Evaluating the greenhouse gas emission reduction benefits from land transport mode shift programmes and projects – a research note

March 2021

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Waka Kotahi, NZ Transport Agency, research note 004
Contracted research organisation – MRCagney

ISSN 2703-5654 (electronic)

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Thorwaldson, L., Thomas, F., & Carran-Fletcher, A. (2021). *Evaluating the greenhouse gas emission reduction benefits from land transport mode shift programmes and projects* (Waka Kotahi NZ Transport Agency research note 004).

MRCagney was contracted by Waka Kotahi NZ Transport Agency in 2020 to carry out this research.

Keywords: greenhouse gas, emissions, transport, vehicle kilometres travelled, measurement, mode shift

An important note for the reader

Acknowledgements

The authors would like to acknowledge the steering group for their generous time and assistance with the project: Rob Hannaby, Joanna Pohatu, Kathryn King, Colin Morrison, Ryan Falconer. The authors also acknowledge the valuable inputs of the peer reviewers for this project: Todd Litman and Helen Murphy.

Abbreviations and acronyms

ACCS	Arlington County Commuter Services
BRT	bus rapid transit
CDM	Clean Development Mechanism
CO_2	carbon dioxide
CTR	commuter trip reduction
GHG	greenhouse gas
GPS	Global Positioning System
HCD	California Department of Housing and Community Development
HQTA	high quality transit area
HUD	U.S. Department of Housing and Urban Development
LOS	level-of-service
LTN	low-traffic neighbourhood
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NTPP	Nonmotorized Transportation Pilot Programme
$PM_{2.5}$	particulate matter 2.5 microns or smaller
PM_{10}	particulate matter 10 microns or smaller
SFMTA	San Francisco Municipal Transportation Agency
TDM	travel demand management, or transportation demand management
SOV	single-occupancy vehicle
tCO_2e	metric tonnes of carbon dioxide equivalent
TOD	transit-oriented development
ULEZ	Ultra Low Emission Zone
UNFCCC	United Nations Framework Convention on Climate Change
VKT	vehicle kilometres travelled
VMT	vehicle miles travelled
WSDOT	Washington State Department of Transportation

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Executive summary

This report outlines the findings of an international scan of literature and land transport programmes that have measured outcomes translatable into greenhouse gas (GHG) emissions reduction. The research sought to answer the question of whether any programmes had measured such data and, if so, what the outcomes were.

MRCagney was commissioned by Waka Kotahi NZ Transport Agency to undertake this research to contribute to mode shift plans in New Zealand cities, support the Sustainable Urban Access workstream in Toitū Te Taiao – the Waka Kotahi sustainability action plan – and inform the development of environmental impact modelling for land transport in New Zealand.

This report outlines 16 case studies of programmes that were identified by the international scan. To be included as case studies, programmes were required to have tangible measured outcomes relating to their effect on either emissions or amount of vehicle travel. The exception to this is the inclusion of a peer reviewed meta-analysis of 'soft' travel behaviour change, used as an indication of the need for more research in this area.[1]

The case studies provide an indication of the types of approaches possible when considering how GHG emissions reduction could be measured, with a general review of the outcomes that have been measured. Table ES.1 below provides a general summary of the case study programmes and findings.

This piece of work should be considered as a preliminary scan of such evidence. Due to the limited timeframe and scope of this research, it is was not possible to provide in-depth detail about each programme type. Priority was given to reviewing a range of intervention types and methods. This work identifies some additional relevant programmes and areas of research that could be investigated to further the knowledge base.

[1] This meta-analysis was not completed by the research team for this research project, but by Semenscu et al. (2020). It was included as a case study for this work.

Table ES.1 Case studies and measurement approaches found within this research

Name of the case study	Type of programme	Measurement approach	Avoid, shift or Improve	Reduction in vehicle miles travelled (VMT) or GHG emissions (%)	Baseline/context	Additional effects
Integrated transport programmes						
Boulder, Colorado, USA: integrated transport planning	Comprehensive travel demand management (TDM)/transport programme	**Outcome data:** • VMT **Data collection:** • Annual travel surveys	Avoid and shift	Estimated 30% lower VMT and GHG emissions in 2016 than could have been expected without transport planning interventions.	Single-occupancy vehicle (SOV) mode share for commuters has dropped from 67% in 1990 to just 34% in 2018 while commute mode share by bike has increased from 10% in 1990 to 34% in 2018.	• Annual VMT per capita reduced from 6,811 miles in 1990 to 5,490 miles in 2018. • EcoPass (public transport pass) holders report driving 2,600 fewer miles annually.
Washington State, USA: Commute Trip Reduction (CTR) programme	Comprehensive employer-based TDM programme	**Outcome data:** • VMT **Data collection:** • Employee travel surveys	Shift	• 13% reduction in VMT between 2007 and 2018 among employees participating in the CTR programme across Washington State. • Equivalent to a 75,000 metric tonne reduction in GHG emissions annually. • Seattle reported a 23% reduction in VMT between 2007 and 2016.	For employees that participate in the CTR programme, statewide, daily VMT reduced from 10.9 miles (17.54 km) to 9.5 miles (15.28 km) between 2007 and 2018. In Seattle the per capita reduction was from 5.9 miles (9.49 km) to 4.4 miles (7.04 km) between 2007 and 2016.	

Name of the case study	Type of programme	Measurement approach	Avoid, shift or Improve	Reduction in vehicle miles travelled (VMT) or GHG emissions (%)	Baseline/context	Additional effects
Arlington, Virginia, USA: Arlington County Commuter Services	TDM	**Outcome data:** • Vehicle trips reduced • Number of people using particular services **Data collection:** • Surveys • Service use data	Avoid and shift	N/A	Baseline data is lacking as the measurement methodology relies on applying a 'change in trips' from a survey to the number of people using the TDM services.	Reduction of 40,000–45,000 vehicle trips per weekday, equating to roughly 350 tonnes of reduced emissions per day.
Land use case study						
California, USA: transit-oriented development (TOD)	TOD effects study	**Outcome data:** • VMT • Vehicles per household • Trips per household • Public transport ridership per household **Data collection:** • Household travel surveys (measuring)	Avoid	Across all income groups: • 25%–30% lower daily household VMT when living in a high quality transit area (HQTA) compared to not • 37%–50% lower daily household VMT when living in a TOD area compared to household living in a non-transit focused area.	• Household travel survey of 36,000 households across the US state of California. • HQTAs are within half a mile of a rail, ferry or bus station. Bus stop headways must be 15-minutes to qualify. • TOD areas are within a quarter of a mile of a rail, ferry or bus stop with 10-minute headways during the peak.	

Name of the case study	Type of programme	Measurement approach	Avoid, shift or Improve	Reduction in vehicle miles travelled (VMT) or GHG emissions (%)	Baseline/context	Additional effects
Parking case studies						
San Francisco, California, USA: *Sfpark*	Demand-responsive parking	**Outcome data:** • VMT associated with searching for parking. GHG emissions were determined to be equal to VMT reduction. **Data collection:** • Parking sensors • Roadway traffic volume sensors • Manual motorcycle occupancy counts • Parking meter data • Parking tickets • Parking garage use data • Parking tax receipts from parking facilities • Manual surveys of double parking and parking search time • Intercept surveys • Public transport passenger counts • Highway traffic data • Sales tax data	Avoid and shift	• 30% reduction in VMT (and GHG emissions) associated with searching for a carpark in pilot areas.) • 57% reduction in VMT (in terms of searching for a carpark on Sundays) in areas where paid parking on a Sunday was introduced.	Daily VMT generated by circling for metered parking weekdays 9 am to 6 pm, SF*park* pilot areas (2011 to 2013): • Before: 8,134 daily VMT associated with searching for parking in pilot areas. • Associated daily metric tonnes carbon dioxide (CO_2) emissions before SF*park* intervention: 7.0.	

Name of the case study	Type of programme	Measurement approach	Avoid, shift or Improve	Reduction in vehicle miles travelled (VMT) or GHG emissions (%)	Baseline/context	Additional effects
Los Angeles County, California, USA: parking cash out	Employer-based parking cash out subsidy	**Outcome data:** • VMT for staff **Data collection:** • Staff surveys	Shift	Average VMT (and associated CO_2) reduction: 12%.	Average commuting VMT per year per employee across eight workplaces: 5,348.	
Traffic restriction case studies						
Stockholm, Sweden: congestion pricing	Central city congestion pricing zone	**Outcome data:** • Vehicle kilometres travelled (VKT) reduction **Data collection:** • Vehicle counts across congestion charging boundary • Vehicle counts on surrounding streets	Avoid and shift	GHG emissions were estimated to reduce by 14% in the inner city and 2–3% in the wider county.	Average weekday vehicle volumes across the cordon before the trial (baseline) were approximately 450,000 per month.	Vehicle volumes across the cordon reduced by approximately 20%.
London, UK: Ultra Low Emission Zone (ULEZ)	Charge for vehicles non-compliant with emissions standards	**Outcome data:** • Estimated CO_2 reduction **Data collection:** • Automatic traffic counts and composition of vehicle fleet using from automatic number plate recognition	Avoid, shift, and improve	Estimated CO_2 reduction is 6% within the ULEZ compared to the estimated scenario without the ULEZ over the 10 months following its implementation.	The 6% reduction corresponds to a reduction of approximately 12,300 tonnes of CO_2 from a baseline of approximately 205,000 tonnes.	

Name of the case study	Type of programme	Measurement approach	Avoid, shift or Improve	Reduction in vehicle miles travelled (VMT) or GHG emissions (%)	Baseline/context	Additional effects
Low-traffic circulation plans	Through traffic restriction across an urban area	**Outcome data:** • Traffic volumes, frequency of car use • Use of modes • Mode share • Air quality **Data collection:** • Concentrations of nitrogen dioxide (NO_2), soot, particulate matter 10 microns or smaller (PM_{10}), and particulate matter 2.5 microns or smaller ($PM_{2.5}$) • Resident surveys • Walking, cycling, and vehicle counts	Avoid and shift	Impacts on GHG emissions and VKT were not measured for these interventions.		Following the introduction of the traffic circulation plan in Groningen, Netherlands, traffic intensity was found to be 47% lower in the city centre. In Ghent, Belgium, air quality improvements of 7– 25% were observed following introduction of its plan. In London, residents of low-traffic neighbourhoods that received more extensive interventions were found to use a car for 43 fewer minutes per week than residents of other neighbourhoods.
Walking and cycling case studies						
USA: walking and cycling infrastructure	Non-motorised transport investment	**Outcome data:** • VMT **Data collection:** • Walking and cycling counts • Travel surveys, supplemented by national, state and local data sources	Shift		Baseline data was collected in 2007 prior to implementation and a three-year rolling average was used to allow more accurate trend reporting.	Following a range of walking and cycling infrastructure and outreach improvements in four pilot areas, mode share was estimated to increase for walking from 13% to 15% and cycling from 1.0% to 1.5% from 2007 to 2013. It was estimated that 85 million VMT were averted between 2009 and 2013 relative to a 2007 baseline.

Name of the case study	Type of programme	Measurement approach	Avoid, shift or Improve	Reduction in vehicle miles travelled (VMT) or GHG emissions (%)	Baseline/context	Additional effects
Cardiff, Wales, UK: walking and cycling infrastructure	Cycling infrastructure	**Outcome data:** • VMT • Vehicles per household • Trips per household • Public transport ridership per household **Data collection:** • Travel diaries • Global Positioning System (GPS) monitoring	Shift	An emissions reduction of 0.5% per surveyed participant was estimated from avoided car trips directly attributed to the traffic-free bridge and Connect2 scheme supporting walking and cycling links.	Baseline data was drawn from travel surveys and GPS trackers. This was a micro-level analysis, so baseline information is limited.	
Seville, Spain: continuous, connected cycle network development	Cycling infrastructure	**Outcome data:** • Average distance of bicycle trips • Mode share change **Data collection:** • Survey data	Shift		The baseline mode share for private vehicles in Seville was 57.1% in 2007 on a typical business day. The actual number of vehicle trips is not documented in studies.	Seville's extensive cycle network is estimated to save over 8,000 metric tonnes of carbon dioxide equivalent (tCO_2e) per year following an approximate 9% drop in private vehicle mode share from 2007 to 2011.
Public transport case studies						
Bogotá, Colombia: bus rapid transit (BRT)	Stage 2 of wider BRT development	**Outcome data:** • Ridership numbers • Bus distances driven • Total fuel consumption of buses • Average distance people would have driven without	Shift and improve	2012 (most recent year) emissions reduction for TransMilenio BRT: • 80,128 tCO_2e (53% reduction from estimated baseline).	Baseline emissions used for 2012 calculation: • 149,987 tCO_2e (estimate only).	

Name of the case study	Type of programme	Measurement approach	Avoid, shift or Improve	Reduction in vehicle miles travelled (VMT) or GHG emissions (%)	Baseline/context	Additional effects
Travel behaviour change case studies						
Various: soft interventions – meta-analysis	Meta-analysis of 41 soft travel behaviour change interventions largely focusing on providing information about travel alternatives	**Outcome data:** • Vehicle trip volumes • Mode share • Travel distance • Travel time **Data collection:** • Travel diaries • Recollection of travel from previous week • GPS measurements • Map-based distance calculation • Interviews	Shift		Baseline not provided due to range of study types.	The meta-analysis of 41 studies measuring soft travel behaviour change interventions found an average reduction in modal split of car travel of 7%, though it found a wide range of effectiveness between studies.
Urban logistics case studies						
Germany: Deutsche Post DHL electric mail scooters	Electric van fleet replacement	**Outcome data:** • Assumed fuel consumption avoided per kilometre travelled by electric van **Data collection:** • Fuel consumption data	Improve		Baseline data was not specifically reported, but emissions are reported as those avoided based on an estimate of what a typical diesel vehicle with a representative payload would produce per kilometre.	• Each StreetScooter vehicle is estimated to save between 3 and 4 tonnes of CO_2 per year. In 2019, Deutsche Post DHL passed more than 10,000 StreetScooters in its fleet. • There were health and safety benefits associated with the new design of the vehicles having a better ergonomic design.

Name of the case study	Type of programme	Measurement approach	Avoid, shift or Improve	Reduction in vehicle miles travelled (VMT) or GHG emissions (%)	Baseline/context	Additional effects
Various: urban logistics – cargo-bike deliveries	Review of several small-scale programmes replacing combustion engine vehicles with cargo bikes	**Outcome data:** • VKT **Data collection:** • Some reporting limitations across programmes, typically distance travelled by cargo bike	Shift	Programmes studied had various impacts on GHG emissions. In Brussels, Belgium, TNT Express tested use of a mobile depot for inner city first-mile/last-mile deliveries by electric cargo bike. This scheme was linked to a 24% decrease in CO_2.	Baseline data was not reported for any of the studies – an ‘emissions avoided’ framework was used based on estimated VMT without the shift to cargo bike use.	Projects reported space-saving benefits as well as perceived amenity improvements by using cargo bikes for first-mile/last-mile deliveries.

The key findings of this research are outlined below.

- This research has found that approaches for measuring or inferring GHG emissions related to land transport programmes vary widely.
- The data most frequently cited for understanding the effect on emissions is vehicle kilometres travelled (VKT) – measured as vehicle miles travelled (VMT) in North American cases. Other relevant data includes public transport ridership, vehicle journey numbers, vehicle ownership and mode share. All of these types of data are used in some way to calculate GHG emissions reduction.
- Methodologies for collecting and measuring this data are largely dominated by vehicle counts (such as over a cordon) and surveys (eg, household travel surveys, staff surveys, and intercept surveys on the street).
- Many interrelated factors influence GHG emissions in each case study, including level of active mode or public transport infrastructure, land use planning, and government policies.
- Many programmes included in this review come from the United States. This may be due to requirements for measurement of outcomes to secure government funding of programmes. Results are often publicly available, particularly for programmes that have federal funding. Likewise, detailed GHG emissions reduction reporting related to Bogotá's BRT system relates to requirements for receiving carbon credits under the Kyoto Protocol. This may suggest that reporting requirements tied to funding generate a greater focus on measurement methodologies and a wider catalogue of publicly available information relating to measured programme outcomes. As this work relied primarily on publicly available information, the effect of measurement requirements that are not publicly reported cannot be stated.
- This review sought to find relevant examples where measured outcomes were publicly available within New Zealand and Australia but was unsuccessful in doing so. This highlights a need to better understand local requirements around such measurement and the publication of such measurements to further knowledge sharing and innovation in this area.
- Parking management was identified as a contributing strategy for several case studies and could support demand management and mode shift outcomes while generating revenue that can be further invested in low-carbon modes.

There is significant potential for further research in this area to contribute to New Zealand's work towards transport-related GHG emissions reductions. This review identifies further opportunities for research in each of the case studies as well as more general opportunities, including:

- analysis of the emissions outcomes of New Zealand- and Australian-based land transport programmes
- development of a consistent approach for New Zealand and Australia in terms of GHG emissions measurement relating to land transport programmes – this may include alignment with the Waka Kotahi Investment Decision-Making Framework
- research into the effects on GHG emissions of low-traffic neighbourhoods, more specific parking examples, campus-based transport programmes, and several specific programmes, including Beter Benutten in the Netherlands, TravelSmart in Australia, and Walthamstow Mini-Holland in London
- research into programmes in non-English-speaking countries
- the effects of staging of programmes on emissions reductions to better understand:
  - how the order of the rollout of interventions impacts benefits
  - the cumulative impacts of multiple interventions.

1 Introduction

Waka Kotahi NZ Transport Agency commissioned MRCagney to investigate land transport and mode shift programmes that have demonstrated post-implementation measurement of greenhouse gas (GHG) emissions reductions. This research aims to provide insights that will contribute to mode shift plans in New Zealand cities and influence the Sustainable Urban Access workstream in Toitū Te Taiao – the Waka Kotahi sustainability action plan – and inform the development of environmental impact modelling for land transport in New Zealand. It also notes an opportunity for measurement of the wider range of impacts associated with transport investments to reduce GHG emissions, and the potential for alignment with Waka Kotahi's recent changes to the Investment Decision-Making Framework.

2 Methodology

2.1 Scope

This research was completed over the course of October and November 2020. The primary scope of this research is limited to understanding the GHG emissions reductions associated with selected land transport programmes. This report and accompanying research catalogue are intended to help end users with their understanding of both the measurement methodologies and the recorded benefits.

The research focused specifically on the 'shift' and 'reduce' elements of Toitū Te Taiao, seeking to reference programmes that help people avoid or reduce reliance on private vehicle travel and shift to shared, active, or low-carbon modes.

The scope of this research was limited to understanding measured effects only, avoiding programmes where emissions outcomes were modelled. Measured effects included programmes where proxy outcomes relevant to GHG emissions, such as vehicle kilometres travelled (VKT) were the measured factor. Individual programmes were reviewed to understand the land transport intervention and GHG measurement methodology, with the understanding that all transport programmes have strong interdependencies with one another. Although this research was not explicitly scoped to detail the co-benefits or dis-benefits of the individual programmes measured, we have reported these where readily available within the literature.

As this report constitutes an initial review seeking to establish evidence of post-implementation measurement methodologies, it is by no means an exhaustive list of transport programmes with relevant measured outcomes. Other examples exist that could warrant further investigation in this area.

2.2 Selection process

The primary goal of this research was to review programmes that reported measured GHG emissions reductions. In order to identify relevant programmes, this research was broken into two steps: an initial desktop review and an in-depth review.

2.2.1 Desktop review

First, a desktop review was undertaken to search for relevant programmes. This review covered both academic and grey literature (that of government agencies or independent organisations). The defining characteristic that determined whether a study or programme was considered for further analysis was the extent to which the programme measured post-implementation outcomes relating to GHG emissions. Such measures could include VKT changes, measured mode shift, number of journeys taken or other suitable proxies for GHG emissions, as agreed with Waka Kotahi. None of the programmes reviewed had a direct measure of GHG emissions reduction without relying on some other level of input or proxy to calculate results. The research team sought to identify a range of programme types and geographic locations in the selection process.

Once the desktop review established that a number of programmes had measured various outcomes that can be translated to GHG emissions, the research steering group and peer reviewers were asked to provide input into the selection of the most appropriate programmes to include in further analysis. The steering group and peer reviewers provided recommendations for additional programmes and literature to consider.

2.2.2 In-depth review

The final stage of this research involved a more in-depth review of the selected programmes and methodology described in the literature. To qualify for inclusion, programmes needed to have a measurable outcome such as VKT reduction that had been translated into a measure of GHG emissions reduction or could be in the future, with a sound measurement methodology. Relevant examples include measures such as vehicle volumes across a cordon, household travel survey data, parking data, vehicle and active mode counts, GPS travel diaries and public transport ridership data.

Sixteen programmes are profiled in this report. This research provides a broad overview of some types of programmes that have shown measured impacts to GHG emissions through reduced vehicle travel. It strikes a balance within the scope and timeframes of the work to provide a diverse range of programme type, scale and location while maintaining a robust analysis of the methodology and outcomes described in the literature. There is opportunity to expand this type of analysis in the future.

2.3 Limitations

This research has been carried out as a preliminary scan to determine whether land transport programmes have been measured for their effects on GHG emissions, and whether these are relevant to New Zealand. The case studies and analysis in this report suggest that not only are examples of such programmes available, but that they are plentiful. Despite this, there are limitations to this type of research. The discussion of these limitations is broken into two sections: firstly, discussing the limitations of this work in particular, and secondly, discussing the limitations around trying to quantify GHG emissions benefits from land transport programmes.

Limitations relating to this work are as follows.

- To ensure delivery of this research with sufficient time to have meaningful input into the development of relevant Waka Kotahi programmes and models such as the Sustainable Urban Access workstream in Toitū Te Taiao, this was by necessity a high-level review to find programmes that had measured outcomes. It was not intended to identify which are the best or most recommended programmes for addressing GHG emissions. The scope of this research was a high-level review to identify and review a broad selection of land transport programmes where measurements have been undertaken to understand impacts on GHG emissions.
- For the most part, only publications in English have been considered when reviewing literature for this work. This is expected to have limited both the geographic and academic scope of the work.
- Transport changes directly associated with COVID-19 are not profiled in this work, in part due to limited evidence of the long-term effects of these changes at the time of writing, with acknowledgement that significant changes to transport have occurred in relation to COVID-19 and associated lockdowns and restrictions.

- This work relies entirely on the research and reporting completed by other agencies or academics. Results reported are not the result of primary research and rely on the accuracy and methodology of cited works.
- Programmes of different sizes/contexts have been assessed within this work. Direct comparison or ranking off interventions is, therefore, not advised.

Identified limitations relating to GHG emissions measurement/calculation are as follows.

- The main limitation of this work is the difference between different jurisdictions and programmes in terms of how GHG emissions, or a suitable proxy (such as VKT), is measured. In this research, methodologies used by each jurisdiction have been profiled directly. While most jurisdictions use VKT or VMT as their emissions reduction measurement proxy, many have different data collection methodologies – due to the different nature of the interventions or settings. A direct comparison of results between such varying methodologies without exploring these context factors is not recommended.
- There are limitations in capturing second-order effects. For example, telecommuting can significantly reduce participating workers' commute trips. However, some workers may make alternative non-work related journeys while working from home, some of which would have otherwise been completed as part of a commute trip; some may choose to live in more isolated, car-dependent locations (which increases non-commute travel and commute travel for people who are still commuting some days per week); and some may use more energy heating and cooling their homes, offsetting emission reductions associated with fewer commute trips (Litman, 2019). Conversely, there is evidence that some strategies, such as improving walking, bicycling and public transport services, tend to leverage additional automobile trip reductions by allowing some households to reduce their vehicle ownership and encouraging more compact neighbourhood development. As a result, under some circumstances, each additional kilometre travelled by people walking, bicycling and using public transport can reduce automobile travel by more than one vehicle-kilometre.
- Many VKT measurements rely on a certain level of self-reporting, particularly in the case of businesses and behaviour change programmes. There is expected to be a level of reporting bias within such results. Where this has been accounted for, this has been noted.

3 Relevant considerations

3.1 Relevance to Toitū Te Taiao

Published in April 2020, Toitū Te Taiao lays out the commitment Waka Kotahi has made towards both environmental and public health through the land transport sector, and the ways in which it can influence these outcomes. Overall, the vision is 'for a low carbon, safe and healthy land transport system' (Waka Kotahi, 2020b, p. 4). As part of this, the agency is targeting four key challenges: Reducing Greenhouse Gas Emissions; Improving Public Health; Reducing Corporate Emissions; and Reducing Environmental Harm. It seeks to achieve this by a number of avenues, including providing sustainable urban access through the avoidance or reduction of car travel and the shift of people to shared and active modes. Toitū Te Taiao recognises the role that land transport plays in New Zealand's GHG emissions, accounting for 20%, with light vehicles making up 73% of that contribution. While Toitū Te Taiao strongly emphasises the need for New Zealand's vehicle fleet to transition to electric vehicles, it also emphasises the need to reduce journeys entirely and increase the proportion of journeys made by shared or environmentally sustainable modes.

This research strongly ties into these aims. Firstly, by assessing the degree to which other jurisdictions are assessing their own contribution to GHG emissions from mode shift and land transport programmes. Secondly, by providing concrete examples of the effects of mode shift interventions. As part of its sustainability action, Waka Kotahi has the capacity to learn from international examples in terms of what work is being carried out internationally and how the effects of this work are being measured. This work recommends the development of a framework to measure New Zealand's own progress in this area and begins to develop knowledge towards this.

3.2 Relevance to *Keeping Cities Moving*

Keeping Cities Moving is the Waka Kotahi plan for supporting the Government's objectives for mode shift, recognising that it is not possible to continue to accommodate increasing numbers of private vehicles in New Zealand. The plan sets out to support the Government's objectives by shaping urban form, making shared and active modes more attractive, and influencing travel demand and transport choices (Waka Kotahi, 2019). This research constitutes an initial review of some programmes with measured emissions reductions that could support the stated Government objectives. In particular, it highlights different measurement methodologies employed to measure these outcomes, which may be of relevance to *Keeping Cities Moving*.

Under the umbrella of 'Making shared and active modes more attractive', the plan seeks to 'ensure investment policies and processes support mode shift and that assessment and prioritisation includes measure of broader environmental and social benefits' (Waka Kotahi, 2019, pp. 8–9). This research provides insights that align with this part of the plan, providing international examples of the ways in which such investment's outcomes are measured.

