructure as the system is now more efficient. Furthermore, greater use of e-bikes could reduce the number of vehicles on the road and change the way people move around cities. The whole system will therefore respond in different ways to these relatively simple changes available in technology.

One of the most disruptive technologies is autonomous vehicles, which combines a number of new and existing technologies to remove the need to have a driver in control of the vehicle. The rate or speed of adoption will be affected by the five features: relative advantage, compatibility, complexity, trialability and observability. Autonomous vehicles have the advantage that a driver is not required, pushing down the costs of new ways of providing transport such as MaaS. If taxi companies or other shared mobility services quickly adopt autonomous vehicles to gain a price advantage then consumers will be able to trial and observe the vehicles in use without necessarily having to purchase one themselves. These factors are likely to be positive for greater adoption. On the other hand, the complexity of the vehicles and supporting infrastructure are likely to slow the adoption process. Outside the innovation itself, the social system could react negatively to the new technology and act to slow the rate of adoption.

EVs are another new technology and are in the early stages of adoption. The main relative advantage of EVs has been the environmental aspects, which appeal more to social conscience advantages rather than practical advantages over petrol powered vehicles. EVs also have a relative advantage in running costs, with some shared mobility services already adopting EVs as a result. Users are able to trial and observe EVs without purchasing one outright. The use of electricity rather than fossil fuels as a power source creates compatibility issues with current refuelling or recharging infrastructure. As the supporting infrastructure improves, these barriers to purchase will decrease. As technology improves, the practical disadvantage of EVs around charging times and range will fall and the rate of uptake is likely to increase quickly as the vehicles will appeal to the majority in the system.

Other new technologies enable greater shared use of vehicles, creating viable alternatives to owning a vehicle. The technologies change the current model towards MaaS – a relatively new concept. In the new paradigm, transport is pay-for-service as opposed to the current model of car ownership, in which payment is for both the option to travel and the travel itself. This change in structure could deliver the same level of mobility with fewer cars on the road. The model has the potential for private companies to start competing with public transport in terms of service and cost to deliver mobility, or to develop new ways to collaborate with public transport.

Collection and distribution of data now plays a bigger role in the transport system, helping users make effective decisions around transport routes and options – the use of smartphones having been a catalyst. Users can now look up real-time traffic information on congestion, access public transport timetables and use mapping software to plan journeys. They can also match riders with drivers for journeys at short notice, making the most of shared mobility services. In the future, increases in computing power and wider collection of data will allow users to make efficient decisions about transport.

The speed and extent of technology adoption are important on the wider impact on the transport system. A fast and high level of adoption can cause radical change and disruption in the sector, whereas a slower or more gradual adoption profile can be managed in a more cohesive manner. Technological advances are able to be adopted quickly to cause disruption, whereas infrastructure is slower to change and is less likely to be the source of disruption. Being able to track and monitor the speed and level of adoption will help inform policymakers on the best steps to deal with and support the change. One way of tracking and predicting changes is through the use of models, such as the Bass model. We discuss Bass models in general and the specific model developed for New Zealand in chapter 3.

3 Bass diffusion models

3.1 Introduction

Models are useful when quantifying the diffusion process, particularly in determining the speed of adoption through the use of S-curves. Meade and Islam (2006) identify eight different S-shaped diffusion models that have been applied to estimating and forecasting cumulative adoption since the 1970s. These models are defined by assumptions about mathematical forms and include the Bass model, cumulative log-normal, cumulative normal, Gompertz, log reciprocal, logistic, modified exponential and Weibull distributions. One well-known S-curve of the modelling literature is the Bass diffusion model and will be the focus for this section.

The model developed by Bass (1969) is a differential equation that models the adoption of a technology or consumer durable product through both external and internal processes, sometimes referred to as innovation and imitation. The model is sufficiently general to explain and help forecast most adoptable technology diffusion processes.

Since the 1960s, the main modelling developments have been in modifying existing models to incorporate greater flexibility to the underlying model (Meade and Islam 2006). These modifications include incorporating marketing variables, different stages of diffusion in different countries or successive generations of technology. This chapter starts by examining the original Bass diffusion model. Then the generalised Bass model, successive generations Bass model and two model extensions are examined.

3.2 Bass model

The Bass model describes how new technologies are adopted through the diffusion process. It presents a rationale of how current adopters and potential adopters of a new technology interact. The basic premise is that adopters can be classified as innovators or imitators and the speed of adoption is influenced by the degree of innovativeness and the degree of imitation among adopters. Bass (1969) presents this interaction in the form of a hazard rate, which is completely parameterised by the coefficient of innovation (p), the coefficient of imitation (q) and the market potential (m):

$$h_t = \frac{f_t}{1 - F_t} = p + \frac{q}{m} Y_t \qquad \text{(Equation 3.1)}$$

Here:

- h_t is the hazard rate, the probability a consumer will adopt the technology at time t given they have not previously adopted the technology
- f_t is the probability density function of adoption at time t
- F_t is the cumulative distribution function
- Y_t is the number of adopters at time t such that $Y_t = mF_t$
- p is the parameter referred to as the coefficient of innovation
- q is the parameter referred to as the coefficient of imitation
- m is the market potential, ie the estimate number of adopters following complete market saturation if the technology

The parameter (p) reflects the importance of innovators in a social system and is a constant equal to the probability of adoption at $t = 0$. The parameter (q) creates a reinforcing process from previous adoption in the social system. This parameter reflects the pressure operating on imitators as the number of adopters of the new technology increases.

Bass (1969) suggests a discrete-time quadratic functional for the change in adoption in order to estimate the parameters set (p, q, m). Equation 3.2 shows the process for estimating the set of parameters given a standard quadratic linear regression.

$$S_t = a + bY_{t-1} + cY_{t-1}^2 \quad \text{(Equation 3.2)}$$

Here:

- $S_t = Y_t - Y_{t-1}$ is the new adoption in time t
- $a = pm$
- $b = q - p$
- $c = -\frac{q}{m}$

Using the set of three regression coefficients, (a, b, c) it is possible to identify the set of three Bass model parameters (p, q, m).

3.3 Generalised Bass model

Diffusion of an innovation rarely takes place in a stable environment. Instead, the environment is often changing, reflecting the real world interactions. There have been many attempts to include environmental variables in diffusion models to capture these real-world effects (Meade and Islam 2006).

The generalised Bass model is an extension of the Bass model that incorporates decision variables, while preserving the fundamental characteristics of the innovation and imitation diffusion process. It was first published in Bass et al (1994) to incorporate decision variables, pricing and advertising into the diffusion model. The authors compare the generalised Bass model with other diffusion models that include decision variables and find their results support the generalised Bass model both theoretically and empirically.

Mathematically the generalised model extends the original model by applying a mapping function called the current marketing effort (x_t) to the hazard rate to adjust the speed of adoption:

$$h_t = \frac{f_t}{1 - F_t} = [p + qF_t]x_t \quad \text{(Equation 3.3)}$$

Bass et al (1994) suggest some alternative functional forms for the current marketing effort, with the most general form being:

$$x_t = 1 + \beta_1 \frac{Pr_t - Pr_{t-1}}{Pr_{t-1}} + \beta_2 \frac{Adv_t - Adv_{t-1}}{Adv_{t-1}} \quad \text{(Equation 3.4)}$$

Where:

- Pr_t is the price of the technology or product at time t
- Adv_t is the advertising expenditure on marketing the technology or product at time t
- β_1 is the price response, which is the percentage increase in the speed of adoption given a 1% decrease in price, holding other factors constant. β_1 is generally negative.

- β_2 is the advertising response, which is the percentage increase in the speed of adoption with a 1% increase in advertising expenditure.

β_1 and β_2 reflect the effectiveness of price and advertising over the time horizon and are generally negative and positive, respectively. In the generalised Bass model, price and advertising expenditure only affect the speed at which a consumer effectively adopts a technology, but does not change the number of potential adopters, m.

The mapping function is not restricted to including only price and advertising expenditure. However, an essential feature of the mapping function is that the decision variables, including price and advertising expenditure, must vary over time for the mapping function be able to shift the hazard rate.

3.4 Why we chose the Bass framework

The original Bass diffusion model developed an empirical growth model to explain the timing of purchases for new products (Bass 1969). The paper drew on prior work that modelled new product growth as a function of the number of previous purchases of the innovation. The behaviours can be grouped as either innovator or imitator behaviours of adoption. The theory was applied to generic classes of products, removing the brand or new models.

Innovations are not adopted instantaneously. Rather, adoption is distributed in some way through the population. Results from the original Bass diffusion and subsequent studies strongly suggest that the diffusion process follows an S-curve pattern (Radas 2005). Within the S-curve, diffusion starts slowly and gradually picks up over time. As the product nears market saturation the diffusion process slows down. Members of a social system tend to rely on either mass media or interpersonal channels when determining whether to adopt the innovation. These variables influence the speed and shape of the S-curve (Mahajan et al 2000). The main factors behind selecting the Bass model for the project are: the simplicity of the model, generalisation to a number of products, flexibility in estimating parameters and the extensions that capture more complex modelling scenarios.

There are three inputs into the Bass diffusion model: potential market size, innovators and imitators. This is a relatively simple specification that captures the diffusion process without a large amount of data. Even though the model has a small number of inputs, the outputs have described the complex S-shaped process of diffusion for many different products. In a meta-analysis of diffusion models, Sultan et al (1990) studied 213 sets of parameters from 15 articles published from the 1950s to the 1980s. They found that the average values of p and q were 0.03 and 0.38 respectively, though the values varied considerably. Market size depended on the good itself and the market the product was diffusing into. Other demographic and economic factors also influenced the potential market size (Kumar et al 2015). Potential market size can also be depicted as a percentage share.

Another benefit of the Bass diffusion model is how it can be applied to a number of different products, to empirically denote the diffusion process. The number of markets tested in the marketing literature has been extensive (Radas 2005). With respect to transport, a number of studies have examined the purchase of new alternative fuel vehicles using the Bass diffusion model (Massiani and Gohs 2015). The wide application of the model indicates it will be able to capture the diffusion of future technologies in the transport system. Generalisation is essential as the next technology to have an impact on the transport system is uncertain.

A number of options are available to estimate Bass diffusion parameters. Early sales data can be used to estimate the innovator and imitator variables (p and q). A regression equation is used to estimate the variables. However, in a number of situations sales data on the new technology may not be available. Private companies may unwilling to share sales data or sales and diffusion may yet be to occur in the market of interest. Two options are available to forecast the diffusion process for the new technology: using other markets as case studies and analogy of products that have similar features to the new technology.

Diffusion of the new technology in other markets can be used as case studies to supplement the information gap on domestic diffusion. Using sales data internationally can provide indicative estimates of the p and q parameters using the regression equation. These estimates can then be applied to the domestic market to give an indication of the diffusion process.

In some situations, the technology may not have reached the market yet and is still in the development phase. Without any sales data, either domestically or internationally, analogy can be used to provide estimates for the imitator and innovator parameters of the Bass diffusion model. Selecting a similar technology with similar features can illustrate how the diffusion process is likely to proceed. For example, diffusion of a new technology like high-definition television is likely to be similar to the diffusion process of colour television as they share a number of similar features (Vanston 2008). Once data from the domestic diffusion becomes available forecasts can be updated to reflect this information.

Extensions to the original Bass diffusion model have been developed, as outlined previously. These model extensions attempt to capture external influences on the level of sales, such as advertising and price changes. Policy actions can also shape the diffusion process. Without them, the practical use of diffusion models would be limited (Radas 2005).

Bass et al (1994) developed a generalised Bass model which enabled the inclusion of decision variables such as price and advertising. The generalised model incorporated a term for ‘current marketing effort’. When this term is a constant, the adapted model is equivalent to the original Bass diffusion model and provides a good fit to adoption data even though it does not incorporate decision variables (Kumar et al 2015). Model extensions are able to incorporate greater flexibility in modelling different scenarios in the diffusion process.

The flexibility and versatility of the Bass diffusion model is the primary reason why the model was selected to produce forecasts of the diffusion process. The versatility enables the user to complete forecasts for a number of different new technologies. The model runs with relatively little data yet captures the complex diffusion process. Where data is unavailable, analogy to similar products can be used to provide guidance on the model parameters. Extensions to the model can include additional variables allowing the modelling to capture greater complexities in the diffusion process. For these reasons, the Bass model was chosen.

3.5 Selection of parameters is critical

It is important there is sufficient confidence in the parameters selected to drive the Bass model. There are three inputs into the Bass diffusion model: the coefficient of innovation, the coefficient of imitation and the potential market share. These variables together describe how fast and how much diffusion of the new technology occurs. The ratio of the innovation and imitator coefficients affects the shape of the diffusion process, while potential market share describes the size of the market the technology can diffuse into.

Estimating the potential market accounts for a number of different factors. Influences can range from GDP and income to population demographics. These variables affect the likely population that is expected to adopt the new technology. In the early stages it can be difficult to accurately estimate the size of the market share given the complexity and number of factors. Incorrect estimates can lead to a potential market that is either higher or lower than the true market share potential. A lower estimate will indicate a diffusion process that stops short of the actual market share and a higher estimate will lead to forecasts of diffusion that are unlikely to reach the expected level of market saturation. To work around the complexities in the early stages, estimates of the potential market share can be updated as more information comes to light to give more accurate estimates of the market share.

Early sales data can be used to provide estimates of the innovator and imitator coefficients. Higher estimates of the innovator coefficient affect the early rates of diffusion, leading to higher adoption in the early stages of the process. In contrast, lower estimates of the innovator coefficient lead to a period of low adoption in the early stages. The imitator coefficient affects the steepness of the S-curve as it reaches the market potential. Higher estimates indicate a steeper and faster diffusion process, whereas lower estimates indicate a flatter and slower diffusion process. The shape of the S-curve can be represented by the ratio between the two coefficients, known as the q/p ratio. High values of this ratio will lead to a relatively fast diffusion process and vice versa.

3.6 Successive generations Bass model

Technology products succeed one another in generations. That is, over time new technology is released that supersedes the previous version of the technology. Norton and Bass (1987) outline a model of dynamic sales behaviour of successive generations of high-technology products. The model is an extension of the Bass model that encompasses diffusion and substitution through successive generations.

The model is a system of equations: one for each successive generation but where coefficients of imitation and innovation are the same over successive generations. The number of generations is defined a priori.

Norton and Bass (1987) argue that one would not expect the behaviour of adoption of successive generations of a given technology to change. The authors further state that the model fits well under the assumption of constant parameters. However, using four generations of IBM mainframes, Islam and Meade (1997) find that using a model with changing coefficients can considerably improve forecasting.

3.7 Applications and examples of modelling

Bass diffusion models have been used in studying technology adoption within the transport sector. They describe the process for which new technology enters the consumer and commercial vehicle markets. The literature has a heavy focus on the uptake and adoption of alternative fuel vehicles and the associated impacts on the environment. Understanding how alternative fuel vehicles are adopted through the transport sector can help policymakers and companies understand how the sector is changing.

Other models outside the Bass model or S-curve literature include stated preference surveys and discrete choice models – part of the choice modelling framework. These models attempt to use discrete choices to position the items on a scale. This information can be helpful in explaining the diffusion process for goods that have limited or no sales information (new technologies in the very early stages of adoption).

The rest of the section summarises the diffusion literature by topic area: alternative fuel vehicles, EVs, autonomous vehicles, commercial vehicles and other technologies.

3.7.1 Modelling and alternative fuel vehicles

Alternative fuel vehicles use sources of energy other than petrol or diesel. They also include any technology of powering an engine that does not involve solely petrol or diesel, for example hybrids. Hybrid vehicles are still reliant on petrol, but through the use of the electric motor and generator they make more efficient use of the fuel. Because of a combination of factors, such as environmental concerns, development of cleaner alternative for vehicles has become a high priority for manufacturers and consumers alike. A selection of recent studies on alternative fuel vehicle uptake is summarised below:

- Park et al (2011) developed a market penetration forecasting model for hydrogen fuel cell vehicles (HFCV) considering infrastructure and cost reduction effects for Korea. Based on their results, HFCV market would be saturated in 2038 in Korea and in 2050 in the US. The parameters of a generalised Bass model were estimated based on the historical sales of the Prius hybrid electic vehicle (HEV) and its prices in comparison with Toyota Corolla as the representation of conventional vehicles.
- Miravete et al (2015) examine the uptake of diesel powered cars in Europe (using Spanish data). They use an equilibrium discrete choice oligopoly model of horizontally differentiated products. Despite widespread imitation by its rivals, Volkswagen was able to capture 32% of the potential innovation rents and diesels accounted for more than 60% of the firm's profits.[6] Government policy to reduce greenhouse gas emissions enabled the adoption of diesels.
- Massiani and Gohs (2015) developed a Bass model based on German data for new automotive technologies. New registrations for liquefied petroleum gas, compressed natural gas (CNG), EVs and HEVs were used in this study as sales data for new automotive technologies. The study estimated the parameters with varying levels of market size (m) and found that the innovation coefficient (p) was highly affected by changes in market size while the imitation coefficient (q) was not influenced by market size. The authors found an inverse relationship between assumed market size and innovation coefficient in this study.
- The study also summarised a number of Bass model coefficients from a range of automotive technology studies. These parameter estimates fall into two groups, authoritative estimates and ad-hoc estimates. The authors argue that due to the limited help from authoritative estimates, practitioners should instead create their own ad hoc estimates of Bass p and q parameters. There is a wide discrepancy between p and q values for modelling market diffusion, making it difficult for practitioners to select the appropriate evidence based estimates. A summary of estimates is provided in table 3.1.

Table 3.1 Literature estimates for p and q parameters

Source technology	Method	Innovation coefficient (p)	Imitation coefficient (q)	Market potential
Becker et al (2009) Electric cars	Authoritative sources	0.01 0.02 0.025	0.4	Exogenous: 70% or 90% of the light-vehicle market in each year
Davidson et al (2013) Electric cars	Authoritative sources, but eventually refers to Becker et al (2009)	0.01 0.02 0.025	0.4	Exogenous : Number of household are '0.03, 0.25 and 0.7 in the low, medium and high growth scenarios'
Gross (2008)	Authoritative sources	0.01	0.1	
Li (nd) Electric cars	Based on 'a statistic model of EVs in US from 1999 to 2008'	0.0000365	0.447	Exogenous: 'At most half of the vehicles in market can be EVs, the ultimate market potential is calculated as 2.5 million'
Cordill (2012) Prius Hybrid	Calibration on US market data 2000–2010	0.0016 0.00343	1.45 0.631	Estimated 2.87 million

[6] Subsequently, it was revealed that certain Volkswagen diesel engines were programmed to activate certain emissions controls only during laboratory emissions testing, misreporting their true emissions (Hotten 2015).

Source technology	Method	Innovation coefficient (p)	Imitation coefficient (q)	Market potential
Civic Hybrid Ford Escape Hybrid		0.036	0.432	3.68 million 0.36 million
Steffens (2003) Conventional cars	First car purchase (not specifically AFV) in Australia 1966–1996	0.0076	0.0905	Exogenous: 91% of the population would finally purchase the technology
Shoemaker (2012)* Passenger vehicles Utility vehicles	Calibration on AFV monthly sales in the US Dec 1995 (Oct 2004 for utility AFV) Dec 2011 in the US	0.0912 0.008124	0.4692 0.4632	Estimated 436 000 2,300,000
Lamberson (2008)* HEV	Calibration on US monthly sales (Feb 2001–Oct. 2007)	0.000618	0.8736	Estimated 1.6 million vehicles
Park et al (2011) HEV	HEV sales in Japan (1997–2006) parameterised to Korea	0.0037	0.3454	10.2 million vehicles
Jensen et al (2014) Electric cars	Norwegian new electric car registration data from (Jan 2003–Jun 2013)	0.002	0.23	Exogenous: result of a discrete choice model
MacManus (2009) HEV	HEV annual data in the US (1999–2008)	0.0026 (0.00124 generalised Bass)	0.709 (0.77922 generalised bass)	Estimated: 1.9 million vehicles
Cao (2004) E85 CNG Hybrids	Calibration on annual sales in the US 1993–2002	0.00441 0.0210 0.000446	0.491 0.265 0.4788	E85: 245 971 CNG : 100 000 Hybrid: Exogenous. Based on EIA scenario of 19 million HEV sold until 2025, subsequently varies in function of HEV awareness and fuel price

Note: * Parameters estimated based on monthly data were annualised by multiplication with factor 12
Source: Massiani and Gohs (2015).

3.7.2 Modelling and electric vehicles

EVs are part of the alternative fuel family of vehicles. EVs use one or more electric motors for propulsion and are powered through batteries that are primarily charged from outside the vehicle. Bass model studies have looked at the adoption of EVs in recent years to predict their diffusion as a technology. Other types of models, including stated preference models, have also been applied to explaining the EVs diffusion process. A selection of the literature is summarised below:

- Redondo and Cagigas (2015) present a sales forecast of EVs in Spain to 2040 under different technological scenarios. The scenarios covered fuel price changes, charge infrastructure development and government grants. In each scenario, two case studies were considered, renting batteries or purchasing batteries. They find that even with the positive attitude towards EVs, the slow pace of uptake from sales data suggests that Spain is moving in a late development scenario with regard to the incorporation of the new technology. That is, technology uptake has been slow to date. Policymakers are able to reverse this slow start if they decide to promote the expansion of EV.

- Becker et al (2009) used a Bass model to predict the adoption of EVs over a 20-year forecast horizon. The model takes into account relative costs, as well as individual preferences and circumstances (ie barriers and assumptions of forced adoption). In the baseline forecast, EVs account for 64% of US light-vehicle sales by 2030. Different assumptions about relative costs of oil alter the uptake of EVs.
- In a study combining survey and sales information, Cordill (2012) proposed a Bass diffusion model to study HEV uptake. Innovation (p) and imitation coefficient (q) were estimated for three EV technologies using 10 years of sales data. Consumer preferences were surveyed to define whether they were innovators or imitators. Respondents who would like to purchase an EV in the near future were classified in the innovation group and other participants were classified in the imitation group. Selected vehicle price, gas saving and price of gas are the three most important factors for both innovators and imitators when purchasing a HEV. Emissions and operational reliability were two other factors affecting the innovators preference.
- Jeon (2010) studied the expansion of different EV types in the US, using a modification of the original Bass model that took into account the number of generations in which the expansion of the technological innovation was developed.
- Liu et al (2014) also used a modified Bass model to predict the spread of plug-in hybrid electric vehicles. In their model, apart from including the price of the vehicle, other factors such as GDP and fuel costs were also included.
- Another group of market penetration studies used stated preference surveys and a choice modelling approach to estimate diffusion models for new automobile-related technologies. Jensen et al (2014) proposed a forecasting method for EV demand in Denmark using regression method and also diffusion model parameters.
- McCoy and Lyons (2014) conducted an agent-based model to simulate market diffusion of EVs in Ireland. Analysis of four neighbourhoods with different socioeconomic and demographic properties was conducted and found that the wealthier neighbourhoods with more homeowners would have much higher adoption level than less wealthy neighbourhoods.
- Brown (2013) simulated the EV diffusion model in Boston using a discrete choice model. Results showed that EVs would share 1% to 22% of the entire vehicle market of Boston in 2030. Regarding factors affecting market share, the availability of financial incentive showed a positive effect on increasing EV adoption.
- Adams et al (2010) estimated the uptake of different EV variants through the use of a choice model. The study examined the economic viability of EVs in the metropolitan New South Wales area. It was noted that vehicle supply constraints and the availability of charging infrastructure were important barriers in the take-up of EVs. Policy recommendations included a focus on these factors if the take-up of plug-in EVs is to be encouraged.

3.7.3 Modelling and autonomous vehicles

Autonomous vehicles are capable of sensing their environment and navigating without human input. This technology is in the very early stages of the diffusion process. As the technology is so new, there are comparatively fewer studies within the literature that use the Bass model to predict the future uptake of autonomous vehicles.

- Lavasani et al (2016) developed a generalised Bass diffusion model for autonomous vehicle technology adoption, based on similar technologies and previous trends in US data. Sales and price data on conventional automobile sales and HEVs combined with usage of internet and mobile phone data were used to calculate values for p and q. With such uncertainty about the future of autonomous vehicles, sensitivity analysis was undertaken to test a range of scenarios. Assuming autonomous vehicles become available in 2025, the market may reach about 8 million in 10 years and saturation may occur in 35 years assuming a 75% market size.
- An OECD (2015) report looks at the changes that could result from a large scale uptake of autonomous vehicles. An agent-based model was used to simulate behaviour of all players in the system. All trips by bus and car were needed to be replaced in Lisbon for two time periods, over a 24-hour average and for peak times only. Results of the modelling showed that autonomous shared taxis combined with high capacity public transport could deliver the same mobility around the city with 10% of the cars. At the same time, total traffic kilometres travelled were expected to increase. The study highlights large potential impact from large scale autonomous vehicle uptake.

3.7.4 Modelling and commercial vehicles

Compared with the passenger car market, the commercial vehicle market has been analysed less due to the different market structure. The adoption and buying behaviour of organisations is generally considered to be different from that of individuals. By comparison, businesses generally conduct a process-related analysis on whether to purchase a vehicle. However, there are studies that examine the uptake of alternative fuel vehicles.

- Seitz and Terzidis (2014) postulate that alternative powertrain concepts in heavy vehicles will start in the coming years following adoption of electrification in the passenger vehicle market. With this in mind, the paper proposes a conceptual framework for analysing the future of CO2-reducing technologies in the heavy commercial vehicle market. The paper identifies the most influential stakeholders of technology adoption, in particular truck manufacturer, customers, energy supply system and government – and how they interact together to influence the uptake of CO2-reducing technologies. The core interdependencies of different stakeholders are integrated into a causal system dynamics model.
- Brauer (2011) questions when hybrid technology will dominate the heavy vehicle market in Europe. Three scenarios are investigated assuming no, some and considerable incentives or legislative CO2 emission levels for heavy duty vehicles. An analogical approach is used, based on sales data for radial tyres, disc brakes and anti-lock braking systems. Results show that the approach and diffusion models are capable of forecasting future market demand.

3.7.5 Modelling and other technologies

The above studies and literature examine the purchase of a new car, considering specific features of the car. However, other new technologies are being adopted in the transport sector that can have an impact on the way transport services are delivered. Smartphone technology is one of the main methods for delivering change, from ridesharing applications, to mapping and reporting on congestion. Ridesharing is a fast-rising technology that can match people with similar itineraries and schedules to rideshare at short notice. This increases the number of travellers per vehicle trip by using car seats that would otherwise be empty – increasing efficiency of the system and reducing congestion. Agatz et al (2011) simulate demand for ridesharing in Atlanta. While this is not specifically a diffusion model, it highlights how sustainable ridesharing can be in urban populations, even with relatively low participation rates. Other modelling studies on mobility and ridesharing include:

- modelling of a fleet of shared autonomous vehicles in a city of a size similar to that of Austin, Texas (Fagnant and Kockelman 2014)
- the effect of a complete removal of the entire private vehicle fleet in Singapore and its replacement by a shared self-driving fleet (Spieser et al 2014)
- modelling of the implementation of a fleet of autonomous taxis in New Jersey, based on origin-destination trips derived from travel surveys (Zachariah et al 2014)
- the potential impact that the sharing of taxi rides could have on taxi fleet operation in New York City (Santi et al 2014)
- a shared, self-driving and centrally dispatched fleet of vehicles in three different environments: a mid-sized US city (Ann Arbor, Michigan), a low-density suburban development (Babcock Ranch, Florida) and a large and densely-populated urban context (Manhattan, New York) (Burns et al 2013).

The studies find that moving to an autonomous fleet could reduce the number of cars currently in operation.

3.8 New Zealand model

We developed an Excel model to forecast diffusion of technology in a New Zealand context. The model is a version of the Bass model and can be used to forecast the timing and level of the diffusion of new technologies in the transport sector and to illustrate which variables have a high or low impact in a particular set of circumstances.

3.8.1 How the model works

The model uses four calculation engines that successively build on the previous engine's results:

- The first is the regression engine. The regression engine uses sales data to estimate the parameters (innovation – p, imitation – q and market potential – m) of the overall S-curve.
- The Bass engine takes the parameters determined by the regression engine, p and q and combines it with a fixed market potential for the technology and uses them to calculate the trajectory of the curve. This produces a forecast S-curve.
- The generalised engine extends this forecast using estimations of price changes and advertising expenditure, as well as forecast of sensitivity to price and advertising changes.
- Finally the extended engine allows the user to vary the market potential over time and to include the effect of government policies encouraging (or discouraging) uptake.

The regression engine is used to determine the inputs for subsequent engines. The results from the Bass, generalised and extended engines are presented separately in the model. The detail of the calculations used in the model is set out in appendix A.

3.8.2 Outputs

The model outputs both summary statistics and graphs showing likely uptake of the technology over time.

The summary statistics worksheet provides some metrics on the Bass model, generalised Bass model and extended Bass model. As shown in figure 3.1 below, these metrics include the amount and time at which new uptake peaks, cumulative uptake for each of time periods 5 to 50 in increments of five. The beginning and ending coefficient of innovation, coefficient of imitation and market potential are also shown for the extended Bass model.

Figure 3.1 Example summary statistics

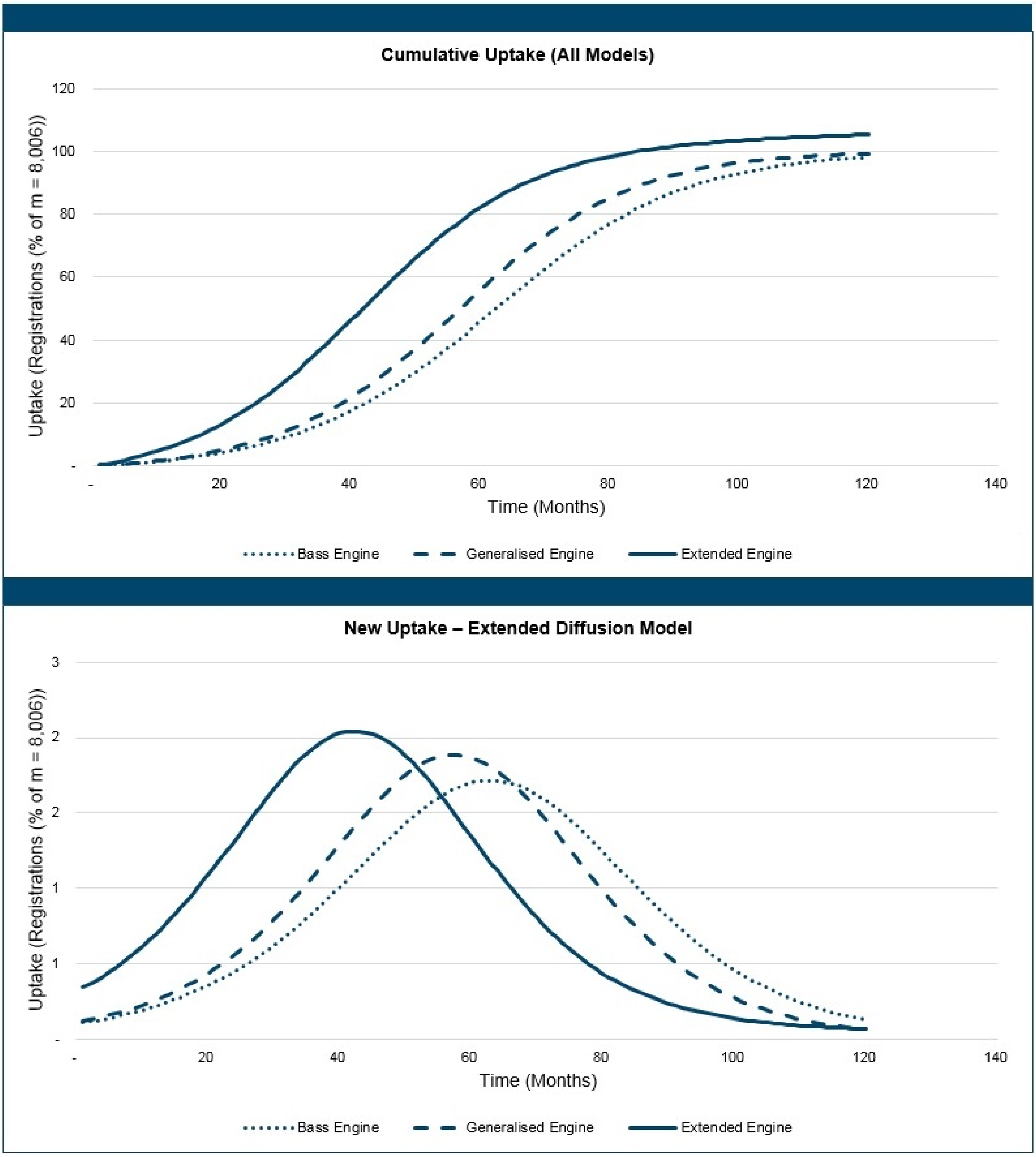
	Bass	Generalised	Extended
Peak uptake	59,851	64,280	75,902
Peak time	Years 14	Years 13	Years 10

	Cumulative Uptake (Vehicles)		
Period	**Bass**	**Generalised**	**Extended**
5	43,874	48,920	48,980
10	193,676	223,941	351,436
15	475,770	525,144	631,650
20	646,328	663,267	687,694
25	681,299	684,139	694,313
30	685,967	686,371	696,441
35	686,544	686,599	698,215
40	686,615	686,622	699,965
45	686,623	686,624	701,716
50	686,625	686,625	703,472

	Extended Parameters		
Period	**Innovation (p)**	**Imitation (q)**	**Market (m)**
-	0.0068	0.3364	686,625
150	0.0368	0.3364	740,088

The charts worksheet shows cumulative and new uptake curves for all models and each model separately. Examples of the uptake curves are shown in figure 3.2. The curves for the separate models also show new uptake generated externally through innovators and internally through imitation.

Figure 3.2 Example graphs from New Zealand Bass diffusion model



3.9 Discussion

The models presented within the literature are unable to capture all aspects of reality when modelling the diffusion process. Instead, simplifying assumptions are required to highlight the most important drivers around the role of innovators and imitators. These assumptions perform well in helping to model the diffusion process. Policymakers are then able to observe the major drivers of change coming through the system.

Bass models are flexible and are able to handle a range of different scenarios and situations. Since their inception in the 1960s, they have been used across a number of academic disciplines including the transport sector. They contain three main inputs: the size of the market (m), coefficient of innovation (p) and coefficient of imitation (q).

Bass models have been used to model adoption of alternative fuel types for cars, often to examine the environmental impacts following the adoption of these technologies. Electric and hybrid vehicles have been the two main alternative fuel types; however, there are several alternative fuel options available. Results show a gradual level of adoption for EVs that will take a number of years to reach full market potential.

Overall, the Bass model is well developed and able to capture and forecast based on adoption trends. Change agents can influence the speed of adoption through policy action, by either speeding up or slowing down the rate of adoption, as well as limiting the market size. Sensitivity analysis is required to understand how these outside influences impact on the rate of adoption. The result is a view of the range of potential futures for technology uptake in the transport sector.

4 Technology roadmap

4.1 Introduction

In order to link the future adoption of technology to the transport network and the planning process for new infrastructure, we have produced a roadmap (figure 4.1) looking at the intersections of technologies and other trends, which puts people and goods at the centre as the users of the transport system. We considered the possible impacts of future technology changes and how they could alter transport needs in the short term and long term. This chapter looks at the systemic changes that technology could bring about in the transport sector. Changes in the transport system will ultimately come back to what is needed for moving people and goods as ultimate users of the transport system.

We ran a workshop with key agents from the transport sector on how technology would intersect with other high-level trends to shape the future of transport in New Zealand. We delved further into the relationship between people and goods – the users of the transport system – and technologies available now and potentially in the future. Rather than focusing on individual technologies and their impact, the general trends and themes of technological change were discussed.

4.2 Roadmap diagram

The roadmap diagram in figure 4.1 categorises the effects of technological change in four ways:

- technology trends (blue) – new technologies that are available or we can foresee in the future
- behavioural trends (green) – changing patterns of human behaviour that affect the transport system
- demographic trends (red) – changes in our populations
- adoption drivers (orange) – external factors driving change.

Working outward from the centre, the roadmap illustrates the connections between current and future trends. Filled dots represent trends and changes occurring already, while empty dots represent likely or potential changes in the future.

Within these categories several transport trends emerge as most relevant to how people and goods rely on the transport system. These zones represent general topics to explore and are discussed in more detail below.

Figure 4.1 Roadmap for the future of the transport sector

4.3 Transport trends

4.3.1 Passengers and freight

Autonomous and connected vehicles are seen as the biggest changes on the horizon for the transport of passengers and freight. Many areas and aspects of the transport system were discussed from personal transport and public transport, to road freight and cargo shipping. The group identified many potential future impacts of the technology – from changing commuting behaviour, to enabling new business models, and to potentially eliminating the need for certain jobs and services. Fully automated vehicles seem certain to change the transport network both directly (eg through changing safety parameters) and also indirectly (eg by changing the way we purchase goods).

Autonomous and semi-autonomous technology is already being rolled out in the passenger vehicle sector and it is only a matter of time before it is introduced to freight transport as well. Connected vehicles, having become established in the passenger market, will allow freight vehicles to also be automated until all freight is carried on autonomous vehicles.

Having discussed the apparent benefits, the workshop group felt that uptake would be constrained by supply – as technical solutions were developed and regulation adapted to cope with change. In the near term, however, the group had interest in semi-autonomous vehicles. In recent years, the Transport Agency has invested in the promotion of active stability control as a purchase decision factor. Other emerging driver aid technology such as highway autopilot, crash avoidance, heads-up displays and connected vehicles may all have an impact on safety and vehicle purchasing decisions.

- Lane following: This feature is being released now in luxury cars and is expected to flow down the price range in the near future. The group questioned how requirements might change when in-car systems depend upon clear lane markings.
- Crash avoidance: With semi-automated systems applying the brakes to help avoid crashes, will drivers change their behaviour? For example the idea of safe following distances might change or the perception of safe speeds might change.
- Autopilot: While not fully autonomous, Tesla currently offer an autopilot mode capable of controlling the vehicle on long highway journeys. The group discussed how this might change the use of New Zealand's state highways and affect the distance individuals are prepared to commute.

4.3.2 Connected cities

Growing urbanisation and an increasing critical mass in New Zealand cities will combine with technologies to change the way we use transport. One of the single biggest technological changes in recent decades is the uptake and rapid development of mobile technology. Mobile devices have the power to put information in the hands of consumers – and increasingly to pre-process and interpret that information to offer a recommended action.

Mobile navigation and planning tools like Google Maps or Waze aggregate data to enable consumers to evaluate travel options in real time or predictively. The transition of GPS technology from the domain of military and specialist civilian use to a ubiquitous capability of mobile devices has enabled a multitude of data-driven opportunities.

As this data is made useful to consumers and businesses it will drive changes to the decisions they make in using the transport network. Further, as the organisers of transport services make use of data to improve the scheduling and routing of those services, the efficiency of the transport network can be improved. Mobile device use enables these changes now and in the near future, and future technology such as connected and autonomous vehicles will increase the potential impact.

4.3.2.1 Navigation and routing

Navigation applications offer users options to bypass chokepoints and understand the impact on journey time. If a critical mass of users were being directed by the same navigation engine, then centrally coordinated routing would become possible, easing peak demand.

Existing applications such as Google Maps already predict traffic patterns from historical data. These models will improve over time, enabling better forecasting of demand on a network level.

Behind the mobile revolution is the infrastructure that enables ubiquitous connectivity. Many of the future developments discussed in the workshop require increased bandwidth. What connectivity requirements will future infrastructure require?

4.3.3 Digital markets and micropayments

Changing technologies and working behaviours are leading to the development of new digital markets that did not exist before.

Ridesharing platforms and other on-demand services are examples of markets that have come about recently thanks to the convergence of digital technology. During the workshop many concepts were discussed that required frictionless small payments to be exchanged. Technologies which allow this are already in use, eg for toll roads or in contactless payment cards used in public transport. However, this is also an area where technology is developing rapidly. Digital currencies, mobile payment and truly frictionless payments seem likely to mature in the near term.

This could allow better incentives to be established for transport users whose behaviour reduces peak demand or levies to be placed on users. These payments can change dynamically depending on routing as congestion occurs.

If this does happen, the resulting transition of transport to a transactional platform is likely to be one of the biggest shifts in decades. The group noted that incentives and penalties can often lead to unexpected and contradictory behaviours.

4.3.4 Future of work

While remote working and video communications have been discussed widely for decades, it is only in recent years as technologies have matured that they have begun to become a practicable solution. Widespread high-speed internet, high-definition video and increasingly powerful mobile devices have improved the capability and quality of telepresence. At the same time, the internet has created new marketplaces for work. From the ‘gig economy’, based on short-term contract work and freelancing, to new forms of collectivism, there are early signs that may indicate longer-term shifts in the framework of employment.

When the impacts of more flexible working behaviours are considered in the context of demographic drivers such as a growing aged population and later retirement, there is potential for a rapid shift in demand that could influence future transport usage.

4.3.4.1 ‘Gig economy’ and virtual markets

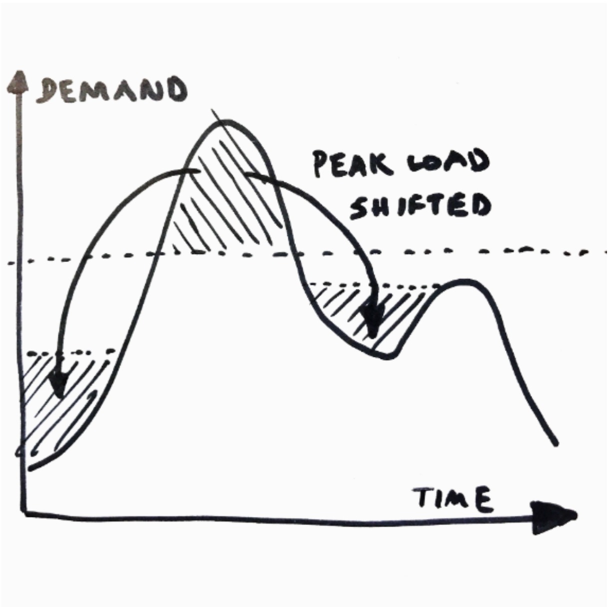
In certain sectors virtual labour marketplaces mean that demand and supply for labour are being more directly connected. Uber, Taskrabbit, Threadless, Etsy and even Amazon and eBay are examples of this. In the gig economy, people are working as contractors across multiple employers on a more flexible schedule.

4.3.4.2 Flexible working

Where traditional employment relationships seem likely to persist, an increasing focus on employee experience and workplace wellbeing and increasing business acceptance of flexible hours could lead to a reduction in peak time commuting. High-speed internet access, ubiquitous in New Zealand's cities, has allowed many professionals to work from home as easily as working in the office.

Policymakers could leverage this trend to encourage demand smoothing. Could mobile technology and micropayments make it possible to incentivise businesses to encourage employees to commute off-peak or take public transport? Aside from incentives or penalties, the impact of peak demand could be smoothed through intelligent routing made feasible by autonomous vehicles and artificial intelligence (AI) traffic control.

Figure 4.2 Workshop illustration of demand smoothing



4.3.5 Green shift

Climate change has become a growing concern for people and policymakers over recent decades. Low-emission modes and technologies are already being encouraged through policy instruments such as carbon taxes and trading schemes and many local government planners are considering how to reduce greenhouse gas emissions through their long-term transport planning.

Alongside low carbon technologies and policy instruments, walking and cycling have gained in prominence as environmentally friendly and healthy transport options.

4.3.6 Demographic trends

Three key demographic shifts were discussed at length during the workshop. The first was the shift that will be created as the generation born after the year 2000 (Generation Z) transitions to adulthood and then to employment. There was discussion about how the values, demands and expectations of that generation differ from those of preceding decades.

With reference to transport demand, trends discussed included a transition to on-demand consumption, a shift toward material minimalism and a perceived trend toward urban living.

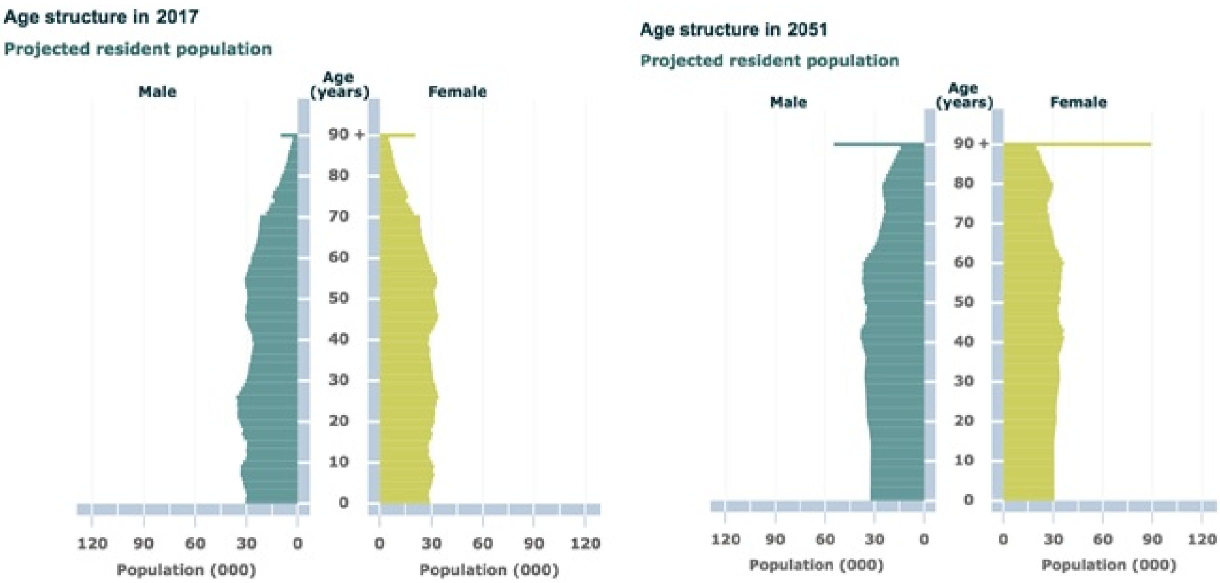
Second, the ageing population was considered with reference to the shifting user needs that it might create. One discussion point was that safety has in the past driven uptake of new vehicles – for example the use of sport utility vehicles (SUVs) by families. It seemed likely to the group that an ageing population might value potential safety benefits associated with semi-autonomous and self-driving vehicles.

Further, as the requirement for aged care increases, there will be a flow-on impact on the working generation who may be required to act as carers. This would seem likely to influence transport use, although the impacts seemed less clear to the group.

4.3.6.1 Ageing population

According to Statistics NZ (2000), by 2051, there will be over 1.14 million people aged 65 years and over in New Zealand. They will represent 25.5% of all New Zealanders. Transport planning needs to be aware of how this shift may affect demand and user needs.

Figure 4.3 Projected demographic changes in New Zealand



Source: Statistics New Zealand

4.3.6.2 Millennials and Generation Z

There was also discussion of a shift in behaviour among the generation presently joining or preparing to join the workforce. Discussion points turned to decreasing car ownership and licence-holding in this segment and also an increased tendency toward minimalist urban living with attitudes geared toward experience and social engagement. Millennials and Generation Z are delaying traditional milestones compared with their parents' and grandparents' generations – often moving out of home later, marrying and buying houses later or not at all and having children later in life. In concert with licence requirements becoming more stringent over time, they are moving away from owning vehicles towards shared services.

4.3.7 Robots and artificial intelligence

Robotics and AI are becoming more ubiquitous and jobs that once were done by people are increasingly being automated. For example, booking flights used to require a travel agent and now online services allow users to book their own travel. AI is improving to the point where it is doing jobs that people used to do. AI is becoming more commonplace among personal digital assistants both in business (such as X.Ai) or at home (such as Amazon Echo or Google Home).

As many jobs done by people come to be automated, this will dramatically alter the landscape of industry, human labour and consequent transport demand.

Within the transport sector, automation has the potential to improve road safety. An automatic system driving a vehicle can remove human error and can have far superior reaction times to a human driver, lowering the risk of crashes.

4.3.8 Adoption drivers

Fundamental to designing any product or service is an understanding of the purpose of that product or service. In planning and designing transport infrastructure, it is critical to understand what use it is being put to, by whom – and what the underlying need or desire of those people are. Similarly, the uptake of new transport technology is driven by a balance of forces – user needs and desires are balanced by constraints and context.

These needs and desires are not static. They evolve through changes in normative patterns of behaviour, organisational structures, technological capabilities, demographics, attitudes and awareness. This is not a homogenous change – different users have different needs, desires and attitudes and so evolve differently. The workshop discussion highlighted some of the key user needs that may drive adoption of new transport behaviours.

- *Safety*. Perceived safety has been observed to drive adoption in the past, eg the use of SUV vehicles for family transport. In particular, older drivers have been found to be more motivated by additional safety features and are more willing to purchase a vehicle that is perceived to be safer for the driver (MIT Agelab 2015). This factor was determined by the group as one prospective driver for uptake of semi-autonomous and autonomous vehicles.
- *Time cost*. Time cost refers to the time spent travelling. On average people devote 60–90 minutes a day to travel (Litman 2009) and this time is usually not considered productive or useful time depending on people’s preferences. While the impact of time cost in transport is broad, some specific instances were mentioned. The first was the impact of self-driving cars in that commuting time will be ‘released’ as productive time. This may increase usage as people will take longer journeys if they can make more valuable use of the time. Second, the use of mobile planning tools and on-demand services to more effectively align journeys across transport modes can reduce the wastage of time through queuing or inefficient routing.
- *Privacy and dignity*. For passenger transit, personal space is a factor that often drives choice toward private vehicles. Ownership of an individual vehicle ensures that travel time will be private and not shared with strangers, whether they be fellow passengers (as with public transport) or drivers (as with taxis or rideshares).
- *Wellbeing*. In New Zealand there has been an increased focus on exercise and personal wellbeing in recent years. Around 38% of New Zealanders walk, cycle or jog for transport purposes (as opposed to sport or recreation purposes) at least once a week (Sullivan and O’Fallon 2011). The New Zealand Household Travel Survey (NZHTS) (2015–2017) indicated that 53% of the sample (3,038 of 5,703

people) made a trip by walking or cycling, although those trips represented only 14% of the trip legs in the sample (20,902 of 153,023 trip legs) (Ministry of Transport 2017b). There are public discussions underway with regard to cycle safety. Public adoption of cycling and other human-powered modes of transport are both a potential input and requirement for the transport planning process.

- *Flexibility*. A common theme of user demand is flexibility – the ability to choose when and where to travel. However flexibility means different things to different people. For older people or people with children it will lean towards private vehicle ownership as that will provide them with an ever present option to be able to travel. For younger people, ownership will be expensive and limiting if they are not in a situation where they have space for parking or enough income to maintain a vehicle of their own. For these people flexibility may mean a variety of transport services available as and when needed so they can tailor their transport use to their budget.
- *Ownership*. Changing attitudes to ownership ran through the course of the discussion. There is an observed generational trend toward on-demand or shared services. These were seen by the group to be likely to have an impact on the types of journeys undertaken in the future, as well as having an impact on necessary infrastructure such as parking.

5 Behavioural monitoring framework

5.1 Purpose of a monitoring framework

New technologies are constantly diffusing through the transport system. The earlier discussion shows that these new technologies interact with the other aspects of the system, affecting how people and goods move, which modes of transport are used and how infrastructure can best support them.

To get a picture of these impacts, it is important to monitor which technologies are being used and how they are being used. This monitoring needs to be done efficiently and effectively. People, agencies and companies involved with the transport system need information about what to monitor and how to monitor it in order to get the best picture of the current state of technology diffusion and the likely future pathways. This report provides a framework for thinking about the monitoring function. It does not try to present a final list of all the things that should be measured – although it provides some suggestions. As technology changes, so does transport and so do the things that need to be monitored. Instead, it provides a structure for thinking about the impacts of technology and how they become visible, so that the Transport Agency and other stakeholders can make informed choices now about monitoring and revisit them over time.

The framework is motivated by several principles:

- Monitoring behaviours is key. The purpose of the transport system is to fulfil the demands of individuals through the efficient movement of people and goods. We can observe what people do – their behaviours – both when it comes to how they move themselves around and when it comes to their demands for the movement of goods. We are less concerned with monitoring plans and intentions; what people intend to do is not necessarily what they end up doing. People may say they want to save fuel, but they still tend to buy cheaper tyres rather than the more-expensive fuel-efficient tyres.
- Metrics should be observable. Technology uptake can be a bit of a black box; people may be innovators or imitators and there may be some psychology behind those categories. However, the key from the perspective of the transport system is whether the technology is actually being used and what impacts it is having. The metrics we use need to capture the observable diffusion and impacts. By way of example, it may be important to understand whether concerns about privacy and dignity are important in the choice to use public transport, but either the concern or the actual behaviours need to be turned into data that can be recorded.
- Monitoring should be efficient. Again, the goal of the transport system is moving people and goods, not monitoring behaviour. Monitoring should be considered a means to improving the system and not an ends unto itself. As a result, any monitoring activity should have a purpose; there should be a reason for collecting that piece of data from that person or that part of the system. In addition, the collection should minimise its cost in time, money and disruption. We should aim for monitoring that is as unobtrusive as possible.
- Monitoring should be connected to technology. This report is focused on technology diffusion and uptake and so is the monitoring proposed here. As the transport system diagram suggests, the system has many parts and they all affect each other. The potential extent of monitoring is therefore very large. However, in keeping with the idea that monitoring should be efficient, it should focus on the behaviours and impacts most directly related to technology and its uptake.

These principles have led us to create a BMF that structures our thinking about behaviours to monitor and potential metrics to use. We have avoided producing an exhaustive laundry list of all the possible metrics, recognising that it will be infeasible, incomplete and subject to change. Instead, we have grounded the BMF in an understanding of the transport system and technology diffusion so that the specific list of metrics can be easily and sensibly modified in response to future developments.

5.2 Key points highlighted by the framework

5.2.1 A framework makes the problem manageable

The issue we are investigating is the impacts of new technologies on the transport system, including the impacts of technologies not yet invented. This is an unmanageable task. However, by creating a framework for thinking about what transport behaviours to monitor and why, we create a way to think about the problem.

5.2.2 The behavioural monitoring framework draws together several strands of research

During this project, we conducted a literature review into technology diffusion, particularly in the transport sector. We then built a spreadsheet model based on the literature to support an analysis of the diffusion of new technologies in New Zealand. We also held a workshop of transport sector representatives to work through their understanding of the sector and the impacts of technology. These strands of work have informed our thinking and we have tried to pull it together into a single monitoring framework.

The framework contains three levels, which break down the task of monitoring behavioural changes into three broad areas. At the first level, the boundary is the whole transport system. This level encourages users of the framework to describe the systemic impacts of technology. The second level focuses specifically on the technologies in the transport sector and how they are being used. This level provides some focus on existing and developing technologies. Finally, the third level draws a wide boundary around science and technology, broadly understood, to promote a scanning function that takes in a wide range of future potential changes. The goal of this third level is to keep thinking open and flexible rather than captured by a certain view of the future.

5.2.3 There is no one model to rule them all

What became clear as we assembled the BMF is that there are several conceptual models that help people think about transport and technology. Trying to pull them all together into a single, overarching model is a fool’s errand. Instead, we developed a simple framework that shows how the different pieces of work fit together and how the conceptual models relate to different questions.