The plan also emphasises that work is underway to ensure progress on its goals are measured, including some detail as to the Ministry of Transport's measurement methodologies. This includes the Ministry's intentions to measure GHG emissions reductions from land transport using a whole-of-system approach (Waka Kotahi, 2019). This includes the requirement to report emissions by mode and by region for absolute GHG value, per capita value, percentage changes between years and as a percentage of New Zealand's total emissions. This report provides a level of guidance as to the methodology other jurisdictions are using to generate this level of data.

3.3 Overview of the impacts of traffic capacity expansion

Although the primary focus of this research is to review how travel demand management (TDM) and other land transport programmes can lead to reduced driving and GHG emissions, it is important to note the potential impacts of traffic capacity expansions on per capita driving and emissions. This research is intended for a diverse set of audiences and uses, including developing carbon budget models or understanding the impacts from wider, multi-faceted programmes that include traffic capacity increases. It will be important to include the impacts from the additional driving that could be induced from expanding road capacity in any assessments of the GHG emissions impacts of such programmes. This section provides a brief overview of induced vehicle travel from roadway capacity expansions and the emissions impacts of increasing vehicle travel speed through congestion mitigation.

3.3.1 Induced vehicle travel from traffic capacity expansion

In most jurisdictions, a major portion of transportation resources are devoted to urban roadway expansions. Business cases for traffic capacity expansion programmes frequently cite reduced traffic congestion and emissions as primary benefits to justify the projects. Unfortunately, these short-run gains are often eroded in the medium term through induced vehicle travel. It has been well established that expanding roadway capacity tends to lead to more driving (Cervero & Hansen, 2002; Downs, 1962, 1992; Litman, 2020). Urban traffic congestion tends to maintain a self-limiting equilibrium based on the capacity available. In that situation, much of the additional roadway capacity tends to fill with additional vehicle trips, called 'generated traffic', resulting in net increases in total vehicle-kilometres, called 'induced vehicle travel'. This is a type of *rebound effect*. This has important implications for evaluating transportation system improvement options, particularly when accounting for GHG emissions.

Several studies have quantified induced travel impacts. Handy and Boarnet (2014) reviewed a range of induced travel research and found the short-run elasticity of demand for travel of increased highway capacity generally ranged from 0.3 to 0.6 with long-run elasticities typically from 0.6 to just over 1.0, meaning that each 10% increase in road capacity increases traffic volumes by 3%–6% within two years and 6%–10% within about five years. Duranton and Turner (2011) confirmed Downs' 'fundamental law of highway congestion' by showing that increases in urban motorway capacity led to one-to-one increases in VKT, regardless of population growth. A recent statistical analysis by Hymel (2019) measured the relationships between highway supply and vehicle travel in the United States. This further supported Duranton and Turner's (2011) research, finding that VKT increased in exact proportion with lane-kilometres, and congestion typically returns to pre-expansion levels within five years of capacity expansion (Hymel, 2019). Odgers (2009) found that freeway traffic speeds in Melbourne, Australia, did not increase as predicted following highway construction, apparently due to induced traffic (Odgers, 2009). These studies indicate that in congested areas, adding highway capacity is likely to increase total vehicle travel and emissions over the long run. Although there may be some initial decongestion-related GHG emissions benefits upon opening, these may be much smaller than expected.

It is important to note that capacity expansions generally only generate significant induced travel on congested urban roads. Modest improvements to intercity highways have much less impact.

3.3.2 Vehicle travel speed and emissions

Urban highway capacity expansion projects are sometimes advocated based on reducing emissions through traffic congestion mitigation. Per-kilometre emission rates are generally minimised between about 30 and 60 km/hour, as indicated in Figure 3.1 and Figure 3.2. Reducing extreme congestion (level-of-service (LOS) E or F) so traffic speeds rise above 30 km/hour may reduce emission rates per vehicle-kilometre. However, reducing mild congestion (LOS C or D) so traffic speeds increase above 60 km/hour are likely to increase emission rates.

Figure 3.1 European speed–emission curves (Source: Fontaras, 2014, figure 7)

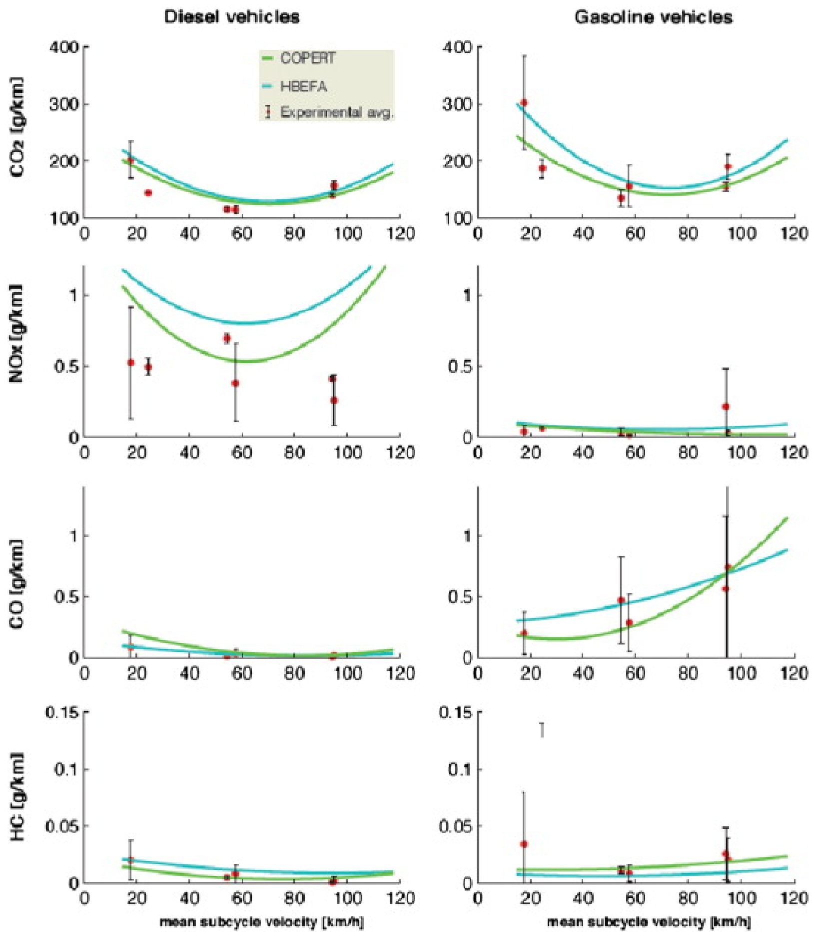
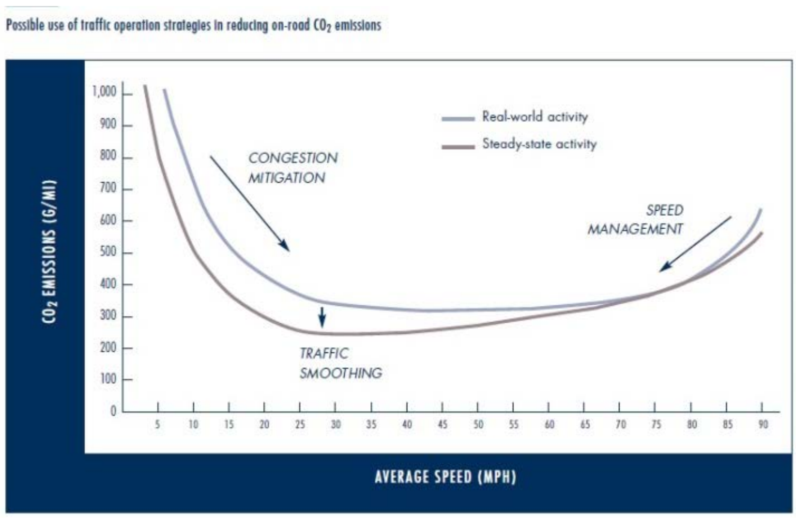


Figure 3.2 United States speed–emission curves (Source: Barth & Boriboonsomsin, 2009, figure 6)



As a result, roadway expansions that reduce extreme congestion may reduce GHG emission rates in the short term, but these impacts may be more than offset over the long run by more high-speed driving and induced vehicle travel (Litman, 2012).

3.3.3 Implications for emission impact analysis

This indicates that there are four impacts to consider when evaluating highway expansion GHG emissions impacts, and comparing them with other congestion reduction strategies:

1. reduced per-kilometre emission rates if roadway expansions significantly reduce the amount of driving that occurs below 30 km/hour
2. increased per-kilometre emission rates if roadway expansions cause a significant increase in travel above 60 km/hour
3. increased total emissions if roadway expansions cause significant induced vehicle travel
4. additional long-term emission increases if highway expansions stimulate more sprawled development.

In contrast, most of the TDM programmes considered in this study reduce both congestion and emissions and help achieve other community goals.

3.3.4 Opportunities for further study

Although this report does not go into the same level of detail about induced vehicle travel as the case study programmes in subsequent sections, the following topics related to induced vehicle travel would provide additional insight if pursued in future research.

- A review of general traffic capacity reduction programmes to understand the scale of VKT and emissions reductions from these programmes and whether they have resulted in increased traffic congestion on the network. If they are found to have emissions benefits without broader network impacts, this could help provide further evidence to support reallocating traffic capacity to public transport, walking or cycling infrastructure. This work could review projects completed in New Zealand and international examples such as the Cheonggye Freeway in South Korea (2003), the Embarcadero Freeway in San Francisco (2003) and Prospect Park in New York (2018).
- A review of recently completed large roading programmes in New Zealand to understand if modelled congestion reductions eventuated. Waka Kotahi conducts benefit realisation reviews (formerly post-implementation reviews) every year on a small sample of completed projects or packages that it has invested in. It would be useful to review a sample of these reports from the perspective of understanding increased demand. Further work could include expanding the review from the individual corridors to understand the impacts on the wider network. This would help inform future modelling of benefits for business cases of transport programmes.
- A review of recent large-scale works in New Zealand that have reduced traffic capacity for extended periods of time to identify if, and how, the traffic network comes to a new equilibrium that produces less VKT and emissions.
- The development of a New Zealand-specific induced travel calculator using the methodology behind the National Center for Sustainable Transportation’s (2019) Induced Travel Calculator, which estimates incremental vehicle travel induced by adding general-purpose or high-occupancy-vehicle lane miles to roadways.

3.4 Individual programme assessment and network benefits

For the purposes of this research, individual programmes have been assessed in terms of their overall effect on GHG emissions or related factors, predominantly VKT. While several programmes include multiple interventions (both incentives and disincentives for particular travel behaviour, for example), others are discrete programmes or land transport programmes. The presentation of programmes in this way does not suggest that any land transport programme has the capacity to influence mode choice or GHG emissions without supporting measures.

When discussing the role of supporting measures for one case study profiled in this work – the Stockholm congestion charge – its lead researcher states that ‘a sustainable urban transport system must incorporate four strategies: attractive public transport, walkability, compact spatial planning, and restraints on car traffic. All these four will strengthen each other, and without one of them, the remaining three will lose effectiveness’ (Eliasson, 2014, p. 3). While some programmes or interventions may have a strong influence on mode choice, and therefore GHG emissions, the success of those programmes generally relies on the strength of the other component. Todd Litman (2014) emphasises the same point within his analysis of TDM, breaking strategies for managing demand for journeys into the four groups: improved transport options; incentives; land use management; and policies and programmes. The strength of a wider approach that includes all four of these categories is that downstream or rebound effects from each policy are more likely to be understood and considered within transport planning.

For these reasons, it is important to recognise that, although this work has sought to report on the GHG emissions reduction and related mode share effects of individual programmes, these do not stand in isolation. Within each case study, other contributing factors have been recognised as much as possible in order to emphasise this. Additionally, it should not be assumed that a 1:1 benefit is likely to be expected in New Zealand as a result of implementation of similar programmes because the local context, availability of public and private transport, land use context and other relevant factors will play a significant role in determining overall outcomes both on mode share and GHG emissions.

3.5 Future trends

This report does not discuss the potential impacts of various future trends, including changing consumer preferences, aging populations and new mobility technologies. The role of COVID-19 or other future pandemics is also not discussed. These are, however, all important considerations for future transport service and infrastructure provision. The scope of this work was to identify programmes with measured outcomes relevant to GHG emissions. Understanding whether the influence of these trends and future changes will influence such outcomes is a further research area.

4 Review of measured reductions

The following sections of the research note summarise each of the key land transport programmes identified in this research. Each programme is summarised in terms of the following details:

- Programme type
- Location of programme
- Scope of programme
- Duration of programme
- Detail of programme (major interventions)
- Methodology for measuring GHG emissions impact of programme
- GHG emissions outcome of programme (according to programme-specific methodology)
- Other contributing factors to GHG emissions reduction (if information readily available)
- Relevance to New Zealand
- Opportunities for further study

Programmes from various countries are reported in this work. Some measure results in vehicle kilometres travelled (VKT) while others measure vehicle miles travelled (VMT). Both measures have been included in this research to accurately report the results of each programme.

Case studies are arranged in the following sections based on type of programme:

- Section 5: Integrated transport programmes
- Section 6: Land use case studies
- Section 7: Parking case studies
- Section 8: Traffic restriction case studies
- Section 9: Walking and cycling case studies
- Section 10: Public transport case studies
- Section 11: Travel behaviour change case studies
- Section 12: Urban logistics case studies

5 Integrated transport programmes

5.1 Boulder, Colorado – integrated transport planning

Programme type	Location	Programme scope
Comprehensive TDM/transport programme	Boulder, Colorado, USA	• Integrated city-wide transport programme. • Boulder city population: 105,673 (2019). • Boulder city/county area: 26.32 mi^2 (68.17 km^2). • Boulder is 42 km from Denver and is part of the wider metropolitan area.

5.1.1 Detail of programme

Boulder's strategy for reducing VMT and GHG emissions is an integrated multi-modal transport planning approach. In 1989, the city of Boulder established its first Transportation Master Plan, the city's long-range plan for travel and mobility, which called for a shift away from single-occupancy vehicle (SOV) travel. In 1996, this was updated with an objective for 'no long-term growth in vehicle travel' over 1994 levels and moved towards a 'complete streets' approach for several major arterials to ensure they could accommodate buses, bikes and pedestrians as well as cars (City of Boulder Transportation Division, 2012).

For context, in 2012, transportation was estimated to account for 22% of GHG emissions in Boulder (City of Boulder Transportation Division, 2012). In comparison, in 2017, transport accounted for 53% of Christchurch's GHG emissions, a city with a similar population to Boulder.

Boulder's approach to reducing VMT has been an integrated set of transport and land use planning interventions. These include:

- **Public transport improvements**
  Starting in 1990, Boulder made major changes to its public transport system, which is largely bus based. Frequencies were increased to 10-minute headways and the city has established funding partnerships (eg, with the university) to maintain these frequencies on specific routes. Figure 5.1 shows bus stop patronage across Boulder's public transport network as of 2013.

- **Cycle facilities**
  An estimated 95% of Boulder's arterial streets accommodate bicyclists, and all local and regional buses in Boulder are equipped with bike racks. Considerable investment in cycle facilities has been made in the past two decades to improve accessibility and support mode shift as part of the integrated planning approach.

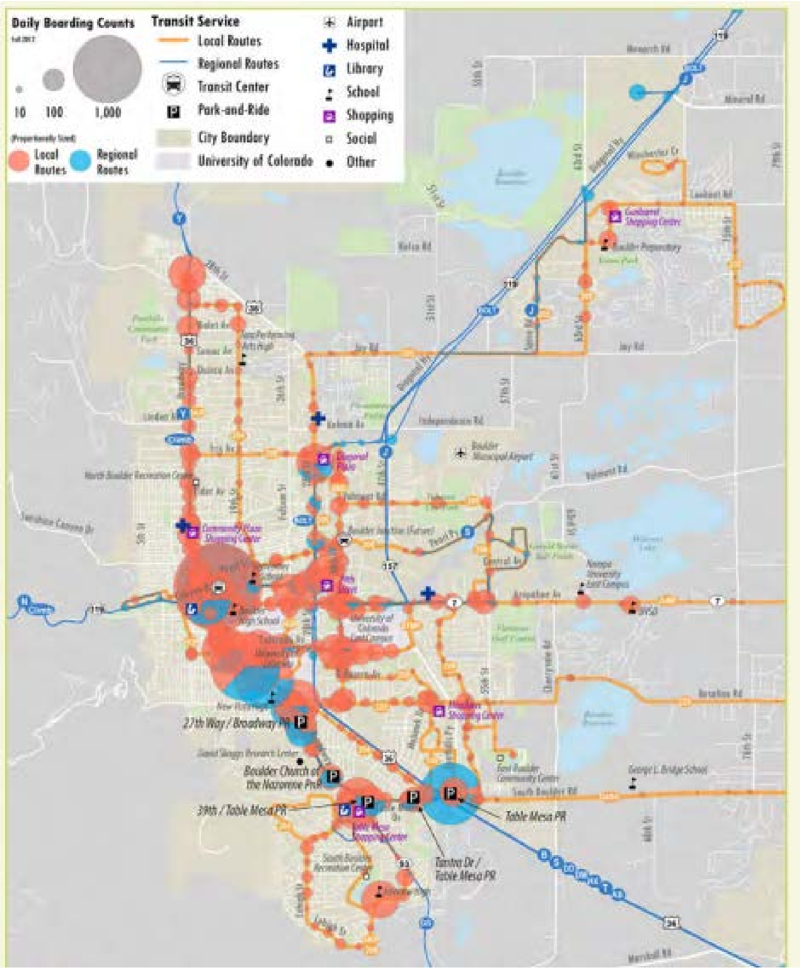
- **Benefit investment districts**
  These have been created so that revenue generated through specific taxes or user pay levies can be used to invest in low-carbon modes. For example, in 2009, US$755,000 (NZ$1,107,000) [2009] of parking revenue was used to subsidise the public transport EcoPass for downtown employees in the Central Area General Improvement District. In addition, 1,300 bike parks were provided to support TDM efforts (Hagelin, 2009).

- **Parking management**
  One of the key goals in Boulder's 2014 Transportation Master Plan is to reduce SOV use to 20% of trips by 2035. The only areas of the city that are on track to achieve this are the areas with paid parking.

- **Coordinated plans**
  Boulder's Climate Action Plan (2002) includes a voter approved carbon tax, revenues from which help subsidise the EcoPass.

- **Land use**
  Boulder has a growth boundary, established by greenbelt investment since the 1960s as well as additional growth management policies (Alternatives to Growth Oregon, n.d.). These measures have supported a compact city and mean transport investments can be made to enhance the existing system rather than support greenfield sites. New development is also planned to be focused on sustainable transport. The development of Boulder Junction, for example, is located next to a commuter rail line, is public transport and pedestrian oriented, and has specific SOV trip targets that are much lower than other neighbourhoods in Boulder.

Figure 5.1 Boulder public transport ridership counts 2013 (Source: City of Boulder, 2013, figure ES-8)



The most substantially researched element of Boulder's approach, however, is its discounted bulk public transport pass programme: EcoPass. This is outlined separately below.

5.1.1.1 EcoPass

The EcoPass programme is the city's most recognised Transportation Master Plan tool, and its effects on vehicle travel have been measured specifically. EcoPass is an annual public transport pass that allows unlimited rides on all local, regional, and light rail services, including free travel to and from Denver International Airport (a distance of 67 km).

It is only available for purchase as a bulk product, not to individuals, due to the pricing mechanism. The EcoPass programme is based on an 'insurance model', which means EcoPasses must be purchased for every employee (or college student or resident of a participating neighbourhood) regardless of use. Since not every employee will use the pass (and some will use it infrequently), the EcoPass can be offered at a substantially reduced price per person compared to a typical monthly public transport pass.

After a successful pilot in 1989, the pass was implemented as part of the University of Colorado's student pass programme. It was subsequently available to employers as the Business EcoPass in 1993, and the Neighbourhood Eco Pass in 1997. Under this last programme, residents within a specific geographic area can coordinate to purchase the pass in bulk to access the significant discount.

These passes are seen to be essential in making public transport competitive with other modes, and EcoPass holders are reported to use public transport 5–9 times more than people without them (Boulder County, 2014). Similar bulk purchase schemes are used at universities around the USA, and the concept seems to have increasing support (Fortunati, 2018).

Benefits of the EcoPass programme include:

- increased public transport patronage
- reliable revenue source for the Regional Transportation District, paid in advance
- improved operational efficiency of public transport system because of a faster boarding process
- reduced parking demand for employers and colleges/universities that participate in the programme (Boulder County, 2014)
- reduced cost of transport for most users.

5.1.2 Measurement methodology

> *'If you don't count it, it doesn't count.'* (City of Boulder Transportation Division, 2012, p. 6)

Boulder has been collecting detailed travel data on both residents and non-resident employees since 1990, allowing for an estimate of daily individual VMT for each transportation sector. Twelve travel surveys have been undertaken between 1990 and 2018, allowing measurement of trends.

Participants in the travel diary studies keep a log of their travel for one randomly assigned day. They record the origin and destination of every trip, the travel mode used, the time of day, the number of people in the vehicle (if applicable), and the distance travelled. Trips are defined as any 'one-way travel from one point to another that takes you further than one city block (about 200 yards) from the original location' (National Research Center, 2019). It should be noted that the city uses these surveys as a means to track changes over time rather than to provide a national comparison, as survey methodologies differ significantly.

Travel diary results are supplemented with vehicle counts, bicycle counts, public transport ridership statistics, travel time studies, and census data to provide a comprehensive understanding of travel in the city (City of Boulder Transportation Division, 2012).

While Boulder reports estimates of GHG emissions reductions, detailed information on the methodology for translating VMT measures into GHG emissions has not been identified during this review.

5.1.3 GHG emissions outcomes

For this case study, emissions reduction estimates are broken into two groups based on the available data. The first is reported changes to VMT and emissions for Boulder, which, while representing an important outcome of integrated planning, are more difficult to attribute to any specific programme. The second group of data reported is for the EcoPass specifically. Mode shift between 1990 and 2018 is also outlined to provide additional context. Boulder had considerable success in reducing VMT in the first decade of the 21st century, meeting its goal of no growth in VMT over 1994 levels by 2009. However, subsequent years have seen limited VMT reductions, and in some cases, increases.

5.1.3.1 Boulder VMT changes 1994–2009

Boulder achieved its 1996 Transportation Master Plan objective to return VMT to 1994 levels by 2009. For perspective, during this period, the city of Boulder's population increased by 10,000 and approximately 12,000 new jobs were added. This success has been attributed to the strong coordination between land use policies and the multi-modal transportation investments made by the city. By 2016, it was estimated that these efforts had reduced VMT, and thereby GHG emissions, by over 30% from where they would have been without transport planning interventions (American Planning Association, 2016).

In 1990, total annual VMT per capita was 6,811 miles (10,961 km), and by 2018 this had reduced to 5,490 miles (8,835 km), as shown in Table 5.1 below.

Table 5.1 VMT per capita in Boulder, Colorado, 1990–2018 (Source: National Research Center, 2019, figure 25)

Calculating per capita VMT	2018	2015	2012	2009	2006	2003	2000	1998	1996	1994	1992	1990
Average number of SOV trips per day per person	1.80	1.75	1.65	1.80	2.03	2.00	2.36	2.28	2.41	2.37	2.34	2.49
Average estimated SOV trip length in miles	4.8	5.2	5.3	6.1	5.2	5.7	5.0	5.1	5.1	5.2	5.2	4.6
Estimated SOV VMT per capita per day (average number of trips x average trip length)	8.64	9.10	8.75	10.98	10.56	11.40	11.80	11.63	12.29	12.32	12.17	11.45
Average number of MOV trips per day per person	1.10	1.11	0.94	1.14	1.40	1.26	1.38	1.44	1.52	1.49	1.44	1.52
Average estimated MOV trip length in miles	7.0	7.8	6.0	7.5	6.2	8.6	6.4	6.1	7.5	6.8	6.6	5.8
Estimated MOV VMT per capita per day (average number of trips x average trip length)	7.70	8.66	5.64	8.55	8.68	10.84	8.83	8.78	11.40	10.13	9.50	8.82
TOTAL VMT per capita per day (SOV VMT + MOV VMT)	16.34	17.76	14.39	19.53	19.24	22.24	20.63	20.41	23.69	22.46	21.67	20.27
TOTAL annual VMT per capita per day (assumes 48 weeks a year, 336 days)	5,490	5,967	4,833	6,562	6,463	7,471	6,932	6,858	7,960	7,545	7,282	6,811

SOV = single-occupancy vehicle; MOV = multiple-occupancy vehicle

5.1.3.2 EcoPass

Boulder residents with an EcoPass report driving 2,600 fewer miles (4,184.29 km) per year than those without an EcoPass, while employees with an EcoPass report driving 2,300 fewer miles (3,701.49 km) than those without (Hagelin, 2009). This is estimated to generate 40% fewer emissions for residents with an EcoPass and 55% fewer emissions for employees with an EcoPass in comparison to those without (Hagelin, 2009).

5.1.3.3 Change in mode share

The 2018 Boulder Modal Shift Report highlights major trends in mode shift for all trips between 1990, when the travel diaries were introduced, and 2018. The shift is measured as the difference in the percentage of trips or miles by each mode between 1990 and 2018. As shown in Table 5.2, there has been a strong shift away from SOV travel to bicycle and public transport for commute trips over this period.

Table 5.2 Change in mode share (all trips and commuters) in Boulder, Colorado, 1990–2018 (adapted from National Research Center, 2019)

Category	All trips	Commute trips
Single-occupancy vehicle	−7.5%	−32.3%
Multiple-occupancy vehicle	−5.0%	N/A
Bicycle	+7.9%	+23.1%
Public transport	+3.4%	+8.3%

5.1.4 Other contributing factors

Boulder's integrated approach to multi-modal transport, along with land use planning, has had an important impact on its success in reducing SOV travel, increasing public transport and cycle mode share, and reducing GHG emissions. While this integrated approach is often critical to achieving transport goals, it does make it more difficult to attribute success to individual programmes. The nature of the programme as an integrated approach means many of the factors that, in a more discrete programme, would be considered to have a supporting role are core elements. The combination of investment in public transport and active modes, coordinated land use and transport planning, and demand management tools such as parking management and large-scale public transport pass programmes have all contributed to Boulder's emission reduction outcomes.