5.2.4 The models lead the way

Once we identified the conceptual models (and their supporting literature), the question of what to monitor and why became simpler. There are limited resources in the transport sector and government for measuring and monitoring technology and impacts; some prioritisation needs to take place. The different models provide a way to think about the most important trends and the most important information and then focus on collecting the right data to measure them.

In the framework, each level contains both a conceptual model and a list of possible metrics. The conceptual model helps provide a rationale for conducting the behavioural monitoring. It helps answer the question, ‘Why do we think this is important?’ The data selected is a consequence of the model. For each level, we provide some suggestions for relevant data that is already collected, as well as new data that could help monitor behavioural changes over time as a result of new technology in the transport sector. For convenience, table 5.1 provides a list of possible metrics.

5.3 Summary of the framework

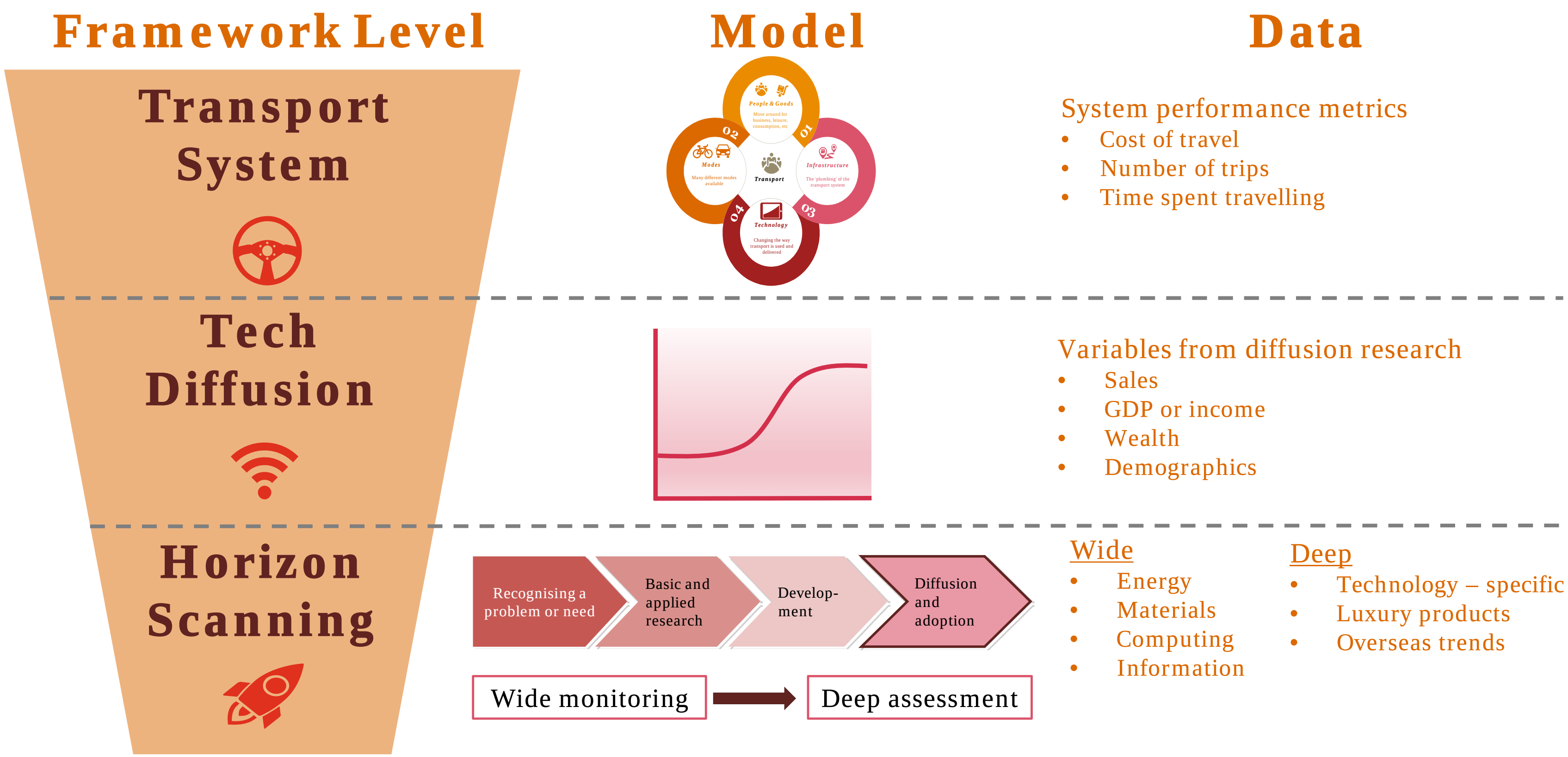
5.3.1 Structure of the framework

The BMF is presented in figure 5.1. Structurally, it has three levels and each level has both an underlying model and associated data or metrics.

- *Levels:* The levels of the framework put some boundaries around what is being analysed. They break down the task of monitoring behavioural changes into three broad areas. At the first level, the boundary is the whole transport system. This level encourages users of the framework to describe the systemic impacts of technology. The second level focuses specifically at the technologies in the transport sector and how they are being used. This level provides some focus on existing and developing technologies. Finally, the third level draws a wide boundary around science and technology, broadly understood, to promote a scanning function that takes in a wide range of future potential changes. The goal of this third level is to keep thinking open and flexible rather than captured by a certain view of the future.
- *Model:* The framework also indicates the underlying or conceptual model that operates at each level. Throughout this project on technology diffusion, it has become apparent there are different mental models that can apply at different times for different questions. The framework brings these mental models to the surface. By including a specific model, we encourage users to consider whether that particular model is appropriate, whether a different one would produce different answers and which model is best for the specific purpose. The models presented in the framework have already been discussed elsewhere in the research and selected for their usefulness. They provide structure for thinking about the transport system, technology diffusion and horizon scanning.
- *Data:* The underlying models also provide a way to select the appropriate data or metrics, which form the third part of the framework. The goal of the framework is to help select metrics to monitor. This selection is based on the principles in the introduction: a behavioural focus, observable metrics, efficient monitoring and a link to technology. Each model provides us with an indication of what is important and what might be changing. By focusing on what should be important, we keep the monitoring efficient. By focusing on changes, the framework should keep users focused on observable behaviours. The framework provides a rationale for what data to collect and what data to ignore, all the while keeping technology at the centre of the work.

The BMF is structured to move users through different levels of the transport system to ensure the framework is comprehensive and to move their thinking from concepts to data to ensure it is grounded and practical.

Figure 5.1 Behavioural monitoring framework for technology in transport



5.3.2 Elements in the framework

With that structure in mind, we can go into further detail about the elements in the framework diagram. In particular, we offer more explanation about the fit between the models and data at each level.

- The top level is the whole transport system. Because technology interactions with the other aspects of the transport system, it is important to have some metrics that take a system-level view. The model that underpins this thinking is the four-lobe transport system model developed earlier in this project, which focuses on people and goods, infrastructure, technology and modes. This model is intended to conceptually capture the whole transport system and encourage users to think about how technology interacts with the other parts of the system. These interactions were explored in more details earlier. The data that could be collected focus on the observed behaviours of people and freight in the system. The data should not be about just technology or behaviours around technology, but also about how the system is functioning overall.
- The middle level of the framework is technology diffusion. This is the process of technology diffusion through the transport system, as described in earlier work in this project. Conceptually, the process of diffusion tends to lead to a sort of S-shaped curve, just because of the nature of earlier and later adoption behaviours. Mathematically, the resulting diffusion can be analysed using a Bass diffusion model as discussed earlier and that model can be parameterised with a few variables. By using the Bass diffusion model and its surrounding literature, we have a very good idea of the data that should be collected in order to forecast (and backcast) technology diffusion.
- The final level of the framework is horizon scanning. One of the key messages from the project, particularly the roadmap workshop, is the need to stay conscious of 'unknown unknowns' – we don't know what we don't know. In order to bring this idea into what is a static framework developed at a point in time, we have included a horizon-scanning function to encourage the Transport Agency and others to become aware of future technologies. The model for horizon scanning is a standard R&D pipeline, which runs from initial idea through science and product development to eventual technology adoption. Because of the behaviour of this system, we have subdivided the scanning behaviour into two types. The first type is wide monitoring of science and technology to stay informed about where they are headed. The areas to be monitored include everything that could affect technology and therefore transport, such as energy, materials, and advanced physics. The second type is deep monitoring of technologies and products that are closer to market. As the new science turns into prototypes and beta products, it is possible to conduct more thorough analysis of the potential contours of the technology and its impacts.

The next several sections go into these elements of the BMF in more detail.

5.4 Level 1: Transport system

5.4.1 Underlying model of the transport system

We identified four main elements that interact to make up the transport system, as illustrated in figure 2.1.

- people and goods
- modes
- infrastructure
- technology.

The BMF focuses specifically on behaviours. Transport behaviours can be broadly defined as the actions and decisions people make to travel or to move goods to their destinations using the transport system. These actions and decisions are a key driver of the transport system. People's behaviours and actions respond to changes in the technology available, affecting the operation of the whole system. It is people who decide whether to buy an electric car or who choose public transport or cycling. Their decisions are made subject to the constraints of the existing infrastructure and from the choice set of technologies and modes available. The use of these technologies in turn affects the other elements of the transport system. Importantly, from the point of view of the transport user, there is increasing diversity in technology and transport modes.

Monitoring transport behaviours is necessary to understand how the complete system is performing and operating. Primarily, because of the behavioural focus of the BMF, this section is focused on the people and goods element of the transport system. First, we look at the user's needs of the transport system. Next, we move to a discussion of possible data and metrics for monitoring the system.

5.4.2 User needs of the transport system

User needs are heterogeneous, dependent on the individual circumstances and preferences of users and subject to change over time. These needs can also influence the adoption of new technologies. Identifying and understanding these needs is a key part of describing the objectives of the transport system and understanding the behaviours that need to be monitored.

A key source of information about user needs was the roadmap workshop discussed in chapter 4. The user needs are what people desire when accessing the transport system, with the four-lobe model of the transport system signalling 'people and goods' at a high level. These user needs separate into categories that provide a better understanding of the drivers of user behaviours. However the focus of the BMF is not the drivers themselves but the behaviours they create. The following sections cover the monitoring of behaviours for people and goods, many of which are influenced by the user needs discussed above.

5.4.3 Monitoring: behaviours regarding people

We have defined transport behaviours as the decisions and actions people make to travel to their destination using the transport system. Often, there is a range of different transport options available at any time, and each option is associated with particular costs and benefits. For example, taking a taxi might get the user to their destination in the shortest possible time, but the cost could be higher than taking a bus or train that takes more time. The choice of one option over another depends on the user's preferences and constraints and user needs.

Individual decisions and actions made around transport options lead to the aggregate performance of the transport system. Monitoring a number of behavioural indicators and metrics can be used to track system performance and explain system performance and trends. Because transport behaviours have been investigated extensively, much of this data is already being collected.

The core behaviours to monitor cover the movement of people around the transport system, including:

- The number of trips people make gives an indication to the amount of times that the transport system has been accessed.
- Distance travelled passenger kilometres both in the aggregate and by different groups tells us about overall transport demand.
- Time spent travelling records the amount of time each day spent travelling for all purposes and the individual trip length.

- The value of travel time takes into account the value of a user's time and not just the amount.
- The destination or purpose of travel details the purpose for travel, work, school, leisure, etc.
- The mode of transport used indicates which modes are being used, when and by whom.
- Passengers accompanied accounts for trip-sharing on the selected mode of transport.
- The time the trip was made can allow travel data to be assessed against times of peak traffic congestion compared with lower-volume travel times.
- The cost of travel includes the relative cost or absolute cost of using one mode of transport compared with another.
- Vehicle ownership indicates mode choices available to users and can be extended to include private cars, bicycles, etc.

Data on new topics also needs to be collected to reflect the changing transport behaviours. We have some indications of current technology use and can develop questions around it, which will need to be modified as technology changes. Some possibilities are:

- Smartphone use can include questions about whether a phone was used to enable or improve travel. Questions could determine whether a smartphone was used, the task for which it was used (eg driving directions) and whether it was used beforehand to plan the trip or used during the trip.
- Multi-modal trips are already investigated, but additional data could be collected on how trips were planned and the method of payment.
- Shared services could be investigated, including which shared service, the mode used and the method of payment.

The purpose of this data is to monitor people's actual travel behaviours. The results tell us what people have actually chosen to do, given whatever options are available to them. As a result, we can investigate how and why the transport system has led to those particular behaviours.

5.4.4 Monitoring: behaviours regarding goods

Freight supports commerce. Businesses are able to get their goods to market and sell them, whether domestically or globally. The movement of goods between locations often needs to occur within certain timeframes to meet demand, but the choice of modes to deliver goods may be limited compared with the number of modes available to move people, depending on the type of good, its destination and requirements in transit.

The main objective of the freight sector is the on-time and efficient movement of goods to their destinations. There are several behaviours for monitoring performance and technology trends in the freight sector, including:

- *Freight volumes* capture the amount of freight moved (by weight) and the distance travelled.
- *Mode of transport* used indicates which modes of transport are being used, most often and where.
- *Goods exports and imports* are reported by volumes of merchandise exports and imports, measured by weight or by the number of containers handled by the ports.
- *Average load of vehicles* can help to monitor the efficiency and utilisation of road freight.
- *Transport costs* are a measure of the relative cost to transport goods to their destination.

These metrics are being captured and changes in them will help monitor system-level changes. Further data could be collected to investigate the use of technology in the freight sector, both the level of use and how the use is changing the movement of goods. Some possibilities:

- Use of technology could be investigated to understand how drivers, trucks, other vehicles and companies are using devices.
- Inventory management activities could also become part of transport data, rather than being treated as wholesale and retail activities.

There is potentially a good deal of additional data being captured by companies in the transport sector and some of it may be very detailed about the goods themselves and how they are being transported. However, there are issues around access to this sort of proprietary data and how to interpret it for the purposes of understanding the transport system.

5.5 Level 2: Technology diffusion

5.5.1 Bass diffusion model

As described in the earlier chapter on transport modelling, the Bass diffusion model is used to graphically describe the diffusion process through S-curves. Bass diffusion models have been proven in many different settings and fields of study. The model describes how new technologies are adopted through the diffusion process. It presents a rationale of how current adopters and potential adopters of a new technology interact. The modelling approach is simple: future adoption is dependent on innovators and imitators.

5.5.2 Monitoring: Bass diffusion model variables

A number of metrics can be used in the Bass diffusion model process. These variables are firstly used to estimate the three coefficients: market size, and innovator and imitator coefficients. Monitoring then extends to wider variables that influence the diffusion process: policy interventions, advertising and price of the new technology. The key variables to monitor are:

- *Innovation (p) and imitation (q)*: Although these cannot be observed directly, it may be possible to understand innovation or imitation behaviour relative to an earlier technology. It may be possible, even if just in a qualitative sense, to investigate the propensity of people to try out something new or to follow the trend for a new technology. This information would be used to select likely values for these coefficients in the model, based on comparisons with prior technologies.
- *Sales (or adoption)*: Sales or adoption data is required to estimate the innovator and imitator coefficients in the model. Sales data to the market of interest is best for calculating these coefficients. Analysis can examine early sales data to calculate the innovation and imitation coefficients. For new technologies that lack a sales history, analogies to similar product sales can be used in place of actual sales. Estimates of innovation and imitation can be updated once sales have started.
- *GDP or income per capita*: High GDP or income countries have more resources at their disposal and can increase the size of the potential market share (m). As a result, technologies are more likely to diffuse through the system compared with poorer countries. Individuals are likely to take more risk as there are sufficient resources to account for failure.
- *Wealth:* Increased wealth, similar to increased income, can lead to a higher potential market share (m). Wealth can be used as collateral for larger purchases, such as vehicles.

- *Demographic profile*: The demographic profile can affect the potential market size (m). New technologies can be targeted towards certain demographic groups and not apply to other demographic groups. Demographic changes over time can affect the size of the potential market.
- *Population density*: High-density areas are sometimes required for new technologies to diffuse and grow and can affect market share (m). For example, MaaS requires dense populations to be profitable – as the transport services provided have greater utilisation. Monitoring the density of each city can provide information on the market potential, as well as cities that the technology could diffuse to next.
- *Policy intervention*: Policymakers can intervene to affect the speed of adoption. The new technology can be deemed favourable by policymakers, which can allow faster diffusion. Subsidies and mandating the new technology are two ways of increasing the speed of adoption. On the other hand, policymakers can slow the rate of adoption by restricting the new technology. Restrictions can be unintentional, through old regulations being incompatible with the new technology or they can be intentional, to slow the rate of adoption.
- *Advertising:* Increased expenditure on advertising can speed up the diffusion process. Increased awareness and knowledge of the new product can lead to more innovators adopting the product in the early stages.
- *Cost*: As the price of the technology declines, the speed of adoption can increase. New technology prices often start expensive and fall over time as expanding production leads to economies of scale and lower production costs. Conversely, price increases can slow the rate of adoption.

The indicators and metrics gathered in this section can complete the forecast then adjust it for external factors. Additional metrics can be added to the above list, depending on the specifics of the new technology.

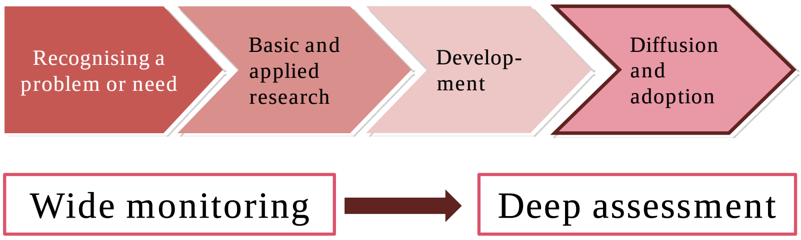
5.6 Level 3: Horizon scanning

5.6.1 Conceptual model for horizon scanning

Many new technologies could affect the transport system. Some of these technologies have the potential to disrupt the transport system, while others are unlikely to make it through the product development process to the market. Even once prototypes are developed, products can require several years to reach the market. Once they reach the market, some technologies will be commercially successful and others will not. In addition, it is not just whole product but also inputs that affect technologies. The relative price of material inputs can affect the types of products that are developed or the diffusion of products that are already in use.

We use a standard product development process to provide a conceptual model for thinking about monitoring developments and scanning the horizon for new technologies. Because of the way R&D works, we divide horizon scanning into two parts. Wide monitoring takes note of the new science and technology in the early stages and the potential impacts. Subsequently, deep assessment investigates later-stage products in greater detail. It captures innovations that are further along the development process and gives more consideration to their particular impacts on the transport system. The link between the product development process and horizon scanning is shown in figure 5.2.

Figure 5.2 Model for horizon scanning



5.6.2 R&D process to first adoption

The R&D process includes the activity involved before a product with new technology is ready to be diffused through the system. It entails innovation and design of the new technology as well as communication to an audience of potential adopters. Monitoring widely captures these new technologies and innovations that are in the early stage of development. At the end of the innovation process the first adoption occurs. Assessing deeply captures new technologies or innovations that are in the later stages of development or are already being adopted.

5.6.3 Wide monitoring

New technologies are constantly being developed. Wide monitoring observes the broader trends in the transport system and identifies future changes in technology. Capturing these trends can provide context for how people are responding to the changes in the transport system.

Wide monitoring covers a number of different factors that are interlinked with the transport system. Energy prices, construction costs and land use all affect the transport system in some way. Analysing these trends provides information on the underlying drivers and context of the transport system. It also covers technologies that are in the early stages of development. Research and development programmes and technology markets are two sources to help identify early-stage technologies. All of these areas are discussed in turn.

- Energy prices are a component of manufacturing costs and transport running costs. Shifts in energy prices can affect the relative pricing of technologies in terms of initial cost and running costs. Consumers can shift towards more energy efficient modes. For example, increased oil prices raise the running costs of petrol and diesel vehicles. Vehicles powered by alternative fuels can become viable as the running costs are relatively cheaper than before, and future developments can be skewed towards investing in technologies that utilise cheaper fuel sources. Oil, electricity, hydrogen and biofuels are the main energy prices to monitor.
- Construction materials are a large input into the construction process, including infrastructure. The price of these inputs can affect the cost to expand and maintain transport system infrastructure, including concrete, steel and labour prices.
- Land use changes can affect the shape and operation of the transport system. Expanding urban limits can lead to an extension of transport infrastructure, while rapid urbanisation can lead to more people living in close proximity to the city centre. Either way, changing land use can shift the behaviours and patterns of how the transport system functions. A key metric here could be the price of land close to central business districts and close to public transport, relative to land farther from these amenities.
- R&D programmes funded by vehicle manufacturers can provide information on early-stage technologies that are under development. Monitoring can be extended to technology companies that

are developing specific transport-related technologies. For example, Google is currently developing an autonomous vehicle – an area far from its original core search-engine business.

- Technology markets can signal where technological advancement is happening. Consumer goods, infrastructure technology and business operation technology are all areas that have an increasing technological component and can affect the transport system. Software developments that are attached to these technologies can increase the range of functionality and options available to users. Similarly, advanced materials technology is likely to be important as they change the components used in vehicles and therefore the cost and ease of operation.

5.6.4 Deep assessment

Wide monitoring can identify science and technology that are in the early stage of development and could affect the transport system in the medium term future. Deep assessment focuses on technologies that are further through the R&D pipeline and may even be available in some forms in some markets. These are technologies that are likely to be implemented in New Zealand in the near future and have a more immediate impact on the transport system.

Deep assessment starts with identifying technologies where the diffusion process has started or is about to start. There several places to look to identify these technologies: overseas markets, domestic markets and luxury goods markets.

- *International markets*: All of New Zealand's vehicles are imported from overseas, with no domestic commercial production. Diffusion of a new technology is likely to be later in New Zealand than overseas, first through new car imports and then with a lag through importing second-hand vehicles (second-hand vehicles comprise a significant proportion of the light and commercial vehicle markets). One key market to watch is Japan, which supplies a large proportion of New Zealand's light vehicles. Assessment of vehicle technology internationally can provide early information on the technologies that are likely to be exported to New Zealand. Early impacts as a result of diffusion can also be seen in international experience. However, monitoring should not be limited to vehicle trends, but also include other technological innovations in transport, such as MaaS.
- *Domestic markets*: Monitoring of technologies can include the New Zealand market. For some technologies, there may be uncertainty about their potential impacts. Deep assessment of these technologies when they do arrive in New Zealand, even just among a small group of innovators, may provide early indications of their potential impacts. The research may rely on case study approaches and qualitative methods in order to create an initial picture of how the technologies are used and the behaviours they entail. Information may also indicate how the technology is weak or failing to deliver on expectations, in particular how overseas technology fits into the New Zealand transport system.
- *Luxury vehicle markets*: New technologies are often expensive in the early stages of diffusion, as production is yet to reach effective economies of scale. These technologies could be implemented in certain sub-sectors before becoming more widely available. Luxury goods markets are one example to monitor for these new technologies. This market is an early adopter of new technology to differentiate their goods and services, and can be an indicator of technology that could be more affordable in the future.

Analysis of new technologies and their impacts on the transport system is limited by resource constraints. Policymakers must select a small number of technologies to analyse in greater detail by using a number of criteria that are available to select the technology. One important criteria is the potential impact the technology could have on the transport system. The impacts of the new technology can relate to any of the other elements from the framework: modes, people and goods or infrastructure, as well as be across a number of the sectors in the transport system. Technologies that appear to have the greatest potential impact – especially if they are having an impact overseas – can be selected for deeper assessment.

A number of metrics can be used for deeper analysis. Below are some metrics that can be monitored when analysing new technology in greater detail:

- *Diffusion metrics*: This is discussed above: sales, GDP, wealth and demographics.
- *Barriers to adoption*: Identifying and monitoring the barriers to adoption can help identify the obstacles to the new technology reaching the potential market share. Barriers can relate to the technology itself or be regulatory barriers. For example, MaaS requires users to have a mobile phone that is connected to the internet and using mobile data, which could be a barrier to adoption for certain population segments. So, monitoring the proportion of potential users with smartphone, mobile data and coverage will be useful for determining whether and for whom it remains a barrier.
- *Relative costs*: Measuring the relative costs of the technology compared with the status quo technology is important. Reducing cost is often a large driver of adoption of a new technology over another. Relative costs can change over time between technologies, so a new technology that starts out expensive can fall in price over time. Inputs can also affect the running costs and costs of production. For example, EVs have higher capital costs but lower running costs than conventional vehicles. Monitoring the two price differentials will be important for understanding future uptake.
- *Relative advantage*: Relative advantage refers to the reasons for adopting the new technology or not. Identifying the relative advantage of the technology can identify the reasons behind why someone would adopt the technology. For example, e-bikes have a relative advantage in efficiency and convenience over conventional bikes, allowing the cyclist to reach their destination faster with reduced effort. Monitoring the relative advantage and reason for uptake can identify changes in attitudes.
- *Operational metrics*: New technologies have the potential to alter the operation of the transport system. Measuring operational metrics can help identify the change in people's perceptions and attitudes towards the new technology, and to identify systemic changes arising out of the technology. Metrics could include the number of shared services available and the number of automated vehicles in operation. Changes in operational metrics are likely to be particularly important for freight and goods services.

There is a range of official sources of information and data for monitoring changes in the transport system for deeper assessment. In some cases, however, data may not be available to track the information required.

5.7 Conclusion of the BMF

New technology is entering the transport system. These technologies have the potential to change behaviours and the way the system operates. The BMF presented here provides a systematic way to think about monitoring the transport system. It considers the system at three levels: the existing parts of the system and how they work together, the process of technology diffusion itself and how it may be modelled and finally the potential to scan the technology horizon for new products and new ideas. For each level, we have discussed the underlying conceptual model and then discussed how the models lead to suggestions of the information that could be collected as well as examples of specific data to collect. This list is not exhaustive, because technology adoption and changes to the transport system only become evident over time. Nevertheless, a summary of the metrics that fall out of the BMF is presented in table 5.1.

Table 5.1 Metrics based on the BMF

Framework level		Metric	What it covers
Transport system			
	Behaviours of people	Number of trips people make	Number of times the transport system is accessed
		Time spent travelling	The amount of time spent travelling
		Destination of travel	Purpose of travel
		Mode of transport used	Utilisation of different modes
		Passengers accompanied	Utilisation of the mode
		Time that the trip was made	Peak or non-peak travel
		Cost of travel	Relative costs of transport
		Vehicle ownership	Availability of mobility
	Behaviours of goods	Freight volumes	Amount of freight transported
		Mode of transport used	Utilisation of different modes
		Goods exports and imports	Freight to/from overseas
		Average load of vehicles	Efficiency and utilisation of road freight
		Transport costs	Relative costs of transport
Technology diffusion			
	Diffusion metrics	GDP or income per capita	Indicator for potential market size
		Wealth	Indicator for potential market size
		Demographic profile	Indicator for potential market size
		Population density	Indicator for potential market size
		Sales	Used to estimate innovator and imitator coefficients
		Policy intervention	Affects shape of uptake curve
		Advertising	Affects shape of uptake curve
		Cost	Affects shape of uptake curve
Horizon scanning			
	Wide monitoring	Energy prices	Change relative running costs of modes
		Construction materials	Cost to expand the transport network
		Land use changes	Extension or intensification of the transport system
		R&D programmes	Capture early stage technologies
		Technology markets	Early stage technologies that could impact transport
	Deep assessment	International diffusion	Technologies already diffused overseas
		Domestic diffusion	Technologies already diffused domestically
		Luxury vehicle market	Technologies already diffused in selected markets
		Diffusion metrics	As above
		Barriers to adoption	Identify any barriers to uptake
		Relative costs	Costs compared to status quo
		Relative advantage	Reason for adopting the technology
		Operational metrics	Transport system changes

From the outset of the diffusion process, all behavioural changes may not be known with certainty. Throughout the process, there could be additional behavioural changes that were not anticipated or were contrary to expectations. Any unintended consequences may be hard to detect at first, but with greater adoption can be identified using data and metrics. Therefore, it is necessary to keep the monitoring of behavioural change sufficiently broad and dynamic to capture these unintended consequences.

To fill data gaps in the consumer sector, one option is to include new questions in the NZHTS. Every year 2,200 households take part in the survey, which collects information on day-to-day travel in New Zealand – such as, how, why, where and when travel occurs. The results give a picture of the travel patterns and choices of all types of people from around the country. In a range of forms, between 1989 and 2014 it has measured the travel of average New Zealanders by surveying two days of travel for everyone in randomly selected households. In 2015 the survey collection method changed to use GPS units to measure the distances travelled by households, and the survey window increased to capture seven days of travel. Online survey questions supplemented the quantitative data from the GPS, where additional questions can be added to the survey to capture changes in the transport system.

The information gathered from the BMF on behavioural changes (anticipated or unanticipated) could identify the case for policy intervention. Policy can act in a number of different ways, depending on the technology and existing regulatory setting. Changes can be around regulation or changing financial incentives through taxes or subsidies, to encourage, mandate, discourage or ban a new technology.

6 Case study: Mobility as a service

This case study, and the following case study on EVs, has been used as an application of the BMF described earlier in this report.

6.1 Introduction

6.1.1 What is mobility as a service?

MaaS is a concept that is gaining a great deal of interest around the world. It brings together a wide range of transport modes into a single digital interface, providing users with tailored transport options based on their requirements and preferences (MaaS Global 2016b; MaaS Australia 2016; Florence School of Regulation 2015). MaaS combines both private and public transport options including buses, trains, taxis, car rentals, car sharing and bike sharing to allow people to move away from vehicle ownership and instead rely on a variety of transport services to be available as and when they are needed, paying as they go (MaaS Alliance 2016; UITP 2016; Transport Systems Catapult 2016). As an ultimate goal, users of MaaS will use one application that pulls together multiple services and transport modes to hire or connect with the best available transport option at that moment. This could be a bus or a shared car or a taxi. MaaS fits into the transport system by linking together separate modes of transport and platforms into one single application that covers everything. The platform also facilitates route planning and payment for services.

MaaS has the ability to make the transport system operate more effectively through greater utilisation of resources, such as shared modes of transport, with the added benefit of reducing the number of cars on the road (Sochor et al 2014). Through bundling of different modes together, MaaS has the potential to offer competitive pricing relative to car ownership, while improving the travel experience (Dotter 2016).

These changes will in turn have an impact on the modes and infrastructure elements of the transport system. MaaS can promote shared services such as cars that can be hired by the hour. Even though short-term car hire is not a new platform, the technology enables easier access and convenience for users making short-term bookings which leads to greater utilisation of existing vehicles. Greater uptake of public transport can lead to better quality services, with user data potentially identifying the areas where new services can be implemented.

Transport operators also look to benefit from the MaaS concept. Transport operators can benefit from increased patronage and utilisation for their services with widespread diffusion of MaaS (Transport Systems Catapult 2016). The MaaS concept provides new opportunities for revenue growth and also has the potential to improve the services offered by transport operators (Transport Systems Catapult 2016; MaaS Global 2016a; Dotter 2016).

This case study uses the BMF to identify behavioural changes to monitor as a result of adopting MaaS (see figure 5.1).

The case study is broken into three sections. The first section on the transport system covers the user needs and monitoring of people's behaviours. The second section discusses the diffusion process for MaaS, as well as producing forecasts of the diffusion process. Horizon scanning is the final section, where more detailed analysis and metrics to monitor MaaS are provided.

6.1.2 Transport system

The primary focus of the case study is on the behavioural change. This section examines how MaaS affects the user's needs of the transport system and is followed by a discussion of the possible data and metrics to monitor the behavioural changes as a result of the technology.

6.1.3 Requirements for MaaS

Based on the elements of the transport system discussed in chapter 2, the framework for thinking about the transport system looks at different components of the system: technology, modes, infrastructure and people and goods. A number of factors must be in place across these elements for MaaS to function.

6.1.3.1 Technology

Communications technology is required to access MaaS. Even though smartphone technology is well diffused, having one that is connected to the internet is still necessary (Transport Systems Catapult 2016). GPS technology is required to establish a user's location and proximity to different services. GPS services are also used to provide accurate data on the location and timeliness of different transport options (The Economist 2016). Potential barriers in regard to mobile connectivity, as described in chapter 5, would need to be considered.

6.1.3.2 Infrastructure/modes

An extensive transport network with a variety of modes available is required for MaaS to operate effectively. The coverage of different services underpinning MaaS can in some situations be incomplete and therefore not be suitable for everyone in the population (Transport Systems Catapult 2016). Typically, highly populated urban areas will have a number of services available. Rural areas are one example of where shared services are unlikely to exist. A similar issue or problem can arise for those further away from the city centre, where public transport and other shared services are lacking. Extending the network over time can capture a larger share of the population to efficiently meet their travel needs (Goodall et al 2017).

6.1.3.3 People and goods

Monetisable benefits to operators from reduced vehicle ownership are required for MaaS to be sufficiently profitable for operators to provide services. To get users to forgo vehicle ownership requires the alternative to have comparable or better mobility options for users. Providing multiple private transport and shared mobility options, which are viable alternatives to vehicle ownership, is expected to be a significant driver for users to no longer own a vehicle. Without being able to do this, the MaaS concept is unlikely to be adopted by operators and consumers alike. One way is to provide users with a service and experience that is superior to the current system, as they are more likely to be willing to pay a premium for those services (Pyythia 2016).

6.1.4 Fragmented MaaS

The traditional view of MaaS is that it is one integrated system providing wrap-around services for a wide variety of modes accessible via a single service. For example, the Helsinki model takes an integrated approach to mobility by offering a number of services through one platform (The Economist 2016). However, this model requires significant coordination in the background between operators to make the service fully operational and seamless for consumers. Operators, under this model, are required to share information with a central entity. Some private companies and operators may be unwilling to disclose operational information to a central organisation, for fear that the information can be used against them by competitors. The coordination required could delay the implementation of a single MaaS platform.

Instead of a single platform where a number of different transport options are covered, MaaS could occur in a more fragmented way, with individual transport options being covered by individual apps (Gifford and Kirkbride 2016). For example, one app could be dedicated to citywide bus transport, whereas another app could be dedicated to rail services. In this situation individual operators have more control over data and operation of the app without having to share information with a central organisation or entity. With more control over the data and payments for individual service options, the coordination barrier is significantly lower for MaaS to begin in a fragmented manner (Gifford and Kirkbride 2016). While this is a benefit to providers of the service, there are downsides to the consumer from a fragmented approach. In this situation, consumers will be required to switch between different applications to use different services rather than using a single platform. Payment will similarly be split between operators, rather than having a single subscription service that covers all transport needs.

One of the main benefits of MaaS to users is the flexibility and convenience it provides, particularly where users are not familiar with the local geography or individual services. A fragmented Maas spread across a variety of local services will provide unequal benefits to different groups.

Local users, who have an understanding of local options, geographies and transport options available, are likely to be the ones who benefit the most from a fragmented approach. They are often creatures of habit that already know the most efficient transport options available for their core set of travel behaviours, ie commuting to and from work each day. An app that covers their mode of transport for the daily core set of movements would meet the majority of their transport needs. For the times that they require non-core or on-demand services, they would then be able to use another service to meet their travel needs. While this is not as efficient as a single app with all services in one platform, it still provides many of the mobility benefits and features of a single platform (Li and Voege 2017).

However users without this local knowledge (such as visitors or tourists) would find it difficult under a fragmented model (Li and Voege 2017) and would benefit more from an integrated model of MaaS where all options are available in a single platform. Being unfamiliar with the variety of local services they will likely default to services they know that span multiple cities or the local taxi service, omitting potentially more efficient options. In contrast, a single platform would enable easy planning and payment for their route to their intended destination.

In New Zealand, a fragmented model may be implemented initially. Under the fragmented definition, there are already services where users can book and pay for transport options using an app, for example Super Shuttle or Uber. Public transport providers are making real-time information about their services more widely available, and further development in this area could lead to more individual service providers distributing their own app for their service (Transport Systems Catapult 2016). Taking this approach would lead to a quicker time to reach the market as there are fewer coordination issues to deal with between operators.

In the remainder of this case study, we discuss MaaS as an integrated rather than a fragmented service.

6.1.5 User needs

The BMF identified six user needs that drive behavioural decisions within the transport system: safety, time cost, privacy and dignity, wellbeing, flexibility and ownership. These needs can also influence the adoption of new technologies. Not all technologies will address or meet the needs of all users as individual preferences differ; however, a technology that meets a number of user needs is more likely to have a faster rate of adoption.

MaaS involves a trade-off in user needs, improving flexibility at the cost of ownership, and in some cases reduced privacy and dignity. It may also provide benefits to safety and to time-cost; however, these will be more marginal. These are discussed in more detail below.

- Safety can be improved through the uptake of MaaS by shifting travel towards public transport and away from passenger vehicles. Public transport is a relatively safe and secure mode of transport (as shown in table 6.1), with a low crash rate and crime risk compared with private vehicle travel (Litman 2014). Injury and fatality rates for New Zealand are highest for motor vehicle occupants and motor cyclist and pillion passengers, accounting for 86% of injuries and 89% of fatalities (Ministry of Transport 2016c). However, public transport is not a necessary requirement of MaaS and this benefit will not apply in all cases. MaaS can also reduce the number of vehicles on the roads, further reducing the likelihood of accidents and crashes (Viechnicki et al 2015).
- Time-cost could improve as MaaS can lower the travel time taken for people to reach their destination. Greater efficiencies in travel are achieved by dynamic routing and increasing the variety of modes that can be accessed (Li and Voege 2017). Different modes will have advantages at different times. For example, a bike could be the fastest travel mode in the city centre at peak travel times. By providing more options, users are free to choose the option that is the quickest at that point in time.
- Privacy and dignity is one of the principal trade-offs users of MaaS make, sacrificing some privacy for greater flexibility. MaaS often relies on coordinating public transport services or ridesharing services, reducing privacy. However, under MaaS there are a number of different options available – each with differing levels of privacy and dignity. Users will be able to choose the mode that matches their preferences.
- Wellbeing can improve where the infrastructure and service provision allows it. MaaS can increase the share of the total distance that is biked for a journey and increase wellbeing in this way.
- Flexibility is improved by linking the user to a variety of services to get them where they want to go (Li and Voege 2017). MaaS provides users with a network of services for reaching destinations as and when needed. Users no longer need to consider many of the constraining factors that limit transport options when using an owned vehicle, eg having a sober driver, considering parking, potential licence restrictions on younger drivers.
- Ownership is reduced. With MaaS, there is no or little ownership required to use the transport system, as everything is used on demand (Greenfield 2014). However lack of ownership may be a deterrent to some users of the transport system.

Table 6.1 Passenger fatalities per billion passenger-miles in the US, 2000–2009

Travel mode	Deaths per billion passenger-miles
Car or light truck driver or passenger	7.28
Commuter rail and Amtrak	0.43
Urban mass transit rail (subway or light rail)	0.24
Bus (transit, intercity, school, charter)	0.11
Commercial aviation	0.07

Source: Savage (2013)

MaaS affects many of the user needs in the transport system. For MaaS, the main benefits of adopting the technology are increased flexibility, reduced travel monetary costs and reduced time cost. However, these benefits are offset by reduced ownership, dignity and privacy – which may act as a drag on the rate of adoption. The rise of MaaS tracks a changing set of user needs as people's needs shift away from ownership towards flexibility. The extent to which each of these differing needs is dominant will be a key driver in the overall uptake of MaaS.

For young people with no children, the greater flexibility may be welcome and, combined with the lack of a capital cost compared with purchasing a car, may be a big driver in the uptake of MaaS. Conversely couples with children or older people may put a greater emphasis on privacy, dignity and ownership. The ownership of a vehicle gives them flexibility in a way that is not required for other demographics. These people are less likely to take up MaaS where it is not so convenient for small children or older family members.

6.1.6 Monitoring: behaviours regarding people

Adoption of MaaS represents a shift in the way people access and pay for transport services. These services are accessed on demand through a mobile application and can be shared with other travellers and not owned by the individual. This changes the current model of owning and operating a personal vehicle for private use. In the BMF we discussed a number of behaviours that should be monitored as part of tracking technological change. We identified the following as particularly important behaviours to monitor:

- *Time spent travelling*: MaaS is expected to make travel more efficient than the current options available and as a result travel time is expected to decline. On average, people spend 6.8 hours per week travelling, with much of it by car (Ministry of Transport 2015). MaaS has the potential to improve efficiency by dynamic routing using a number of different modes. Dynamic routing selects the best route available to the user given their preferences rather than being fixed into one mode, and can also adjust travel plans when certain routes are over-crowded (The Economist 2016). This allows more efficient use of the transport system and can reduce congestion and thus overall travel time for all users. However, over time there is potential for a rebound effect if the reduction in commuting travel time leads to more people commuting in privately owned cars from further afield.
- *Destination or purpose of travel*: If people change their commuting behaviour, one element to monitor will be how far people are willing to commute. If people commute from further afield this has the potential to offset reductions in travel time, so should be monitored closely.
- *Distance travelled*: This is a useful metric of overall uptake of MaaS against other ways of accessing transport.
- *Value of travel time*: MaaS can make travel time more productive or enjoyable. Some shared services, such as bus or train travel, are able to increase the value of travel time. For example, time spent on the train can be used for reading, while time driving a private vehicle cannot.
- *Mode of transport used*: This indicates which modes of transport are being used the most often. MaaS posits that by providing users with the flexibility to choose their preferred method of transport it will be easier to use a variety of modes, which can be tested by monitoring the modes of transport used and the number of multi-modal trips taken. Large and dense cities can have a number of transport modes available for users. MaaS provides all these modes of transport on a single platform, meaning users do not have to switch between websites and apps, reducing waiting and administration time (Kamargianni et al 2015; MaaS Global 2016a). It also has the potential to steer users away from modes of transport that may be at capacity.
- *Passengers accompanied*: This metric accounts for trip sharing on each mode of transport. The push towards shared services under MaaS is expected to increase the vehicle occupancy and the number of passengers in each vehicle. This is for both public transport vehicles and cars alike.

- *Cost of travel*: MaaS has the potential to reduce costs for consumers by replacing car ownership or reducing private car usage. Car ownership is a large expenditure for many and the ongoing expenses related to owning and running a car, including insurance, parking and petrol costs, are high (The Economist 2016; Markman 2016). The NZHTS shows that time spent travelling in a vehicle per person (for private use) is approximately 33 minutes per day (Ministry of Transport 2015). By making the vehicle available for others, and by making greater use of public transport services, costs of travel are expected to fall if MaaS is successfully adopted (Transport Systems Catapult 2016). How the actual cost of travel using MaaS compares with private vehicle ownership will be an important factor in its uptake and so should be monitored.
- *Vehicle ownership*: Ownership increases the accessibility of different mode choices. Ownership can be extended to include cars, bikes etc. Transport behaviours are changing as consumers move away from the traditional desire for car ownership and instead look to utilise transportation services (Herrlin 2017; Transport Systems Catapult 2016). MaaS takes advantage of changing consumer demands and provides a viable alternative to car ownership (Simpson 2016). As such we would expect that as uptake of MaaS grows, vehicle ownership rates would flatten or decline compared with previous trends.

In the BMF we discussed how, in addition to the core behaviours above, some monitoring data will need to be collected specific to each technology that is being monitored. Additional questions can be added to the NZHTS based around the following areas to monitor behaviours relevant to MaaS:

- Smartphone use can include questions to capture the way people use a phone in the transport process. The questions can relate to a number of possible smartphone uses covered by MaaS, including: planning options, routing options, booking trip and payments. Supplementary statistics on smartphone penetration and data availability/connectivity can indicate the availability of these options to users.
- Multi-modal trips are already covered in the NZHTS, but additional questions about how trips were planned and the method of payment can also be developed.

In table 6.2 we summarise the suggested metrics to monitor, the expected change as MaaS grows and our reasoning.

Table 6.2 Behaviours to monitor that track the impact of MaaS on the transport system

Metric	Expected change	Reason
Time spent travelling	↓	As MaaS makes travelling using shared services and public transport simpler and more efficient, overall travel time is expected to decline.
Destination or purpose of travel	---	While we do not expect the destination or purpose of travel to change, if MaaS reduces travel times people could choose to travel longer distances in the same time and commute from further away.
Distance travelled using MaaS	↑	As MaaS gains traction in New Zealand, this is useful metric for tracking uptake.
Value of travel time savings	↓	As commuters move away from private vehicles to MaaS, the number of other activities they can do while travelling increases, reducing the value of travel time savings.
Mode of transport used	↑	We expect the number of modes of transport used will increase as MaaS makes a wider variety of options more convenient.
Passengers accompanied	↑	MaaS encourages ridesharing and shared vehicle services, which is expected to increase the number of passengers per vehicle trip.
Cost of travel	↓	As MaaS replaces vehicle ownership and makes more efficient use of shared vehicles, costs to consumers are expected to fall.
Vehicle ownership	↓	MaaS replaces the need to own a private vehicle, so vehicle ownership rates should fall or grow more slowly as MaaS grows.
Smartphone use	---	Smartphones are needed for MaaS and should be monitored as a requirement.

Metric	Expected change	Reason
Multi-modal trips		As MaaS links currently disparate services, we expect the number of multi-modal trips to increase.

6.2 Technology modelling

A Bass model was developed as part of the project to forecast the diffusion of the new technology through the market. The model can be applied to MaaS to demonstrate how the forecast process works in practice and the speed of adoption. Sensitivity analysis can be performed to give a range of estimates around the central Bass diffusion forecast. Finally, alternative scenarios can examine the effect of policy intervention, changing costs and greater advertising.

6.2.1 Estimating potential market share

The Bass diffusion model requires three variables to be input into the model: potential market size (m), coefficient of innovation (p) and the coefficient of imitation (q). The model then uses these variables to produce an S-shaped curve forecasting the rate of uptake of MaaS. Market share represents how widely the technology could diffuse through the market and is defined as the number of users (rather than sales). The coefficient of innovation and imitation affect the rate and speed of diffusion as the technology reaches its full market share. The variables that affect the market share of MaaS are:

- GDP and wealth influence the ability to pay for and use the innovation. MaaS does not require large up-front costs from the user's perspective to use the system, making it accessible for many users. A high percentage of the population is expected to be able to afford and pay for MaaS in New Zealand.
- Smartphones with access to data and connectivity are required. New Zealand is a developed country with relatively high wealth and GDP. Accordingly, the majority of adults own a smartphone. In 2015 smartphone penetration had reached 70% in New Zealand (Research New Zealand 2015). Greater smartphone adoption over time will increase the potential market share of those who can access MaaS.
- Population density is required for MaaS to be viable from an operator's point of view. Without density, shared assets are likely to be underutilised. Furthermore, highly populated areas are likely to have a greater number of shared transport options available to consumers. As a result, MaaS is likely to start in major cities where population and density are greatest. Monitoring of density can be undertaken at the citywide level or at the suburb level. City level density can indicate whether MaaS can be viable in that city, where suburb level density can indicate the areas that are likely to be serviced within the city.
- Demographic structure affects those who will uptake the technology first and those who will be later adopters. Younger generations living close to the city centre are likely to be early adopters of MaaS. This demographic is more likely to be technologically savvy when it comes to using the mobile platform. Older generations are expected to adopt more gradually; however, this demographic is likely to benefit from an improvement in mobility options under MaaS.

Operators require a high population density to utilise assets effectively. As a result, MaaS is likely to be implemented in cities that have high population density and the required transport services available. The potential market share for MaaS in New Zealand has been assumed to be limited to the three densest cities: Auckland, Wellington and Tauranga. All these cities have population density above 700 people per square kilometre (table 6.3). Auckland is the largest and most dense city with a 2017 urban density of 1,413 people per square kilometre. The three cities highlighted have a combined estimated population of 2.1 million people; however, the market potential will be only a proportion of this figure.

Table 6.3 Population and density of New Zealand cities

City	Population	Land area (km^2)	Density (people per km^2)
Auckland	1,534,700	1,086	1,413
Hamilton	235,900	1,100	214
Tauranga	137,900	178	775
Wellington	412,500	444	929
Christchurch	396,700	608	652
Dunedin	120,200	255	471

Sources: Population is from Statistics New Zealand (2017c) and land area is calculated based on Statistics New Zealand (2017b)

Within the cities there will be people who are not potential adopters for a number of different reasons including individuals who would not be willing to adopt or change their approach to transport and those who do not have access to a connected smartphone. Accordingly, of the 2.03 million population of these three cities, the market share is estimated as 70% of the population or 1.42 million people. This excludes the 30% who currently do not have access to a smartphone. Over time the potential market share can change as population changes or additional cities adopt MaaS.

6.2.2 Estimating innovator (p) and imitator (q) parameters

MaaS is a relatively new concept which has not yet been fully implemented commercially. This has provided some challenges when estimating the innovation and imitation coefficients (p and q respectively). Uptake data is used to estimate the coefficients to be used in the Bass diffusion model. Without any diffusion to date in New Zealand, other methods have to be used to estimate the coefficients.

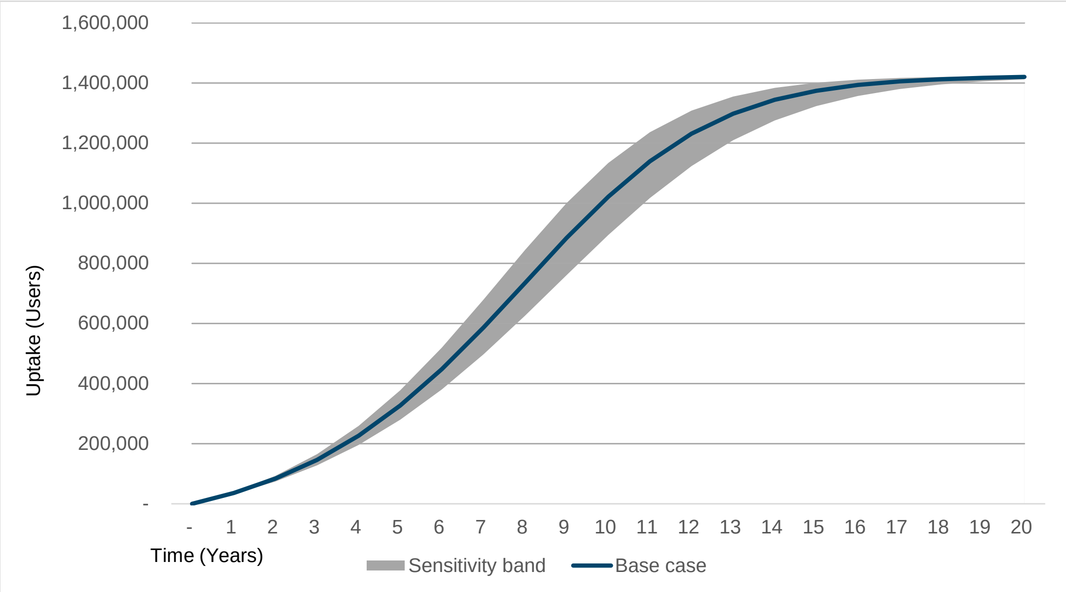
Diffusion of MaaS has started on a trial basis in Helsinki, Finland. To date, availability of the service has been limited to a small number of people while issues are addressed and sorted before being rolled out more widely. As a result, data from this case study could not be used to guide estimates for the New Zealand diffusion process. Services such as Uber were looked at as well; however, as Uber is a private company, data availability was still an issue. Without relevant data on available diffusion, analogy is used to produce p and q estimates.

Other similar electronic services were looked at to provide an analogy on the diffusion of MaaS. From the literature, online shopping was identified as a feasible proxy for estimating the p and q values for the diffusion model. Online shopping provides consumers with a wider range of product alternatives and enables them to compare alternatives more efficiently. This is similar to the MaaS concept as it provides consumers with a range of transportation options and the one app enables consumers to compare different routes and travel options more easily. Another feature of online shopping is that it provides an alternative to shopping instore and users are able to pick between the two alternatives. Some consumers will only shop online, where as other consumers will switch between shopping online and instore. This will also be the case with MaaS as the service offers an alternative to a car; however, consumers are able to use the MaaS concept but still have the option to use a personal car if they desire. MaaS also offers a better service at a lower cost which is the same as online shopping where people have the increased ability to identify cheaper alternatives.

Using the online shopping service as a base case for the MaaS Bass diffusion model has provided estimates for the innovation (p) and imitation (q) values. A previous research study into the Bass model for online shopping has identified a p value of 0.025 and a q value of 0.371 (Naseri and Elliott 2013), and these values were used in the creation of the MaaS Bass diffusion model. From these values it can be seen that for this type of service imitation is expected to have a greater impact than innovation. This indicates that adoption tends to be driven more by word of mouth rather than the innovation of new adopters (Naseri and Elliott 2009). As more data on MaaS becomes available, these coefficients can be updated.

Inputting the variables into the Bass model produces the diffusion forecast in figure 6.1. The timeline starts from when the first adoption occurs. For New Zealand this could occur anywhere up to 10 years away depending on a number of factors. Once diffusion occurs, it is forecast to take around eight years for diffusion to reach 50% of the potential market. Full diffusion occurs around 16 or 17 years from the first adoption of the technology. Sensitivity bands are provided around the forecast to give a range of possibilities. The band represents a change of 10% plus and minus for both coefficients. The main uncertainty with the uptake of MaaS is when it will begin – the Bass model does not tell us this. We discuss this further below.

Figure 6.1 Bass diffusion forecasts for MaaS



6.2.3 Scenario analysis

Scenarios can be used to understand the factors that influence the diffusion of MaaS through the market. These different factors can change the when, how fast and how much diffusion occurs in the market. Four different scenarios are discussed:

- delays in implementing technology
- policy intervention
- cost declines
- advertising growth.

6.2.3.1 Technology delays

Two factors can influence the timing of when the first diffusion of MaaS occurs: technology and cooperation between suppliers. For MaaS to be adopted within New Zealand the technology has to be ready and available for use, as it relies on applications and data in order to operate effectively. MaaS requires a variety of technologies to be feasible including:

- mobile internet
- location services
- the use of smartphones
- traffic monitoring systems
- real-time transport information on services.

All these technologies are available and becoming widely used in New Zealand. It is already possible to use a smartphone to get a real-time estimate of the time until the next bus arrives at the nearest stop or to find the location of the nearest car available for ridesharing.[7] Although these facilitate the MaaS concept, one of the biggest technology requirements is the app that will be used and the integration of real-time data between the different transport platforms and monitoring systems. The implementation of software integrating different services and types of data can take some time, and these delays in development of the application will shift the S-curve to the right. This was highlighted in Wellington as the local council investigated implementing a similar system of integrated ticketing and identified that it would take a minimum of two years to develop (Radio New Zealand 2016).

For MaaS to be implemented successfully it will require cooperation from a range of different transport operators. Private sector operators will have to be willing to join the service and share resources and data with the MaaS provider. Private operators may be hesitant to share their data and adjust their business model to fit with the MaaS concept and this could result in there being gaps in the service (Transport Systems Catapult 2016; The Economist 2016). If MaaS is unable to gain cooperation from certain private service providers then they may be unable to offer certain services. Lack of cooperation could also delay the implementation of MaaS, shifting the S-curve to the right.

The Transport Agency is addressing some of the barriers to the uptake of MaaS by trialling MaaS systems in Queenstown and Auckland Airport in 2017. The Transport Agency is building a common data infrastructure to make sharing real-time data easier, and to support the coordination among operators required for MaaS to come about in New Zealand. These are described in more detail below.