5.1.5 Relevance to New Zealand

Several of the interventions undertaken by Boulder to support a shift to low-carbon modes are of relevance to New Zealand. Bulk public transport passes purchased through employers and large educational institutions such as the EcoPass have been found to have a positive impact on ridership numbers in several jurisdictions. This could be investigated for large urban areas as well as locations with large campuses. The neighbourhood EcoPass is a particularly interesting model where community members work together to access the bulk discount. This is a model that could be considered for new or regenerated communities such as those being developed by Kāinga Ora where a central body could mitigate some of the coordination and equity challenges associated with this model by purchasing these passes separately and supplying to residents rather than bundling it into the price of housing. This type of bulk pass may also be supported by local transport authorities as a secure revenue stream generated by the passes being purchased in advance. More broadly, there are insights that can be drawn from Boulder's coordinated multi-modal planning approach and strong target setting and monitoring programmes.

5.1.6 Opportunities for further study

- Tracking VKT per capita in New Zealand, both nationwide and in smaller jurisdictions, would allow progress tracking as well as identification of trends. This is something that warrants further investigation as we seek to meet emission reduction goals.

5.2 Washington State – Commute Trip Reduction programme

Programme type	Location	Programme scope
Comprehensive employer-based TDM programme	Washington State, USA	• This is the only comprehensive statewide employer-based commute trip reduction (CTR) programme in the United States. • Washington State has a population of 7.6 million. Seattle is the state's biggest city with a regional population of 3.87 million and shares many geographical similarities with Auckland.

5.2.1 Detail of programme

In 1991, the Washington State Legislature passed the Commute Trip Reduction (CTR) Law (renewed in 2006 as the CTR Efficiency Act). The law seeks to meet environmental goals as part of the state's Clean Air Act by reducing vehicle emissions, congestion, and fuel consumption. It requires major employers (100+ employees) to implement strategies to reduce the number and length of drive-alone commute trips for employees. More than 1,000 worksites and 550,000 commuters participated statewide.

Participating employers are required to establish an employee transportation coordinator to administer the programme, distribute information about the programme at least twice per year, and select trip reduction strategies from a toolkit of interventions. These are developed by local jurisdictions, similar to city or district councils in New Zealand, rather than at the state level. As an example, recommended programme elements in Seattle's CTR toolkit include (Commute Seattle, 2017):

- providing free or subsidised public transport passes
- providing secure bike parking and end-of-trip facilities
- providing pre-tax benefits linked to choosing alternative modes of transport (Seattle.gov, 2020)[2]
- charging for parking.

The CTR programme is funded at US$6 million (NZ$8.9 million) statewide every two years (2006 onward). For every taxpayer dollar that goes into the programme, businesses invest an estimated US$20 (NZ$29) in their CTR transport management plans (Washington State Commute Trip Reduction Board, 2017). Approximately half the state funding is allocated to the Washington State Department of Transportation (WSDOT) for administering the programme at the statewide level, including a biennial travel behaviour survey. The remaining funds are allocated to jurisdictions on a per capita basis to support local programmes.

The CTR programme has historically included statewide performance goals and targets. In the 2015–2019 Statewide Plan, one of the three goals was to 'reduce the state's greenhouse gas emissions to 1990 levels by 2020' with a target of an 18% daily GHG emissions reduction per employee, which reflects a VMT reduction target of the same percentage (Washington State Commute Trip Reduction Board, 2015, p. 1). In 2019, WSDOT moved to a more comprehensive approach to demand management and renamed the statewide plan as the Transportation Demand Management Strategic Plan 2019–2023. This also appears to include a move to less concrete targets, with the performance indicator relating to emissions framed as 'increased statewide CTR programme participation and performance (e.g. mode shift, energy conservation, air quality, and GHG reductions)' (Washington State Commute Trip Reduction Board, 2018, p. 7).

[2] In 2020, Seattle instituted a commuter benefits ordinance that requires organisations with more than 20 employees to offer a pre-tax deduction for public transport expenses.

5.2.2 Measurement methodology

Measurement of VMT/GHG emissions reductions from the CTR programme is largely achieved through a biennial travel behaviour survey administered centrally through WSDOT for CTR-affected employers (WSDOT, 2020). Employers are required to conduct a baseline measure of employee commute behaviour, via a state-provided employee questionnaire, within 90 days of becoming a CTR-affected employer.

WSDOT calculates per employee VMT as:

*(Adjusted Trips / Potential Trips) * (Total Miles / Total Respondents)*

(Washington State Commute Trip Reduction Board, 2019b, p. 1)

Adjusted trips are measured as the sum of all full and partial drive-alone trips for all employees for all days of the week. Partial trips are divided by vehicle occupancy. Potential trips are measured as the sum of 'all trip modes' (includes telework and compressed work weekdays but excludes 'overnight trips' or days not worked).

WSDOT calculates Average Annual GHG Emissions as:

*Average GHG emissions per mile * Total VMT * 0.001*

(Washington State Commute Trip Reduction Board, 2019a, p. 1)

This conversion of VMT reductions to GHG emissions reductions is based on the Greenhouse Gas Equivalencies Calculator published by the United States Environmental Protection Agency (Washington State Commute Trip Reduction Board, 2017). The inclusion of the multiplier 0.001 is used to convert kilograms to metric tonnes.

WSDOT reports that statewide performance goals for GHG emissions are measured or tracked by WSDOT themselves, the Department of Ecology and the Governor's office. At the local level, implementation partners are responsible for measuring the effectiveness of their local management strategies (Washington State Commute Trip Reduction Board, 2015).

5.2.3 GHG emissions outcomes

WSDOT reported a statewide 13% reduction in daily VMT per CTR-participating employee between 2007 and 2018, from 10.9 miles (17.54 km) to 9.5 miles (15.28 km). This reduction in VMT is indicated as being equivalent to an annual reduction of 75,000 metric tonnes in GHG emissions (WSDOT, n.d.). In comparison, the city of Seattle reported a decrease in daily VMT per CTR employee from 5.9 miles (9.49 km) to 4.4 miles (7.04 km) between 2007 and 2016, a reduction of 23% (Seattle Department of Transportation, 2019). This indicates an ability to have a greater impact on travel behaviour in large urban areas with more transportation alternatives. This is to be expected but provides some insight into potential benefits of such a strategy for New Zealand's urban areas.

For a finer-grained analysis, a 2007 study by Georggi et al. (2007) looked at the impacts of the CTR programme on the interstate highway I-5 corridor, which runs through downtown Seattle. The study corridor was selected in an area with a high concentration of CTR-participating employers where quality data was regularly collected through the biennial travel survey. By comparing the CTR programmes of 189 employers (62,947 employees) against traffic conditions that would have existed without these plans, the study authors report savings in terms of carbon emissions in the order of 1,109 and 1,545 kilograms daily for the morning and evening peak, respectively. The study also notes reductions in congestion, travel delay, vehicle speed and fuel use. In terms of measuring the system-wide impacts of this type of programme, the authors of this study note that the dispersed nature of employer-based programmes does pose a challenge (Georggi et al., 2007).

5.2.4 Other contributing factors

At the state level, a key piece of legislation that has supported mode shift and emissions reductions through integrated land use transport planning is the Growth Management Act. This was passed in 1990 in response to dramatic population growth in the preceding decade. The Act established statewide goals and procedures for managing growth, requiring state and local governments to designate urban growth areas, prepare comprehensive plans, and coordinate a regional transport strategy. Critically for emissions reductions, this had a requirement for TDM strategies and programmes to be included in county and local plans, and by public transport agencies. Examples of strategies included efforts to:

- shift the timing and mode of trips to avoid peak travel times and to increase the share of trips by public transport, ridesharing, cycling, and/or walking
- decrease trip lengths
- eliminate certain vehicle trips all together.

As Seattle's regional population represents half the state's population, identifying supporting factors to the CTR success of cities is also interesting to note. Key strategies and programmes include:

- **Public transport investment**
  Seattle has invested heavily in its bus network and increasingly in light rail, through voter-backed tax increases to fund public transport improvements. Bus patronage increased from 87.5 million trips in 2010 to 102.3 million trips in 2015. In comparison, Seattle's population grew by approximately 70,000 residents over the same time period. Furthermore, in 2015, an estimated 25% of residents lived within a 10-minute walk of a frequent service, and this jumped to 64% in 2017 (Thomas et al., 2020).
- **Employer-based public transport passes**
  Employers are able to purchase the 'ORCA Passport' for their employees at a discount as part of a benefits package. This pass, along with the 'business choice' pass, which employers can purchase at retail cost, accounted for over half of the regional transit pass's initial adoption when it was first introduced in 2009 (Shared-Use Mobility Center, 2017).
- **Property-based plans**
  New developments are required to establish transportation management programmes as part of their Master Use Permit to 'mitigate traffic congestion and parking impacts by reducing drive-alone automobile and motorcycle trips' (Commute Seattle, 2020, para. 1). This includes an SOV commute rate goal as well as specific strategies to achieve it such as parking management goals. Transportation management programmes share the same overall goal as the CTR programme but affect buildings (and all the tenants therein) while the CTR programme affects employers (Commute Seattle, n.d.).

5.2.5 Relevance to New Zealand

One of the reasons given for the success of the CTR programme is employer buy-in, as the strategies are viewed as a way to attract and retain employees. While the programme is embedded in legislation, it is implemented as a partnership rather than a requirement, which is an important lesson if such a programme were to be considered in New Zealand. The longitudinal relationships established between the government and the employers are reported as being particularly important to success. The centralised administrative support for measuring outcomes through the biennial travel behaviour survey, and the secure annual funding source, are also reported as important supporting elements of the statewide CTR programme.

A key element for success is the availability of employee transit benefits subsidised by the central government. This would require a much larger policy and programmatic shift in New Zealand. This is an important tool for employers to be able to offer as an alternative to a company car or parking benefit and has demonstrated results in supporting a shift to higher public transport patronage for commute trips. Employer-provided public transport passes are currently subject to the fringe benefit tax in New Zealand, whereas free carparking and company cars are not (Scott et al., 2012). Removing the fringe benefit tax from public transport offerings could unlock this option for employers to more easily partner with government to meet policy goals of reducing VKT and emissions.

5.2.6 Opportunities for further study

- Adopting trip reduction strategies into legislation and therefore establishing a robust and consistent monitoring programme and secure funding would allow jurisdictions to invest in these sorts of programmes with confidence. These warrant further study in New Zealand as cities and towns seek to meet carbon reduction goals.

5.3 Arlington County Commuter Services – TDM agency

Programme type	Location	Programme scope
TDM	Arlington, Virginia	A comprehensive TDM agency for Arlington County that provides various services (from information sharing to providing advice and recommendations) to people living in, working in or visiting Arlington. Arlington County is a county and city in the Washington, DC, metropolitan area, with a population of 236,842 and area 67.34 km^2.

5.3.1 Detail of programme

Arlington County Commuter Services (ACCS) is the TDM agency for Arlington County. It is composed of nine business units with varying focuses (ACCS, 2013):

- **Arlington Transportation Partners** is a business-facing unit that aims to help implement commuter benefit programmes, such as providing transit information, bulk fare card purchases, and providing customised TDM plans for planned developments.
- **Commuter Stores™** provide information, brochures and assistance at physical stores and at several mobile stores.
- **The ACCS Marketing Team** is an internal team that provides marketing support for all programmes and events coordinated by any branch of ACCS.
- **Commuter Information Center and Distribution Group** provides information, assistance, transit pass sales, online information and call centre support for all other business units.
- **BikeArlington** promotes bicycling as a transport option by providing information, programming and advocacy.
- **WalkArlington** promotes walking both as a transport option and recreationally by providing information, programming, advocacy and walking tours.
- **Capital Bikeshare** operates and markets the regional bike sharing service for the Arlington area.

- **TDM for Site Plan Development** develops infrastructure requirements for buildings before they are constructed, and monitors implemented site plans to enforce their responsibilities.
- **Mobility Lab™** is an internal research and development team that measures and evaluates the effectiveness of all TDM programmes.

The common theme across all units within ACCS is about providing information and supporting organisations to encourage modes other than SOVs. The following points summarise the types of activities that ACCS engages in.

- Organise bicycle safety classes and walking tours in residential areas.
- Promote ride-matching services for people wanting to travel with others.
- Provide information and resources both in physical locations and online to help people understand different transport options.
- Provide information to organisations (eg, employers, service providers) and the people accessing them (eg, employees, customers).
- Help organisations develop transport plans, understand the impacts of transportation options, and apply for awards for sustainable transport use.

5.3.2 Measurement methodology

ACCS has a performance tracking plan based on 17 performance measures. Of particular interest for understanding GHG emissions are the 'Average Weekday Vehicle Trips and Miles Reduced in Arlington by ACCS' and 'Greenhouse Gas Emission Reductions Attributed to ACCS'. The methodology for calculating these two measures is as follows (ACCS, 2008).

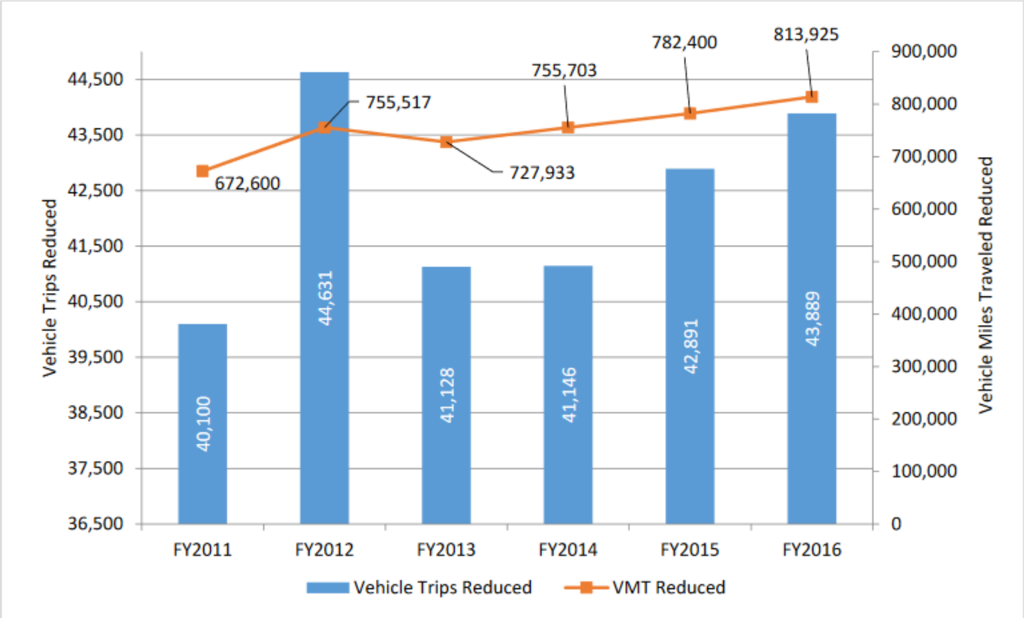
1. **Estimate the affected commuters**: Estimate the number of commuters who have used services from each ACCS business unit.
2. **Estimate 'placements'** (travellers whose choices were influenced by an ACCS programme): Apply a 'placement rate' (collected from surveys) to the number of affected commuters from step 1.
3. **Estimate vehicle trips reduced**: Apply a 'vehicle trips reduced' factor (collected from surveys) to the number of placements.
4. **Estimate reduced VMT**: Multiply the vehicle trips reduced by the average travel distance for each trip (collected from surveys).
5. **Estimate emissions reduced:** multiply vehicle trips and vehicle miles reduced by emissions factors obtained from the Metropolitan Washington Council of Governments for oxides of nitrogen (NO_x), volatile organic compounds (VOCs) and carbon dioxide (CO_2).
6. **Correction to avoid double counting:** For people who use multiple ACCS services, their travel behaviour change is attributed to the 'primary' service they used.

5.3.3 GHG emissions outcome

From 1980 to 2013, Arlington saw a 38% growth in population and 35% growth in employment, with almost no increase in road infrastructure or in vehicular traffic (Victoria Transport Policy Institute, 2019a).

ACCS reports that in the years 2011–2016, its activities resulted in 40,000–45,000 fewer vehicle trips per weekday, equating to 673,000–814,000 fewer VMT (1,083,088–1,310,006 km) (ACCS, 2017), which equates to around 350 tonnes of reduced emissions per day (Jennings, 2014). This change, including both VMT and vehicle trip reduction, is shown in Figure 5.2 below.

Figure 5.2 Arlington County vehicle trips/VMT reduced FY2011–FY2016 (Source: ACCS, 2017, figure 6)



ACCS reports also note the estimated reduction of CO_2 emissions; however, these results are not reported here as the reported results appeared erroneously high, potentially due to incorrect units of measurement being reported in the study.

5.3.4 Other contributing factors

Arlington is a relatively dense inner suburb of Washington, DC,[3] that is well-connected with frequent, high-capacity public transport to Washington and the rest of the region. The Rosslyn-Ballston Corridor is an example of highly successful comprehensive transit-oriented development (TOD) planning, which has significantly increased population and employment around five stations along the Washington Metro Orange Line through Arlington (Maryland Department of Planning, n.d.). The presence of this land use and infrastructure likely affected the upper limit of potential success from the TDM programmes. Another contributing factor is that Arlington did not significantly expand road capacity to match population and employment growth. As described by Downs' Fundamental Law of Road Congestion, increases in road capacity would likely have led to increased VKT through induced demand (Downs, 1962; Duranton & Turner, 2011). ACCS engaged in multiple TDM programmes simultaneously. These varied approaches would have supported one another to provide a combined impact that is likely greater than the sum of the parts.

[3] Arlington is located across the Potomac River from Washington, DC, and was part of the original District of Columbia before being returned to Virginia State.

5.3.5 Relevance to New Zealand

5.3.5.1 Applicability to New Zealand

The ACCS agency and case study is applicable to New Zealand because it shows how a single agency can be structured to provide support and information to the public and other organisations and the impacts these activities can have on GHG emissions. In particular, detailed surveys have been conducted, and findings collated from work done by the Arlington Transportation Partners and TDM for Site Plan Development units provide insights into what TDM activities appear to yield the greatest mode shift away from SOVs.

5.3.5.2 Insights from the programme relevant to New Zealand

Analysis of surveys from 36 properties across Arlington County between 2010 and 2015 (with over 2,900 individual responses) were used to summarise the TDM features with the greatest and lowest impact on travel behaviour change away from SOVs (Mobility Lab, 2018).

- The TDM measures with the greatest influence on 'drive alone' mode share are:
  - **availability of public transport information**
  - **convenient access to carshare**
  - **ability to buy public transport cards on site.**
- **Travel information** is the most used TDM service. The least used (although most frequently provided) is secure, weather-protected bicycle parking and/or visitor bicycle parking.
- **Parking unbundled from housing**: Where parking is unbundled from residences, car ownership is, on average, 6% lower per residence.
- **Paid parking at work**: When parking shifts from free to paid at a workplace, the 'driving alone' mode share reduces from an average of 71% to 28%.
  - Nearly 75% of people that drive alone to work have free parking.
  - 60% of people that use 'other modes' do not have free parking at work.
- **Proximity to metro station**: The commute mode share by metro for residential buildings within half a mile (800 m) of a metro station was 43% compared to just 26% for buildings more than a mile (1,600 m) away from a metro station.
- **Proximity to public transport**: Of people that do not drive alone to work, 81% live within half a mile (800 m) of public transport and 84% work within half a mile (800 m) of public transport.

5.3.6 Opportunities for further study

- Through its single TDM agency, ACCS has been able to identify activities that have had the greatest impact on travel behaviour such as accessible travel information for public transport services and the ability to purchase public transport cards on vehicles. Further study could be undertaken to learn from these outcomes to prioritise investment in New Zealand.

6 Land use case studies

6.1 California – transit-oriented development

Programme type	Location	Programme scope
Transit-oriented development (TOD) and high quality transit areas (HQTAs) (areas within a defined distance of public transport with designated frequencies)	State of California (USA)	Household travel survey data from 40,000 households across various income groups and types of housing development. Not constrained to one city within California.

6.1.1 Detail of programme (major interventions)

This analysis profiles the results of a US-based study looking at the role that household proximity to public transport – specifically, TOD and HQTAs – has on VMT (California Housing Partnership Corporation & TransForm, 2014). This study specifically focused on understanding variability of impacts at different levels of household income.

Other studies have found (by way of modelling) significant differences in GHG emissions based on proximity to public transport. For example, a modelled study in the city Chicago, Illinois, found that living in an area within half a mile of public transportation can enable an average household to reduce GHG emissions by 43%, while living in the central city areas with the highest concentration of public transport and local services can enable average households to reduce emissions by 78% (Center for Neighbourhood Technology, 2010). The California-based case study profiled here supports the hypothesis that TOD and HQTAs can potentially lead to significant GHG emissions reductions via reduced VMT of residents.

Two types of areas were identified within the analysis as being relevant in determining relationships between travel and proximity to public transport. These 'transit rich' areas were made up of:

- TOD, defined by the California Department of Housing and Community Development as housing within a quarter mile (400 m) of a qualifying rail or ferry station or a bus stop with 10-minute headways during the peak period (defined as 7 am to 10 pm and 3 pm to 7 pm on weekdays). For any transit stop to qualify, it must offer hourly service on weekday evenings from 7 pm to 10 pm and have at least 10 trips on both Saturday and Sunday (California Department of Housing and Community Development, 2013).
- HQTAs, defined as 'the area within ½ a mile [800 m] of a rail or ferry station, regardless of service frequency at that station, as well as all bus stops with at least 15-minute headways during the peak period' (California Housing Partnership Corporation & TransForm, 2014, p. 6).

6.1.2 Measurement methodology

Rates of VMT are obtained from the California Household Travel Survey, which collects one-day travel surveys from more than 40,000 households from every county in California. A total of 36,197 surveys from between February 2012 and January 2013 were used for the TOD analysis.

Household income was broken into five categories:

- **Extremely Low Income**: Households earning 30% or less of median family income
- **Very Low Income**: Households earning 50% or less of median family income
- **Low Income**: Households earning 80% or less of median family income

- **Moderate Income**: Households earning between 80% and 120% of median family income
- **Higher Income**: Households earning more than 120% of median family income

The effects of the two relevant housing types outlined in section 6.1.1 above were independently assessed.

There are two main methodological limitations of this piece of work. First, this is a point-in-time analysis of household travel survey data, and not a longitudinal study, so does not discuss the results over time for particular households, which would provide more in-depth data. Second, the influence of selection bias is not discussed in the report – ie, people who choose to live in these types of developments may be more likely to use public transport than the general population. If this is the case, then results may be overstated or not able to be generalised to other developments. However, it is important to note that there is relative scarcity of this type of development, and people who would prefer not to drive may be forced to do so because the only housing available to them is not transit-accessible. In this case, providing TOD would still lead to desired mode shift because the choice to use transit was not previously available.

Other research has discussed the role of selection bias in the analysis of TOD and its effect on VKT. This is discussed by Chen et al. (2017) in a study of the VKT reduction effects of TOD in the Chinese city of Shanghai. The study controlled for self-selection while measuring the effects of TOD among 2,038 residents. It found that, while self-selection is a contributing factor, the built environment plays the dominant role in influencing travel behaviour in such cases. This study also summarises the results of several other studies that find similar results in both North American and European studies, noting that the Chinese context is unique due to restrictions on residential choice (Chen et al., 2017). Studies within a New Zealand context would provide more accurate detail as to the effect of self-selection compared to built form.

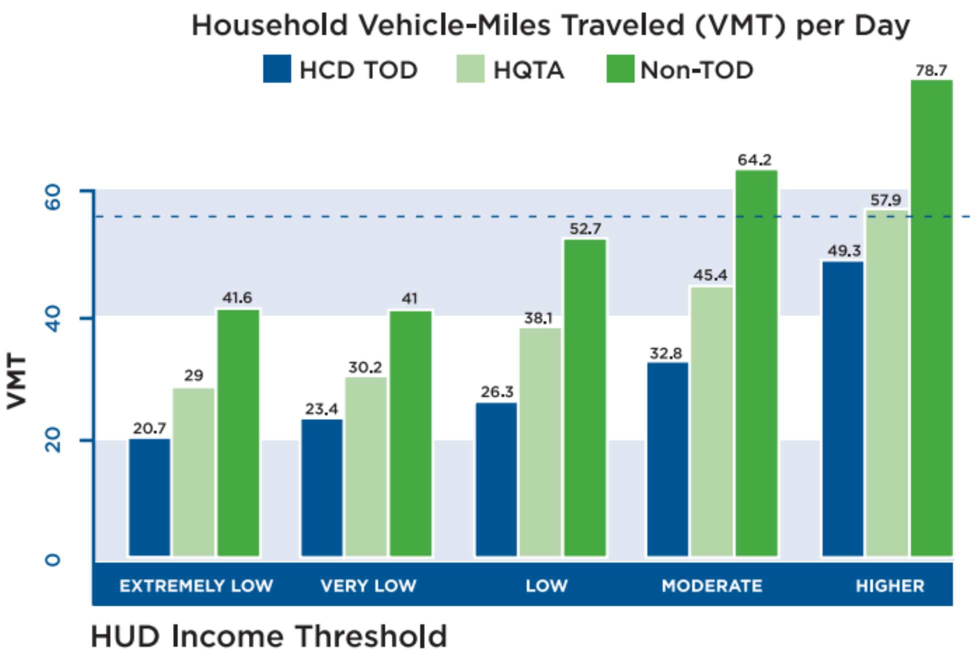
6.1.3 GHG emissions outcome

The study of household travel survey data found that proximity to public transport has a large effect on both the number of household trips and total household VMT (California Housing Partnership Corporation & TransForm, 2014).

All income groups had lower rates of VMT when living in both TOD areas and HQTAs. Daily VMT was lower for all types of public transport access areas among low-income households when compared to high-income groups.

The study found that all income groups living in HQTAs had 25%–30% lower VMT than households with similar incomes living in areas with fewer public transport options. Results were even stronger for TOD areas compared to non-TOD areas. Households in TOD areas were found to have between 37% and 50% lower VMT rates compared to households with comparable income levels in non-TOD areas. The household VMT per day between the different areas, by income, are shown in Figure 6.1 below.

Figure 6.1 Average household VMT per day between different public transport accessible locations and income, California, 2012–2013 (Source: California Housing Partnership Corporation & TransForm, 2014, figure 1)



HCD = California Department of Housing and Community Development

HUD = U.S. Department of Housing and Urban Development

It should be noted that this is not a reduction based on the implementation of a programme; rather, it is a measure of difference in vehicle use between two different types of neighbourhood. However, the study authors followed up this research with analysis of the potential GHG emissions reduction benefits of investing in providing more affordable housing in similar TOD environments.

The analysis estimates that, based on household travel survey data, adding 15,000 public transport connected homes would reduce annual VMT by 105 million (168 million VKT), resulting in a reduction of 1.58 million metric tonnes of GHG emissions over the estimated course of the lifetime of the buildings (55 years) (California Housing Partnership Corporation & TransForm, 2014). The calculation translating VMT into GHG emissions is not included in the referenced report. The study suggests that these estimates are conservative, due to their lack of accounting for on-site trip reduction strategies, access to other services such as carshare, and the potential vehicle efficiency differences between low- and high-income households. The study suggests using travel surveys and vehicle counts to monitor outcomes as affordable TOD housing is developed.

In addition to measuring VMT, the study also measured the average vehicle ownership for households in the different income brackets in different housing types, and household public transport trips per day for each. These are represented in Figure 6.2 and Figure 6.3 below, taken directly from the original report.

Figure 6.2 **Average household vehicle ownership for households in the Californian Household Travel Survey, grouped by TOD household type and income, 2012–2013 (Source: California Housing Partnership Corporation & TransForm, 2014, figure 2)**

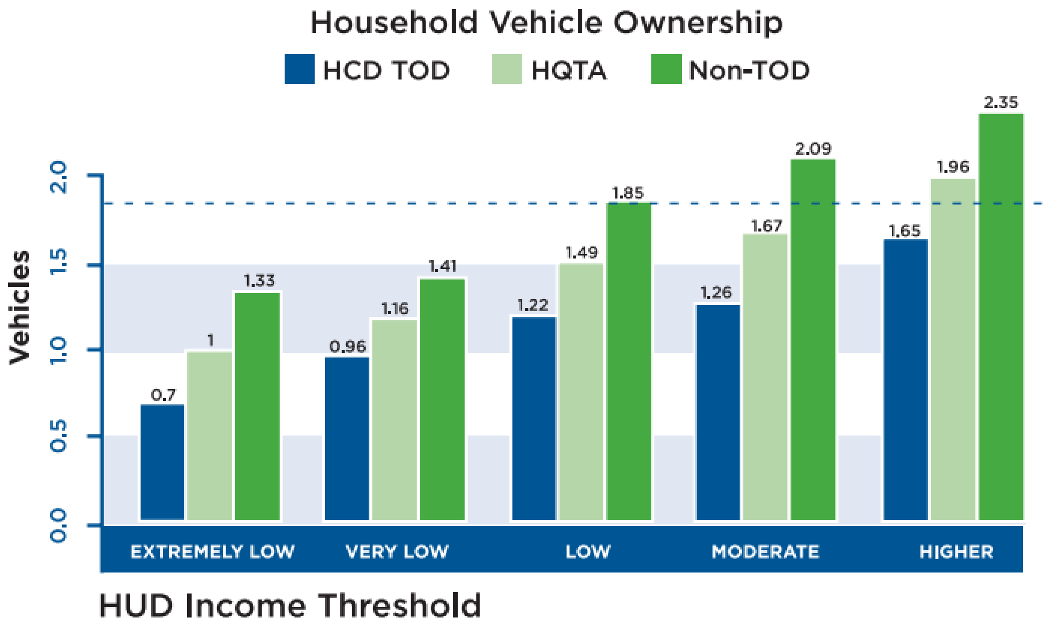
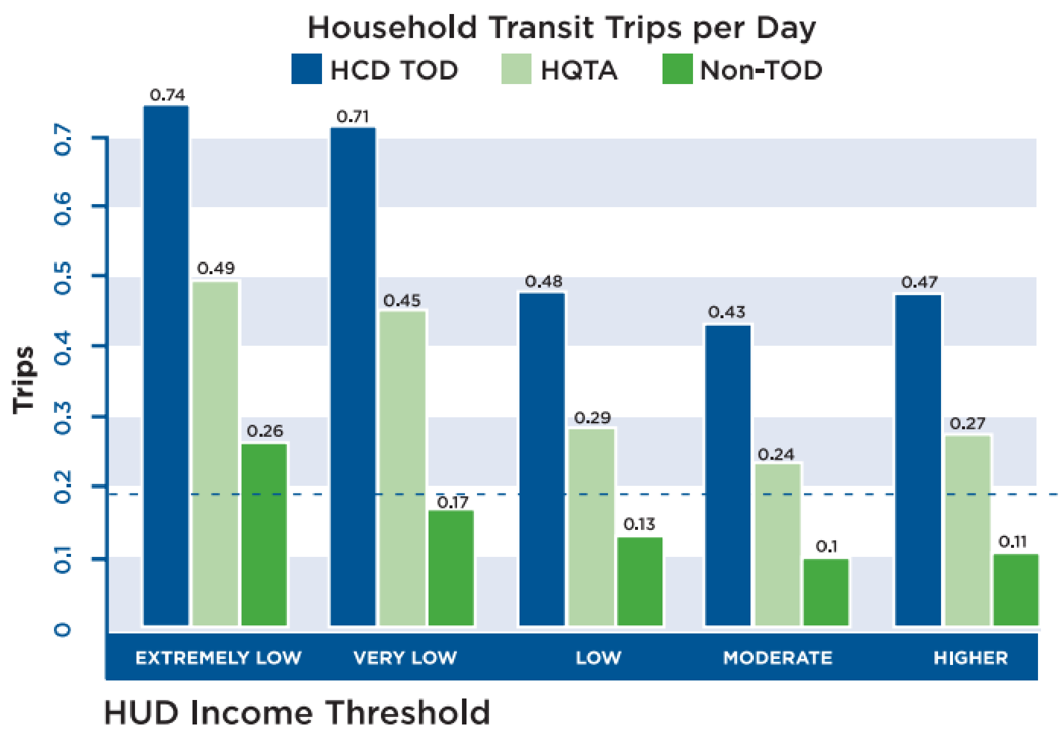


Figure 6.3 **Average household public transport trips per day for households in the Californian Household Travel Survey, grouped by TOD household type and income, 2012–2013 (Source: California Housing Partnership Corporation & TransForm, 2014, figure 4)**



6.1.4 Other contributing factors

The effects of TOD can be amplified by additional accompanying measures. The study profiled in this section points out that additional contributing factors that made the sites studied successful were:

- suitable access to services and job centres
- the availability of additional benefits such as:
  - free or discounted public transport passes for residents
  - innovative parking approaches such as shared parking between different car uses
  - dedicated parking spaces for carshare vehicles.

Other studies have suggested pricing policies, including parking pricing or road pricing, and public transport system improvements as necessary tools to complement TOD (Bedsworth et al., n.d.).

6.1.5 Relevance to New Zealand

The benefits of TOD have a high degree of relevance to New Zealand. The National Policy Statement on Urban Development will enable a greater density of development within walking distances of existing and planned rapid public transport routes. The policy mandates a minimum six-storey height limit in these areas. Furthermore, it removes minimum parking requirements from urban areas with populations over 10,000 (Ministry of Housing and Urban Development, 2020). These changes create conditions particularly suitable for TOD in New Zealand's urban centres in particular. The results from the California case study support this policy and provide evidence to suggest supporting councils in efforts to encourage these types of developments.

Understanding the role that TOD in general, and affordable TOD in particular, can have on VMT (or VKT) among residents, as seen within the California example, will be relevant as New Zealand cities develop methods for reducing reliance on private vehicles and as public transport systems evolve. The study found the biggest difference in public transport trips was for households with low and very low income in TOD/non-TOD areas. It also found that extremely low-income households had the largest decrease in VMT (when combining the effects of both TOD areas and HQTAs), with 50% fewer VMT on average. This may indicate an important equity co-benefit for New Zealand, with such policies creating opportunities for low-income households to reduce vehicle ownership and associated financial burdens.

Issues of housing affordability and transport inequity highlighted by the California-based research are equally relevant across New Zealand, and the case study provides some insight into an approach that generates benefits both in terms of housing provision and GHG emissions reduction. It is expected that inclusionary zoning and the provision of social housing relating to TOD will be important in New Zealand to ensure community members with lower incomes are not priced out of TOD areas.

6.1.6 Opportunities for further study

- The opportunity for affordable and social TOD in New Zealand, with particular reference to the National Policy Statement on Urban Development.
- The co-benefits for equity and emissions reduction around TOD.

7 Parking case studies

7.1 San Francisco – SF*park*: demand-responsive parking

Programme type	Location	Programme scope
Demand-responsive parking	San Francisco	Three-year pilot study (2011–2014) across 25% of San Francisco's metered parking spaces and 75% of the city's parking garages

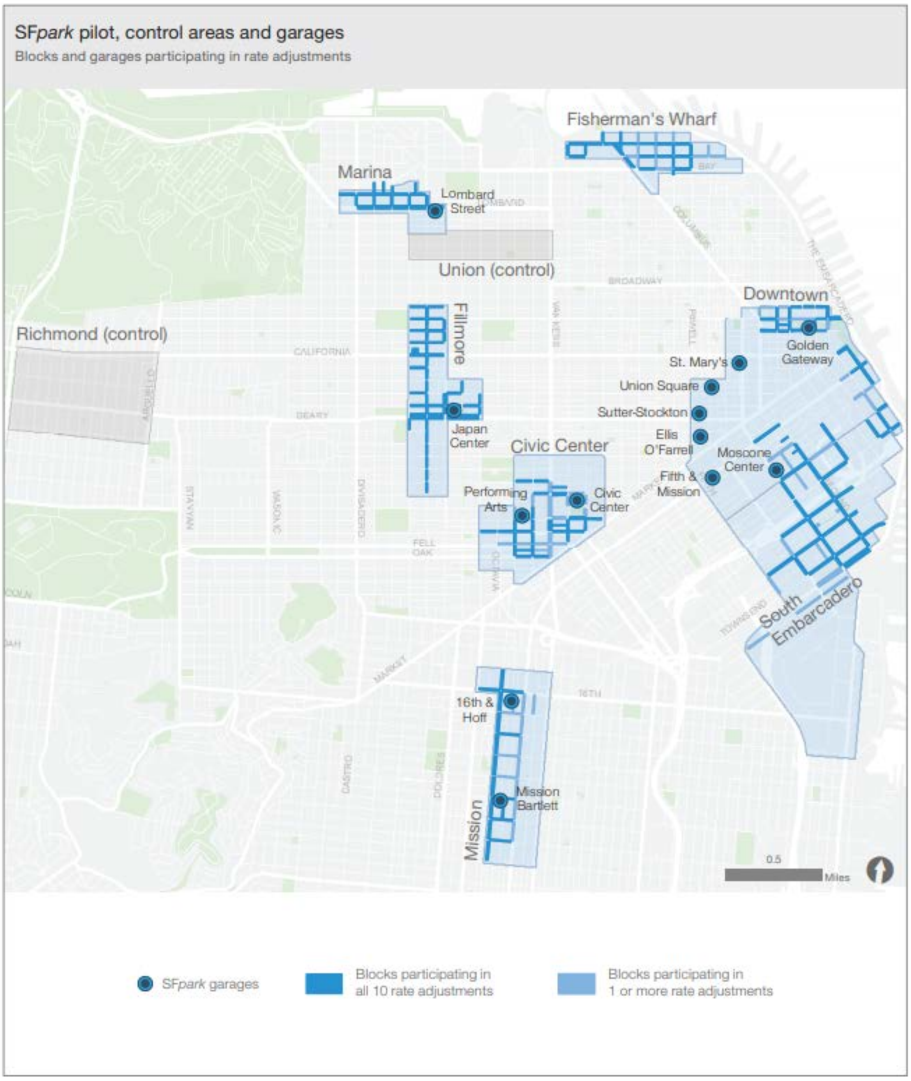
7.1.1 Detail of programme (major interventions)

In 2011, the San Francisco Municipal Transportation Agency (SFMTA) launched SF*park*, a pilot programme testing demand-responsive parking technology at a quarter of the city's metered parking spaces and 75% of the city's parking buildings. The pilot programme ran between 2011 and 2013, using parking sensors to allow the city to adjust parking rates on demand, later developing a formula to continue the practice without sensors. A website and app were developed to provide drivers with information about the real-time availability of parking. The demand-responsive parking programme is now being expanded across the city. The purpose of the pilot was to improve the awareness of drivers about where parking was available and to reduce 'cruising' for parking (driving while searching for a parking space) by way of correctly pricing parking to ensure a target occupancy of 60%–80% was never exceeded. This would mean there was always one parking space available on each block.

This was achieved through the use of sensors to both provide customers with real-time information as to where there was available parking in the city, and inform transport planners by way of allowing them to understand whether parking was priced correctly in the city. Prices were then adjusted regularly (roughly every second month) based on observed demand to meet the target occupancy.

Figure 7.1 shows the areas across San Francisco where the pilot was carried out, and the pilot areas used as a comparison to determine rates of parking occupancy and relevant vehicle travel behaviour.

Figure 7.1 Areas of San Francisco where SF*park* was tested, and control areas used for comparison (Source: SFMTA, 2014, p. 21)



7.1.2 Measurement methodology

In 2014, the SFMTA published a project evaluation report, which included the analysed outcomes of the SF*park* programme using a range of data types (SFMTA, 2014). These included:

- parking sensor data (parking session start/stop)
- roadway traffic volume sensor data
- manual motorcycle occupancy counts (sensors did not assess motorcycle occupancy rates)
- parking meter data (payment session, amount, time)
- parking tickets
- parking garage use data
- parking tax receipts from parking facilities
- manual surveys of double parking and parking search time

- intercept surveys on the street
- roadway sensors for traffic counts
- passenger counters on public transport vehicles
- highway traffic data
- sales tax data
- collision data.

7.1.3 GHG emissions outcome

The use of meter payment transaction data, meter payment compliance data and manual surveys that observed the time and distance it took to find a park within the pilot zone (SFMTA, 2014) showed that pilot areas saw a 30% decrease in VMT among vehicles finding a car park under the programme. Drivers in control areas were found to have a decrease of 6% in this same time, so the difference in effect was measured as 24%. This was estimated by the SFMTA as creating an equal percentage reduction in metric tonnes of CO_2. Drivers in pilot areas were found to have originally generated 7 metric tonnes of GHG emissions per day while looking for parking, and the reduction relates to this measure. Additionally, surveys of areas where Sunday metering was introduced (where previously there were no parking meters at all) were found to have a 57% reduction in VMT (in terms of searching for parking) and an according 57% reduction in CO_2 was described.

Other studies have analysed the overall effect and benefits of the programme on other transport factors, including increased public transport ridership and reduced lane occupancy in the programme areas, having further benefits on GHG emissions relating to the programme (Krishnamurthy & Ngo, 2018).

7.1.4 Other contributing factors

SF*park* was a well-funded, headline aspect to San Francisco's overall programme to manage demand and reduce VMT in the city. It sits within a wider group of TDM programmes within the city that have been in place since roughly 2014 (some have existed longer). The individual programmes are divided into three focus areas: land use and policy coordination; city-wide parking demand management; and customer-oriented travel choice marketing, education and outreach. Current programmes include improvements to public transport travel times, wayfinding, reduced public transport prices, bicycle sharing, a 'guaranteed ride home' programme, carpool and vanpool services, tourism TDM, and commuter shuttles. Additionally, the city has introduced a TDM ordinance that requires new developments to implement a series of measures relating to demand management (such as discounted travel passes and bicycle facilities) in order to be granted building consent. These programmes are expected to all contribute to any travel and GHG emissions reductions in the city; however, the data presented in this analysis has been attributed specifically to the SF*park* programme. It is important to note that the GHG reductions reported here are specifically due to reduced driving searching for parking, which would likely have been achieved without the wider TDM programmes implemented by the city.

7.1.5 Relevance to New Zealand

The SF*park* programme is highly relevant to New Zealand in several ways. Firstly, the introduction of demand-responsive parking has clear relevance to New Zealand cities as they develop varying methods of managing parking within central city areas over time. The programme particularly sought to address the problem of cruising for parking, which is cited as making up an average of 30% of traffic in central cities globally (Shoup, 2006). The programme is considered by some planners as an alternative to the concept of congestion pricing for the city, which is seen by some to be politically unpopular. New Zealand cities are likely to require various alternatives that appropriately distribute the costs of driving and parking if they are to create environments that encourage the use of alternative modes, such as public transport. While cities such as Auckland conduct a degree of monitoring of parking occupancy, which influences prices, there is not a programme in place with the same level of structure around demand-based pricing and publicly available information as that used in San Francisco.

Additionally, the programme provides evidence for the argument that pricing parking at all (ie, the change from free parking to paid on-street parking) will have a significant effect on the volume of cars on the road and, therefore, GHG emissions. This has significant relevance for parts of New Zealand where parking is currently provided as a free resource and the introduction of demand-responsive pricing would be too resource intensive.

SF*park* was established as a pilot programme that would provide understanding of the value of demand-responsive parking, and related technologies, to other jurisdictions, particularly those in the US. The programme was funded by the U.S. Department of Transportation, with approximately US$20 million of central government funding. Due to this funding, there was a heavy reporting requirement associated with SF*park.* This means that significant volumes of data, recommended methodologies and lessons learned are publicly available. In particular, the data and analysis developed as part of this programme includes the development of an algorithm to determine parking occupancy rates based on parking meter data, if sensors are not suitable for use. Understanding the methodology behind the development of this algorithm may well provide New Zealand jurisdictions with the opportunity to develop their own demand-based parking without the cost of using sensors. The programme did run into some reported difficulties in terms of costs of the programme, and the reliability of the sensors. Understanding the financial impact of using this technology is important within New Zealand jurisdictions.

7.1.6 Opportunities for further study

- The effect of current demand-responsive parking in place in New Zealand (eg, Auckland) on VKT.
- Case studies/primary research into the effect of parking pricing in New Zealand urban areas.

7.2 Los Angeles County – parking cash out

Programme type	Location	Programme scope
Parking cash out – an employer-funded payment for alternative forms of transport in lieu of subsidising parking spaces on-site	Los Angeles County, Southern California	Eight employers in the Los Angeles County in California, with a total of 1,684 employees

7.2.1 Detail of programme (major interventions)

This case study profiles the work of Donald Shoup in evaluating the effects of a parking cash out scheme in California in the early 1990s. While this case study only reports on the findings of the study's experiment, significantly more detail around the concept of parking cash out is available in Shoup's (2005) full report, published by the American Planning Association.

In 1992, the state of California put legislation in place that made it a requirement for employers to give their employees the choice of a cash allowance instead of a parking subsidy that was already offered. Parking subsidies were exempt from taxation and the cash allowance was not. The legislation applies to employers:

- with at least 50 employees
- who subsidise commuter parking in spaces they do not own
- who are able to reduce the number of spaces they lease without incurring a penalty for their lease
- who are within a certain geographic area specified by the state of California.

Employers are allowed to offer a subsidy for a different type of transport instead of a direct cash payment to staff. This could include:

- eliminating the parking subsidy completely
- only offering parking subsidies for carpooling
- a cash payment of equal value to the parking subsidy
- a cash payment of more value than the parking subsidy
- a commuting allowance for any mode (Shoup, 1997).

The cash out is funded by the money employers save by not renting spaces, so does not generally require additional expenditure by employers.

This case study profiles a review of the effects on staff commuting patterns of the implementation of this policy at eight firms in the California County of Los Angeles. The review of the firms was undertaken by Donald Shoup and published in 1997, with subsequent analysis undertaken by Shoup in 2005. All data and information contained within this case study references Shoup's work.

The eight employers profiled were an accounting firm, a government agency, a healthcare provider, a bank, a video production company, and three law firms. They were spread over various suburbs and downtown areas of the Los Angeles County area.

Each firm offered a different size of commute subsidy both before and after the introduction of parking cash out. Each of the changes is highlighted in Table 7.1, taken directly from the Shoup study.

Table 7.1 Commute subsidies in profiled workplaces in Los Angeles County before and after parking cash out (US$ per employee per month) (Source: Shoup, 2005, table 4-1)

	Before parking cash out		After parking cash out	
Case study	Parking	Alternatives	Parking	Alternatives
(1)	(2)	(3)	(4)	(5)
Case 1	$110	$55	$0	$55
Case 2	$65	$45	$65	$65
Case 3	$100	$0	$100	$100
Case 4	$120	$50-$90	$120	$150
Case 5	$90-$145	$0-$15	$100	$150
Case 6	$55	$0-$15	$55	$55-$70
Case 7	$62	$25-$175	$62	$77-$165
Case 8	$30	$0	$11	$50

7.2.2 Measurement methodology

Data for this case study was gathered from the Trip Reduction Plans that employers submitted as part of a local government compliance requirement. The data comes from a staff survey from each employer, taken over the course of a specified week each year. In addition to this data, Shoup surveyed transport coordinators from five out of the eight firms profiled.

For each employer, the base case was the year before the cash out offer existed, and the subsequent data is based on either the first, second or third year after it was introduced, depending on the data available. Years after cash out were either 1993, 1994, or 1995 (Shoup, 1997).

The results measured by the survey were the solo driver share at each firm (as a percentage) and the vehicle trips per commuter per day (the number of journeys to and from work per employee each day). From these measures, the reduction in VMT was calculated through multiplication of the reduction in vehicle trips to work and average round trip commute distance in Southern California (determined as 15 miles (24.14 km) based on local surveys).

The study also calculated CO_2 emissions reduction as being the same percentage as the VMT reduction, due to this relating directly to the amount of petrol used.

Additionally, the study calculated the effect on air quality emissions (carbon monoxide, NO_x, and particulate matter 10 microns or smaller (PM_{10})). These are not considered the same as GHGs but reflect the overall reduction in vehicle use related to the parking cash out system.

7.2.3 GHG emissions outcome

Between the eight case study businesses, the average reduction in single driver share was 13%, the average reduction in vehicle trips per commuter per day was 11%, and the average reduction in VMT per employee per year was 12%. This is shown in Table 7.2. Table 7.3 shows the calculated emissions reductions associated with the programme. In particular, CO_2 reductions are shown to be 387 kg per year – calculated based on CO_2 reduction being the same as the percentage VMT reduction per employee. Both tables are taken directly from Shoup (2005).

Table 7.2 Summary of travel changes in Los Angeles County after parking cash out (Source: Shoup, 2005, table 4-2)

	Solo driver share			Vehicle trips per commuter per day				VMT per employee per year			
Location (case)	Before	After	Change	Before	After	Change	% Change	Before	After	Change	% Change
(1)	(2)	(3)	(4)=(2)-(3)	(5)	(6)	(7)=(5)-(6)	(8)=(7)/(6)	(9)	(10)	(11)=(9)-(10)	(12)=(11)/(9)
Downtown LA (5)	75%	53%	−22%	0.79	0.60	−0.19	−24%	5,297	4,013	−1,284	−24%
Downtown LA (8)	61%	45%	−16%	0.75	0.63	−0.12	−16%	5,281	4,418	−864	−16%
Century City (1)	71%	58%	−13%	0.81	0.74	−0.07	−9%	5,461	4,862	−599	−11%
Century City (4)	88%	76%	−12%	0.93	0.85	−0.08	−9%	6,578	6,006	−585	−9%
Century City (3)	79%	67%	−12%	0.85	0.78	−0.07	−9%	6,113	5,589	−524	−9%
Santa Monica (7)	83%	75%	−8%	0.83	0.79	−0.04	−5%	6,294	5,960	−334	−5%
Santa Monica (6)	85%	78%	−7%	0.90	0.82	−0.08	−9%	6,478	5,910	−568	−9%
West Hollywood (2)	72%	70%	−3%	0.76	0.72	−0.04	−5%	N/A	N/A	N/A	N/A
Weighted average	**76%**	**63%**	**−13%**	**0.82**	**0.73**	**−0.09**	**−11%**	**5,348**	**4,697**	**−652**	**−12%**

Table 7.3 Summary of calculated emissions reductions in Los Angeles County after parking cash out (Source: Shoup, 2005, table 4-3)

EMISSIONS REDUCTIONS AFTER PARKING CASH OUT (PER EMPLOYEE PER YEAR)	
ROG	819 grams
NO_x	683 grams
CO	7.2 kilograms
PM_{10}	500 grams
CO_2	367 kilograms

7.2.3.1 Other contributing factors

In his analysis of the case studies, Shoup (2005) points out the characteristics of the sites with both the largest and smallest decreases in the share of people driving to work alone. Site five had the largest decrease in SOV arrival by staff, with a 22% reduction, which was calculated to be a 24% reduction in VMT. This employer changed from offering between US$90 (NZ$133) and US$145 (NZ$214) per month in parking subsidies and US$15 (NZ$22) per month in public transport subsidies, to offering a flat rate subsidy of US$100 (NZ$147) per month for parking or a US$150 (NZ$221) public transport subsidy. The large decrease at site five was believed to be a combination of the significant changes in the site's subsidy options and the availability of public transport options at the site's downtown location.

In contrast, the site with the smallest decrease in staff arriving by SOV (site two), saw only a 3% reduction. This employer had previously offered a US$65 (NZ$96) per month parking subsidy, or US$45 (NZ$66) per month in cash. The company changed to make the cash offer US$65 (NZ$96) per month to match the parking subsidy. Shoup (2005) indicates that the small reduction in drive-alone rates at this company are likely a combination of the small increase in the cash subsidy, and the fact that the site was located in West Hollywood, which had very limited public transport services at the time of the case studies.

To understand whether any other factors influenced the reduction in SOV commuting in Los Angeles at the time of the study, Shoup (2005) analysed both overall commute mode share for Southern California over the course of 1990 to 1996 and the commute patterns of an additional employer that did not offer the cash out opportunity. This firm continued to offer a parking subsidy that was US$75 (NZ$111) greater than any other subsidy (specifically, a carpool subsidy). In both the regional data and the case of the additional employer, there was no downward trend in SOV as the mode for travelling to work.