6.2.3.2 Policy intervention

The MaaS concept has the potential to address some of Government's key transportation concerns through reducing private car usage and encouraging increased use of shared resources such as public transport. The MaaS concept looks to reduce traffic congestion and air pollution in major cities and this should in turn reduce costs for the government in the long run (The Economist 2016; MaaS Global 2016a; Kamargianni 2015).

One of the key drivers behind the development of MaaS in Helsinki has been the support provided by the government as they look to alternative options to address their transport policy issues (MaaS Global 2016b; Tyson 2016). This makes government intervention an important factor in the adoption of MaaS and is

[7] Metlink in Wellington provides GPS based real-time data estimating time for their central city buses to users of their app and at selected stops around the city. Uber provides GPS locations of their drivers to potential users through their mobile app.

incorporated explicitly and implicitly in the Bass model.[8] The impact of the policy shock will depend on the level of government involvement and the policies that they implement to develop MaaS within New Zealand.

There are two approaches to government support for MaaS:

- a top down system where the government organises and/or pays for the system to be put in place
- or a bottom up approach where the government supports the cooperation and data sharing required, and allows the private sector to build upon it

The Finnish government has taken the first approach. They have rewritten legislation and removed national restrictions that might act as a barrier to MaaS's success, and have organised for the provision of a MaaS service in Helsinki (Koskue 2016; MaaS Global 2016b).

In New Zealand, the second approach is being taken. The Transport Agency is building an open data infrastructure that brings together real-time data from transport providers. Any private operators can build an application on top of this data infrastructure, and everybody can build on the same complete set of data. The Transport Agency is working with providers to gather and share the necessary data for the data infrastructure and are encouraging relevant private organisations such as Auckland Airport to develop MaaS applications on top of it.

Beyond this, the government could further promote MaaS with advertising, subsidies, or by supporting the development of a wider range of transport options.

Box 6.1 NZ Transport Agency MaaS pilot projects

The mobility marketplace

The Transport Agency is piloting a 'mobility marketplace' that aims to address many of the barriers to the uptake of MaaS uptake. Initial pilots are being run first in Queenstown, and then at Auckland Airport.

The 'mobility marketplace' will bring together real-time information on services and on transport demand from users. The Transport Agency in partnership with Machine Zone's Satori platform have developed the digital infrastructure and standards necessary to ensure data from different operators can be compatible. The Transport Agency is working alongside providers to help them meet the data format and standards requirements.

The mobility marketplace will use only open data, in accordance with the New Zealand Data and Information Management Principles (Cabinet Office 2011). For providers to offer their services through the marketplace, they must contribute their own data under an open access licence. Providers have a financial incentive to cooperate, as the marketplace provides a new channel to sell their services and because the real-time data from the marketplace can help them identify where there is unmet transport demand, and tailor services accordingly. The mobility marketplace provides a consistent set of open access information that multiple private services or application developers will be able to build services upon.

MaaS pilots

The Transport Agency is piloting MaaS systems in Queenstown and Auckland Airport. Using the mobility marketplace and by working with transport providers to bring data together, the Transport Agency is trialling the mobility marketplace before building a case for rolling it out nationally.

In Queenstown, the Transport Agency has developed an app – *Choice* – that sits on top of the data infrastructure. The Choice app will provide users with options for getting between Queenstown airport, the centre of the city and the major ski fields.

[8] Existing policies are included in the estimated p and q values. Potential new policies can be modelled explicitly as policy shocks.

Auckland Airport will be the second pilot. It will provide an integrated network-wide mobility service for airport customers. The front-end app will be provided by Auckland Airport building on the digital infrastructure provided by the mobility marketplace.

The two pilot projects involve journey planning, real-time information on congestion and service availability, and travel booking, but not payments at this stage. Payments for travel booked will remain with individual services payment systems.

Barriers and the role for Government

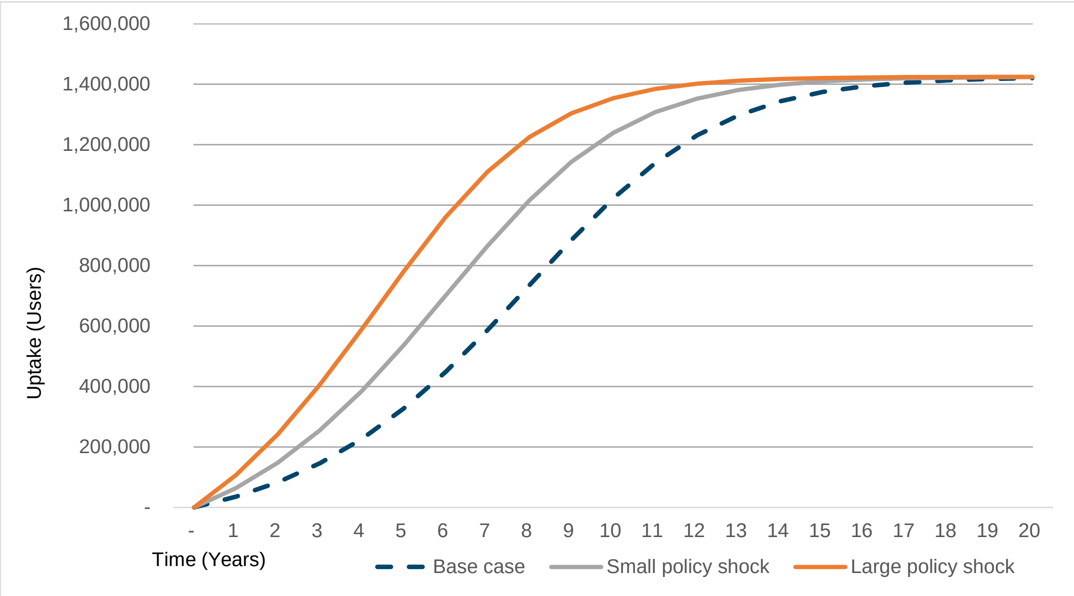
The Transport Agency recognises that there are several barriers to MaaS becoming established in New Zealand, as discussed below. The MaaS trials are responding to the three main barriers:

- Data quality and availability – the Transport Agency is working directly with providers to help them ensure their data is compatible with the standards set for the system
- Incentives on private operators – by making participation conditional on open data provision, transport providers are incentivised to provide data as they gain insight into otherwise invisible segments of the market, and the ability to more precisely tailor their services to transport demand
- Cooperation between private operators – by acting as a trusted neutral party, the Transport Agency can bring together the data of otherwise competing parties.

The mobility marketplace responds to these barriers by developing a digital infrastructure for sharing real-time transport data as both a natural monopoly and a public good. It would be inefficient for different providers to build competing data sharing services, and competition between them would fragment the services making them each less useful. By requiring providers to make data open access, the Transport Agency ensures that the MaaS systems built on the data infrastructure can include all providers, and that no one MaaS provider can capture the market.

If the government is going to have a high level of involvement, like the Finnish government, then the policy shock is estimated to be a coefficient of around 0.05. At lower levels of involvement and policy change, then the policy shock will be around 0.02. Both of these scenarios increase the rate of adoption compared with the base case. It is expected that policy support will occur from the first adoption. These different scenarios from the base case are shown in figure 6.2.

Figure 6.2 Policy intervention on diffusion of MaaS

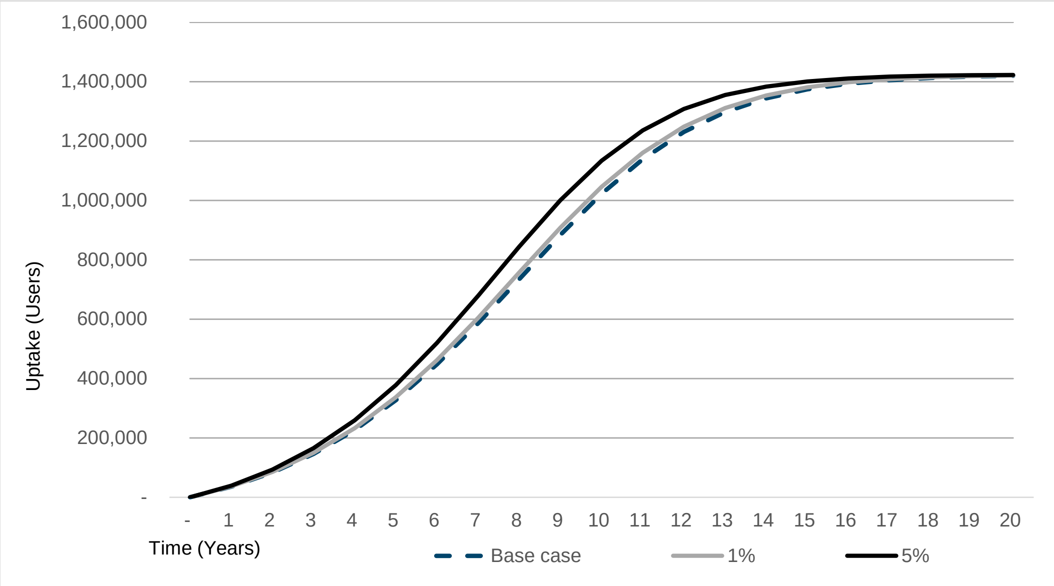


6.2.3.3 Cost declines

Initially there is likely to be a price differential between car ownership and MaaS, with MaaS expected to be a cheaper alternative to running and owning a private vehicle (Transport Systems Catapult 2016; The Economist 2016). This price difference will have an influence on the initial adoption of MaaS and cost savings from MaaS are also expected to increase as more people adopt the service.

Additional cost declines can be reflected in the MaaS Bass model. In this situation MaaS is going to experience negative price growth as over time the price for the service is expected to decrease and this should in turn increase the rate of adoption over time. It is assumed that the decrease in price is likely to be within 1% and 5% per annum (figure 6.3). Within the model, price responsiveness is set to high; even with the price declines and high price responsiveness, these changes make relatively small changes to uptake. This indicates that the decreasing costs of MaaS are unlikely to significantly alter the base case scenario.

Figure 6.3 Price declines affecting the rate of uptake

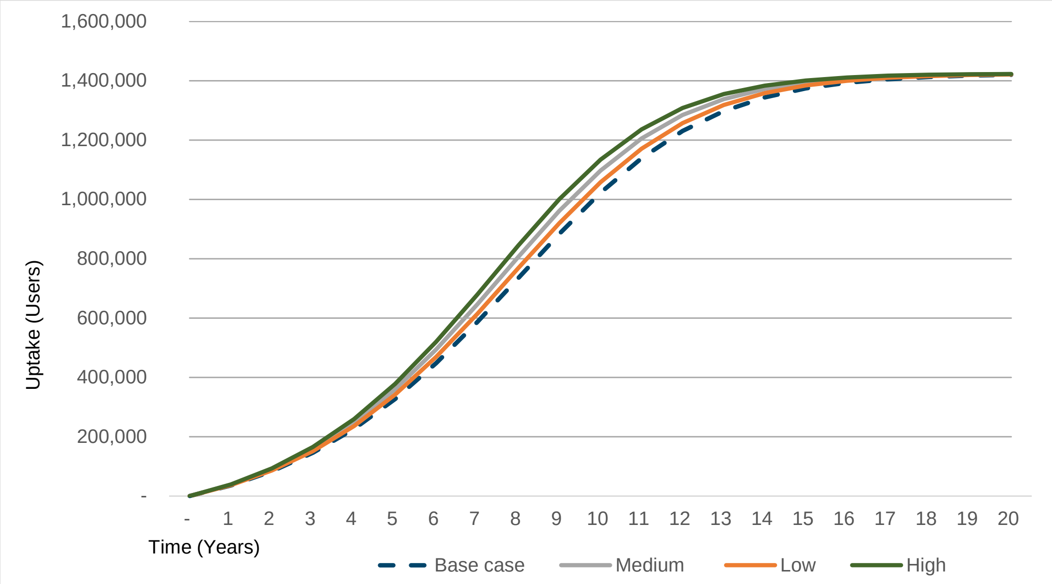


6.2.3.4 Advertising growth

If the MaaS provider looks to increase the advertising for the innovation then it is assumed this will result in the MaaS concept being adopted faster than the base case. There is also the potential for the government to invest in increasing advertising surrounding MaaS, depending on their level of support and involvement in the implementation of MaaS.

The effect also depends on the level of advertising response from consumers. If there is low advertising response then an increase in advertising growth of 10% results in little change to the adoption of MaaS. If there is high advertising response in the model, then 10% advertising growth sees a reasonable change in the adoption speed for MaaS. It is assumed that consumers are unlikely to be highly responsive to advertising for a product such as MaaS, so it is more likely the response will be low to medium. The different responses to a 10% increase in advertising are shown in figure 6.4.

Figure 6.4 Response to a 10% change in advertising.



6.2.3.5 Potential market growth

Population increase will lead to a gradual rise in the market potential for MaaS. Population growth within New Zealand was 2.1% in the year ended June 2016 and is predicted to remain around 1% to 2% in the next few years (Statistics New Zealand 2017a). The population growth has been largely driven by high levels of net migration which was 68,400 in the year ended May 2016 (Statistics New Zealand 2016). Migrants tend to move to the main centres and this coupled with increased urbanisation has meant most of the population growth is within New Zealand's five largest cities. In 2015 and 2016 it was estimated that Auckland, Hamilton and Tauranga experienced population growth above 2%, while Wellington and Christchurch experience population growth of 1.5% to 2% (Statistics New Zealand 2017c).

With the population growth experienced being highest in the cities, such as Auckland, this will result in potential market growth for MaaS within these cities, similar to the population growth rate. Population growth in some of the less dense cities such as Hamilton might in future lead to these cities also being potential markets for the MaaS concept. If additional cities become viable locations for MaaS as their population and density increases, this will result in a higher market potential for MaaS adoption.

Table 6.4 Summary table of metrics to monitor for diffusion modelling

Metric	Reason
GDP per capita Median net wealth per person	Newer technologies are often first picked up in the wealthiest countries and by the wealthiest individuals. As GDP per person and median net wealth increase over time, so too may the segments of the population who would use MaaS.
Population density	MaaS requires a variety of public transport modes. For this variety to be viable, a high population density is needed. Monitoring population density will identify locations where MaaS could be possible.
Demographic structure	Different demographics are more likely to use MaaS than others. Monitoring demographic changes can focus on people likely to be early adopters.

6.3 Horizon scanning

MaaS is one of many new technologies moving through the R&D pipeline to the diffusion and adoption phase that could affect the transport system. Based on the BMF, this section considers two stages of scanning: wide monitoring and deep assessment.

6.3.1 Wide monitoring

We have already selected MaaS as a technology to examine, so wide monitoring is not as relevant here. However, we have considered the BMF and highlighted some trends that could have been followed that would have selected MaaS for closer examination:

- *Use of shared transport services*. MaaS relies on shared services as the main transport model. A number of shared services have increased the number of modes available to use on a short-term basis without ownership. These include car and bike hire that have hourly rental options – with convenient rental locations for people to gain access. Users require a favourable attitude towards sharing for this model to work effectively. A growing set of shared services in New Zealand and overseas indicates that MaaS is becoming more of a possibility.
- *Congestion in cities*. Congestion creates unpredictability in travel times, creating frustration for users. Congestion and increasing population of cities have also been factors behind the rise of shared services. MaaS can assist with reducing congestion in two ways. First, routing options can move users away from congested or overcrowded routes. This helps spread the load of the transport system to be more efficient. Second, greater utilisation of vehicles reduces the number of vehicles on the road, while transporting the same number of people.
- *Mobile technology and data*. MaaS combines a number of recent technologies that when combined together change the way in which transport services are delivered. These technologies have advanced enough that they can be accessed on a mobile platform. In addition, the lower cost and greater availability of mobile data has further increased accessibility for users. Information can in turn be fed back to operators who are able to adjust service offerings to meet user needs. Without these advancements MaaS as a platform would be difficult to implement. The wide penetration of mobile technology and consistently growing mobile bandwidth makes MaaS much more feasible.

In addition, other technologies still in development could affect the potential impact of MaaS. Examples include:

- *Autonomous vehicles*. Autonomous vehicles have the potential to change the expectations of drivers of private vehicles. Being driven by one's own vehicle is not so different from being driven in a taxi or rideshare vehicle. As drivers of private cars get used to being driven on their commute, they may become more open to the use of shared services such as Uber or Lyft. This could help facilitate a cultural shift away from private ownership of vehicles.
- *Artificial intelligence* (AI). A variety of companies are developing personal AI assistants such as the Amazon Echo, Google Home or Apple's Siri. These digital assistants are currently capable of parsing queries, searching online for answers or solutions and assisting with some digital tasks such as calendar bookings, online shopping and ordering transport. The Amazon Echo can already integrate with apps for Uber and Lyft allowing users to order a ride simply by asking for one. As AI becomes more sophisticated, sorting through a variety of transport options and choosing the best one may become something that an AI assists with, with users simply needing to request transport and the AI organising options and providing directions.

6.3.2 Deep assessment

In the BMF, deep monitoring is the second stage of the horizon scanning process. Having selected a possible technology it identifies several factors that would indicate it could be significant enough to warrant deeper examination. The BMF also identifies categories of technology specific metrics that ought to be monitored to track and assess the current and future impact of technologies. From the BMF the factors that indicate a new technology could be significant include:

- *International markets*. Overseas diffusion is an indicator of when New Zealand could begin to import the technology. MaaS is beginning to roll out in international markets, although diffusion is still at a relatively early stage and has reached only a few markets so far. Along with the Helsinki MaaS project, West Midlands in the United Kingdom is the second metropolitan area where the service is to be trialled (MaaS Global 2016c). A product in the early stages does limit how much analysis can be done on the potential impacts of the new technology. However, teething problems can be solved before the product rolls out more widely. Given the technology is software based, the diffusion to New Zealand could occur more quickly compared with a physical technology.
- *New Zealand uptake*. The uptake of the pilot projects in New Zealand will potentially be illustrative of whether MaaS can succeed here.
- *Luxury vehicle markets*. Many new technologies first roll out in this market; however, because MaaS uses sharing services, public transport and is not a physical technology, luxury markets are not relevant to its uptake.

We applied the metrics identified for monitoring in the BMF to MaaS across several categories:

- *Diffusion metrics*. While MaaS has yet to roll out in New Zealand, once a MaaS service is established in New Zealand its use and uptake should be monitored to see how successful it is and to identify any unexpected barriers to adoption or unintended effects.

The BMF set out different factors to monitor for assessing and forecasting uptake. Each factor is discussed in turn below:

- *Relative cost*. MaaS can be cheaper than the status quo, which for many people in New Zealand is owning and operating a car as the main form of transport. With the relative cost lower for MaaS there could be a switch from car ownership towards the service. A lower relative cost has been seen as a large driver for adoption of a new technology. Where possible, the total costs of different transport options (including ownership costs) should be monitored. This would allow the Transport Agency to evaluate whether MaaS offers sufficient incentive over other options to gain significant traction in the market.
- *Relative advantage*. The benefit of using MaaS is the convenience and range of different transport services included within one platform, providing flexibility without requiring ownership. Instead, transport services are paid for as they are used by the traveller. For example, users can select from bike, car, walking and public transport services depending on their circumstances and preferences. If a crash has caused congestion on a motorway, the user may be directed to train services instead. The greater range of options available helps to solve the first and last mile problem, making travel efficient, timely and accessible. The increased range of options can be provided at a reasonable cost to the traveller. To monitor MaaS's relative advantage, the variety of transport options available in different city centres should be tracked, as should their integration together.
- *Operational metrics*. Key operational metrics track how a technology is affecting the transport system as a whole. For MaaS, this will overlap with metrics measuring MaaS's relative advantage. Key metrics include:

– the number of ridesharing services available

– the number of vehicles in ridesharing services

– the number of trips taken using MaaS.

Table 6.5 Metrics of factors for MaaS adoption in New Zealand

Indicator	Expected change	Reason
Trips taken using shared transport services or public transport	↑	Shared transport services are a key part of MaaS.
Congestion levels in likely cities	↑	Congestion acts a driver for uptake of shared services and MaaS
Mobile data speeds and prices	Speed ↑ Prices ↓	Mobile data is a key requirement for MaaS to be flexible enough to succeed
International diffusion of MaaS. Number of examples of MaaS in operation	↑	If MaaS succeeds overseas that will likely be replicated here, if conditions permit.
Domestic uptake/trips using MaaS in New Zealand	↑	When MaaS begins in New Zealand its uptake should be monitored directly rather than indirectly if possible.
Relative cost of MaaS: • cost of MaaS subscriptions • cost of private vehicle ownership	- - - ↑	The relative costs of different options will be a key driver of uptake.
The number of transport options available in different centres	↑	As population in the main centres continues to grow, a greater variety of transport options become viable. A variety of options are required for MaaS to succeed.
The number of transport providers available in each location	↑	A variety of options are required for MaaS to succeed.
The number of vehicles in ridesharing, public transport or other shared transport services	↑	The number of vehicles in service is a better measure of coverage of shared transport services since some operations may be small.

6.3.3 Barriers to adoption

The future adoption of MaaS is not certain, as there a number of issues to deal with before the technology is ready for diffusion. Five main barriers are discussed: data quality and availability, technology barriers, lack of collaboration among private operators, infrastructure availability and mode barriers.

- *Data quality and availability*: Improvements in data bandwidth and connectivity at an individual level have enabled MaaS to be viable; however, the availability of specific datasets can be a barrier to the adoption of MaaS. One barrier to operating MaaS is the data required from commercial operators to run the service. Some providers of services will not cooperate in making their data available, reducing the number of modes that are captured on one platform. Data compatibility and quality can also make it difficult to coordinate different data services (Crane 2016). Also, one of the key challenges for the MaaS system is getting data that is sufficiently complete and accurate (Herrlin 2017).
- *Technology barriers*: Reliance on smart devices to provide the service can limit the availability to those who own a smart device connected to the internet with mobile data (Sochor et al 2014). A field trial of the

MaaS service also identified that relying on smart devices had restraints in terms of battery life and the necessity to have mobile access to the internet in order to operate the application (Sochor et al 2014).

- *Private operators*: To operate effectively there needs to be collaboration and co-operation between the private transport operators, the public transport operators and the MaaS provider. The model is structured with a central MaaS provider who aggregates the different transport operator services through an application (Transport Systems Catapult 2016). This model draws in many different operators to provide services, thereby reducing the required investment to achieve economies of scale for a single supplier. However there need to be enough incentives for private operators to join and provide services under the model. New Zealand operators may not wish to collaborate if they feel their existing market share or their business model may be threatened. Some operators may also be hesitant to collaborate because changes could affect their employees (Transport Systems Catapult 2016).
- *Infrastructure*: Shared services rely on roads, railways and water access to run the network of services. Inner city areas have the greatest provision of infrastructure for transport services, as space is constrained with a dense population. Outside of these areas the infrastructure needed to make the service efficient may not be available. For example, railway lines run through some outer suburbs but not others. This limits the variety of transport options available and thus the viability of MaaS as a model.
- *Sufficient modes*: In some areas, there are not sufficient different transport modes to make MaaS viable. Having a variety of transport modes is crucial for the adoption of MaaS as it provides the user with choice and reliability, which drives adoption of MaaS.

Table 6.6 Barriers to adoption of MaaS

Barrier	Importance	Impact
Potential lack of quality and comparable transport service data	Important – data that is not suitably comparable will need to be cleaned or refined to make it useful. Absent data sets could prevent MaaS from becoming established.	Medium – as data and connectivity technology has improved, so too has the quality and quantity of data available.
Reliance on smartphones to access MaaS	Very important – the flexibility to rely on MaaS requires that it can be accessed from anywhere.	Medium – smartphone penetration is very high among younger demographics, but not as high among older people who may also benefit from MaaS.
Potential lack of cooperation among providers	Very important – if transport providers do not cooperate to provide integrated services, MaaS cannot be established.	High – different elements of the transport system run competing business models and likely do not view cooperation as in their interests, eg taxi companies and Uber.
Infrastructure limiting transport options	Medium – the existing infrastructure is a large determinant of which transport options are available or feasible, eg the spread of rail links makes rail possible. Cycle paths or cycle lanes make cycling a safer option.	Low – as MaaS develops it will work around the transport options available and new options will fit around existing infrastructure, eg if rail links are not present, buses and ridesharing services will be instead.
Sufficient modes	High – without a variety of transport modes there will not be sufficient services for MaaS to integrate.	Low – MaaS requires a certain population density. While the variety of modes available and participating may not be as comprehensive as desired, centres that already meet this population density threshold will likely have a number of different types of transport services already.

6.4 Reflections on the behavioural monitoring framework

This case study has been used as an application of the BMF described earlier in this report. Here we reflect on how well the BMF was able to be used to assess the future development of MaaS.

6.4.1 Generality/applicability

The BMF operates at a fairly general level – people and goods, technology, infrastructure and modes – while including some specific elements and metrics to consider. The framework was sufficiently general to be applied to a wide variety of technologies, although not all elements included will apply to all technologies. In the user needs section for example, 'safety' and 'wellbeing' are less relevant to MaaS. The user needs section focuses attention on the key tradeoffs people will be making in this technology – greater flexibility in exchange for privacy and ownership. This helped us identify the key demographics who are most likely and least likely to use MaaS.

6.4.2 Modelling

In attempting to model the diffusion of MaaS, we encountered some difficulties due to the overall lack of data. This was due to the very early stage MaaS is at globally, meaning there is little data in existence. There are also issues accessing the data that does exist, since it is often not publicly available. As a solution we analogised online shopping as detailed above.

The model is flexible enough to allow such an analogy to be useful where the key characteristics are identified. As more data becomes available for diffusion overseas (and in New Zealand) the modelling can be updated and the forecast revised to be more accurate.

6.4.3 Monitoring

The BMF was a useful framework for identifying metrics to monitor and likely barriers to the uptake of the technology. By moving from the general to the specific through wide monitoring to deep monitoring the framework helped us identify what we thought was significant about MaaS, how it would manifest in the transport system (and therefore what to track to monitor its progress) and what metrics to track that are necessary prerequisites to the technology becoming established.

The framework is not prescriptive; it does not provide a detailed process for identifying particular metrics and indicators. Rather it guides the reader to consider categories of thinking and how they would apply to the technology at hand.

6.5 Conclusion regarding MaaS

MaaS has the potential to re-shape the way transport services are provided – away from vehicle ownership to a flexible pay-per-use model. Within this model, customers are able to use a number of different modes to travel efficiently to their destination. For society as a whole, one of the main benefits is for congestion to be reduced, making travel more efficient with existing infrastructure.

These changes will in turn have an impact on the modes and infrastructure elements of the transport system. MaaS can promote shared services and enables easier access and convenience for users making short-term bookings. The technology is leading to greater resource use of existing vehicles; however, infrastructure provisioning can also change as a result of MaaS. Greater uptake of public transport can lead to better quality services, with the data potentially identifying the areas where new services can be implemented.

However, not all support industries will benefit from the implementation of MaaS. A shift in the transport system away from personal ownership of vehicles towards MaaS could see manufacturers change to support service providers. MaaS could reduce the number of vehicles on the road and shift the areas where travel costs are spent. Key sectors that could see MaaS as detrimental include:

- Reduced car sales can affect those operators who support the vehicle industry. Mechanics, panel beaters and other service industries could see reduced work due to fewer cars being on the roads. In addition, the cars are likely to be newer if they are owned by businesses, leading to fewer problems and breakdowns. Reduced vehicle sales could reduce the variety of models available for sale in New Zealand.
- Shifting travel expenditure could redirect where resources are spent. These changes could see public transport operators receiving higher revenues and operators that serviced private forms of ownership could see a reduction in revenue.

Because MaaS is still in the early days of adoption, the system effects of MaaS are not precisely known. It is expected that MaaS will result in greater use of public transport and the existing vehicle fleet, lowering congestion. However, an increase in taxi or rideshare services could also increase the number of journeys taken in private cars, partially offsetting this effect. This will need to be monitored over time as MaaS is established to fully assess the benefits and costs of MaaS to the transport system.