The main limitation of this work is that the case studies profiled by Shoup (2005) are relatively old, having been undertaken after the law was first implemented in the early 1990s. The study is still, however, widely referenced as an example of the potential value of a commuter cash out policy. The major dependency in implementing the programme is the existence of firms that lease (rather than own) their parking, and therefore have the choice of reallocating funds to a cash out scheme (Sorensen et al., 2008). If the majority of firms own their own parking, the policy would have less relevance.

In California, the uptake of the policy has not been widespread, despite evidence of its success and it technically being a requirement for particular businesses. There was no penalty in the original legislation, which was updated in 2010 to enable cities to penalise non-complying businesses, but most cities have chosen not to do this. Further understanding as to why the practice has not been enforced would be useful. In part, this appears to relate to limited understanding of the concept (Bhatt & Ryan, n.d.; Shoup, 2017).

There were further benefits of the programme beyond the vehicle travel reduction and associated environmental benefits. These include tax benefits to the state. Because people chose to swap their tax-exempt parking subsidies for cash (which was taxable), tax incomes rose by US$65 (NZ$96) per year, per employee after the introduction of the scheme.

7.2.4 Relevance to New Zealand

Parking cash out is a policy with a significant amount of relevance to New Zealand. Not only is driving the largest mode share for journeys to work in all New Zealand's cities (Stats NZ, 2020), but also large numbers of New Zealand businesses provide parking and/or vehicles for their employees. A 2012 NZ Transport Agency research report completed by Booz and Company found that among 11 Auckland workplaces with workplace travel plans covering 5,777 employees, on average, 33.5% of staff were provided with a car parking space by the employer (Scott et al., 2012). This suggests that there is significant potential to influence demand for these spaces by way of changing the incentive for their use. It will be important, however, to better understand what proportion of these spaces are owned and what proportion are leased by the employer, although in the case of owned parks, there may be opportunity in some locations for employers to lease these parks out to others or redevelop the space.

The case studies used within Shoup's work are all within Los Angeles County, a city well known for its traffic and congestion problems, tied to development largely focused on private vehicle travel. The city has, since the publication of the case studies in the early 1990s, seen a marked increase in public transport provision but has, in more recent years, seen a reduction in ridership, with a reduction of approximately 17% between 2013 and 2018 (Zillac, 2019). Public transport ridership in New Zealand's largest cities have, however, been increasing over this time, with the exception of some reductions relating to the Canterbury earthquakes of 2010 and 2011 (Waka Kotahi, 2020a). The high prevalence of employee parking and the contrasting public transport use between the two locations indicates there could be significant relevance of adjustments to employer parking provision (by way of parking cash out or reduction in employee parking altogether), with potentially larger results, which should be further explored as a GHG emissions reduction measure in New Zealand.

7.2.5 Opportunities for further study

- Inventory of the volume of company-provided parking in New Zealand, including developing an understanding of the amount of leased versus freehold parking.
- Research into the emission reduction potential for parking cash out programmes for employers in New Zealand.

8 Traffic restriction case studies

8.1 Stockholm – congestion pricing

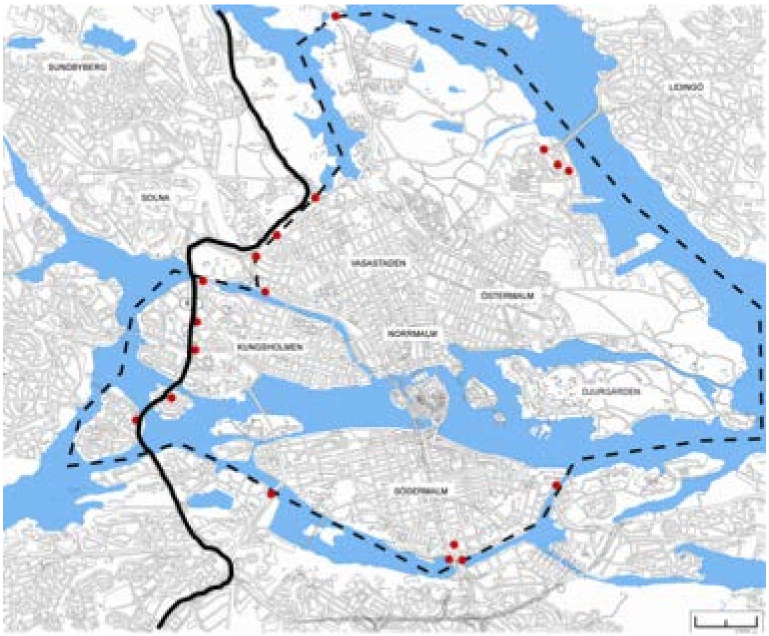
Programme type	Location	Programme scope
Congestion pricing	Stockholm (central city). City population is approximately 970,000, with two thirds living within the congestion pricing cordon.	Central city congestion charging implemented first as a seven-month trial in 2006, and subsequently as a permanent measure in 2007. The charge covers the central part of the city.

8.1.1 Detail of programme (major interventions)

The Stockholm congestion charging zone consists of 18 charging points, which are located at the city's major bottlenecks (Figure 8.1). The large number of waterways within and around the city mean there are numerous bridges and crossing points that make suitable cordon charge/check points. Prices vary by time of day. As of 1 January 2020, charges ranged from 11 SEK (NZ$1.90) (between 9.30 am and 2.59 pm) and 45 SEK (NZ$7.65) (peak times of 7 am to 8.30 am and 4 pm to 5.30 pm) (Transport Styrelsen, 2020). Charges are in place from 6 am until 6.30 pm every day, with the exception of public holidays.

Since the introduction of the charge, changes have been made to the system both in terms of pricing amounts and times of charging, reacting to trends seen in congestion across the city. In Sweden, the charge is legally a tax, but is generally referred to as a 'congestion charge', as this is the structure it most closely resembles in terms of comparison to other programmes (Eliasson, 2014). Prior to 2012, there was an exemption to the charge for low-emission vehicles, which was removed in 2012. The charge was initially put in place as a trial during 2006. It was removed once the trial ended in 2007, which provided researchers with insights into the effect the charge had, compared to any other general travel trends. Pricing was reinstalled permanently in 2007 after a referendum was held and the public voted in favour of the intervention.

Figure 8.1 Stockholm congestion charging zone boundary and checkpoints (shown in red) (Source: Eliasson, 2014, figure 1)



8.1.2 Measurement methodology

Different measurements have been made in terms of the effect of the congestion charge in Stockholm. These include:

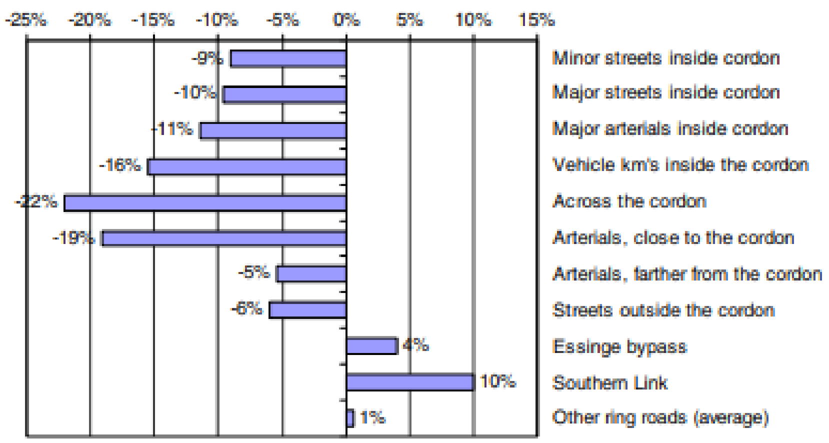
- traffic effects entering/leaving the cordon area – measured by counters at the cordons
- traffic effects on outer streets – manual vehicle counts
- travel behaviour of people who no longer travelled across the cordon in private vehicles – panel surveys
- GHG emissions – reductions measured during the congestion pricing trial (2006) based on a calculation involving VKT and exhaust-emission factors. VKT were measured through a combination of analysis of vehicles crossing the cordon and travel habit surveying (Hugosson & Eliasson, 2006).

8.1.3 GHG emissions outcome

Researchers reviewing the congestion charging scheme have suggested that the most important measure is the change in vehicle volumes across the cordon between 2005 (the year before the charge was introduced) and 2006 (the first introduction of the congestion charge). There was a 21% reduction in traffic crossing the cordon during charged times following the introduction of the charge in 2006 compared to 2005. This trend has roughly stabilised over subsequent years, with an approximately 20% reduction in vehicle travel across the cordon compared to 2005.

Over the course of the 2006 trial, traffic volumes at different parts of the city were measured to verify if overall traffic was reduced or if it was simply diverted to other parts of the network. These are outlined in Figure 8.2. The area of largest increase, the Southern Link, was not believed to be a result of the congestion charge, as traffic on this link had been increasing independently of the policy and did not decrease when the congestion charge was temporarily lifted following the trial.

Figure 8.2 Average changes of traffic volumes for different road types on weekdays between 6 am and 7 pm in April 2006 compared to April 2005. The Southern Link increase is not believed to be attributed to the congestion charge. (Source: Eliasson et al., 2009, figure 3)



Estimates (based on measured vehicle count reduction) over the course of the 2006 congestion pricing trial found the reduction of CO_2 emissions to be approximately 2%–3% in the wider Stockholm County, and 14% in the inner city. This reduction only relates to data from vehicle accounts; it does not, for example, include any analysis of increased public transport mode share, although other studies have found this to be a co-benefit of the congestion charge (Hugosson & Eliasson, 2006).

In addition to the traffic count effects described above, a travel panel survey was carried out relating to the behaviour of those people who no longer crossed the cordon in private vehicles. This change was referred to as 'disappearing traffic' (Eliasson, 2014). Nearly 25% of 'person trips' across the cordon disappeared. The surveys found that these people either transferred to public transport (10%), changed their destination or decided to combine journeys (trip chaining) (6%), or took a different route that avoided paying a fee (1% for work journeys and 1% for discretionary journeys). The remaining journeys are made up of 'professional traffic' such as taxis and deliveries, and travel surveys were not completed for this group. Interview evidence from this group found that professional drivers changed their behaviour to avoid crossing the cordon as much as possible.

8.1.4 Other contributing factors

The Stockholm congestion charge has been extensively studied and is generally considered to be a success. As a comparison, another congestion charge in the Swedish city of Gothenburg is less well-known internationally. Comparing the two may provide some explanation as to the success of the Stockholm system and what other factors have contributed to its effect on traffic volumes and travel behaviour. While the Gothenburg congestion charge is also considered a success, it had lower effects on vehicle travel, with an average 12% reduction in traffic crossing the cordon, compared to approximately 20% in Stockholm. Additionally, while the Stockholm example has noted greater demand elasticity effects on vehicles over time (ie, a greater influence on the choice not to drive), price elasticity in Gothenburg relating to its congestion charge has decreased over time (Börjesson, 2018).

One major difference between the two cities is the level of vehicle dependency and provision of public transport. The public transport share in Stockholm was 77% in 2012 for origin–destination paired trips across the cordon, while the comparable share in Gothenburg was 12% (Börjesson & Kristoffersson, 2015). Gothenburg is less dense than Stockholm, and not as many major employers are located in the central city. Congestion was generally considered a more significant problem in Stockholm, therefore the need to fix the problem was greater.

The Stockholm public transport system was bolstered in advance of the introduction of the congestion charging scheme. Through the introduction of both new routes (16 new bus lines), and increased capacity, services were extended by 7%. Park-and-ride capacity increased by 29% ahead of the charge's introduction.

Natural barriers (eg, water crossings) in Stockholm have been credited as simplifying the charge compared to Gothenburg, which does not have the same natural bottlenecks and therefore required more charging points to prevent rat-running.

Political support for the congestion charge in Stockholm was gained by a national agreement that Stockholm would receive a major infrastructure package, funded in part by the congestion charge and in part by a large government grant (Börjesson & Kristoffersson, 2015). The same was true of the Gothenburg congestion charge.

8.1.5 Relevance to New Zealand

Congestion pricing is a travel demand intervention that is relatively contentious, with numerous international examples of governments or transport agencies failing to implement or deciding against implementation. Both the Stockholm and Gothenburg examples, however, show positive effects on vehicle travel reduction, although to varying degrees. The comparison between Stockholm and Gothenburg emphasises this point: the two cities are geographically different and have different transport systems, with varied results for their congestion pricing schemes. New Zealand cities have lower public transport mode share than Stockholm (although Auckland's public transport mode share is higher than that of Gothenburg), meaning the supporting public transport infrastructure investment needs should be understood in New Zealand in relation to such an intervention.

Generally, congestion pricing could have relevance in New Zealand cities, but would need to be part of a wider transport investment. Ministry of Transport work investigating the role that congestion pricing may play in Auckland's transport system identified potential congestion reduction benefits for the city of 8%–12% (Ministry of Transport, 2020). The Ministry report suggests that some elements of the Stockholm congestion pricing system are relevant to Auckland, but also includes a preference for a focus on strategic corridors in Auckland. The Ministry workstream on this issue is highly relevant for the suitability of congestion pricing to New Zealand's emissions reduction.

The role of public acceptance was significant in the case of the Stockholm congestion charge. The use of a trial period and subsequent referendum allowed the public to understand the realities of the congestion charge, which helped with buy-in for the concept (Eliasson, 2014).

This case study is also of relevance to New Zealand's cities in understanding the wider co-benefits of a reduction of vehicles into a city centre, regardless of the mechanism used to achieve this. Co-benefits in Stockholm included improved travel time for public transport, improved health outcomes, enthusiasm for the scheme from the public, and no negative reported impact on retail, alongside associated environmental benefits (Daunfeldt et al., 2009).

8.1.6 Opportunities for further study

- Ongoing investigations into the role that congestion pricing can play in New Zealand's GHG emissions reductions work (ongoing workstream with the Ministry of Transport's Congestion Question work).
- Wider effects of congestion pricing on uptake of other modes – in particular, active modes.

8.2 Ultra Low Emission Zone – London

Programme type	Location	Programme scope
Ultra Low Emission Zone (ULEZ)	London central city	A ULEZ was launched in April 2019 covering roughly 21 km^2 of central London. Vehicles that do not comply with strict emissions standards are required to pay for entry.

8.2.1 Detail of programme (major interventions)

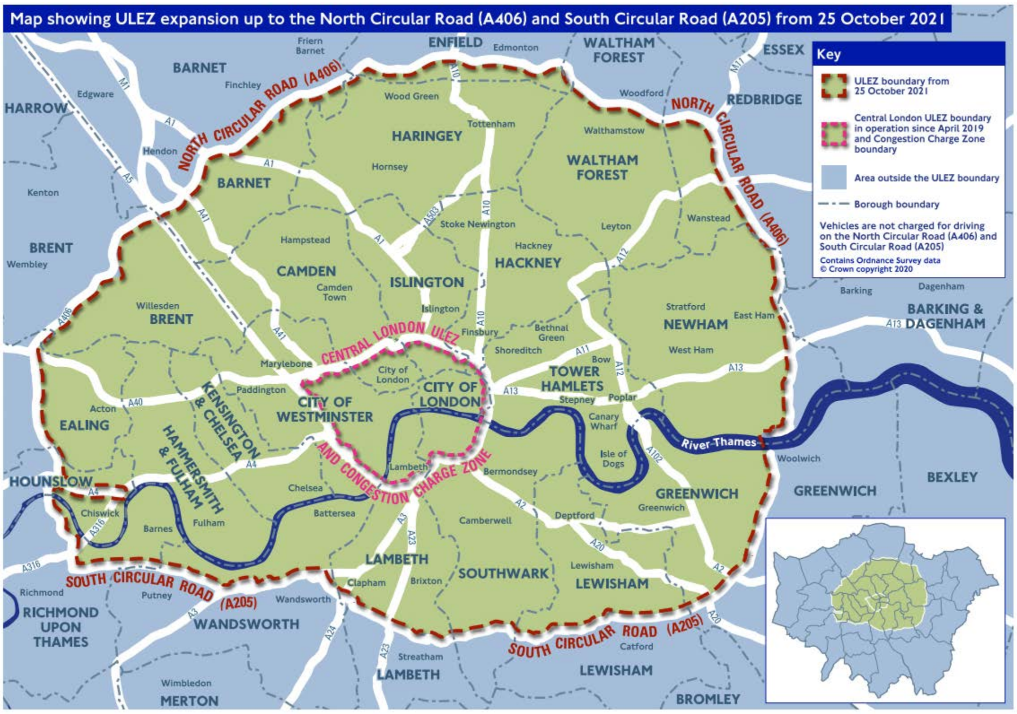
London instituted a ULEZ in April 2019. Vehicles must pay a charge to enter the zone if they do not meet strict standards for NO_x, particulate matter, and other vehicle exhaust emissions (Mayor of London & Transport for London, 2020). Cars, motorcycles, and vans that do not meet the required emissions standards must pay £12.50 (about NZ$24), while trucks, buses, and coaches that do not meet the required standards must pay £100 (about NZ$195) per day (Transport for London, n.d.). The Greater London Authority has regularly studied the impact of the ULEZ since its implementation, including on vehicle volumes and air quality. It has also estimated the ULEZ's impact on CO_2 emissions.

The ULEZ covers the same geographic area as London's existing congestion charge – a 21 km^2 area within the London Inner Ring Road. While the congestion charge operates daily between 07:00 and 22:00, the ULEZ operates 24 hours per day. The ULEZ charge is additional to the congestion charge (Transport for London, n.d.).

Implementation of the ULEZ appears to have had an immediate impact. The number of vehicles in the zone that do not meet the ULEZ emissions standards decreased by 49% from March 2019 to January 2020 during congestion charging hours. After 10 months of operation, nearly 80% of vehicles complied with the ULEZ standards over a 24-hour period, compared to about 40% in February 2017 (Mayor of London, 2020).

In October 2021, the geographic area covered by the ULEZ will be significantly expanded to the London's North and Circular Roads (Mayor of London & Transport for London, 2020). Figure 8.3 shows the extent of the existing ULEZ in orange, and the planned expansion for October 2021 in yellow.

Figure 8.3 Current and future ULEZ, London (Source: Mayor of London & Transport for London, 2020, p. 10)



8.2.1.1 Measurement methodology

The Greater London Authority's estimate of the ULEZ's impact on CO_2 emissions is based on a combination of observed data and modelled impacts from the first 10 months of the ULEZ's operation, from April 2019 to January 2020.

Observed data from automatic number plate recognition cameras – which enforce London's congestion charge and ULEZ – was used to determine the characteristics of the vehicle fleet in the ULEZ, including vehicle year and manufacturer, vehicle type (petrol car, diesel car, and van), and Euro Standard (European regulations that set vehicle exhaust emissions limits) (Mayor of London, 2019).

Traffic flows were observed using Transport for London automatic traffic counts at representative sites across the city. Traffic flows were found to be 3%–9% lower in central London (where the ULEZ is located) from April 2019 to January 2020 compared to the prior year (Mayor of London & Transport for London, 2020). To calculate estimated CO_2 reductions, it was estimated that total VKT reduced 5%, based on the observed reduction in vehicles volumes.

An air quality transport model ('COPERT') was used to estimate the emissions reductions following the ULEZ based on the change in vehicle fleet composition and reduction in VKT.

Additional data over a longer time period will be required to more fully ascertain the scale of traffic reductions and to what degree they can be attributed to the ULEZ.

8.2.2 GHG emissions outcome and co-benefits

CO_2 emissions were estimated to have reduced by 6% (about 12,300 tonnes) within the cordoned zone compared to the estimated scenario without the ULEZ over the 10 months following implementation of the ULEZ (Mayor of London, 2020).

The ULEZ has also appeared to significantly improve air quality. NO_2 and $PM_{2.5}$ levels are recorded at monitoring sites throughout the city. Compared an estimated 'no ULEZ' scenario, recorded NO_2 and $PM_{2.5}$ levels were reduced by 35% and 15% (Mayor of London, 2020).

8.2.3 Other contributing factors

London has several policies that discourage private car use and support uptake of sustainable transport, including a congestion charge and extensive railway network and bus system. The city experiences heavy traffic congestion, while residents have high levels of satisfaction with public transport (Thomas et al., 2020).

London has experienced a gradual reduction in private vehicle mode share and corresponding increase in public transport mode share over the past 20 years. Londoners have also reduced their overall number of trips by 20% over the past 12 years, which is expected to be due to economic factors, increased home deliveries, and flexible working (Thomas et al., 2020).

London's congestion charge of £15 (about NZ$30) operates in addition to the ULEZ from 07:00 to 22:00 across the same geographic extent. London also has a Low Emission Zone (separate from the ULEZ) that covers a wider area to encourage the most polluting heavy diesel vehicles to become cleaner. The Low Emission Zone was implemented in phases starting in 2008, with increasingly strict emissions standards and more vehicle types included over time (Transport for London, 2017).

Private hire vehicles (such as taxis and Uber) had previously been exempted from London's congestion charge. This exemption was removed about the same time as the ULEZ was introduced, making it difficult to disentangle any potential impacts of each intervention (Transport for London, 2020).

8.2.4 Relevance to New Zealand

London shares common challenges to some New Zealand cities, despite its much greater size. These include high house prices, rapid growth, limited space to build new infrastructure, and a need to transport people over significant distances (Thomas et al., 2020).

Low-emission zones exist in cities of various sizes – including cities with populations below 100,000 – particularly throughout Europe (European Low Emission Zones, n.d.). In New Zealand, the concept may be most relevant for areas within Auckland, Wellington, and other cities with walkable centres. Additional research would be necessary to understand the impacts these interventions have had on emissions in smaller cities.

The concept is already being explored in New Zealand. 'Access for Everyone' is a transport strategy adopted by Auckland Council as part of its City Centre Masterplan 2020 to transform people and freight movement in the Auckland city centre. Among other goals, Access for Everyone aims to deliver a zero emissions area across the Waihorotiu/Queen Street Valley (Auckland Council, 2020). This would fulfil Auckland's commitment to the C40 Fossil Fuel Free Streets Declaration to have a zero emissions area in the city centre by 2030. A 2016 report prepared for the Ministry of Transport examines the potential costs and benefits of low-emission zones in New Zealand, though it focuses on harmful local emissions and not GHG emissions (Denne & Atkins, 2016).

8.2.5 Opportunities for further study

- Further study should consider the outcomes of the expansion of London's ULEZ in October 2021. There may also be an opportunity to investigate in more detail the staging and key common elements of a broader range of low-emission zones in other countries to identify the package that has the most potential impact as Auckland considers the implementation of a zero emissions area as part of its C40 declaration.

8.3 Low-traffic circulation plans

Programme type	Location	Programme scope
Low-traffic circulation plans	• Groningen, Netherlands: population 231,037 (2019) • Ghent, Belgium: population 262,219 (2019) • United Kingdom: Waltham Forest (London)	Several cities have implemented changes to traffic circulation patterns that maintain driving access to an urban area but prohibit private vehicle through-movements across the area.

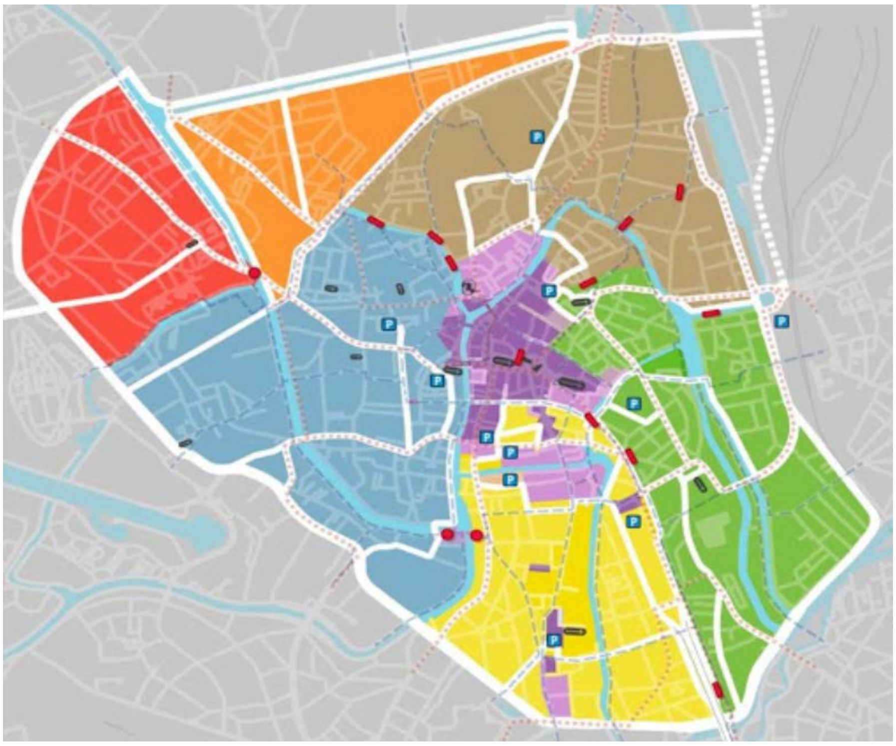
8.3.1 Detail of programme (major interventions)

Several cities worldwide have implemented changes to their traffic circulation systems to limit private vehicles' ability to travel across an urban centre or neighbourhood while maintaining or improving access for public transport, walking, and cycling across the same area. These traffic circulation plans are sometimes referred to under the 'low-traffic neighbourhood' concept.

Such circulation concepts divide an urban area into distinct zones that cars can enter or exit from designated routes. Modal filters prohibit private vehicle access between zones while allowing free movement for other modes between zones.

Figure 8.4 shows how the traffic circulation plan of Ghent, Belgium, divided the city centre into zones between which cars were prohibited from crossing.

Figure 8.4 'Zones' of Ghent's city centre under new traffic circulation plan (Source: Joly, 2019)



Although Groningen, Netherlands, first implemented the concept in the 1970s, it has only become common in recent years. To our knowledge, no studies have attempted to clearly measure how much these programmes have reduced VKT or GHG emissions. The examples discussed below, however, have documented reduced private vehicle trips, increased mode share for public transport and cycling, and improved local air quality in response to such changes. It is expected that such changes are likely to be associated with reduced GHGs.