While it is still very early days for the technology and MaaS is currently still in the trial stage in New Zealand, this chapter on MaaS has identified a set of indicators that would be useful both to identify prerequisite conditions for MaaS and to track its uptake.

7 Case study: Electric vehicles

7.1 Introduction

EVs are alternative fuel technology vehicles that use electric motors and motor controllers for propulsion instead of an ICE. EV sales have started to gain traction in developed countries. At the same time, companies are spending large amounts on research and development of the technology, leading to an increase in the range of options available for users. EVs can include electric cars, electric buses, electric trains, electric trucks and electric motorcycles or scooters. For the purpose of this case study, EVs will refer to electric cars.

There are two main types of electric cars in New Zealand (EECA 2017):

- Battery electric vehicles are a purely electric vehicle, fuelled only by the battery which is charged by plugging into an electric power point.
- Plug-in hybrid electric vehicles have two engines – one fuelled by a battery which is charged by plugging into an electric power point, the other engine is fuelled from a fuel tank and generally uses petrol or diesel.

Hybrid electric vehicles that cannot be plugged in are not considered electric vehicles. Even though these vehicles are more fuel efficient than a comparable ICE car, their batteries are charged from electricity generated by the petrol or diesel engine or from re-capturing energy from braking, not directly from an electricity supply. These vehicles still use liquid fuels as their only fuel so are not considered to be EVs.

EVs function in a similar way to existing ICE cars, making them highly compatible with the current transport system. People can use EVs to get from one point to another, in a similar way to their current travel patterns. The cars use the existing transport network of roads and bridges and operate under the same road rules as other vehicles. Once EVs comprise a significant share of the vehicle fleet, the transport system is expected to operate in a broadly similar fashion to the current system.

Users can benefit from the adoption of EVs through lower running costs. In New Zealand, fuelling an EV is equivalent to paying 30 cents per litre for petrol, a significant price differential to fuelling ICE cars (EECA 2017), because the cost of petrol is around $2 per litre (Ministry of Transport 2017c). This is due to a combination of the lower price of electricity, higher fuel taxes on petrol and the significantly greater efficiency of the electric engine. Users of EVs can also charge their vehicles at home making refuelling more convenient. However, there is currently a significant initial price premium for purchasing an EV over an equivalent ICE vehicle. The price premium that users face when purchasing an EV is due to battery costs, which are currently an expensive component to manufacture. With greater adoption and manufacturing of batteries it is expected that in time the cost of EVs will fall to be on par with or lower than ICE cars (Randall 2016).

In order for EVs to be viable in New Zealand, there are two main barriers that need to be overcome:

- Charging infrastructure is required to ensure that EVs have a publicly available fuel source for longer journeys. Consumers can primarily use charging facilities at home but in public it is necessary to have sufficient charging facilities along public roads and highways, similar to the network of petrol stations. Charging times also need to be reasonable for users to view the technology as viable.
- Support industries such as mechanics, car part retailers and auto supply stores are required to maintain the fleet of EVs. For mechanics and other skilled technicians, this may require further training and certification.

The case study uses the BMF to identify behavioural changes to monitor around EV adoption. The case study is broken into three sections. The first section on the transport system covers the user needs and monitoring of people's behaviours. The second section discusses the diffusion process for EV, as well as producing forecasts of the diffusion process. Horizon scanning is the final section, where more detailed analysis and metrics to monitor EV are provided.

7.2 Transport system

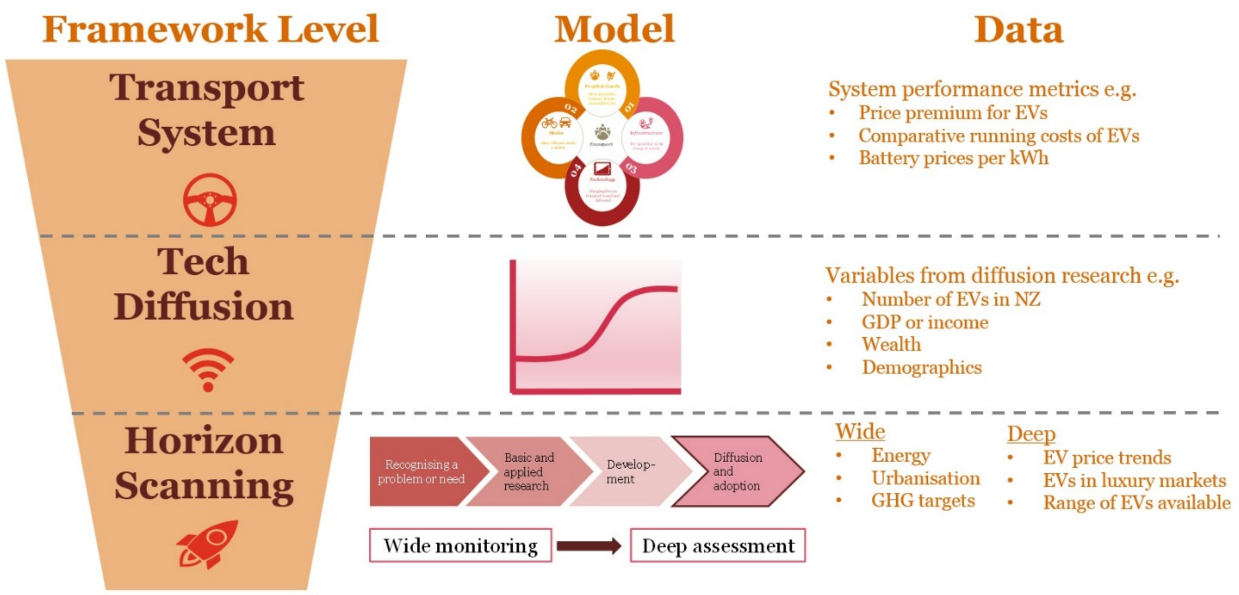
EVs replace the current use of fossil fuels in the transport sector with electricity to fuel personal vehicles. The innovation lies with the way cars are powered rather than changing the mode that is available. As they are only a change in the fuel source, EVs are highly compatible with the current transport system. Having a different fuel source requires different infrastructure to ensure cars can be charged. Since EVs rely on electricity this is largely straightforward since New Zealand already has a comprehensive and reliable distribution network for electricity. As a result many users can charge their vehicles at home, although some charging stations will need to be built to allow users to charge their vehicles in public. Some charging stations have already been established throughout New Zealand and more are under construction.

In this case study we will be using the BMF to assess EVs' fit with New Zealand and their likely uptake. The framework considers a technology at three different levels:

- How and where it fits within the current transport system including which user needs it, can use it or has a conflict with it
- Modelling of the likely diffusion of the technology using a Bass diffusion model
- Horizon scanning considering the variables to monitor that are likely to influence the uptake of the technology.

Figure 5.1 in chapter 5 describes this structure in a generalised way for transport; figure 7.1 uses the same structure and includes data observations specific to the question of EVs. graphically.

Figure 7.1 EVs in the transport system: application of the behavioural monitoring framework



7.2.1 User needs

The BMF identified six user needs that drive behavioural decisions within the transport system: safety, time cost, privacy and dignity, wellbeing and flexibility and ownership. These needs can also influence the adoption of new technologies. Not all technologies will address or meet the needs of all users as individual preferences differ. The main user needs affected by EVs are:

- *Safety*: EVs are not expected to lower the likelihood of a crash over and above ICE cars due to the similarities in operating both vehicles. While safety ratings vary from vehicle to vehicle, EVs have the potential to be safer in a crash than ICE vehicles because the engine is much smaller and is placed close to the wheels. The entire front of the vehicle can be used as a crumple zone, reducing impact of crashes on passengers. The lithium-ion battery in most EVs is a particularly heavy component, and depending on how this weight is distributed it can also reduce the chance of the car rolling (Plugin Cars 2014).
- *Flexibility*: This is one of the main drivers of and barriers to uptake of EVs. EVs are in some ways more flexible than ICEs since they can be charged at home – one need never go to a gas station again since users have their own fuel source at home and can charge their vehicles overnight. However, this is counterbalanced by the current absence of charging infrastructure in public spaces. This causes potential users to be anxious about getting caught short while driving and not having sufficient charge to get home or to another charging point. This fear is often referred to as 'range anxiety' and is a key barrier to widespread adoption of EVs (Human Factors and Ergonomics Society 2015).
- *Wellbeing*: The widespread adoption of EVs is not expected to raise the level of exercise and personal fitness in New Zealand. However fully electric vehicles do not produce any carbon or particulate emissions (unlike their ICE counterparts), so the reduction in pollution and emissions as a result of EV adoption will have the added benefit of improving environmental conditions.
- *Time cost, privacy and dignity and ownership*: These needs are not expected to be affected as a result of adopting EVs.

The main benefits of adopting the technology from a user needs perspective are an increase in safety and reducing pollution. Apart from user needs, reduced cost of operation will be the major factor driving adoption.

7.2.2 Monitoring: behaviours regarding people

Adoption of EVs represents a shift towards the use of electricity as the main fuel source for cars. As a result the behavioural changes from EV adoption are likely to be minimal. The only expected change in behaviour is the amount spent on travel:

- *Cost of travel*: Monitoring can include the running costs of EVs, which is a combination of electricity costs and maintenance costs. Once an EV has been purchased, the running costs of the vehicle are lower than for ICE vehicles. Part of this price benefit is the reduction in taxes on EVs to use the transport system. In New Zealand, the government has provided an exemption on road user charges for EVs out to 2021. EVs are also expected to need much less maintenance than ICEs since they have far fewer moving parts (EECA 2017).
- *Number of trips, mode of travel, time spent travelling, value of travel time, destination, passengers, trip timing and vehicle ownership*: These behaviours are unlikely to be affected by the introduction of EV cars in the transport system.

Various studies have considered whether the use of electric vehicles will change driver behaviour in terms of the number of trips taken or the style of driving. Most have found that switching to EVs alters charging/refuelling behaviour but does not usually change driving style or habits (Mocanu 2015; Rolim et al 2012).

The change in technology is highly compatible with the current transport behaviours and there is little change in behaviour expected with the adoption of EVs, hence many of the monitoring behaviours are already captured within the existing framework of the NZHTS. An additional question that can be added is around charging behaviours:

- Charging behaviours can be monitored to determine how and when users are charging EVs, whether at home or in public. New Zealand motorists drive on average 29 km per day, with average commutes being shorter at 22 km. Electric vehicles are able to achieve those commuting distances on a single charge (Ministry of Transport 2017c), whereas on longer journeys public charging stations can provide charging opportunities for users. ICE cars require re-fuelling at petrol stations, with no alternatives – so the adoption of EVs changes the behaviours around how vehicles are fuelled.

7.2.3 Monitoring: Behaviours regarding goods

Businesses can use the technology to deliver goods easily, but the ratio of costs and benefits of using EVs and the perceived reliability are likely to be significant drivers of adoption for freight businesses dealing with the movement of goods. Changing from ICE to EVs is likely to affect some behaviours of how businesses operate in delivering goods. Behavioural responses of businesses to EVs are discussed below:

- Transport costs are expected to decline following the purchase of an EV. For businesses, this is expected to be a bigger driver of adoption to reduce input costs and increase profit. Energy costs are a substantial share of input costs for these services. Monitoring can cover the reduction in transport costs for freight businesses.
- Mode of transport used indicates which modes of transport are being used over another. Monitoring can include whether EVs result in shift from other modes such as rail. While it is not expected in the first instance, the lower transport costs could result in a change in modes.
- Goods exports and imports, average load of vehicles and freight volumes are not expected to change with the introduction of EVs to the freight sector.

Changes in the above metrics will help monitor system-level changes for the freight sector. Further data on behavioural changes could be collected to investigate the use of EVs in the freight sector. Given that EVs are highly compatible with the current system, two additional monitoring variables are suggested:

- *Charging behaviours*: Firms are likely to use their vehicles for a larger share of the day compared with private users. In this situation, charging could become more of an issue for businesses to keep their vehicles running. Monitoring can gather information on how businesses charge their delivery vehicles if the range of one charge is not sufficient for the worker’s shift.
- *Utilisation:* Since EVs have a higher capital cost but lower running costs than equivalent ICE vehicles, businesses might look to running their vehicles more than they do currently. We should monitor the amount of time vehicles are being used to see if overall usage is affected by the change in costs.

Table 7.1 Variables to monitor behavioural changes

Monitoring variable	**Expected change**	**Reason**
Cost of travel (private and business use)	↓	EVs allow for cheaper charging costs compared with fossil fuels
Mode of transport used (private and business use)	- - -	EVs do not change the mode; however, a change in costs could alter modes chosen for freight
Use of public charging by private users	- - -	Most journeys are short, therefore home charging will be able to cover most journeys
Use of public charging by business users	↑	Greater use of vehicles is likely to require use of public charging stations

7.3 EV diffusion modelling

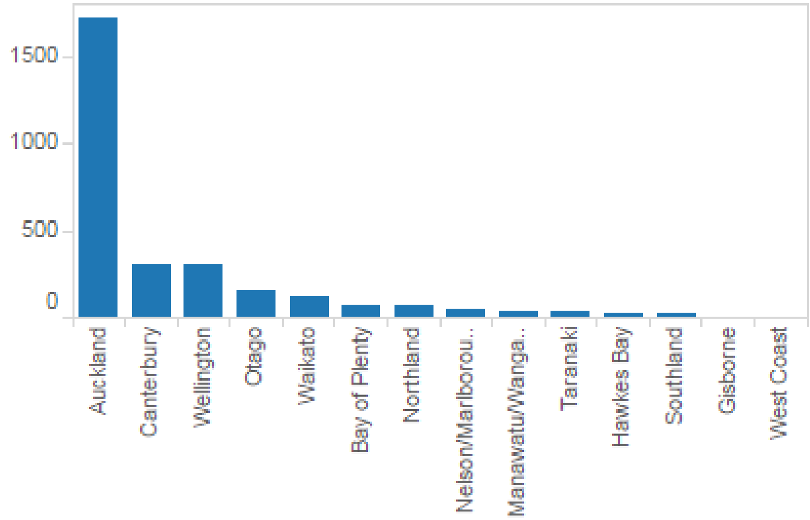
A Bass diffusion model was developed as part of the project to forecast the diffusion of new technologies through the market. The model was applied to the uptake of EVs to demonstrate the forecast process in practice and the speed of adoption. Sensitivity analysis can be performed to give a range of estimates around the central Bass diffusion forecast. Finally, alternative scenarios can examine the effect on timing of policy intervention, growth in the potential market and reduction in purchase costs.

7.3.1 Estimating potential market share

The model produces a forecast of EV sales over time. Market share represents how widely the technology could diffuse through the market and is defined as the cumulative sales. The coefficients of innovation and imitation affect the rate and speed of diffusion as the technology reaches its full market share. With respect to EVs, the variables that affect the market share are:

- *GDP and wealth*: Currently the purchase price of EVs is higher than other vehicles (Barton and Schütte 2015; Maetzig 2017). Higher levels of wealth and income indicate a greater ability to pay for new technology. While EVs cost more than conventional ICE vehicles, the potential market size of EVs is limited to those who are able and willing to pay for the additional price premium. Over time the price premium could be reduced and even reversed so the price of EVs becomes lower than the price of ICE vehicles. Although New Zealand has the income and wealth for users to be able to afford newer vehicles and the price premium, purchasers have proved largely unwilling to pay a higher capital cost for an EV. New Zealanders have also shown preferences for second-hand vehicles over new vehicles and for holding onto them for an extended period. The average age of the New Zealand fleet is 14 years, compared with 10 years in Australia (IHS Markit 2016; Australian Bureau of Statistics 2016).
- *Demographic structure*: One clear trend has been around the location of the early adopters. Auckland has seen the greatest adoption of EVs thus far with more than half the national EV fleet (figure 7.2) compared with 32% of the total light vehicle fleet (Ministry of Transport 2016d). Greater demand could be due to a number of factors, with high levels of wealth and population density could be influencing factors, along with a greater provision of infrastructure compared with other cities.

Figure 7.2 Regional registrations of EVs



Source: Ministry of Transport (2016d)

For modelling purposes, the market potential for EVs is assumed to be 400,000 vehicles, compared with approximately 3 million cars currently in New Zealand (Ministry of Transport 2016a). The Government has stated its goal to double the number of EVs each year to reach 64,000 vehicles by 2021, indicating a gradual uptake over the next four years (Bridges 2016). This level of adoption will be made up of both new and second-hand vehicles. The number of second-hand EV imports will depend on the availability of the vehicles in overseas markets, particularly in Japan and Europe. However, the technology is expected to change and evolve from its current state, moving EVs out of the luxury goods market and more towards the mass market. As the shift occurs and the barriers to entry are reduced, the speed of adoption is expected to increase more quickly. Bloomberg forecast that EVs could comprise 40% of new vehicle sales worldwide by 2035 (Randall 2016), and extending this to second-hand imports into New Zealand as well, we feel an initial market potential of 400,000 vehicles is in line with overseas medium-term forecasts.

7.3.2 Estimating innovator (p) and imitator (q) parameters

EV adoption is in the early stages both internationally and domestically. Globally, EVs represent around 0.15% of the total vehicle fleet in 2016 (Cobb 2017). However, the growth rate of sales is increasing with vehicle manufacturers experiencing rising demand for EVs. Greater production and sales are also likely to increase the range of models available for purchase.

The Bass model we have developed for the BMF uses early sales figures to estimate the modelling parameters innovation (p) and imitation (q), in order to forecast the future rate of uptake of EVs. The two types of EVs (fully electric and plug-in hybrid) are grouped together in the modelling to estimate the total EV uptake and diffusion through the transport system. To ensure the p and q values are well estimated, they can be compared with the international literature on diffusion of EVs in other countries where the Bass model has been applied to other markets, particularly Japan, from which New Zealand imports a large number of used vehicles.

There are two ways electric vehicles can enter the transport system in New Zealand: either as new or used imports. Retrofitting ICE cars with electric vehicle motors is not considered within the modelling. New Zealand has imported a significant number of used Japanese vehicles in the past and the trend is expected to continue for EVs. Used imports will depend on the new purchases of EV technology within Japan, which will then turn to used imports for New Zealand after a time lag. Monitoring the Japanese market will give some indication as to the types of models that are likely to be imported and the technology that accompanies them.

This creates four categories of vehicles for EVs entering the transport system: new purchase of plug-in hybrids, imports of second-hand plug-in hybrids, new purchase of electric vehicles and imports of second-hand electric vehicles. Modelling the uptake of EVs will group all these four categories together.

7.3.2.1 Our modelling process

We initially used two data sources to estimate Bass diffusion model parameters for New Zealand. The first is new sales data from the Motor Industry Association (MIA), which accounts for light vehicle sales (less than 3,500kg) broken down by make and model (MIA 2017). Data is further broken down by propulsion, separating electric and plug-in hybrid vehicle sales since 2012. The second data source is registrations from the Ministry of Transport, which publishes registration data for new and used electric vehicles (Ministry of Transport 2016d). This dataset can be used to monitor second-hand EV imports of used vehicles as New Zealand imports a number of second-hand used vehicles from Japan. Registrations account for the stock of vehicles and are made up cumulative sales minus cumulative scrappage. Taking the monthly difference of registrations gives an indication of monthly uptake of the technology as scrappage rates are relatively low for EVs. Due to scrappage affecting sales numbers, it is preferable to use sales data where possible.

This monthly data from the MIA and the Ministry of Transport from 2013 was used to estimate the EV diffusion model parameters (p and q). A regression equation using the early sales data estimates the parameters and guides the forecast process.

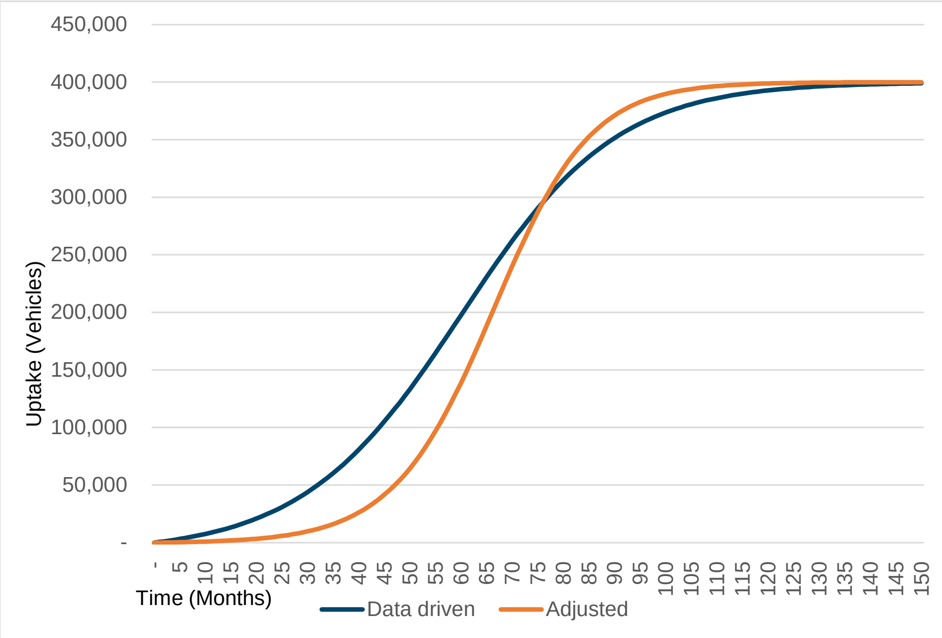
However, the early sales data did not fully mesh with the regression equation and led to anomalous results. Because the early data of New Zealand uptake was coming off a base of zero, through sales of tens of vehicles increasing to hundreds of vehicles per year, the model saw this trajectory as exponential and quickly led to a forecast of more vehicles arriving in New Zealand than was feasible or realistic. This occurred because the model did not fully account for barriers to New Zealand uptake due to distance and lack of supply. As a result the model assumed no constraints on the speed of uptake beyond the market size, so exponential growth would continue until saturation was reached. We addressed this issue by removing the last several observations until the model returned a stable result.

This resulted in a p value of 0.0014 and a q value of 0.064. To compare these estimates to yearly parameters discussed in Massiani and Gohs (2015), these estimates were multiplied by 12 to convert from monthly to annual parameters. The estimate for innovation (0.0169) is towards the upper end of the range and the imitation coefficient (0.765) is around average. These parameters result in a rapid diffusion pathway, with around 120,000 EVs in New Zealand by 2021, almost twice the government target. The diffusion forecast from this data is shown in figure 7.3 below.

We had some concerns that this forecast might overestimate the speed of diffusion, since it might underplay the barriers to adoption. High capital cost, low driving range, low number of models and a lack of charging infrastructure are likely to keep diffusion low initially in New Zealand. This would indicate a lower innovation coefficient than suggested by the Bass diffusion model. A lower level of innovation lines up with New Zealand's preference for purchasing second-hand vehicles, rather than innovating and purchasing new vehicles. Once these issues are solved or addressed, the speed of uptake is expected to increase more quickly and a steeper S-curve, through a higher amount of imitation. Imitation is expected to become easier as EV uptake overseas continues to increase and grow.

Taking these two factors into account, we added a scenario for comparison with a lower level of innovation (p of 0.0001 on the monthly coefficient) and a higher level of imitation (q of to 0.104 on the monthly coefficient). The differences between the adjusted diffusion curve and the data driven diffusion curve are shown in figure 7.3.

Figure 7.3 Bass diffusion forecasts for EVs



This graph shows that in the first four years the two scenarios modelled are very different with rapid uptake in the data-based scenario compared with much slower uptake in the adjusted scenario. However by the six-year mark both scenarios have converged around the 300,000 vehicle mark and in the following five to six years the two scenarios are quite similar. This shows us that uptake in the next four to five years should be monitored closely to see which trajectory we are on and how far off the tipping point for EVs will be. It also shows that uptake is likely to be increasing rapidly by the early- to mid-2020s no matter which scenario we choose.

For the model we have explicitly assumed a maximum market size of 400,000 EVs. In the model this determines how much uptake will reach upon saturation. The 400,000 vehicles are an estimate based on government targets and external forecasts as discussed earlier. For this reason, readers should focus more on the shapes of the curves and the timing of uptake changes than on the absolute values reached.

In the next section, two scenarios are tested to alter the forecast diffusion process. The first assumes a stronger policy intervention in support of EV technology and the second assumes that falling costs and new models increase the available market share further over time – relaxing the assumed market potential of 400,000 EVs. The adjusted model parameters will be used as the base case for the scenario analysis below.

7.3.3 Scenario analysis

Scenarios can be used to understand the factors that influence the diffusion of EVs through the market. These different factors can change the when, how fast and how much diffusion occurs in the market. Two different variables have been modelled for scenario analysis:

- policy intervention
- market share growth.

7.3.3.1 Policy intervention

EVs have the potential to address some of the government's concerns around emissions from the transport sector. Emissions from road transport are the second largest source of national emissions (Ministry for the Environment 2016). Switching the vehicle fleet from ICE vehicles to EVs would help reduce the amount of greenhouse emissions and improve health outcomes. New Zealand can leverage its high proportion of renewable electricity generation to power the vehicle fleet.

International policies

Internationally, different jurisdictions have implemented different rules to speed the uptake of EVs by the population. Subsidies or tax breaks have helped to lower the cost of purchasing an EV and have been implemented in a number of countries. For example, purchase of an EV for use in the US comes with a tax credit of between USD$2,500 and $4,000 for each new EV (US Office of Energy Efficiency & Renewable Energy 2017) and there are exemptions from purchasing taxes in Norway which can be prohibitive for conventional car purchases (Barnato 2016). Other policies target favourable use of EVs over other vehicles, for example, no charges on toll roads, free parking and access to public bus lanes in Norway (Barnato 2016).

New Zealand's policies

The New Zealand Government has announced a package of policies to support the uptake of EVs. This package includes (Ministry of Transport 2017a):

- an extension to the existing exemption from road user charges for EVs until they make up 2% of the light vehicle fleet
- a new exemption from road user charges for heavy vehicles, also established until EVs are 2% of the heavy vehicle fleet
- work across government and the private sector to investigate the bulk purchase of electric vehicles
- $1 million per year for five years for a nation-wide electric vehicle information and promotion campaign
- a contestable fund of up to $6 million per year to encourage and support innovative low-emission vehicle projects
- changes to regulations permitting local authorities to allow electric vehicles to use special vehicle lanes such a bus lanes.

In addition to the specific measures, the government said is working on a range of other barriers and incentives including:

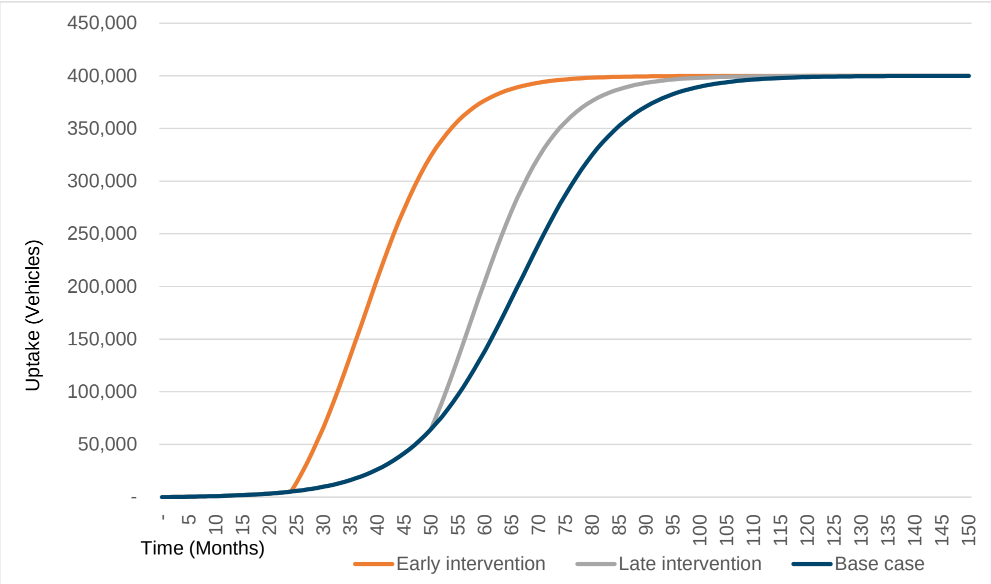
- coordinating activities to support the development and roll-out of public charging infrastructure including providing information and guidance
- reviewing tax depreciation rates and the method for calculating fringe benefit tax for electric vehicles to ensure electric vehicles are not being unfairly disadvantaged
- reviewing ACC levies for plug-in hybrid electric vehicles
- establishing an electric vehicles leadership group across business, local and central government.

Additional policies

The impact of the policies on uptake will depend on the level that government becomes involved and the policies it implements to assist the EV adoption and its diffusion within New Zealand. The existing policies have affected the early rate of uptake of the technology and are already included in the base case scenario forecast.

Additional policies to speed the rate of adoption are included in the Bass model as a policy shock. The adjusted scenario is used as the base case in this forecast. If the government committed to additional policies to encourage uptake over and above what it is already doing, uptake would accelerate more quickly. Because policy interventions generally bring uptake forward but do not increase the final maximum number of users, the timing of these policies is also important. An early policy intervention can have a significant impact on the rate of uptake of EVs. But the later the policy intervention is left, the lower the impact on the rate of the diffusion compared with a business as usual trajectory of uptake. Figure 7.4 demonstrates this phenomenon with a hypothetical policy shock, compared with the base case scenario.[9]

Figure 7.4 Policy intervention on diffusion of EVs



This graph illustrates how government intervention to lower barriers and encourage use of a new technology can bring forward expected uptake. However the final level of uptake remains the same since this depends on the available market size. It emphasises the importance of knowing where on the S-curve the market is when intervening to ensure a policy intervention provides value for money and makes a significant difference in uptake.

7.3.3.2 Potential market growth

In the previous scenarios the potential market share was assumed to be fixed at 400,000 EVs, compared with the 3 million light vehicles registered in New Zealand. Due to a number of factors discussed through the case study, we assumed a lower potential market share compared with the level of total car ownership in New Zealand. However over time, technological advances could lead to EVs becoming superior to ICE vehicles in how they fit into the transport system and lead to a growth in the market share more rapidly than what is assumed currently. This would require a number of improvements for EVs in terms of price,

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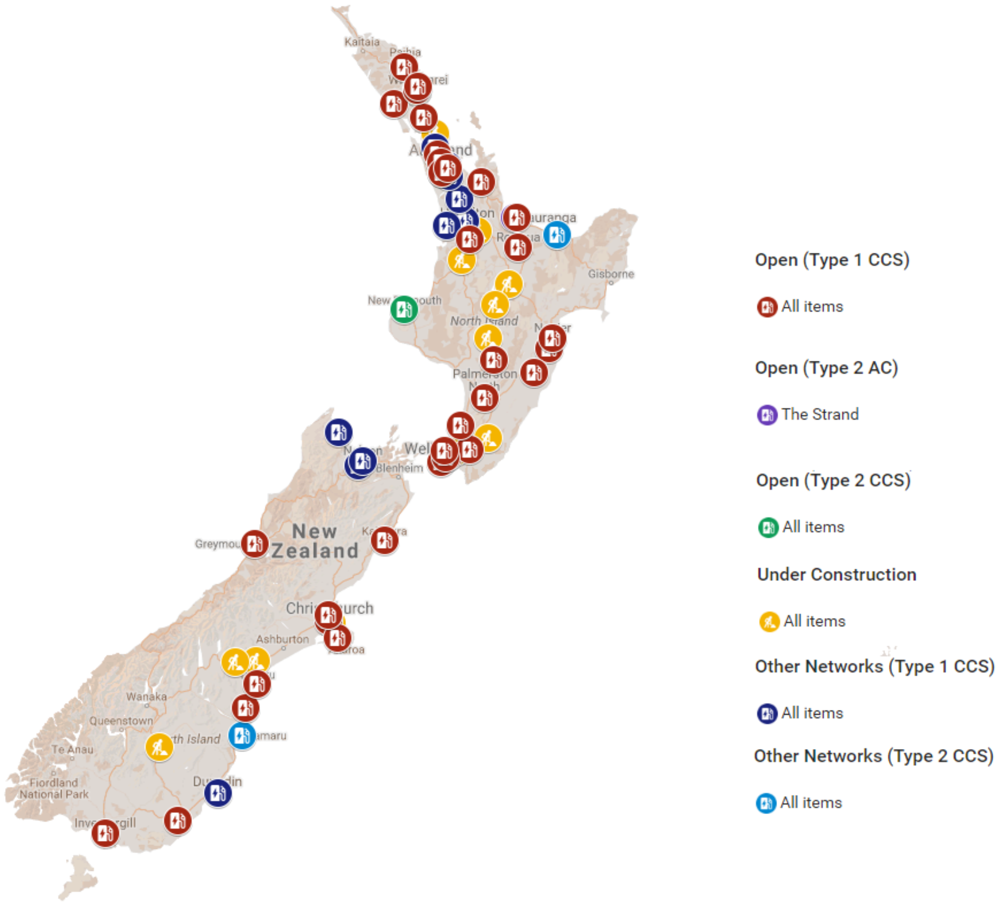
[9] In the model, we included a policy shock of 0.02, which adds to the innovation coefficient. This is at the upper end of potential levels of innovation for technologies in the transport sector.

manufacturing and supply and charging infrastructure. However, trends in each of these categories are heading in the right direction for greater uptake:

- EV prices are falling and range is increasing.
- The number of manufacturers making EVs has increased.
- New Zealand has a network of charging stations that is growing in coverage as illustrated by figure 7.5 below.

Improvements in these areas can increase the potential market growth over the assumed 400,000.

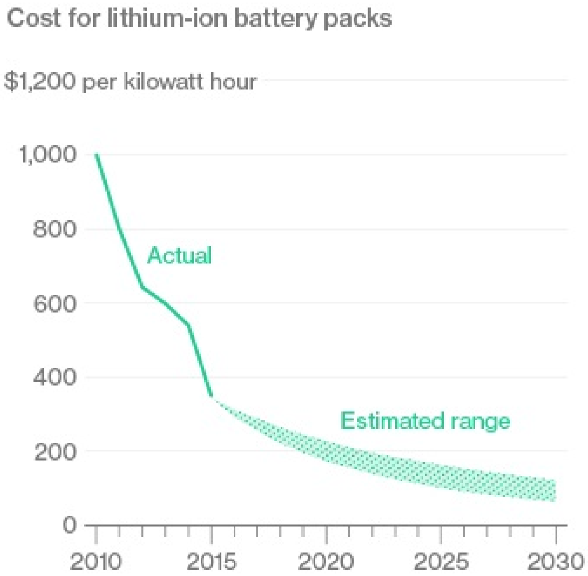
Figure 7.5 ChargeNet charging station coverage



Even though there are a number of drivers to increase the market share, the largest driver of growth is expected to be the reduction in the cost difference of EVs over ICE vehicles. High battery costs have contributed to this price premium and have acted to slow adoption in the early phases.

Over time it is expected that the cost of EVs will decline. Economies of scale in manufacturing and the continued fall in battery costs are two factors behind the decrease in costs. As shown in figure 7.6 below, battery costs have already fallen sharply. Between 2007 and 2014 battery costs fell from an estimated US$1,000 per kWh to around US$410 per kWh, a decline of approximately 14% annually (Nykvist and Nilsson 2015).

Figure 7.6 Cost of lithium-ion batteries over time



Source: Bloomberg New Energy Finance

Outside of the technology itself, other factors can lead to increased potential market growth. Growth in population, wealth and transport infrastructure can lead to increasing vehicle ownership and potential market share of EVs.

As a result of these falling costs and improving conditions, potential market share growth can rapidly expand the market for EVs. Two scenarios are tested shown in figure 7.7. The first scenario is a 0.5% increase in the potential market share each month. The second is a 0.1% increase in market share each month. Both scenarios are compared with the base case scenario. Growth in market share makes a small difference in the early stages of the diffusion process, but after a few years there is a noticeable gap. After 10 years, monthly growth of 0.5% can result in a level of adoption more than 50% higher compared with the base case.

Figure 7.7 Potential market growth

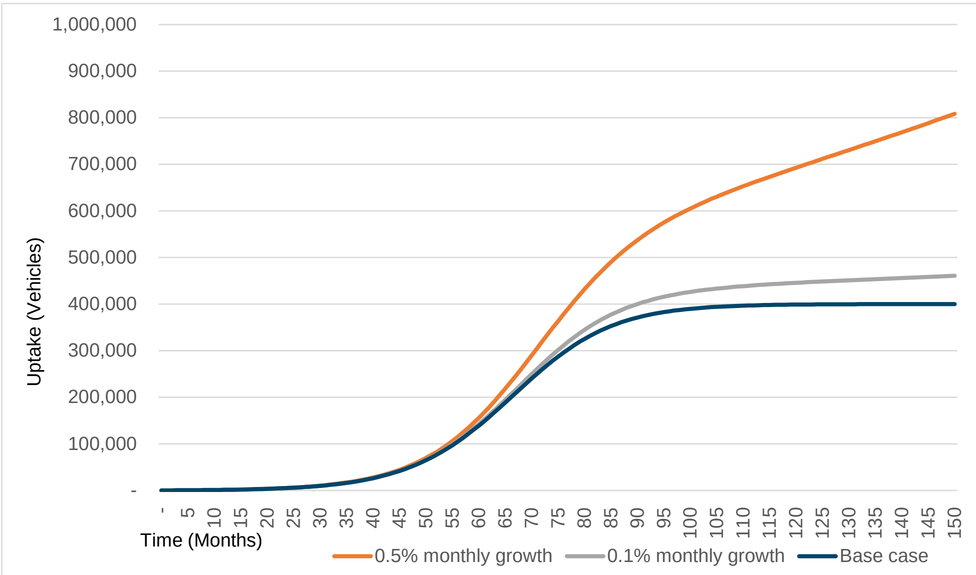


Figure 7.7 illustrates that if the technological and cost barriers continue to change significantly, the market potential for EVs could grow and keep growing over a long time frame. In these scenarios, a changing market potential will not affect New Zealand's uptake in the first five to six years, but after that time the differences become very significant.

This tells us that in the short term, uptake will be determined by New Zealand preferences – the level of enthusiasm for new technology. But in the longer term, New Zealand's uptake will be determined by how fast the technology itself is changing and evolving to increase the number of potential users.

Price declines could be greater than that implicit within the model, leading to the price of EVs falling below the price of ICE vehicles. If this was to occur, the potential market share of EVs would grow into the market for ICE vehicles. Having an absolute purchase price advantage over ICE vehicles and lower operating costs would make the technology more affordable to purchase and operate for users. Lower prices and increased manufacturing would in turn increase the supply of EVs internationally and domestically. In this situation there would be fewer constraints on adopting an EV over an ICE vehicle. The speed of adoption in this situation could increase very rapidly.

7.3.4 Summary of diffusion modelling

While the total market share available for EVs is relatively uncertain, what the modelling does show clearly is that different factors are important at different times. In the short term, New Zealand's barriers and preferences will determine when the tipping point for EVs arrives – the modelling indicates it is likely to be between two and four years away.

In that time, falling costs will make EVs more competitive with ICE vehicles and their advantage in lower fuel costs and running costs will become more persuasive. A growing network of charging stations in public places and along public highways will help to address range anxiety and, alongside expanding support services, will give consumers confidence that an EV is as easy and reliable a vehicle as any other.

At a point beyond four to five years, the size of the available market becomes more important in driving uptake. This will be determined by the external development of EV technology, driven by factors such as the cost of EVs relative to ICE vehicles, the driving range of EVs and the range of models available. If the technology has developed sufficiently in that time, the potential market available to convert to EVs would be growing at the same time that uptake is accelerating and very rapid uptake of vehicles is possible.

7.4 Horizon scanning

Electric vehicles have been around for over a century. The first EVs were popular in the 1890s and early 1900s, being deployed by taxi companies in New York and London in the late 1890s (NPR 2007). They were overtaken by fossil fuel-powered vehicles as technology improved, extending the range of the ICE car and as oil discoveries increased, lowering the relative price of fuel.

In recent decades, advances in battery technology have allowed EVs to have a greater range and once again be a viable alternative. Based on the BMF, this section considers two stages of scanning: wide monitoring and deep assessment.

7.4.1 Wide monitoring

While we have already chosen EVs as the technology to examine, this section applies the BMF to identify some of the high-level trends that would have led to choosing EVs as a technology to examine more closely.

EVs as a technology have been around for some time. However, significant adoption has only occurred more recently due to the technological advancement in battery technology, allowing for an increased range of travel between charging the batteries. Without the development of battery technology, the uptake of EVs as a commercial model would not be viable. The technology has been supported by a general shift towards greener technologies to reduce pollution and greenhouse gas emissions. Using renewable sources of electricity can reduce greenhouse gas emissions and pollution from transport activities. Each of these factors is discussed in turn:

- Technological advancements have enabled EVs as a viable competitor to the dominant ICE vehicles, with R&D programmes having led to many of the breakthroughs. Advancements have primarily occurred in battery technology since the main limitation was the short range of an EV on a single charge. Not only was the range a limiting factor, but the price of batteries were expensive, making EVs unaffordable for the mass market. Battery prices have declined in recent years, down nearly 80% in the past six years (McKinsey&Company 2017). This price decline has helped to reduce the gap between the price of electric and combustion engine cars. Despite the drop, battery prices still make EVs significantly more expensive than ICE cars to purchase, by approximately $5,000 – $10,000.
- Rapid urbanisation has seen an increasing shift in people moving from rural areas to urban areas. This is leading to a density of population where the vast majority of people's trips are short – less than 15 km. These short trips are far more suited to the low range of EVs (King 2007). These users will benefit from the much lower running costs of EVs, while not being hampered by the lower driving range between charges. This indicates that people's transport habits have changed in a fashion that makes them more suited to EVs.
- Climate change and environmental awareness around the world have increased over recent decades. Burning fossil fuels is the world's main source of anthropogenic greenhouse gases, and road transport contributes 16% of New Zealand's total greenhouse gas emissions, second only to agricultural methane emissions (32%). These emissions from road transport in New Zealand have been increasing steadily since 1990 (Ministry for the Environment 2016). Given New Zealand's high share of renewable electricity generation, switching from ICE vehicles to EVs would lower greenhouse gas emissions and reduce the cost of fuel imports. This growing concern with climate change is leading to policies in many countries to encourage technologies that use alternative fuels such as EVs (Schütte 2015).

7.4.2 Deep assessment

EVs have started to diffuse internationally and domestically. Norway has adopted the technology widely, with a number of supporting policies from government, whereas other countries' adoption has been slower (Hockenos 2017). Domestically EVs are in the innovator stage of adoption, with a small percentage of market share captured thus far. However, large R&D programmes are underway by many carmakers to further enhance and develop the technology and push for greater adoption internationally. This development and research is lowering the cost of EVs for users. The BMF identifies several factors that indicate a technology could have a significant uptake in the near term. The framework also suggests that we think about barriers and technology-specific factors to monitor to track its current uptake and forecast future uptake. These are discussed below:

- International markets supply all cars to the New Zealand market, as there is no domestic production. Typically, New Zealander imports second-hand vehicles from Japan, Europe and North America. The types of vehicles currently on the road in these markets are an important metric to monitor for determining the types of vehicles that New Zealand is likely to import. Faster diffusion of EVs internationally can increase the rate at which they enter the New Zealand market.

- Domestic markets are expected to increasingly adopt EVs, with diffusion currently in the 'innovator stage'. Monitoring the effects of EVs on this group of users may provide an early indication of the potentially wider impacts of EVs. Early diffusion can also highlight which of the barriers are most pertinent to the New Zealand situation and whether the technology fits as well within the transport system as expected.
- Luxury vehicle markets are typically early adopters of new technology. Some EV models are classed within the luxury vehicle market, with features of these models having a greater range than cheaper EV models. For example, the Tesla Model S at a price of US$92,500 has a range of 540 km on a full charge, making it the longest-range EV in the market (Morris 2017). Monitoring developments in these markets can indicate the features that are likely to become available in mainstream models in the future.
- Relative costs affect the rate of uptake of the technology. For EVs, there are two relative prices to monitor: purchase price relative to ICE cars and operating costs relative to ICE cars.
  - The purchase cost of an EV is currently significantly higher than an ICE vehicle. This is one of the major deterrents to adopting the technology. Bloomberg New Energy Finance forecast that by 2022 the price of batteries will have dropped to the point where there will be no additional cost for an EV over an equivalent ICE vehicle. Once this occurs, uptake is expected to accelerate rapidly (Randall 2016).
  - Operating costs of an EV are cheaper compared with ICE vehicles. The operating cost advantage comes from the lower cost of electricity relative to petrol, the current absence of fuel taxes on electricity and the greater efficiency of electric motors over ICE engines. Monitoring the relative operating cost advantage of EVs can indicate the speed at which they will be adopted in the future.
- Relative advantage refers to the reasons for adopting the new technology. There are two main relative advantages for people to adopt the technology: lower operating costs and reduced environmental impact. Both of these relative advantages have been discussed earlier. Monitoring the relative advantages and user preferences can determine whether users are motivated to adopt the technology to capture these gains, given the barriers and trade-offs.
- Disadvantages should also be considered. While EVs have potential benefits, the introduction of EVs will not benefit everyone. In particular:
  - Petrol suppliers are expected to see a reduction in petrol demand and sales with increased adoption of EVs. However, while this shift will cause petrol companies to contract their petrol supply, they could adjust their approach by investing in providing charging stations at their existing facilities.
  - Automotive mechanics and support industries will need to upskill in order to service and support EVs. This will require mechanics to incur costs to learn how to maintain electronic engines and it could discourage mechanics from upskilling if the costs are too high.

7.4.3 Barriers to adoption

Monitoring the barriers to adoption can help identify the impediments to the new technology reaching its potential market share. In addition to the price barrier, discussed earlier, there are four main barriers that can slow the rate of diffusion: lack of support services, range of vehicles between charges, lack of charging infrastructure and a relatively slow turnover of vehicles in the New Zealand fleet.

- Support services are required to maintain and repair the EV fleet. These requirements are different (in some instances) from maintaining and repairing ICE vehicles. Provision of these support services is required to ensure EV ownership is as convenient as ICE ownership. This includes mechanics and service technicians, spare part suppliers, electricians and providers of training such as electricity companies and polytechnics. At the moment, the provision of such services is limited because demand for support is low.
- Range anxiety has been a barrier to adoption of EVs since their invention. Early models lacked the range on a single charge that ICE vehicles had on a single tank of petrol. Recharging stations for EVs are currently not nearly as ubiquitous as petrol stations, and this caused potential users to fear being stranded without the ability to recharge their vehicle. As developments and technology have improved so has the range, with a current, affordable electric vehicle being able to meet 87% of vehicle days (Needell et al 2016). However, range anxiety has persisted as a barrier to adoption. The motivation to purchase a vehicle that enables regular social/recreational trips has been a strong factor behind the uptake of vehicles and the size of the vehicle that is purchased – even infrequent trips requiring a larger-than-regular vehicle, such as holiday trips, strongly influence the type of vehicle purchased (Dravitzki et al 2009). Provision of charging infrastructure outside main travel areas can help ease range anxiety by allowing users to charge in publicly available stations in a wider number of locations.
- Key infrastructure to support the operation of EVs is currently lacking, mainly charging infrastructure. At present, there are few public charging points available, adding to range anxiety. In the short term, the key purpose of investment in public charging infrastructure is to make EVs visible and provide comfort to purchasers that charging will be available as and when needed (including outside main travel areas), in order to promote demand. In the longer term, as more vehicles come into New Zealand, greater levels of public fast charging will need to accommodate this increased stock of EVs (PowerNet 2016).
- Trialability can promote uptake. If potential users can try out an EV before they commit to buying a car they are more likely to feel comfortable purchasing one. Volkswagen for example is addressing this issue by allowing corporate users who fly frequently to use an EV for free when they travel to other cities (Volkswagen 2017). This both segments the market by focusing on the higher income end of the market and addresses trialability.
- An older fleet may slow diffusion. New Zealand’s vehicle fleet is on average older than those of other countries, slowing diffusion of new technology. Local consumers tend to buy more used light vehicles than new vehicles, maintaining the age of the fleet at around 14 years. Because of our preference for older vehicles, new technologies will diffuse more slowly throughout the fleet.
- Availability of overseas vehicles is a key determinant to the importation of second-hand EVs. Without increased rates of adoption internationally the ability to import second-hand EVs will be limited.

Table 7.2 Variables to monitor to assess future uptake of EVs

Monitoring variable	Expected change	Reason
Proportion of EVs in international markets	↑	As the technology is maturing and costs are falling, uptake is increasing
Proportion of EVs in luxury markets	↑	Due to the initial high price premium, some EVs are penetrating luxury markets first
Number of EVs in New Zealand (domestic EV market)	↑	As the technology is maturing and costs are falling, uptake is increasing
Purchase price premium of EVs over ICEs	↓	Economies of scale in manufacturing are expected to further reduce costs
Operating cost difference between EVs and ICEs	↑	EVs have lower operating costs than ICE vehicles. This difference may grow as carbon pricing increases
Number of charging stations and their location	↑	Building charging infrastructure is already underway and will be needed to assuage range anxiety
Support services. Number of: • qualified technicians • EV capable service centres	↑	As uptake increases, the greater number of EVs will lead to demand for more support services
The range on a single charge	↑	As battery technology improves, range is expected to increase
Average age of the light fleet	- - -	For EVs to diffuse quickly, older cars will need to be scrapped earlier. If the age of the fleet falls it could potentially indicate faster adoption

7.5 Reflections on the behavioural monitoring framework

This case study has looked at the application of the BMF (as described in chapter 5). Here we reflect on how well the BMF can be used to assess the future development and uptake of EVs.

7.5.1 Generality/applicability

The framework was sufficiently general to be applied to a wide variety of technologies. Because EVs are so compatible with the existing transport system, there were few behavioural changes expected from the uptake of EVs.

7.5.2 Modelling

The model initially had some difficulty estimating appropriate parameters from the existing uptake data for EVs. However, once these issues were overcome, the model was flexible enough to model a variety of different scenarios.

We modelled six different futures for EV uptake in New Zealand and each usefully illustrated different facets of technology diffusion. The model was flexible enough to allow us to illustrate these different scenarios to draw out useful insights. By modelling different p and q values, we could see how New Zealand's circumstances and preferences would set the level and speed of early uptake. The model showed that these preferences and circumstances made much less difference after four to five years. After that time, the market potential based on the development in the technology itself would have a much greater impact on the trajectory of technology uptake. Looking ahead, the barriers to adoption are more likely to slow the initial adoption phase, but once sorted adoption could increase quickly.

7.5.3 Monitoring

The BMF is a useful framework for identifying metrics to monitor and likely barriers to uptake of the technology. The framework focused our thinking more on the barriers to adoption rather than the impact on the transport system, as the technology is already highly compatible with the current transport system.

7.6 Conclusion regarding EVs

Electric vehicles have the potential to replace ICE vehicles as the main mode of transport and are highly compatible with the current transport system. The two main benefits of switching to EVs are lower operating costs and reduced environmental emissions (both greenhouse and particulate pollutants).

Switching to EVs is expected to result in lower operating costs of vehicles, which are currently offset by the higher purchase price of an EV. Over time it is expected that developments in battery technology and achieving economies of scale in manufacturing will close the price premium and even result in lower prices compared with ICE vehicles.

Pollution and greenhouse gas emissions from road transport are expected to decline with the adoption of EVs. Powering vehicles with renewably generated electricity will lower emissions for the sector and the country as a whole. Reduced pollution in urban areas can also improve health outcomes for those living and working in the area.

EVs are not expected to change behaviours of the people and goods element of the transport system, as users will be able to use and operate EVs in a similar way to ICE vehicles. However charging behaviours are likely to change with more refuelling occurring overnight in the owner’s home. For longer journeys, publicly available charging stations will be required for users to continue their journey.

Key barriers to uptake are:

- higher upfront purchase price, discouraging purchase of EVs
- lack of public charging infrastructure, reducing consumer confidence in their ease of use.

In the short term, these barriers will continue to slow the uptake of EVs. However, as technology improves, EVs reach price parity with ICE vehicles and public charging infrastructure is rolled out to cover wider areas, uptake will likely increase from the early- to mid-2020s. Monitoring both of these barriers will allow a more informed picture of the timing for future uptake to develop.

Given New Zealand’s preference for second-hand vehicles, a key leading indicator that will signal future uptake of EVs is likely to be the uptake of EVs in our key import markets for second-hand vehicles. Monitoring the diffusion of EVs in these regions will be a useful signal for when these vehicles will begin to arrive in New Zealand in greater numbers.

8 Conclusions

The report set out to deliver well-researched, practical solutions to understanding the technology diffusion process and subsequent impacts on transportation and the economy. The research provided a robust framework to understand the potential changes to the transport system as a result of rapid technological and societal change. The framework focuses on two main areas. The first is understanding and predicting the uptake of new technology. A Bass diffusion model was developed to forecast the future diffusion of new technologies and to explore how different variables affect the path of diffusion over time. Second, the framework helps to identify behavioural changes to monitor in response to the adoption of new technologies. It covers several types of indicators: leading indicators that suggest change is coming, necessary prerequisites to change to see if change is possible and indicators to show a change has occurred or is occurring. These two pieces of work formed the backbone of the research.

Developing the framework and the model and applying them to the case studies illustrated some key conclusions which are described below.

8.1 Diffusion of new technology frameworks

8.1.1 Benefits of the Bass diffusion model

The Bass model proved to be a useful tool for forecasting uptake and illustrating the impact of different variables. The model has been well studied within the literature and is flexible enough to be useful for a number of new technologies. The flexibility of the model was a driver behind the choice of the modelling approach, as there are a number of potential technologies that could change the way transport works and a flexible model is required to deal with the uncertainty in new technologies.

Another feature of the model is that it is relatively straightforward to operate due to the low data requirements. Early sales or adoption, as well as estimates for the potential market share, are required as inputs into the model. The model is flexible enough to deal with situations where data on the diffusion is not yet available, as parameters from similar products with similar features can be used instead.

While all forecasts are uncertain, one benefit we found with the Bass diffusion model was its ability to illustrate the relative magnitude and timing of different changes. For example, in the modelling of EVs, while the timing of the tipping point varied by scenario, it usefully illustrated that those differences will be significant in the first few years, but much less significant in later years as different scenarios converged. In this way the model was able to provide useful insights even when it was uncertain about uptake at a particular point in time.

8.1.2 Benefits of the future roadmap

The future roadmap (see figure 4.1) is a useful tool for thinking about the possible changes to transport in the medium term and long term. By putting people and goods at the centre of the transport system as drivers of demand, it illustrates how other types of changes will link together.

The roadmap is a good way to go wide in our thinking on future trends and considers different kinds of changes that will affect the transport system:

- demographic changes
- behavioural changes
- technological changes

- wider societal trends that drive changes.

The roadmap provides a useful starting point for thinking about the future – which changes can we see coming and which are most likely to occur? This provides ideas that can be considered in more detail using the BMF.

8.1.3 Benefits of the behavioural monitoring framework

As the diffusion process continues, behaviours of people and goods can be affected and altered in response to the technology. As the technology becomes more widely diffused through the system, the behavioural changes are expected to increase in intensity. The BMF was developed to monitor how behaviours changed as a result of the diffusion of new technology.

The BMF can be applied to many different new technologies and suitably capture the essence of behavioural response to them through monitoring indicators. This flexibility will also keep the BMF relevant and prevent it from becoming outdated in the near future.