This case study summarises results from three cities that have implemented the described traffic circulation concept. We suggest that these and other examples be monitored in coming years, as future research may attempt to draw a more direct link between such traffic circulation changes and GHG emissions.

8.3.2 Groningen

In 1977, Groningen implemented a traffic circulation plan aimed at 'keeping out the through traffic from the inner city' (Tsubohara, 2007, p. 1). It divided the city centre into four zones and created a one-way system so that cars could not pass between zones.

Several studies measured traffic patterns before and after the scheme was adopted, in 1977 and 1978 (Tsubohara, 2007, p. 1). The city measured traffic volumes at 29 locations in the inner city and found a 47% drop in hourly traffic intensity in the city centre. A separate study found that the share of cars travelling *to* the city centre decreased less significantly, from 36% to 34% of all trips. This discrepancy may show that the scheme was effective at reducing through-traffic across the city centre, while traffic *to* the centre was less significantly impacted.

A substantial increase in bus passengers and cyclists was also observed after introduction of the traffic circulation plan (Tsubohara, 2007, p. 1). Under the plan, buses can travel deep into the city centre and cyclists can pass between city centre zones. The plan also included additional cycle paths, bike parking, and bus lanes in the city centre. The share of bus and train passengers increased from 17% to 21% of all trips to the city centre from 1977 to 1978. Surveys also found a substantial decrease in perceived odour from traffic in the city centre, and noise measurements in 29 inner city locations registered a nearly 50% decrease in average noise.

In 2015, *The Guardian* suggested that Groningen's traffic circulation plan from the 1970s laid the foundation for it having a high cycling mode share and the cleanest air of all large Dutch cities (van der Zee, 2015).

8.3.3 Ghent

In 2017, the city of Ghent introduced a circulation plan that divided the city into six zones that cars cannot pass between.

The city monitored the number of cyclists using bicycle counters and periodic counts across the city (Engels, 2018). In his analysis of Ghent's circulation plan, Engels compared cycle counts between March 2017 (before the circulation plan) and October 2017 (after the circulation plan), and between March 2017 and October 2018. His 2018 report found increases in the number of cyclists in the city centre of up to 50% compared to before the circulation plan in 2017. He found a 35% increase in cyclists entering and exiting the city centre in 2017 and a 60% increase between March 2017 and October 2018. Meanwhile, the mode share of public transport increased from 9% in 2015 to 14% in 2018.

Air quality improved throughout the city centre following introduction of the traffic circulation plan (Engels, 2019). Concentrations of NO_2, soot, PM_{10}, and $PM_{2.5}$ were estimated based on a combination of direct measurements throughout the city and model simulations. Air quality improved substantially on residential streets (with reductions of 7% in particulate matter, 25% in soot, and 19% of NO_2). Air quality improved to a lesser degree on access roads, while it worsened by 4%–13% on the ring road around the city centre.

The traffic circulation plan was implemented as part of a broader Mobility Plan that included other elements aimed to support mode shift away from private vehicles. For example, it included a parking plan and improvements to cycling infrastructure. These likely also contributed to Ghent's observed mode shift.

8.3.4 London

Several London boroughs are implementing or investigating low-traffic neighbourhoods (LTNs) (also referred to as 'mini-Hollands'), which are based on the same key features of the low-traffic circulation concepts introduced in Groningen and Ghent, though they are being implemented in urban neighbourhoods rather than the city centre.

A 2020 study found living in an LTN was associated with decreased car ownership and use (Aldred & Goodman, 2020). It surveyed residents in three areas in outer London that received funding from the Transport for London Mini-Hollands programme. It separated survey respondents into those living in areas that received funding and those who did not. It further specified whether the area received a 'high-dose' intervention (with substantial infrastructure improvement) or 'low-dose,' and whether it implemented an LTN (by removing private vehicle through-access). It measured results in 2017, 2018, and 2019 compared to a 2016 baseline.

People in LTNs became less likely to own a car each year studied; by 2019, the survey found residents of high-dose LTNs were 20% less likely to own a car, while no change was found in the other intervention groups (Aldred & Goodman, 2020). In 2018, residents in high-dose LTNs reported 43 fewer minutes of car use per week than people living in neighbourhoods that did not receive funding from the Mini-Hollands programme. In 2019, they reported an average of 17 fewer minutes per week compared to 2016. Residents of LTNs were also more likely to report spending more time walking and cycling than residents from other areas. The study contained wide confidence intervals, suggesting it is too early to draw firm conclusions from this initial study. However, these results suggest LTN interventions may have contributed to reduced VKT among residents in LTNs.

Other early research also suggests that reduced traffic within an LTN is not offset by increased traffic elsewhere. Early research from trial LTN interventions suggested that the decreases in vehicle volumes within the neighbourhood were more significant than increases on streets surrounding the neighbourhood (London Borough of Waltham Forest, n.d.), though further research is needed to draw more precise conclusions as to the relationship on area-wide traffic volumes.

8.3.5 Other contributing factors

Low-traffic circulation plans restricting private vehicle access through a city centre or neighbourhood have typically been accompanied by improvements for cyclists, pedestrians, and public transport. In Groningen, the circulation plan was accompanied by new bike parking and cycle and bus lanes in the city centre (Tsubohara, 2007, p. 1).

Ghent's circulation plan has also been accompanied by complementary improvements for sustainable modes (Streetfilms, 2020). The city has invested in new and expanded separated cycle paths and cycling streets – which allow vehicle access but restrict vehicles to slow speeds and give priority to cyclists. Improvements include both cycling upgrades *within* the city centre and new connections in and out of the city centre. Ghent's efforts also include repurposing street space away from vehicles and parking to pedestrians and public space in the city centre. Some additional park-and-ride facilities have been provided outside the city centre, with a new free shuttle service connecting the park-and-ride facilities with the city centre (Engels, 2018).

In London, the implementation of LTNs has been part of the broader Mini-Hollands programme, which has included other transport and public realm improvements. Improvements include redesigned town centres, new cycling lanes, and new 'cycle hubs' at train stations with cycle parking and hiring (Aldred et al., 2019). These interventions sit within broader city-wide policies that support sustainable modes, including a congestion charge, a low-emission zone and new ULEZ, and continuing investments in the train, bus, and cycleway network (Thomas et al., 2020).

8.3.6 Relevance to New Zealand

To our knowledge, research has not yet drawn a clear link between the described low-traffic circulation concept and a reduction in GHG emissions. Several cities, however, have experienced effects that may be associated with GHG reduction in low-traffic areas (eg, reduced car ownership and mode shift). Early research appears to indicate that decreases in car usage in such areas are not fully offset by increased car usage (and thus GHG emissions) in other parts of the network.

The traffic circulation concept has shown success in both small and large cities. It is expected that it would be most relevant in New Zealand cities with strong walkability and co-investment in alternative transport modes. The concept forms the basis of Access for Everyone, a transport strategy adopted by Auckland Council as part of its City Centre Masterplan 2020 to transform people and freight movement in the Auckland city centre. Under the plan, the Auckland city centre would be split into zones that private vehicles can access from the city's edge. Private vehicles would largely be unable to travel between zones. This would provide a prime opportunity to collect before and after data regarding vehicle travel changes and resulting GHG emissions impacts.

8.3.7 Opportunities for further study

- There are opportunities to track outcomes from cities that are currently implementing these sorts of interventions overseas. There is also an opportunity to consider how changes in emissions could be tracked for programmes that are being considered for implementation in New Zealand, such as Access for Everyone in Auckland. This could include monitoring city centre cordon counts pre- and post-implementation as well as surveys to gauge the scale of VKT avoided.

9 Walking and cycling case studies

9.1 United States – walking and cycling infrastructure

Programme type	Location	Programme scope
Walking and cycling infrastructure	United States: • Columbia, Missouri • Marin County, California • Minneapolis area, Minnesota • Sheboygan County, Wisconsin	Between 2005 and 2013 the Federal Highway Administration Nonmotorized Transportation Pilot Programme (NTPP) provided US$25 million (NZ$36.9 million) each to four pilot communities for pedestrian and bicycle infrastructure and non-motorised programmes.

9.1.1 Detail of programme

Between 2005 and 2013, the Federal Highway Administration funded cycle and pedestrian infrastructure programmes in four pilot communities across the United States to investigate the mode shift potential of significant investments in non-motorised transportation (Lyons et al., 2014).

The locations represent a cross-section of different geographies, demographics and levels of existing cycle infrastructure to provide for more robust results:

- Columbia, Missouri: population 123,180 (2018) – college town with large institutional employers
- Marin County, California: population 258,826 (2019) – steep topography with limited connections between communities
- Minneapolis area, Minnesota: population 4,014,593 (2018) – a large diverse population, densely developed
- Sheboygan County, Wisconsin: population 115,340 (2019) – a large land area with 16 communities.

Through the NTPP the four communities were each funded at US$25 million (NZ$36.9 million) between 2005 and 2013 and were able to allocate this money to different programmes to meet their specific goals. The communities also leveraged other local and private funds to contribute towards programmes. Investments included:

- bicycle parking
- on-street infrastructure – of the 325 miles (523 km) of on-street bicycle facilities, 58% were bicycle lanes (187 miles or 300.9 km), 32% were shared lane markings (104 miles or 167.4 km), and 10% were bicycle boulevards (34 miles or 54.7 km)
- off-street infrastructure
- programmes with both on-street and off-street components, including those with footpath improvements and on-street bicycle lanes
- outreach, education, and marketing to promote walking and bicycling.

Figure 9.1 shows the percentage of funds that were spent on each type of investment in the four communities.

Figure 9.1 NTPP pilot community investment percentages by type (Source: Lyons et al., 2014, figure 1)

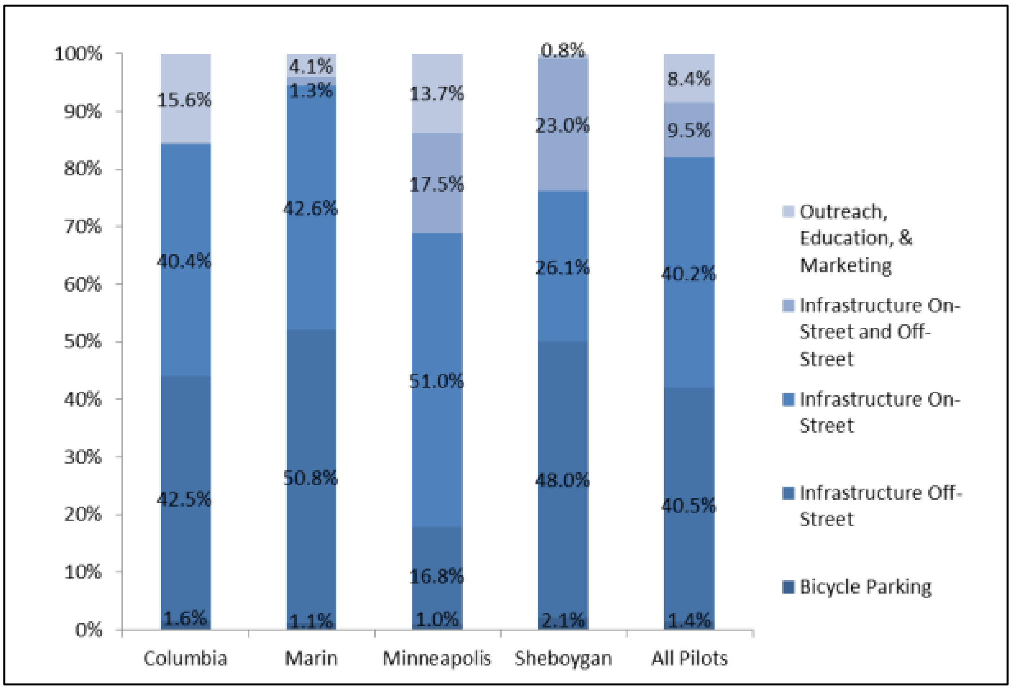
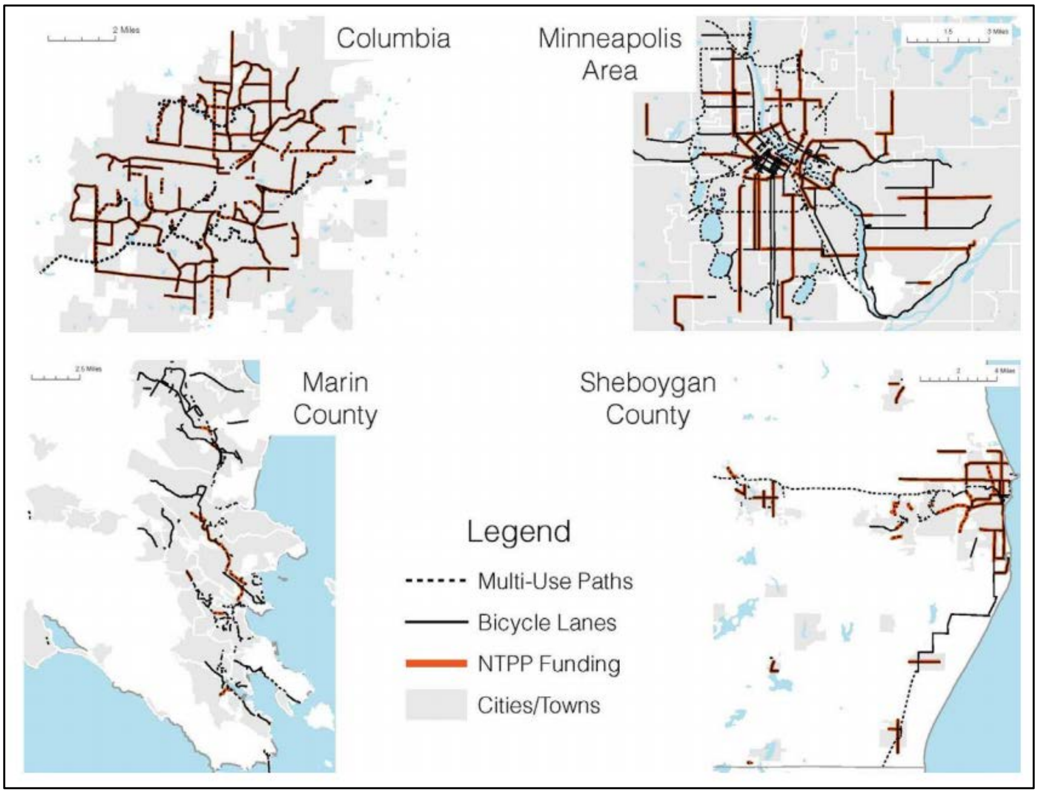


Figure 9.2 shows the level of pre-existing cycle infrastructure in each of the pilot communities as well as the extent of the infrastructure implemented under the NTPP.

Figure 9.2 Pilot communities showing cycle infrastructure pre- and post-NTPP funding (Source: Lyons et al., 2014, figure 2)



9.1.2 Measurement methodology

Evaluation and reporting requirements were included in the legislation through which this initiative was funded. Cycle and pedestrian counts were conducted at the same locations across the communities at annual intervals over seven years. Data collection was based on the National Bicycle and Pedestrian Documentation Project (n.d.) methodology. Annual changes in non-motorised trips and vehicle miles averted were modelled based on locally administered surveys as well as national, state, and local data sources that were used to supplement the counts.

To address the potential for significant daily variability in cycling and pedestrian activity at a particular location, results are presented as a three-year moving average. This means that each annual count is calculated as the average of the current and previous two years to provide a smoother trend over time. Actual counts are also available.

Evaluation reporting occurred at three levels:

- **Project-level evaluation** identifies the specific impact of individual investments. Each community selected a sample of infrastructure and non-infrastructure programmes to both highlight and report localised results.
- **Community-wide evaluation** identifies the community-wide and synergistic impacts of investments across each individual pilot.
- **Programme-level evaluation** identifies the overall impact of investments across the four pilots.

Emissions reductions were derived from changes in VMT associated with mode shift to walking and cycling. The programme focused on emissions of criteria pollutants identified under the federal Clean Air Act amendments as well as CO_2 emissions. The methodology for calculating emissions from VMT reductions is shown in Table 9.1.

Table 9.1 Air quality conversions (Source: Lyons et al., 2014, table 14)

Pollutant	Amount		Conversion	Equation
Hydrocarbons	x	pounds/program	1.36	Yearly mileage reduction multiplied by 1.36 grams per reduced mile
PM10	x	pounds/program	0.0052	Yearly mileage reduction multiplied by 0.0052 grams per reduced mile
PM2.5	x	pounds/program	0.0049	Yearly mileage reduction multiplied by 0.0049 grams per reduced mile
NOX	x	pounds/program	0.95	Yearly mileage reduction multiplied by 0.95 grams per reduced mile
CO	x	pounds/program	12.4	Yearly mileage reduction multiplied by 12.4 grams per reduced mile
C02	x	pounds/program	369	Yearly mileage reduction multiplied by 369 grams per reduced mile

9.1.3 GHG emissions outcomes

The evaluation reports outcomes at the programme level for mode shift, VMT averted, and emissions reductions (National Bicycle and Pedestrian Documentation Project, n.d.). While more detail for programme-level outcomes would also be beneficial to investigate at a further stage, this higher-level reporting has been presented here to provide an idea of the scale of outcomes in relation to the scale of investment in active mode infrastructure. As noted above, these results are derived from model estimates using count data, surveys and other sources. The following results are reported across all study areas, unless otherwise noted.

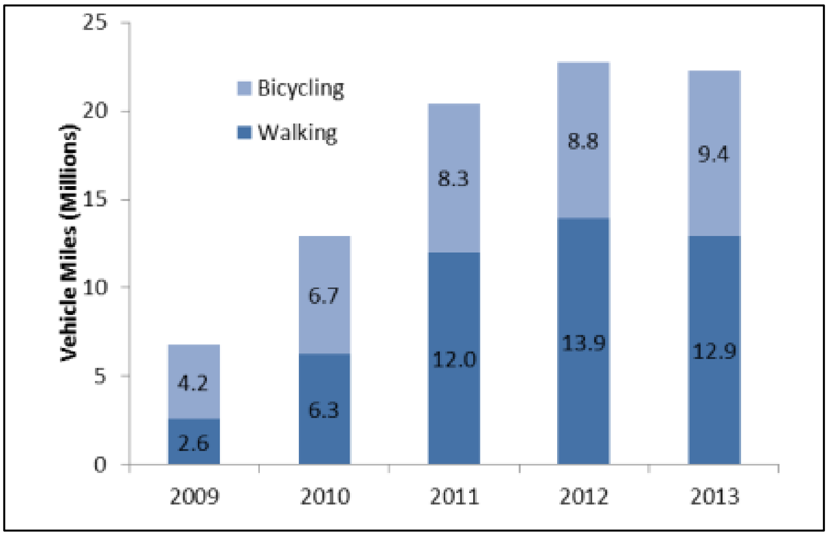
9.1.3.1 Mode share

Walking mode share increased 15.8% from 2007 to 2013. This represents an increase from an estimated 12.8% of mode share to 14.8%. Bicycling mode share increased 44% from 2007 to 2013. While this is a positive result, it is from a low base with mode share increasing from 1.0% to 1.5% in pilot communities. Cycling trips increased every year in each of the four communities.

9.1.3.2 Vehicle miles travelled

Project reporting estimated that 85.1 million VMT were averted by non-motorised trips between 2009 and 2013 relative to the 2007 baseline. Figure 9.3 shows the number of averted vehicle miles for 2009 to 2013 to account for the three-year moving average methodology.

Figure 9.3 Annual averted VMT compared to baseline (2007) (using three-year moving average) (Source: Lyons et al., 2014, figure 12)



9.1.3.3 GHG emissions

The evaluation estimates that the pilot communities saved nearly 3.6 million gallons (13.63 million litres) of petrol between 2009 and 2013. Each gallon of petrol is estimated to produce 19.64 pounds (8.9 kg) of CO_2, almost a pound per mile driven (U.S. Energy Information Administration, 2020). These petrol savings are estimated to be equivalent to 34,629 tons (31,414 metric tonnes) of CO_2 emissions averted. The evaluation also provides details on other emission reductions, as shown in Table 9.2. This table shows estimated reductions in these pollutants in 2013 and from 2009 to 2013 based on averted VMT figures presented in the 'Mode Share Shift' section.

Table 9.2 Estimated emissions reductions associated with the NTPP (Source: Lyons et al., 2014, table 8)

Pollutant	Reduction/Savings in Pounds		
	Per Day	Total in 2013	Total from 2009-2013
Hydrocarbons	183	66,821	255,262
Particulate Matter $(PM)_{10}$	0.70	255	976
$PM_{2.5}$	0.66	241	920
Nitrogen Oxides (NO_X)	128	46,677	178,308
Carbon Monoxide (CO)	1,669	609,255	2,327,391
Carbon Dioxide (CO_2)	49,672	18,130,244	69,258,658

Evaluation results from the programme include the caveat that these are affected by a range of factors including the presence of existing infrastructure, concurrent programmes, and demographic and economic changes occurring throughout the programme period. The study does not refer to any steps taken to consider these external elements in the reporting.

9.1.4 Other contributing factors

The report identified several common elements across the four pilots that could inform the successful implementation of walking and cycling programmes in other jurisdictions, including:

- **Community engagement**
  Outreach efforts need to be broad and extend beyond those groups that already support walking and cycling. Efforts should include elected officials, community organisations, and the business community in selecting and designing programmes to ensure more effective support for implementation.
- **Consistent, system-level data collection**
  Strong baseline data and ongoing data collection was identified as being crucial to evaluate programme outcomes and report annual progress.
  - Establish a budget for data collection and evaluation.
  - Identify data collection needs at the beginning of the programme (count data, safety data, health and economic impact data).
  - When possible, identify a longer history of baseline data to understand pre-programme trends.
- **Identifying most appropriate implementation organisation**
  Partnering with local agencies or organisations with the on-the-ground experience and capacity to support timely and effective programme delivery.
- **Coordinated timing of public outreach and infrastructure investment**
  Gradual and strategic outreach throughout construction and upon completion was found to be more beneficial than a large investment in outreach early on before the majority of facilities were in place in terms of familiarising people with the new facilities.
- **A holistic approach**
  A focus on the entire active mode system of infrastructure and planning rather than just one or two major programmes. Enhancing network connectivity through smaller programmes or providing bike parking can

have big impacts on overall success. Allowing central government funding to be allocated to these smaller-scale programmes was identified as an important tool.

- **Behaviour change takes time**
  Just as it takes time to build a comprehensive active mode network, it also takes time for the community to factor new infrastructure into their transport decisions and routines.

The programme was evaluated on several streams: mode share shift; access and mobility; environment and energy; and safety and public health. Metrics associated with each of these criteria are provided in the final Federal Highway Administration evaluation.

Some co-benefits related to safety and public health are as follows.

- Despite increases in pedestrian and bicycle trips over the course of the programme, between 2002 and 2012, the communities observed a 20% and 28.6% respective decline in pedestrian and bicycle fatalities on roadways.
- The added bicycling trips observed in 2013 alone reduced the economic cost of mortality in the pilot communities by an average of US$46.3 million (NZ$68.35 million) [2013] due to the health benefits of active transport. This may also under-report the benefits because it does not include reduced economic costs of morbidity, which are likely greater than those for mortality (National Bicycle and Pedestrian Documentation Project, n.d.).

9.1.5 Relevance to New Zealand

This type of large programme across a diverse set of jurisdictions offers salient lessons for New Zealand as active mode programmes, funding mechanisms and requirements are considered. It demonstrates that at a programme level, there are measurable mode shift and emission reductions associated with active mode infrastructure investment across a range of city sizes and types. It also highlights the importance of delegating programme design and implementation authority to local jurisdictions for best results. Finally, one of the key elements of this case study is the requirement for robust, regular measurement and evaluation, including the identification of a specific data collection budget within the programme as well as a clear understanding of data requirements at the programme outset.

9.1.6 Opportunities for further study

- Identifying a mechanism for robust and consistent post-implementation evaluation of active mode interventions in New Zealand warrants further investigation. A requirement to both measure and share the results, perhaps tied to the receipt of central government funding, would create a knowledge base of both qualitative and quantitative outcomes that could improve implementation across jurisdictions.

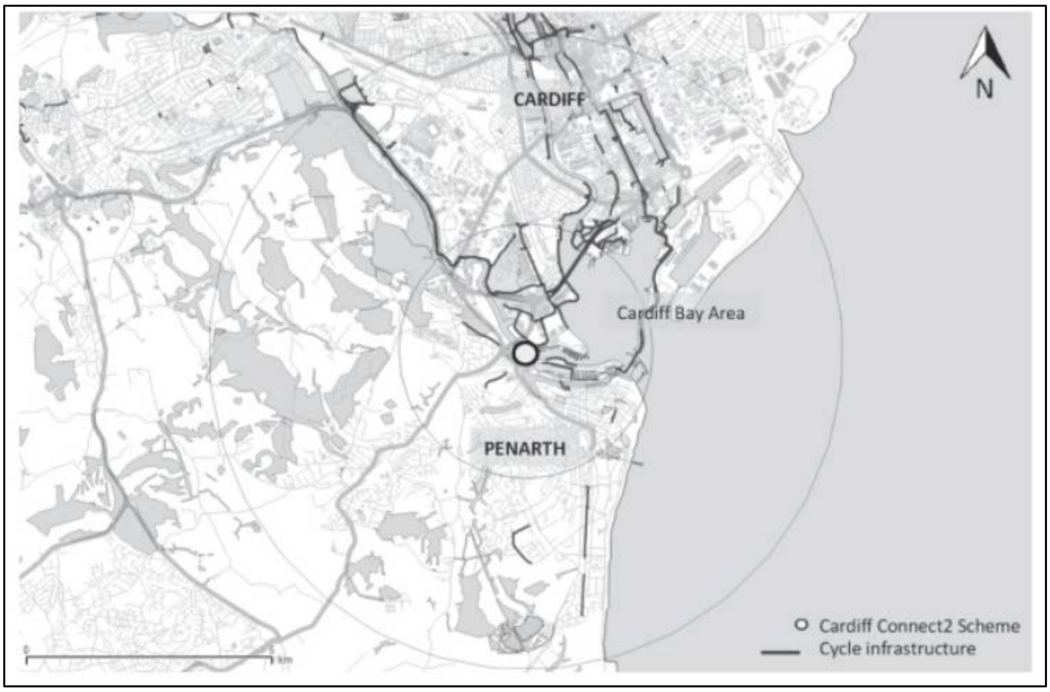
9.2 Cardiff, Wales – walking and cycling infrastructure

Programme type	Location	Programme scope
Walking and cycling infrastructure	Cardiff, Wales: population 364,248 (2017)	A traffic-free bridge to establish walking and cycling links as part of the nationwide Connect2 scheme

9.2.1 Detail of programme

A new traffic-free bridge across the River Ely in Cardiff was built in 2010 as part of the nationwide Connect2 scheme. This was a five-year programme operated by Sustrans (n.d.) to establish walking and cycling links to connect local areas in 79 communities throughout the United Kingdom. The Cardiff programme was established to support commuter trips into the city centre from Penarth, as well as local and recreational trips, as shown in Figure 9.4. The inner and outer circles represent 2.4 km and 6.4 km buffers around the core element of the scheme, the bridge over the river Ely.

Figure 9.4 Study area for the Connect2 cycling infrastructure in Cardiff, Wales (Source: Neves & Brand, 2019, figure 1)



An observational study of 50 participants was conducted to explore the potential for CO_2 emissions reductions from substituting short car trips by walking and cycling in an observed setting (Neves & Brand, 2019). The research investigated the role of new walking and cycling infrastructure in supporting mode shift and reducing emissions as well as providing insights into people's travel behaviour and potential for change.

This study emphasises the importance of collecting micro-level data to inform potential emissions reductions from a shift towards active modes and to understand the factors influencing people's decision to cycle for everyday travel or recreation, including route selection, destinations and the role of the new infrastructure to support change.

For context, in the United Kingdom, approximately one fifth of CO_2 emissions come from car journeys of less than 8 km, which could reasonably be completed by cycling or walking (Neves & Brand, 2019).

9.2.2 Measurement methodology

The study collected qualitative and quantitative data for each of the 50 participants using the following tools:

- a personal GPS device
- 7-day travel diaries
- contextual interviews.

The study was conducted over two matching 7-day time periods in 2011 and 2012 to allow for improved measurement and data validation as well as measuring change across the two years (Neves & Brand, 2019).

Utilising GPS trackers provides more detailed information on journey distance, duration, and route choice than traditional travel surveys or diaries. However, the travel diary provided extra information such as trip mode and trip purpose, which cannot be captured using GPS raw data. Qualitative data collected in interviews was used to provide a more realistic assessment of the potential for change.

GHG emissions for motorised travel modes were calculated using trip distance; vehicle details such as car size, age and fuel type; and average speeds accessed from the GPS data. The emission mitigation potential of walking and cycling trips was estimated by simulating a similar trip by car based on the same elements described previously. For annual CO_2 emissions, weekly totals were multiplied by 47 weeks to account for holidays (Neves & Brand, 2019).

9.2.3 GHG emissions outcomes

The study estimated that, extrapolating from the directly measured results of the study, walking or cycling could realistically replace approximately 41% of short car trips. This takes into account people's individual travel patterns and constraints, which is important for predicting a realistic replacement value. This mode shift for short trips represents a potential saving of nearly 5% of CO_2 emissions from car travel and is in addition to a 5% of 'avoided emissions' due to existing trips completed by walking or cycling. Cycling contributed to the largest share of potentially avoided savings at 4.1% (Neves & Brand, 2019).

One key factor that the researchers point to in the value of replacing shorter trips by alternate modes is the comparatively higher impact that short car trips have on per kilometre air pollution and CO_2 emissions due to 'cold start' excess emissions during the start phase of trips.

However, the study found a comparatively low reduction of 0.5% of emissions from avoided car trips directly attributable to the Connect2 scheme and the traffic-free bridge. A further 1.2% of avoided emissions can be added to this number when walking and cycling trips completed on routes adjacent to the Connect2 interventions are counted (Neves & Brand, 2019).

9.2.4 Other contributing factors

The study of emissions reductions associated with the Connect2 programme in Cardiff notes the importance of understanding trip purpose and composition when seeking to identify the potential for short trips currently made by car to be shifted to walking or cycling. Typical reasons given by participants for completing a trip by private vehicle rather than active mode included the need to transport goods or children; time constraints and convenience; and the lack of a suitable alternative (Neves & Brand, 2019). Identifying short car trips that are part of a trip chain for a much longer journey is also important as the potential emissions reductions associated with a longer trip completed by rail, for example, may outweigh the disbenefit of the emissions from the shorter car journey for the first or last leg of the trip. However, providing alternative ways of completing the first and last leg of a longer journey by non-car-based modes should still be the goal.

One of the potential reasons cited for the limited observed shift to cycling, for commuting trips in particular, was the poor quality of connecting links to the newly constructed bridge.

While this analysis demonstrated some reduction in emissions attributable to the creation of a new walking and cycling link, it also noted that a more comprehensive approach to supporting mode shift, including improving the wider cycling network, car reduction and parking pricing strategies, is likely required to have a more substantive impact on travel behaviour.

9.2.5 Relevance to New Zealand

While this study showed limited impact on emissions reductions from the creation of a single cycle facility, it does have value in demonstrating the potential for further savings by taking into account personalised trip characteristics. This micro-level analysis provides a stronger underpinning for estimating the percentage of short car trips that could realistically be expected to be completed by walking or cycling if high-quality facilities were available, and the need for more comprehensive cycling network interventions. It also highlights the importance of supporting policies to disincentivise private vehicle travel and promote and encourage use of new facilities once they are built.

9.2.6 Opportunities for further study

- There may be an opportunity for micro-level analysis around the installation of new cycle facilities, including in-depth interviews to understand the specific behavioural incentives and disincentives associated with shifting to active modes. However, any such analysis needs to consider the importance of supporting policies as noted above.

9.3 Seville – continuous, connected cycle network development

Programme type	Location	Programme scope
Cycle network	Seville, Spain	• The rapid development of a continuous, connected cycle network (120 km) that focuses on separation from traffic, connectivity between trip attractors and residential areas, continuity of the network, homogeneity in design and pavement, and bi-directionality. • Seville population: 688,711 (2018). • Seville land area: 140 km^2 (50 mi^2).

9.3.1 Detail of programme

Between 2006 and 2010, Seville approved a masterplan with 120 km of cycle network, as shown in Figure 9.5 (since expanded to a 175 km network) (Interreg Europe, n.d.). By 2015, 164 km of mostly bi-directional, separated cycle lanes had been built, and in 2013 they scored 76 in the Copenhagenize Index[4] (Marques et al., 2015).

The main characteristics of Seville's cycle network are:

- continuity and connectivity: connecting (without gaps) main trip attractors and residential areas
- cohesion and homogeneity: bike paths throughout the network are designed similarly
- directness and visibility: the cycle network follows the main streets, so is quite visible
- comfort: comfortable for everyday cycling, with no major barriers (such as steps)
- quick building: the core network (77 km) was built in less than two years (Marques et al., 2015).

[4] The Copenhagenize Index is a ranking of cycling networks in cities around the world (https://copenhagenizeindex.eu/).

Figure 9.5 120 km cycle network developed in Seville, Spain, between 2006 and 2010 (Source: Marques et al., 2015, figure 1)

Seville's cycle network was able to be rolled out so rapidly because of their early requirement for the infrastructure to be 'quick to build', the standardised bike path design that reduced complexity in implementing bike paths on different streets, and the development of the City Masterplan that identified where the early network should be prioritised to connect major trip attractors (Calvo & Marques, 2020). The ability to build the network fast was also enabled by having the political support required to make it happen.

Seville also has a public bike share scheme (BiciSevilla) that was launched in 2007 with 2,650 bikes and 260 stations around the city: the average distance between the bike share stations is less than 300 m. In 2009, the bike share had nearly 60,000 users, and more than 10 trips were taken per bike per day (Marques et al., 2015).

9.3.2 Measurement methodology

Marques et al. (2015) used survey data to determine the average distance of bicycle trips and what modes those trips would have previously used. The savings in GHG emissions from this cycling network were then estimated using a methodology developed by the European Cycling Federation.

This methodology evaluates a life cycle assessment of emissions by taking into account:

- production phase: the energy and material inputs to create the vehicle (eg, car or bicycle)
- operation phase: fuel production and utilisation (eg, petrol for cars, or food for bicyclists)
- maintenance phase: all activities required to keep vehicles safe on the road (Blondel et al., 2011).

The methodology excludes the emissions of infrastructure (eg, roads or cycle paths) and disposal (of the vehicle and waste material).

9.3.3 GHG emissions outcome

Using the above methodology, Seville's extensive cycle network is estimated to save over 8,000 tonnes of carbon dioxide equivalent (tCO_2e) per year, equivalent to around 26,000 oil barrels or €2 million (NZ$3.45 million) of fuel imports per year.

Some interesting survey findings include:

- there was a substantial decline in mode share of car trips: ~9% reduction in private vehicle mode share from 2007 to 2011
- new bicycle trips shifted from the following modes:
  - walking trips (26%–28%)
  - public transport (37%–40%)
  - private vehicles (31%–32%) (Marques et al., 2015).

The following mode share changes were observed (Hitchcock & Vedrenne, 2014).

- Mode share by bike increased from 0.5% in 2006 to 7% in 2013.
- Mode share by car was 55% in 2004 and 35% in 2012.

9.3.4 Other contributing factors

The methodology for estimating GHG emissions considers the emissions effect from cycling compared to the alternative modes of travel. The number of cyclists could be affected by other transport programmes if those programmes encourage or disincentivise certain modes of travel, thus affecting the number of cyclists actually using the network.

Other transport programmes in Seville around the same time include:

- a public bike share scheme (BiciSevilla) launched in 2007
- public transport: the first line of the metropolitan subway (18 km) was completed in November 2009 (Marques et al., 2015)
- public transport: extending and improving public transport infrastructure (Hitchcock & Vedrenne, 2014)
- modal choice: promotion of non-motorised travel options (Hitchcock & Vedrenne, 2014)
- cars: restrictions to private car use (such as car-free zones in the city centre) and incentivising high-occupancy vehicles (Hitchcock & Vedrenne, 2014)
- parking: removal of around 8,000 car parking spaces (as part of the cycle network development) (Marques et al., 2015)
- highways: construction of 21.5 km of metropolitan city highways (Marques et al., 2015).

The study period includes the Spanish economic crisis, which may have had some impact on the number of car trips taken.

Although not explicitly calculated in the literature, co-benefits would include improved safety for non-motorised transport users (improved cycle facilities and reduced traffic), improved air quality and reduced noise from lower traffic volumes, and improved health outcomes for people who increase their use of active modes for transport.

9.3.5 Relevance to New Zealand

9.3.5.1 Applicability to New Zealand

The case study of the rapid development of the cycle network in Seville is applicable to New Zealand, particularly in cities where distances between residential areas and trip attractors (such as business districts) are cyclable; for example, 50% of commutes in Auckland are less than 4.6 km.[5] This case study shows that large gains in cycling mode share can be obtained by providing a comprehensive cycling network.

The applicability to New Zealand is supported by responses to a Waka Kotahi survey (NZ Transport Agency, 2019) in which 67% of respondents agreed that investing in cycle lanes is important and gives people more travel options, while only 38% of respondents were satisfied with the availability of cycle paths in their community and only 24% agreed that cyclists are sufficiently separated from traffic.

According to this New Zealand survey, 39% of respondents would cycle more (or start cycling) if the cycling infrastructure was improved (NZ Transport Agency, 2019).

9.3.5.2 Insights from the programme relevant to New Zealand

Given that New Zealanders would be willing to cycle more if safe and comprehensive infrastructure was provided, a key insight from Seville includes the importance of understanding the core requirements of the cycle network. In Seville, a key characteristic was 'quick building', which is uncommon for cycle paths. However, this characteristic enabled them to lay out 77 km of cycle network in less than two years, bringing forward the associated benefits of having an extensive, connected and continuous cycle network. This rapid building tactic was also used by New York City with a rapid rollout of 'temporary' cycleways and plazas starting in 2007 that were later made permanent (Koska & Rudolph, 2016).

In Seville, the associated bike share scheme, BiciSivilla, was initiated at the same time as the cycle network construction and had nearly 60,000 users two years after it was launched, dropping to around 45,000 users after another four years (Marques et al., 2015). This suggests that people initially used the bike share scheme to 'test' whether cycling was a suitable mode for them without having to own a bike. The high ongoing use of the cycle network suggests that the drop in users of bike share likely corresponds to an increase in bicycle ownership.

9.3.6 Opportunities for further study

- Identifying appropriate funding and construction mechanisms to support the rapid rollout of cycle facilities that are connected, safe, and accessible for all ages and abilities may be an area for further research. This could build on lessons learned from the innovating streets programme to identify common opportunities in different communities.

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[5] Based on Stats NZ Journey to Work analysis using Euclidean distances between zone centroids for Statistical Area 2 zones.

10 Public transport case studies

10.1 Bogotá – bus rapid transit

Programme type	Location	Programme scope
Bus rapid transit (BRT)	Bogotá	• TransMilenio BRT system covering the capital city of Colombia and the nearby area of Soacha. The system has eight lines, with a total of 114 km of routes. • Bogotá population: 7,413,000 (2018). • Bogotá urban area: 307.36 km^2 (118.67 mi^2).

10.1.1 Detail of programme (major interventions)

The Bogotá BRT system, called TransMilenio, is the highest-capacity BRT system in the world and generally considered a standout international example. This case study reviews research identifying the mode shift and GHG emissions benefits of the system. There are, however, several other international examples of comprehensive BRT systems that would warrant further investigation in this space in the future. These include Jakarta, Mexico City, Guangzhou, Brisbane, and the first BRT network in Curitiba, Brazil, though there are dozens of BRT lines worldwide ('List of Bus Rapid Transit Systems', 2020). The first construction for the TransMilenio started in 1998, and the first parts of the system opened in 2000. Construction has been split into phases, with phase four ongoing. The system currently has 114 km of lines.

Buses in the TransMilenio system use dedicated lanes, which are served by stations more similar to a metro or light rail system than a bus system. Passengers pay fares at stations using an electronic ticket system prior to boarding. The system carries approximately 2.2 million journeys per day (Tsivanidis, 2019).

It is important to note that the Bogotá system had its most significant positive response in the early days of its implementation. Since that time, there have been 'growing pains' with the system, as excess demand has negatively affected the quality of the service (Hidalgo, 2019). This has meant that public satisfaction with the service has declined. Upcoming upgrades to the fleet and service are expected to improve capacity. This case study largely reports on the scheme's emissions reductions, based on user uptake, from 2006 to 2012, as this is the period with publicly available information relating to emissions published by the Clean Development Mechanism (2012) of the United Nations Framework Convention on Climate Change (UNFCCC).

10.1.2 Measurement methodology

A 2010 analysis of the GHG emissions effects of the TransMilenio provides the most comprehensive analysis (Hook et al., 2010). The TransMilenio programme receives credits under the Clean Development Mechanism (CDM), a UN-based programme that analyses and

> *allows emission-reduction programmes in developing countries to earn certified emission reduction (CER) credits, each equivalent to one tonne of CO_2. These CERs can be traded and sold, and used by industrialised countries to a [sic] meet a part of their emission reduction targets under the Kyoto Protocol. (UNFCCC, n.d.-b, para. 1)*

To qualify for the scheme, programmes have to follow a detailed methodology for both initially estimating the GHG emissions reductions of the programme, and then follow through with regular monitoring and reporting on the actual GHG emissions reductions through the use of the CDM methodology calculation. This involves collecting data on the programme through four methods:

- passenger data through electronic ticketing
- distance driven by buses, obtained through odometer readings and GPS devices on buses
- total fuel consumption for buses, logged at fuel stations
- passenger surveys, carried out by an external third party (generating data on modal split, average distance they would have travelled in private vehicles if the BRT was not in place, and the fuel type they would have used).

Greater detail as to the particular methodologies for each of these data collection methods can be found in the CDM reports for each year 2006–2012 (CDM, 2012). General methodologies for BRT evaluation for the CDM can be found in the detailed report published by CDM (2019).

The measurements gathered are then used to calculate overall CO_2 reductions compared to a modelled scenario where the programme was not in place. The calculation includes (mostly estimated) factors for potential 'leakage', such as infrastructure construction, bus manufacturing, fuel production, and rebound effects, such as increased driving on roads that become decongested as a result of the BRT programme (Hook et al., 2010).

10.1.3 GHG emissions outcome

Based on the CDM methodology, phases two to four of the programme are expected to generate reductions of 578,918 tCO_2e per year (UNFCCC, n.d.-a). This is, however, significantly higher than the actual amounts measured between 2006 to 2012,[6] which averaged 72,917 tCO_2e per year. The discrepancy between CO_2 emissions reduction projection and the calculation based on measured outcomes results from various problems with the implementation of the programme. Namely, in the years since 2006, the system has struggled to implement local and feeder routes sufficiently. Planned upgrades were also delayed, significantly affecting the emissions reduction results due to the system having fewer passengers than predicted. Despite being unable to meet expectations, these measurements show that BRT infrastructure provides a significant reduction in GHG emissions compared to a baseline situation without such infrastructure.

CDM reporting finds that the TransMilenio BRT reduces GHG emissions by:

- improved efficiency (more people able to be carried by fewer buses)
- mode switching from private cars and taxis
- integration with feeder lines
- reduction of the fleet of buses that existed prior to the introduction of the BRT (the retirement of older buses).

The actual emission reductions of the programme are reported for every year from 2006 to 2012 (UNFCCC, n.d.-a), as shown in Table 10.1.

[6] This is the most recently published time period with actual post-implementation results for the project under the CDM methodology.

Table 10.1 Emission reductions of the TransMilenio BRT programme (adapted from UNFCC, n.d.-a)

Year	Reported emissions reduction attributed to TransMilenio BRT (CDM methodology)	Estimated
2006	59,020 tCO_2e	Not provided in report, but actual reduction stated as 40% lower than prediction
2007	70,109 tCO_2e	134,011 tCO_2e
2008	68,813 tCO_2e	230,201 tCO_2e
2009	79,326 tCO_2e	304,432 tCO_2e
2010	76,466 tCO_2e	298,719 tCO_2e
2011	76,560 tCO_2e	312,220 tCO_2e
2012	80,128 tCO_2e	307,300 tCO_2e

10.1.4 Other contributing factors

The TransMilenio system is considered the keystone of Bogotá's Mobility Strategy. The GHG emissions results reported in this case study are very specifically related to the BRT alone. Despite this, the city has implemented other policies and programmes under mayors Antanas Mockus and Enrique Peñalosa that can be expected to contribute at least in part to any success seen by the BRT system. These include:

- significant investment in a city-wide bicycle network (344 km) for daily commuting
- the closure of 121 km of roads to create temporary active transport spaces on Sundays and public holidays, called Ciclovía
- annual car-free day
- a 17 km pedestrian corridor connecting low-income neighbourhoods to business districts
- roadway restrictions that prevent people driving on odd/even days depending on their licence plate number, called pico y placa.

The total GHG emission effects reduction of the entire approach was reported by the Centre for Clean Air Policy as being 2 million tCO_2e in 2013, but the methodology for this calculation is not clear (Centre for Clean Air Policy, n.d.).

10.1.5 Relevance to New Zealand

Work has been done to identify the relevance of the Bogotá BRT system to urban areas in the United States, and much of this work is equally relevant to New Zealand (Cain et al., 2007). Bogotá is characterised as a highly populated, dense city (210 people per hectare), with an urban form focused on a central business district. The lowest income areas in the city are located on the city's periphery, rather than in the urban centre, and there is less of a trend towards suburban living or working (compared to the United States and New Zealand). A 2018 analysis of transport accessibility in the city found that public transport made up 61% of motorised journeys (Guzman et al., 2018), while a 2019 analysis found total public transport mode share to be 36% (Deloitte, 2019). The political environment of Colombia and the United States (and New Zealand) is also significantly different. Generally, in countries considered to be 'developing', a strong executive has greater autonomy and ability to implement policy more quickly, without strict review processes. This was demonstrated by the three-year implementation window for the Bogotá system. Although these differences make some aspects of the BRT system less relevant to New Zealand and more relevant to developing countries, analysis finds that the general lessons from the Bogotá BRT system are still important for developed countries such as New Zealand or the United States.

The lessons from the TransMilenio system are relevant for transport agencies that wish to consider the potential benefits of making use of existing infrastructure and address the problem of private vehicle users not paying the full marginal cost of travel. Cain et al. (2007) highlight numerous similarities and differences between the Bogotá system and what is achievable in developed countries such as the United States. The paper does not assess the expected level of emissions reduction between the two settings, but it is reasonable to assume that significant benefits could be observed should similar levels of emissions analysis be conducted for BRT programmes such as the bus network in Brisbane, Australia, or Auckland's own Northern Busway. For example, Auckland's Northern Busway has generated ridership that far exceeded original expectations, with flow-on effects in terms of the carrying capacity of the Auckland Harbour Bridge and expected environmental benefits (NZ Transport Agency, 2012). The measurement methodologies used within the Bogotá example may provide a way to further determine these benefits in the context of GHG emissions reduction.

10.1.6 Opportunities for further study

- Analysis of the GHG emissions or VKT reduction from single BRT interventions, such as Auckland's Northern Busway or the wider network in Brisbane.

11 Travel behaviour change case studies

11.1 Soft interventions – a meta-analysis

Programme type	Location	Programme scope
Meta-analysis of 'soft' interventions aimed at motivating people to modify travel behaviour	Studies from Japan (17), United Kingdom (9), Sweden (3), Taiwan (2), China (1), Australia (1)	41 studies from locations in Asia, Australia and Europe involving 11,206 participants

11.1.1 Detail of programme (major interventions)

This case study summarises an academic meta-analysis by Semenscu et al. (2020) of 41 studies that attempted to show the results on vehicle travel from 'soft' interventions. These are defined as interventions that aim to influence people's attitudes towards transport by way of persuasion and motivation, rather than 'hard' measures (such as infrastructure or financial disincentive methods) (Möser & Bamberg, 2008). In general, such soft measures are most familiar to the general public as promotional campaigns, individualised travel planning, travel advice and other similar interventions.

The meta-analysis only reviewed programmes that had strong methodological designs. Eligibility criteria included:

- experimental or quasi-experimental study design (ie, the use of random assignment, intervention or control groups, or controlling variables accounted for)
- adult participants
- soft interventions only (although minor incentives such as free public transport tickets were included)
- reporting of quantitative outcomes within the context of car journeys (eg, distance travelled, VKT, number of journeys)
- completion between 1988 and 2018
- reporting in English language.

A high-level review of the abstracts of 3,749 studies found 169 publications matching the criteria, following which 41 were deemed appropriate for inclusion in the meta-analysis. The full research report outlines the selection process in more detail.

The most common types of interventions profiled within the meta-analysis were Travel Feedback Programmes, which are generally defined as the receipt of information designed to modify travel behaviour. This can range from personalised information, such as personalised travel planning, or non-personalised information, such as information about how to use public transport (eg, letter drops). Other methods included the development of 'action plans' and 'coping plans'. Action plans are personalised plans to help individuals use different forms of transport, asking questions of 'when and where' behaviour can change, and developing choices for this. Coping plans build on action plans by allowing participants to explore potential barriers to their travel behaviour change and developing mechanisms to overcome those barriers (Hsieh et al., 2017). Other programmes focused on the provision of information about travel opportunities while also offering a level of incentive, such as free public transport tickets.

The researchers also split the interventions by the type of 'psychological variable' targeted. Successful programmes targeted:

- social, cultural and moral norms
- knowledge and awareness of people's own driving behaviour
- capability and self-efficacy (trying to affect people's belief in their ability to make a change).

11.1.2 Measurement methodology

In the studies and interventions included in the meta-analysis, various measures of outcome were used:

- number of trips conducted by car (20 studies)
- proportion of trips by car (11 studies)
- travel distance (5 studies)
- travel time (1 study)
- multiple outcomes (4 studies).

The methodologies to measure these outcomes varied slightly, but for the most part they relied on self-reporting of some type, including:

- travel diaries (34 studies)
- recollections of travel from the previous week (5 studies).

Measurements that did not involve self-reporting were limited to:

- GPS measurements (1 study)
- calculated distances on a map (1 study).

11.1.3 GHG emissions outcome

Based on the selection process, the meta-analysis considered all of the results from each of the included studies and summarised the overall effects on behaviour and travel based on a series of tests of the type of intervention, the targeted psychological variable and the method of data collection.

In general, the study found that, among the 41 studies, there was a wide range of effectiveness on the modal split share for car use from soft interventions. The average reduction in the modal split of car travel was 7%, but this includes a wide range of difference between studies so should be considered in this context. The studies had an associated effect size of 0.163 using Hedges' meta-analysis methodology (95% confidence interval 0.113–0.213). An effect size (the amount an experimental group differs from a control group) of less than 0.2 is considered small.

The analysis findings indicate that the effect of these interventions was small generally and with large variation, depending on the context and target of the intervention.

The average reduction in car modal split share of 7% among the studies is in line with other meta-analyses of soft travel behaviour change examples completed in the last 15 years (Fujii et al., 2009; Möser & Bamberg, 2008). This average must be considered alongside the large variations between different types of programmes, and different psychological variable targets. Not all details of these variations are provided in this summary, but the major differences reported by the study are that interventions targeting cultural and moral norms saw the highest average decrease in car modal split share, followed by interventions targeting knowledge and awareness of own-driving behaviour, and interventions targeting capability (those trying to affect people's belief that they can achieve a certain task).

The study found that other targets (eg, people's general travel habits) did not return particularly strong results in terms of mode shift from soft behaviour change interventions.

Within the 41 studies examined, many of these effects will be quantified in terms of changes to VKT or reduction in distance travelled, which can then be translated into a GHG emissions effect. However, given the range of results observed both within this meta-analysis and in other studies, it is recommended that a conservative average is used when considering the potential emissions effects of soft intervention programmes. It should be noted that reduction in mode split for car use does not translate directly into reduction in GHG emissions, due to the lack of knowledge available in terms of what alternative choice drivers made. This is particularly important when looking at behaviour change programmes and understanding the methodology used to assess them.