Some of the suggested behaviours to monitor in the BMF have been monitored for some time. This allows the monitoring of behavioural change to be implemented right away, without any additional data collection required. These are usually the core behaviours in the transport system – how far do people travel, at what time, at what cost? Changes can be compared to history to determine the significance of the changes and place the response in context. However, there will likely be gaps in the behaviours or indicators monitored that are specifically relevant to particular new technologies.

New indicators can be developed to gather additional information on the behavioural changes. The BMF is a useful guide for considering which additional behaviours and indicators should be monitored and for what purpose.

8.1.4 Limitations of using the framework

The BMF provides a flexible structure around thinking about the impacts of new technology diffusion, but does not capture all features of the behavioural response to new technology diffusion. In particular changes to system dynamics have not been included. Changes are considered here in isolation and second-order effects have not been accounted for. For example, this report discusses how the uptake of MaaS may lead to lower congestion on the roads. A possible second-order effect is a greater number of people commuting by cars since lower congestion has lowered travel times – this is outside the scope of our model, which considers single changes in isolation, holding the rest of the system unchanged. However changes such as these will need to be addressed by transport planners when considering infrastructure investments.

8.2 Constraints and barriers in the transport system

8.2.1 Path dependency

For the transport system, there are a number of constraints and barriers that resist changes to the way the system operates. Path dependence locks in certain attributes of the transport system, particularly around urban form, based on historic and current decisions. This path dependence can affect both the diffusion of new technology and the behavioural response to adoption. There is the potential for transport to have a high degree of path dependence due to the cost and inflexibility of its infrastructure. Past decisions can make it difficult for significant change to occur in the transport system. Previous investment decisions become fixed and can affect the types of technologies that are diffused, as well as the impacts of these technologies. Given the current infrastructure in New Zealand, the use and operation of private vehicles have been catered for as the main form of personal transport. With respect to goods, roads and a large commercial fleet move goods to their intended destination. To enact changes, more than one factor needs to be considered.

8.2.2 System thinking on barriers to change

There is often not one single barrier to overcome to create large-scale changes in the transport system. Dealing with these barriers in isolation is unlikely to be sufficient to increase uptake of a technology. It is only when sufficient barriers are removed that uptake shifts rapidly. A systems approach is required to think about the adoption of innovative technologies, taking into account the barriers and benefits in the wider transport system.

For example, the case study revealed a number of significant barriers to the uptake of MaaS, including:

- development of a software platform
- requiring a mobile phone that is connected to mobile data
- integrated payments
- cooperation between transport providers
- sharing of data by service providers.

For MaaS, dealing with these barriers in isolation is unlikely to be successful. Rather, it would be better to consider MaaS in a systems approach which moves more into thinking about the overwhelming preference for vehicle ownership as the primary mode of transport and whether and how that is changing and if so why and for whom.

Other technologies are more compatible with the transport system and have smaller barriers to the uptake of the technology, such as the case study examining the uptake of EVs. Taking a systems view of vehicle ownership highlighted that there are some barriers that government can address – the lack of visible charging infrastructure and the lack of supporting services. However other barriers such as price can be left to come down through technological innovation.

8.2.3 Behavioural changes

The rigidness of the transport system (highlighted above) also influences the individual and collective behaviours that make up the transport system. Individual behaviours can become entrenched in many similar ways to how path dependence influences the form of the transport system. These current behaviours are influenced by many factors and are not caused by a single factor affecting everyone equally.

Each individual also has a different set of preferences that are distinct from other users. For example, the cost of travel may be an important factor for some people, whereas for others the time taken for travel could be more important. People weigh up all the options given their set of preferences and circumstances to make decisions about travel. Individuals do not make decisions in a vacuum and one person’s decision can impact on other transport users. For example, many people starting work at a similar time can create rush hour congestion that slows travel times compared with when the number of road users is lower.

Changing behaviours in the transport system can be difficult given the complexity of each individual’s preferences. However, new technology can shift the balance of the decision-making process and influence the current set of behaviours.

The BMF usefully prompts the reader to consider users' needs when considering new technologies, as differing needs will determine which technologies users are attracted to and which they are not so enthusiastic about.

8.3 Gaps in the research

The scope of the report was limited to the analysis of technology diffusion in the transport system. Through the research process, some possible extensions to the analysis were identified for potential future work, specifically, general equilibrium analysis and linking the transport system to the wider context such as land use.

8.3.1 Comparative static analysis vs general equilibrium analysis

Comparative static analysis rather than general equilibrium analysis was used in this research to simplify the process. In comparative static analysis, one element is changed while all else is held to be the same and the final end states are compared. This allows the effect of the change to be forecast in isolation. Comparative static analysis is simpler, quicker and easy to understand and to demonstrate than general equilibrium analysis. However, it ignores the second-order effects of the technology diffusion process. Instead it focuses only on how behaviours move from one state to another, without regard for the path of the change or resulting knock-on effects. The drawback to this approach is the assumption that all else will remain the same often does not hold true and a change in the transport system will have flow-on effects in the economy which will circle back to the transport system. A comparative statics analysis will not account for these effects.

A general equilibrium approach uses a more complex model of the wider economy and models how changes in the transport sector flow into other sectors and show these second-order effects. By modelling the wider economy over time it can also account for differences in the timing or path of changes. If the transport system could be modelled effectively, then it could more accurately forecast how the transport system as a whole would respond to a technology change. This is one area for potential further exploration.

One limitation of all models is that they necessarily simplify and a general equilibrium model of the transport system would need to include transport's place in the wider economic and land-use systems. This complexity may not deliver sufficient insight to make it worthwhile.

8.3.2 Land use

The scope of the project could be expanded to include land use, as the transport system sits within a wider national context – changes in the transport system affect wider land use and vice versa. As transport links are developed, other land-uses become available or more convenient. Conversely, the transport system itself has a sizeable footprint on land use and new infrastructure is often dependent on land use permissions. Different technologies will have different land use impacts. Some may be negligible, such as MaaS or EVs and some such as the theorised Hyperloop[10] could be considerable.

[10] Hyperloop is a proposed mode of transport that sends people and goods in specialised carriages or pods through a low-pressure tube. Magnetic levitation and low air pressure combine to reduce friction, allowing high-speed land transport. See https://hyperloop-one.com

Land use is a large part of the transport system with transport links, such as roads and bridges, required to enable access. New developments in greenfield sites in the outer suburbs could require new roads to access and expand the transport network. Other forms of transport could also be provided depending on the intensity and population of the new development. The increasing size, number and capacity of transport networks is linked to the intensity of land use. The location of where people live and where they want to go is included within land use, and as such, changes in land use can change the transport system.

8.4 Technology diffusion drivers

The diffusion drivers are well known and studied within the literature. Since the 1960s the diffusion process has been studied extensively, both theoretically and empirically. New technologies require a relative advantage over the status quo in some way to achieve the first sale or adopter. From that point onwards, the characteristics of the new technology determine the speed of diffusion.

Outside the new technology itself, economic, social and demographic factors influence the diffusion process. Income, wealth and demographic profile have been identified in the report as influencing the diffusion process. Higher incomes and wealth can lead to more risk-taking in the early adopter stage of the diffusion process as a smaller share of resource is put into the new technology. If the technology does not work out for the user, then the sunk costs can be absorbed without too much financial cost. Higher income also affects the ability to purchase higher-value technologies, such as vehicles, to drive the diffusion process. A population of younger transport users may have a different set of preferences compared with older generations, favouring more use of shared services and less vehicle ownership. Older people may be more concerned with the availability of travel and mobility.

Synthesising these drivers of diffusion with Bass parameters is more difficult and uncertain in the early stage of the diffusion process. For the modelling of EV uptake, early data was used to estimate the Bass parameters, giving initial results that were exponential and did not provide viable diffusion forecasts. The strong diffusion, relative to history, of EVs led to the exponential results. Shortening the time series to exclude the strong uptake towards the end of the data series provided stable results. However, a review of current international literature showed there is little agreement on the parameters of EV diffusion. As more data on the diffusion process becomes available, greater insights can be gained on the Bass parameters.

8.5 Transport policy

Policy may be required to reflect changes in behaviours and to respond to the technology innovations. These new technologies may require additional rules and regulations to ensure the efficiency and safety for users. Regulations can also either increase or decrease the rate of diffusion of the new technology, ie where regulations are not compatible with the new technology, the rate of diffusion can be slowed. Conversely, other policies can favour the new technology over alternate technologies, thereby speeding up the rate of diffusion.

Using the case studies as examples, both technologies could benefit from policy intervention to remove or reduce the barriers to adoption. For EVs, the government has announced a set of policies including tax exemptions and support for charging infrastructure. In part this is due to the public benefits such as reduced greenhouse gas emissions that result from EV diffusion in New Zealand. MaaS is not yet established in New Zealand, but overseas examples show how it has benefited from policy intervention.

One of the main issues with new technology diffusion can be unexpected policy barriers. For example, road user charges are charged on any vehicle that uses a fuel that is not petrol, since the cost of petrol is inclusive of dedicated road taxes. However, plug-in hybrid electric vehicles attract both road user charges and fuel taxes and are thus currently penalised by the policy regime. This penalty is not deliberate – the rules for road user charges were established long before EVs became popular and were designed to distinguish diesel vehicles from petrol vehicles.[11] However, this is an example of the kind of inadvertent policy barrier than may inhibit uptake of a new technology.

8.5.1 Existing policy tools

One of the potential policy responses to the change in technology is to increase investment. When considering additional investment into the transport system, the NZ Transport Agency's *Economic evaluation manual* (EEM) can be used to evaluate the economic efficiency of transport activities. The EEM sets out the national standards, values and procedures used to calculate the benefits and costs associated with investment in the transport system. Narrowing the potential investment responses can help identify investments that could require further analysis under the EEM.

Another policy tool already in use is the NZHTS, which is a good tool for monitoring people's travel behaviours. As new technologies start to diffuse through the transport system, new questions can be included in the survey to monitor systemic changes. We have included some suggested additional technology-specific areas for monitoring in the two case studies, earlier in this report. For MaaS, questions were centred on booking and paying for services using a mobile device, and for EVs questions related primarily to when and where vehicles are charged.

[11] Road taxes are not charged on diesel as a significant portion of diesel is used for industrial purposes and used in off-road vehicles such as farm vehicles.

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Appendix A: New Zealand technology diffusion model

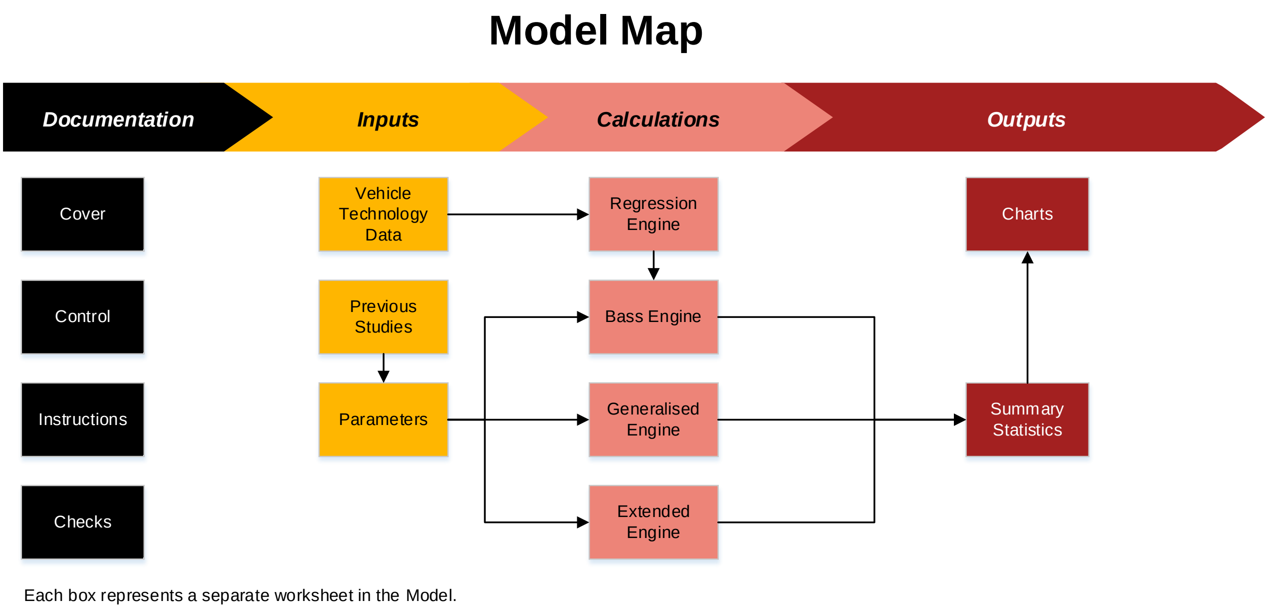
A1 Introduction

We developed an Excel model to forecast diffusion of technology in a New Zealand context. The model is based on the Bass diffusion models discussed in the main body of the report. The model can be used to forecast the timing and level of the diffusion of new technologies in the transport sector and to illustrate which variables have a high or low impact in a particular set of circumstances. This appendix explains and describes how the model works and how it is used.

A2 Model map

Figure A.1 shows the model map. The model map is an overview of the general logic, structure and functionality of the model and how the inputs flow through the model to the outputs. Each box represents a separate worksheet in the model. The arrows show how the inputs feed into the calculations and how the calculations produce outputs.

Figure A.1 Model map



A3 Model timeline

The model performs calculations spanning 150 time periods. The end user can choose how many periods to display on the charts between 0 and 150. The user can also choose the frequency of time periods and outputs are presented in that chosen frequency.

A4 Documentation

A4.1 Cover

The cover worksheet is the cover page of the model. It presents NZ Transport Agency's name and the name of the model.

A4.2 Control

This worksheet contains fundamental details of the model such as titles that flow through the worksheets of the model, the start date and error tolerance in the model.

A4.3 Instructions

The instructions worksheet provides an overview of the model. It outlines which cells the user should and should not alter and the above colour-coded model map to show how the model performs calculations to generate output.

A4.4 Checks

The checks worksheet lists all the internal checks built into the model's worksheets to ensure the integrity of the model is maintained as it is built and as the parameters are flexed. If work on the model triggers an error, this worksheet will inform the user which worksheet contains the error. This worksheet only captures errors that we are checking for. It is possible for the model to contain other errors even if the internal checks are satisfied.

A5 Inputs

A5.1 Vehicle technology data

The vehicle technology data worksheet contains a set of variables for each vehicle technology. Each vehicle technology is given a unique alphanumeric identifier, technology ID. A drop-down box allows the user to choose which technology they want to analyse by selecting the appropriate technology ID. Each row of the data frame includes columns that list the following variables:

- vehicle technology type
- units of uptake
- frequency of uptake
- whether new uptake per period or cumulative uptake is to be recorded in the row
- 50 cells to input new or cumulative uptake data.

Users are free to update and modify these fields.

A5.2 Previous studies

The previous studies worksheet contains a list of previous studies that have analysed vehicle technology uptake using a Bass model. Each study is given an alphanumeric identifier and the user is able to select a study from a drop down box in order to analyse uptake based on coefficients estimated in that study.

A5.3 Parameters

The parameters worksheet shows the set of parameters that can be used to generate the new and cumulative uptake curves. The user can first choose how many time periods to analyse between 1 and 150. This will limit the charts' time horizons. Parameters are grouped according to the type of curve being analysed.

The Bass model includes the following set of parameters $(p, q, m, units, frequency)$. All parameters here can be selected based on the data recorded in the vehicle technology data worksheet or the previous studies worksheet. There is also a field to implement the user's own set of parameters. A drop down box is available to choose the data source.

- Coefficient of innovation (p) – positive real number – this is the parameter commonly referred to as the coefficient of innovation. This parameter reflects the percentage of innovators in the market in the first period of uptake.
- Coefficient of imitation (q) – positive real number – this is the parameter commonly referred to as the coefficient of imitation. This parameter reflects the reinforcing process from previous uptake in the system, ie the pressure operating on imitators as the cumulative uptake increases.
- Market potential (m) – positive real number – this is the estimated number of adopters following market saturation.
- Units – this parameter describes the units that are being analysed, eg cars or electric vehicles.
- Frequency – this parameter allows the user to input the frequency of uptake that is being analysed.

The generalised Bass model parameters include the Bass model parameters bullet-pointed above and the following additional set of parameters: $(\beta_1, \beta_2, \%\Delta Pr_t, \%\Delta Adv_t)$.

- Price response (β_1) – high/medium/low – the percentage increase in speed adoption given a 1% decrease in price, holding other factors constant.
- Advertising response (β_2) – high/medium/low – the percentage increase in speed of adoption with a 1% increase in advertising expenditure.
- Change in price ($\%\Delta Pr_t$) – percentage – this parameter is the percentage change in price of the technology or product at between time t and time $t-1$ and influences the speed of uptake in the generalised Bass model and the extended Bass model.
- Change in advertising ($\%\Delta Adv_t$) – percentage –this parameter is the percentage change in advertising expenditure from marketing the technology or product between time t and time $t-1$ and influences the speed of uptake in the generalised Bass model and the extended Bass model.

The extended Bass model parameters include the generalised Bass model parameters and the following set additional set of parameters: $(\varepsilon_t, t_\varepsilon, g_m, t_c)$.

- Policy shock (ε_t) – positive real number – the policy shock amplifies the coefficient of innovation in the extended Bass model at the selected policy timing. For example, $\varepsilon_t = 0.3$ will amplify the coefficient of innovation by 30% at time t_ε.
- Policy timing (t_ε) – integer – the policy timing is the time at which the policy shock permanently amplifies the coefficient of innovation in the extended Bass model.

- Growth rate of market potential (g_m) – percentage – the growth rate of market potential is the compounding rate at which the market potential, m, appreciates in the extended Bass model. The frequency chosen by the user is also the compounding frequency of the growth rate.
- Cut-off timing (t_c) – integer – the cut-off timing disrupts the uptake process in the extended Bass model by collapsing both the coefficients of innovation and imitation to zero at this time.

A6 Calculations

The model uses four calculation engines that successively build on the previous engine's results:

- The first is the regression engine. The regression engine uses sales data to estimate the parameters (innovation – p, imitation – q and market potential – m) of the overall S-curve.
- The Bass engine takes the parameters determined by the regression engine, p and q and combines it with a fixed market potential for the technology and uses them to calculate the trajectory of the curve. This produces a forecast S-curve.
- The generalised engine extends this forecast using estimations of price changes and advertising expenditure, as well as forecast of sensitivity to price and advertising changes.
- Finally the extended engine allows the user to vary the market potential over time and to include the effect of government policies encouraging (or discouraging) uptake.

The regression engine is used to determine the inputs for subsequent engines. The results from the Bass, Bass generalised and Bass extended engines are presented separately in the model. The four engines are described in more detail below.

A6.1 Regression engine

The regression engine worksheet uses the vehicle technology uptake selected from the vehicle technology data worksheet to estimate the Bass model coefficients. The parameter set, (p,q,m), is estimated using ordinary least squares regression. As outlined above, the estimated Bass model coefficients can be selected in the parameters worksheet and viewed in the charts worksheet.

Bass (1969) suggests a discrete-time quadratic functional form for the change in uptake to estimate the parameter set, (p,q,m). Equation A.1 shows the reduced form coefficients, (a,b,c) used to identify the Bass model parameters, (p,q,m):

$$S_t = a + bY_{t-1} + cY_{t-1}^2 \qquad \text{(Equation A.1)}$$

where:

- $S_t = Y_t - Y_{t-1}$ is the new uptake in time t
- Y_t is cumulative uptake at time t
- $a = pm$
- $b = q - p$
- $c = -\frac{q}{m}$

A6.2 Bass engine

The Bass engine worksheet calculates uptake using a standard Bass model and based on the selected (p, q, m) parameters supplied in the parameters worksheet. The Bass engine is driven using the discrete-time version of the Bass(1969) differential equation:

$$S_t = pm + (q - p)Y_{t-1} - \frac{q}{m}Y_{t-1}^2 \qquad \text{(Equation A.2)}$$

where:

- p is the coefficient of innovation
- q is the coefficient of imitation
- m is the market potential

A6.3 Generalised engine

The generalised engine worksheet calculates uptake using a generalised Bass model and based on the parameters supplied in the parameters worksheet and outlined below. The generalised engine is driven using the discrete-time version of Bass et al's (1994) differential equation:

$$S_t = \left[pm + (q - p)Y_{t-1} - \frac{q}{m}Y_{t-1}^2\right]x_t \qquad \text{(Equation A.3)}$$

$$x_t = 1 + \beta_1 \times \%\Delta Pr_t + \beta_2 \times \max(\%\Delta Adv_t, 0)$$

where:

- $\%\Delta Pr_t$ is the percentage change in price of the technology or product at between time t and time $t - 1$
- $\%\Delta Adv_t$ is the percentage change in advertising expenditure from marketing the technology or product between time t and time $t - 1$. A decrease in advertising does not affect the speed of uptake.
- β_1 is the price response, ie the percentage increase in speed adoption given a 1% decrease in price, holding other factors constant. β_1 is negative
- β_2 is the advertising response, ie the percentage increase in speed of adoption with a 1% increase in advertising expenditure. β_2 is positive.

A6.4 Extended engine

The extended engine worksheet calculates uptake using a generalised Bass model and based on the parameters supplied in the Parameters worksheet and outlined below. The extended engine is driven using the discrete-time version of Bass et al's (1994) differential equation where p and m are free to time-vary in accordance with some policy and market potential growth parameters, respectively:

$$S_t = \left[p_t m_t + (q - p_t)Y_{t-1} - \frac{q}{m_t}Y_{t-1}^2\right]x_t \qquad \text{(Equation A.4)}$$

$$x_t = 1 + \beta_1 \times \%\Delta Pr_t + \beta_2 \times \%\Delta Adv_t$$

Where:

- $m_t = m(1 + g_m)^t$ is the time-varying market potential in time t
- g_m is the compounding growth rate of market potential
- $p_t = p \times \varepsilon_t$ is the coefficient of innovation, which is permanently amplified by a policy shock, ε_t, at time t_ε.

A7 Outputs

A7.1 Summary statistics

The summary statistics worksheet provides some metrics on the Bass model, generalised Bass model and extended Bass model. As shown in figure A.2, these metrics include the amount and time at which new uptake peaks, cumulative uptake for each of time periods 5 to 50 increments of five. The beginning and ending coefficient of innovation, coefficient of imitation and market potential is also shown for the extended Bass model.

Figure A.2 Example summary statistics

	Bass	Generalised	Extended
Peak uptake	59,851	64,280	75,902
Peak time	Years 14	Years 13	Years 10

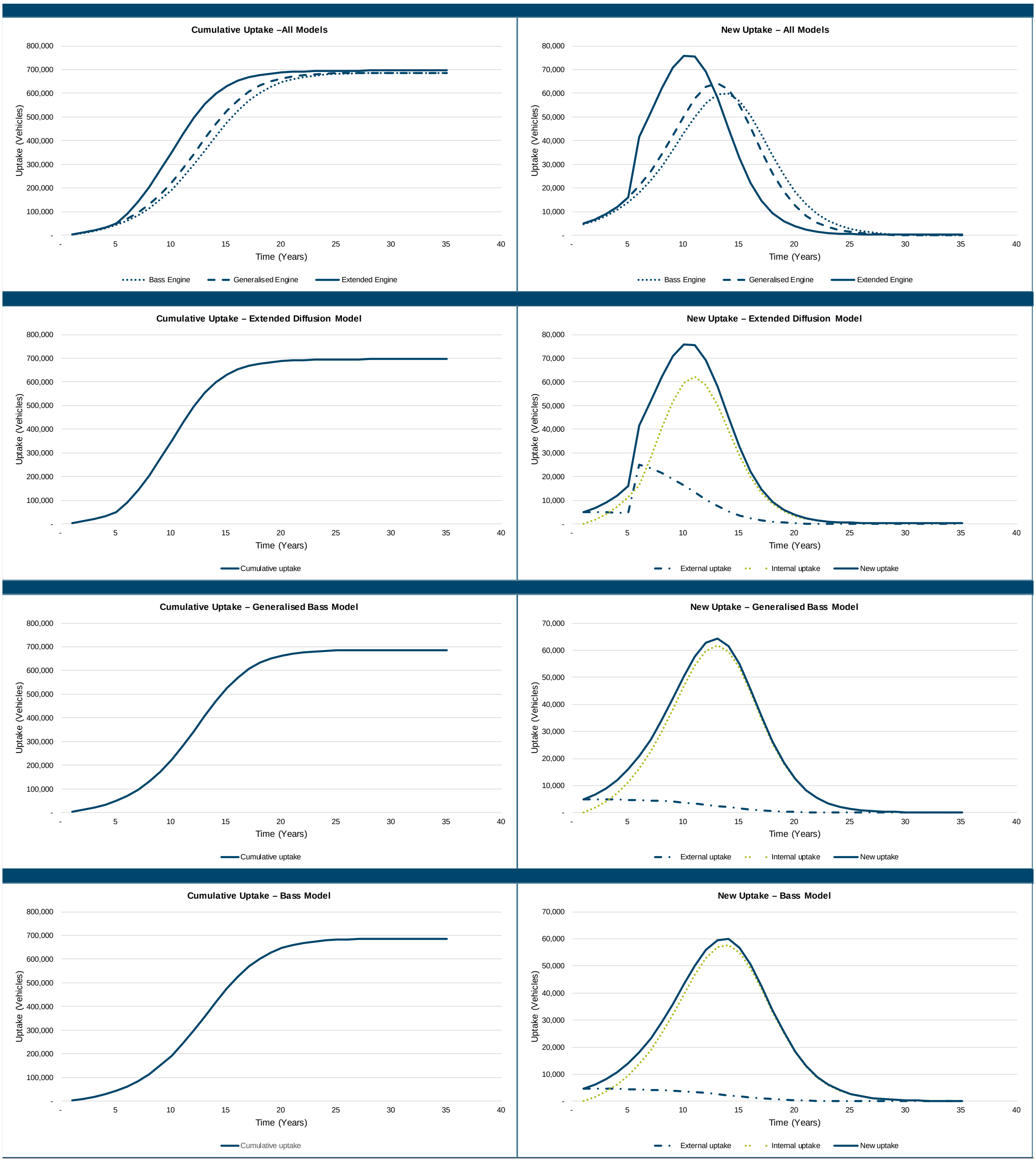
	Cumulative Uptake (Vehicles)		
Period	**Bass**	**Generalised**	**Extended**
5	43,874	48,920	48,980
10	193,676	223,941	351,436
15	475,770	525,144	631,650
20	646,328	663,267	687,694
25	681,299	684,139	694,313
30	685,967	686,371	696,441
35	686,544	686,599	698,215
40	686,615	686,622	699,965
45	686,623	686,624	701,716
50	686,625	686,625	703,472

	Extended Parameters		
Period	**Innovation (p)**	**Imitation (q)**	**Market (m)**
-	0.0068	0.3364	686,625
150	0.0368	0.3364	740,088

A7.2 Charts

The charts worksheet shows cumulative and new uptake curves for all models and each model separately. As example of the uptake curves is shown in figure A.3. The curves for the separate models also show new uptake generated internally, by the coefficient of innovation and externally, by the coefficient of imitation.

Figure A.3 Example uptake curves



A8 Model limitations

The following limitations are known at the time of this guide:

- The model does not include any functionality to perform stand-alone sensitivity testing or scenario analysis. Users will be required to change inputs of the model manually in order to test sensitivities or different scenarios.

- The outputs of the model are not designed to link directly to any external Transport Agency financial information, data or reporting models.
- The frequency on which outputs are presented is chosen by the user.
- The model will contain forecasts for up to 150 periods only and does not include any ability to track actual uptake to the forecast.
- Outputs are dependent on the quality of inputs and assumptions.