11.1.4 Other contributing factors

The meta-analysis found that the effectiveness of interventions was not affected by any of the following factors:

- gender of participants
- presence of incentives for participation in interventions
- time to follow up with participants
- type of measurement instruments
- size of city where the interventions took place.

These are significant findings in the sense of helping to develop an understanding of how soft travel behaviour interventions can be designed, and in what context.

The authors warn that the study sample size of 41 is relatively small and that some of the smaller relationships observed (particularly the lack of effect of the type of measurement instrument) would require further study.

Likewise, much literature points to the need for soft travel behaviour change programmes to be integrated with other improvements to the transport system. Providing information about alternatives to travel requires alternatives to be appropriate and adequate for people's needs (Victoria Transport Policy Institute, 2019b).

11.1.5 Relevance to New Zealand

Firstly, this study finds that much of the research into voluntary travel behaviour change is lacking a level of robustness, mostly relating to measurement methodology, with a lack of a control group or reliance on a single qualitative survey. This fits with other research that has critiqued such studies, finding that benefits of soft behaviour change interventions can, in some cases, be overstated (Stopher & Bullock, 2003). For New Zealand, this means there is a local need to monitor behaviour change interventions with an agreed-upon and robust methodology that makes use of control groups where possible to understand the effects of such interventions. The relative lack of such methods internationally points to an opportunity in New Zealand to set standards in this area and contribute to the field. Travel behaviour change programmes were, for example, highly popular in Australia between 1997 and 2017, but many are no longer in use, with analysis citing one reason being a lack of appropriate measurement methodology tied to some (but not all) programmes (James, 2017). This was despite a number of programmes having successful outcomes.

Secondly, the findings of this analysis show there may be some benefit to the use of travel behaviour change initiatives but are unable to fully answer the question of what interventions can have the greatest effect on GHG emissions. The analysis ends by suggesting that significant further research is needed into the field, and particularly into the right mixture of hard and soft travel behaviour levers. This is important for the New Zealand context, as results from other programmes cannot be expected to deliver matching results to programmes seen overseas if the public and active transport systems involved are significantly different.

11.1.6 Opportunities for further study

- Qualitative analysis or interviews of staff in jurisdictions where soft behaviour change programmes have been implemented to assess effectiveness of programmes. Particular examples include programmes in place in Australia between 1997 and 2017.
- New Zealand examples of soft behaviour change programmes should also be investigated for effectiveness.

12 Urban logistics case studies

12.1 Germany – Deutsche Post DHL electric mail scooters

Programme type	Location	Programme scope
Delivery vehicle mode-shift programme	Germany	Nationwide

12.1.1 Detail of programme

Deutsche Post DHL has made a considerable investment in electric vehicles to replace diesel vans for mail and parcel delivery in towns and small cities in Germany. This move was in response to a commitment to decarbonisation of their operations, and as of 2019, 10,000 electric vans have been added to the fleet (Figure 12.1).

Figure 12.1 StreetScooters charging (Source: Deutsche Welle, 2017)

One of the unique aspects of this move to electric vans is that their adoption was generated through a collaboration between Aachen University and Deutsche Post DHL, which allowed vehicles to be developed specifically for the needs of the business and tested by employees. This led to the creation of a company known as StreetScooter GmbH, which was subsequently purchased by Deutsche Post DHL, which took over production of the vehicles. The first prototype was tested in 2012, and in 2014, 150 vehicles were trialled at various location across Germany (Deutsche Post DHL Group, 2017).

The StreetScooter e-vans have a battery range limited to 80 km, a maximum speed of 85 km/hour, and a battery output of 48 kW. Their electric traction is ideal for frequent start–stop traffic. Each vehicle makes 300 stops every day, 300 days a year (European Environmental Agency, 2019). From an emissions perspective, electric vehicles are considered to be particularly beneficial for trips involving many stops because the frequent ‘cold starts’ of shorter trips are typically associated with a higher rate of emissions (Neves & Brand, 2019).

The StreetScooter fleet is part of the company's GoGreen environmental programme, which has a goal of reducing all logistics-related emissions to zero by 2050. In addition to the electric StreetScooter delivery vans, the company operates approximately 12,000 e-bikes and e-trikes (DHL Global, 2019). To support this move to electrification, as of 2019, Deutsche Post DHL has installed around 13,500 charging stations at depots and delivery bases across the country. In comparison, there were estimated to be 20,650 public charging stations in Germany in 2019 (DHL Global, 2019).

12.1.2 Measurement methodology

Establishing the specific methodology used to calculate GHG emission reductions associated with the adoption of the StreetScooters was challenging. Deutsche Post DHL reports the use of two key systems, or tools, for tracking GHG emissions. The first is the Carbon Efficiency Index, which is calculated based on specific emission intensity measures for each part of the business. GHG emissions are calculated separately to feed into the Carbon Efficiency Index using recognised standards such as tools developed by the Greenhouse Gas Protocol (Deutche Post DHL Group, 2019).

The Greenhouse Gas Protocol (n.d.) provides specific tools for the measurement of GHG emissions from transport or mobile sources. These tools indicate that fuel use data is the most accurate means of calculating GHG emissions, and the assumption is therefore made that the reported emissions savings from the use of StreetScooters is based on fuel consumption rates of combustion engine vehicles used prior to the introduction of the electric vehicles.

12.1.3 GHG emissions outcomes

In 2019, Deutsche Post DHL celebrated reaching 10,000 StreetScooters in their fleet. The company reports that each vehicle saves between 3 and 4 tonnes of CO_2 and between 1,100 and 1,500 litres of diesel per year, depending on the vehicle type as shown in Table 12.1. This translates into annual emissions reductions of over 36,000 tonnes per year.

Table 12.1 StreetScooter technical details (Source: Deutsche Post DHL Group, 2017, p. 2)

	StreetScooter Work	**StreetScooter Work L**
Area of use	Joint deliveries	Joint deliveries
Engine capacity (in kW)	48	48
Battery type	Lithium-ion	Lithium-ion
Battery size (in kWh)	20	30
Range (in km)	Up to 80	Up to 80
Maximum speed (in km/h)	85	85
Overall dimensions (L/W/H in m)	4.71 / 2.08 / 2.04	5.78 / 2.09 / 2.35
Volume (in m^3)	4.3	8
Load capacity (in kg)	740	960
Permissible total weight/unladen weight (in kg)	2,180 / 1,440	2,600 / 1,640
Charging time	4.5 – 7 hours	8 – 10 hours
CO2 savings and diesel per year and vehicle	3 tons and 1,100 liters	4 tons and 1,500 liters

12.1.4 Other contributing factors

The company's commitment to zero emissions by 2050 has guided their investment decisions. Two factors that have been reported as being particularly significant in the success of the programme are the support and involvement of the company's senior management in developing the programme, and funding received from the German Environmental Ministry to further develop and test the vehicles between early 2016 and the end of 2019 (European Environmental Agency, 2019).

12.1.4.1 Co-benefits

- Electric vehicles are quiet at low speeds, which can help to reduce noise pollution in urban areas.
- Using electric vehicles reduces urban exposure levels of other pollutants that are harmful to health.
- These vehicles were specifically designed as delivery vehicles with ergonomic requirements in mind as the drivers have to get into and out of the vehicle up to 200 times per day.

12.1.5 Relevance to New Zealand

New Zealand Post has made a similar commitment to decarbonisation with a goal of becoming carbon neutral by 2030 and has invested in both electric delivery vans and the 'paxter' vehicles. While New Zealand Post has reported CO_2 emissions reductions over several years, no reporting of reductions directly attributable to the electrification of the fleet was found during this review (New Zealand Post Group, 2019).

Perhaps most importantly for New Zealand, this case study shows how a partnership between academic innovation hubs and industry can generate positive results in reducing emissions that are also viewed as a financial benefit for business. While the electric vehicles require a larger initial capital investment, they are estimated to have maintenance costs 60%–80% lower than combustion engine vehicles. This indicates a role for the public sector in supporting companies with large carbon-intensive fleets to make the transition to electrification. The Energy Efficiency and Conservation Authority currently operates a Low Emission Vehicle Contestable Fund, which uses petrol and engine fuel levies to fund programmes that will increase the uptake of electric vehicles (Genless, 2020). Finding additional revenue sources to increase available funds for this sort of programme may be beneficial in accelerating fleet replacement.

Another opportunity may lie in partnering with large-scale organisations in the provision of charging infrastructure. Deutsche Post DHL has been able to establish an extensive private network of charging facilities. Establishing a similar system here could relieve some pressure from government in establishing a comprehensive vehicle charging network in a short period of time to support large-scale electrification.

12.1.6 Opportunities for further study

- Opportunities for partnerships between the public, private and academic sectors to accelerate fleet transition to electric vehicles.

12.2 Various locations – cycle logistics

Programme type	Location	Programme scope
Cycle logistics – cargo-bike deliveries	Various	Small-scale programmes shifting deliveries from combustion engine vans or trucks to cargo bikes for first-mile/last-mile urban logistics. This is almost exclusively in conjunction with the establishment of delivery hubs in proximity to dense urban centres.

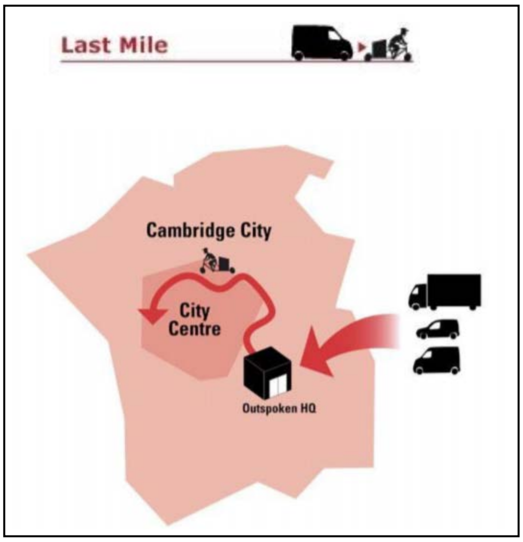
12.2.1 Detail of programme

Cycle logistics represent an important tool in replacing combustion engine delivery vehicles over short trips in urban environments. A 2014 report from CycleLogistics estimates that while goods delivery vehicles account for 15% of urban trips, they represent 30% of energy consumption due to vehicle fuel types and time spent in congested traffic and searching for parking (Reiter & Wrighton, 2014). There are of course limitations on the effectiveness of cargo bikes to replace vans due to smaller carrying capacity and range. Researchers also have varying estimates of the volume of van deliveries that could be replaced by cargo bike. Melo and Baptista (2017) estimate that they could replace up to 10% of existing van deliveries within a 2 km delivery area without impacting network efficiency, while CycleLogistics estimates that this could be closer to 25% (not specifying a radius). This indicates an opportunity for shift in some of New Zealand's larger towns and cities that have the density or small area to make cycle logistics an economical alternative.

Due to the small-scale nature of many cycle logistics programmes, the findings of this case study will be presented in a slightly different format, reporting on several discrete programmes at a higher level to give a broad view of potential GHG emissions savings.

- **Cambridge, United Kingdom**
  In 2014, the Cambridge City Council outsourced its internal mail delivery to Outspoken Delivery cycle logistics. A key aspect of this programme was the council ensuring that the tender for this procurement was written in a way that did not preclude cycle logistics solutions from bidding. This is critical, as the standard language of many procurement processes may unintentionally exclude this type of provider. This is seen as an important way that local governments can support the growth of the cycle logistics industry (Swennen & Rzewnicki, 2015). Figure 12.2 shows the configuration of the Cambridge delivery hub process.

Figure 12.2 Cargo bike last-mile delivery hub, Cambridge (Source: Armstrong, 2016, p. 28)



- **Maastricht, Netherlands**
  In 2017, a subsidy scheme saw four companies swap a van for a cargo bike in their daily operations, including a mobile hairdresser, an events agency, a student services company and a coffee-roasting company (Cairns & Sloman, 2019).
- **Nuremburg, Germany**
  In 2016, DPD/GLS established a pilot combining micro depots and cargo bikes. The bikes were capable

of making 15 stops per hour or up to 100 stops per day. The pilot phase replaced the carbon-intensive profile of their fleet by switching from 10 trucks to 5 bikes and 6 trucks (Cairns & Sloman, 2019).

- **Brussels, Belgium**
  In 2013, TNT Express tested the concept of a mobile depot as an inner city base to support first-mile/last-mile deliveries by electric cargo-bikes (Verlinde et al., 2014). The three-month pilot was part of the EU-funded STRAIGHTSOL (Strategies and measures for smarter urban freight solutions) programme. The mobile depot is a trailer fitted with a loading dock, warehousing facilities and an administrative area. In the morning and evening it is used to move shipments to and from a remote depot. During the pilot, TNT reported that their service levels decreased slightly due to the additional time required to load the cargo-cycles. Moreover, operating costs per delivery doubled; however, this was largely because the mobile depot was only being utilised at 40% capacity, and costs were expected to drop as utilisation increased to full potential. Figure 12.3 shows the TNT mobile depot.

Figure 12.3 TNT Express mobile depot in Brussels (Source: Verlinde et al., 2014, figure 2)

Chiara et al. (2020) estimate that a combination of cargo bikes and delivery hubs can progressively reduce kilometres travelled for deliveries up to a density of 150 deliveries/km^2. This provides an interesting anchor point for companies considering a shift to this mode. For freight carriers with a demand density of 25 to 90 deliveries per km^2, the authors estimate that the total fleet size could be reduced by up to 36% and the total distance travelled could be reduced by up to 70% (Chiara et al., 2020). This study is largely modelled data rather than measured outcomes. However, the results are developed using data from an actual firm and is included in this section only as an additional example of potential for this mode.

12.2.2 Measurement methodology

Due to the small-scale nature of many of the cycle logistics programmes, there is limited reporting on the measurement methodology for the estimated GHG emissions reduced or avoided. Typically, this calculation is based on an estimate of how much GHG emissions could have been expected to be produced if the service had still employed combustion engine vehicles for delivery needs, and then this is reported as avoided emissions.

The exception to this is the Brussels mobile depot pilot, for which a detailed methodology is provided. Avoided emissions were calculated using the number of kilometres driven by a specific type of vehicle using the STREAM freight transport numbers, which provide emissions factors per tonne-kilometre (tkm) (CE Delft, 2016; Verlinde et al., 2014). Table 12.2 shows the representative emissions factors per mode used in the STREAM methodology.

Table 12.2 STREAM – representative emission factors per mode, bulk/packaged cargo transport (Source: CE Delft, 2016)

Mode	Vehicle/Vessel	Type of freight	CO_2 (g/tkm) (WTW)	PM_c (g/tkm) (TTW)	NO_x (g/tkm) (TTW)
Road	Large van	Med.-weight	1,153	0.148	5.03
	Truck, medium-size	Med.-weight	259	0.017	1.75
	Tractor-semitrailer	Med.-weight	82	0.003	0.29
Rail	Electric, medium-length*	Heavy	10	0	0
	Diesel, medium-length*	Heavy	18	0.005	0.19
Inland shipping	Rhine-Herne canal (RHC) vessel	Heavy	38	0.017	0.46
	Large Rhine vessel	Heavy	21	0.008	0.23
Short-sea	General Cargo 10-20 dwkt	Heavy	15	0.005	0.25

* Share of electric: 70%–90%; share of diesel: 10%–30%
WTW = well-to-wheel; TTW = tank-to-wheel

During the pilot, there were a weekly average of 504 km travelled by cargo bike, and 141 km travelled by truck trailer. In the absence of recorded data, it was assumed that to complete the same number of deliveries within a pilot area, it would need two diesel vans and, assuming they followed the same routes as the cargo cycles, that would represent 1,291 large diesel van kilometres at a load factor of 50%. This could be considered a conservative estimate because cargo cycles can typically travel in a more efficient routing pattern due to city centre traffic restrictions and vans would spend more time idling in traffic and searching for parking. Table 12.3 shows the estimated comparison between emissions associated with the business-as-usual model using diesel vans for deliveries, and the adoption of the mobile depot in combination with cargo bikes.

Table 12.3 Emissions reductions results associated with the use of a mobile depot using STREAM emissions factors (Source: Verlinde et al., 2014, table 3)

	Business As Usual	Mobile Depot	Impact MD
CO_2 (g/vkm)	340	258,5	-23,97%
SO_2 (mg/vkm)	2,6	1,97	-24,23%
NOx (g/vkm)	1,25	1,85	+ 47,78%
$PM_{2,5}$ (mg/vkm)	145	59,73	-58,81%
PM_{10} (mg/vkm)	30,5	23,77	-22,07%

MD = mobile depot; SO_2 = sulphur dioxide; vkm = vehicle kilometres

12.2.3 GHG emissions outcomes

Emissions outcomes reported for each of the programmes outlined above are reported in Table 12.4.

Table 12.4 Reported emissions reductions of each cycle logistics programme

Programme location	Reported emissions reductions
Cambridge, United Kingdom	In 2014, the couriers cycled 100,000 km, saving an estimated 45 tonnes of CO_2 (Swennen & Rzewnicki, 2015).
Maastricht, Netherlands	Car/van routes were 20% longer than the cycle routes taken. A total of 5,720 car/van kilometres and 1.15 tonnes of CO_2 were saved. Two organisations decided to permanently get rid of their van; another postponed buying a new car (Cairns & Sloman, 2019).
Nuremburg, Germany	Pilot phase (from November 2016) reported savings of '65kg NO_x, 8kg PM_{10} and 56t CO_2'. The pilot phase led to permanent operation in March 2017 (Cairns & Sloman, 2019).
Brussels, Belgium	This new way of working resulted in a decrease of the number of diesel kilometres from 1.34 km per stop in the business-as-usual scenario to 0.52 km per stop in the mobile depot scenario. This decrease can be linked to a positive environmental impact with, for example, 24% less emission of CO_2 and up to 59% less emission of $PM_{2.5}$, as shown in Table 12.3 above (Verlinde et al., 2014).

12.2.4 Other contributing factors

Each of the programmes outlined above reports various supporting factors in the success of shifting to cargo bikes for urban logistics. One of the most important elements in many cargo bike logistics solutions is the establishment of urban micro-hubs, or staging areas where goods are moved from a larger vehicle for last-mile delivery by cargo bike. Identifying suitable locations for these hubs may require coordination between cities and private partners. New legal frameworks may also be required to make such stations possible. Once these hubs have been developed and integrated into the network, greater efficiencies may be seen over time.

Other supporting policies and strategies include:

- public service tender processes, which include allowances for cargo bike logistics solutions and/or contain carbon-neutral requirements
- motorised vehicle restrictions in dense urban areas
- pilots to support behaviour change and promote acceptance of the new mode

- congestion charges
- low-emission zones
- time restrictions based on vehicle type
- two-way cycling allowed on one-way streets (common in Europe).

A paper by the Transport Decarbonisation Alliance (2019) outlines coordinated strategies at the national, city and company-level aimed at achieving a comprehensive shift towards an emission-free urban freight system. This includes addressing challenges such as 'logistics sprawl' in cities as well as understanding the highly competitive nature of supply chains when tailoring interventions to be effective. It specifically highlights the need for a high level of policy and strategy coordination between government and the private sector to be successful.

12.2.5 Relevance to New Zealand

This type of service is most likely to be successful in dense urban environments in larger cities and towns. One company in Auckland (On a Mission, n.d.) is already offering this type of service with an indication that micro-hubs are in the process of being introduced. Further review of this service may provide additional insight into some of the challenges faced when seeking to establish such a service and how these could be addressed by the public sector.

There may be an opportunity to consider changes to current e-bike regulations to support greater shift to this mode for urban logistics. New Zealand has adopted a power restriction of 300 W for power-assisted cycles. This is in contrast to many other jurisdictions, which typically favour a speed restriction.

The higher load capacities necessary to make cargo bikes a competitive option for first-mile/last-mile logistics means that this may not provide adequate power for commercial e-cargo bikes. For example, Lieswyn et al. (2017) estimated that a 500 W power output would allow a fully loaded cargo bike reasonable ability to negotiate New Zealand's hilly terrain such as the Port Hills in Christchurch.

A major shift to cargo-bike deliveries also needs to consider design standards for cycleways to accommodate a higher volume of cargo bikes, which have a larger profile than standard bikes. For example, in Amsterdam, city planners found that the increasing volume of deliveries made by cargo bike created safety concerns for other users on existing bike lanes and is considering design changes to accommodate this movement safely (Thomas et al., 2020). Other policy changes around kerbside parking management may also be important to support uptake.

12.2.6 Opportunities for further study

- There is an opportunity for further research to be undertaken identifying some of the perceived barriers to greater uptake of this type of service by both the public and private sectors. This piece of work could include stakeholder workshops to identify opportunities to establish cargo bike pilots as well as learning from those who are already operating this type of service.

13 Key findings

This report outlines the findings of a scan of international literature and land transport programmes that have measured outcomes translatable into GHG emissions reductions. The research sought to answer the question of whether any programmes had measured such data and, if so, what the outcomes were. This work has found several relevant programmes as well as indications that there are many more of relevance that could be investigated to further knowledge in this area. This report should be considered a preliminary scan of such evidence. This section outlines the key findings from this review.

- **While there are several measurable variables that can be used to calculate or determine associated GHG emissions reduction, programme evaluators most commonly relied on measuring VKT reduction.** Typical data sources used to measure both VKT reduction and other relevant inputs to GHG emissions calculations include:
  - vehicle counts (both manual and with monitoring equipment)
  - counts of other modes such as walking and cycling
  - parking sensor data
  - intercept surveys
  - workplace surveys
  - household travel surveys
  - census data
  - ticketing information
  - fuel consumption data for public transport services.
- **The examples reviewed in this report vary widely in type, conditions, impacts and data quality**. Their results demonstrate the principle of GHG emissions reduction measurement, largely through VKT or VMT measurement. Their results demonstrate the principle but may not be directly transferable to New Zealand conditions. Section 14 below discusses the ways in which further research may establish such transferability.
- **There are many interrelated factors that influence GHG emissions in each case study**. Such factors can include existing level of active mode or public transport infrastructure; historical relationships between transport and land use planning; central government policy and funding mechanisms; and demographic and/or economic changes throughout the programme timeframe. The result of these external factors means that readers should be cautious making direct comparisons between cities and should not assume that the same programme would produce the same results in New Zealand. Although the local and temporal context will influence the outcomes of applying these types of programmes in New Zealand, these case studies can provide valuable guidance as to the type and approximate scale of outcomes that could be expected, all else equal. These case studies also provide valuable insights about methods of measurement, programme development, and co-benefits and supporting factors that could be used to influence policies and decisions in New Zealand.
- **Many of the case studies with measurable emissions reductions come from the United States**. This is largely a result of stringent public reporting requirements in federal legislation, such as the Congestion Mitigation and Air Quality Improvement programme. The federal government provides a

measurement framework for reporting. The funding for many transport programmes is tied to reporting, which means that outcomes can be tracked and compared between jurisdictions and over time.

- **There were no identified case studies in either New Zealand or Australia that were found to be appropriate for inclusion in this work**. This does not mean that outcomes relevant for GHG emissions calculations have not been measured in New Zealand or Australia, but it does indicate that this may not be common or not publicly reported.
- **Parking management was an important supporting measure for several of the case studies.** This is in addition to the two parking-specific programmes or interventions reviewed in the report. Common themes include appropriate parking pricing, demand-responsive parking, and alternative incentives to parking.
- **Government has an important coordination role in supporting mode shift for urban logistics.** This can include:
  - changes to procurement processes to ensure that carbon-neutral modes such as cycle logistics solutions are eligible to tender
  - financial and marketing support for pilot programmes to encourage uptake
  - changes to policies to support higher power capacity for electric cargo-bikes among other factors.

14 Recommendations for further research

This research has been undertaken as an initial scan of international practice and literature to understand the measurement of the GHG emissions impacts of land transport programmes. The scope of this research was limited to capture a broad diversity of programme types from a wide geographic scope and therefore did not go into extensive detail on any specific topic. Each case study includes opportunities for further study related directly to that specific programme, and these are not replicated here. This review has also identified the following broader avenues of research and investigation that would contribute to a more in-depth understanding of this area of research.

- **Consistency of approach for measuring/estimating GHG emissions or VKT.** This review has highlighted that the most common approach to measuring GHG emissions reductions from land transport programmes is through the measurement of VKT. Various approaches are used to capture changes in VKT, including cordon counts, travel surveys, and GPS tracking. Further analysis of which measurement approaches are being used in New Zealand, and which tools are most appropriate for different contexts, will support GHG emissions target setting and progress tracking. Such analysis may require both quantitative and qualitative analysis of experiences in New Zealand and in other jurisdictions to support decision making. This may help inform a centralised results measurement framework that could be applied consistently to programmes across New Zealand to allow for improved measurement over time.
- **Additional case studies.** There are a number of additional case studies that were identified as being of interest in the future, but they were not included in this analysis for various reasons, including insufficient publicly available data, programmes being relatively new and so having insufficient data for analysis, or the specific scope of the programme. Many of these studies could warrant further investigation. These include, but are not limited to:
  - Mini-Hollands projects in London – including Walthamstow (London Borough of Waltham Forest, n.d.)
  - additional and more-specific parking examples
  - additional cities implementing programmes detailed in this work (eg, BRT, congestion pricing, low-emission zones)
  - campus-based transport examples, such as universities and hospital campuses (Jackson, 2011)
  - Beter Benutten (Dutch 'Better use' programme) (Ministry for Infrastructure and the Environment, 2020)
  - the effects of TOD on VKT in Shanghai and other high-density cities (Chen et al., 2017)
  - the TravelSMART programme in Adelaide (Tideman et al., 2006)
  - the effect of working from home on VKT and emissions, particularly following changes resulting from COVID-19
  - the rapid introduction of 'temporary' cycling infrastructure and pop-up plazas in New York City during the Bloomberg Administration (Cohen, 2015).
- **Non-English case studies.** We expect that there are relevant examples discussed in non-English literature relating to transport interventions and experience. Relevant countries identified as part of background research for this report include the Netherlands, Scandinavian countries, France and Germany. Further research in this field could benefit from the establishment of key contacts in these

countries for qualitative analysis of practice in each, or the use of researchers with the relevant language skills to gain insights from these places.

- **Dissimilar locations.** This report sought to find examples relevant to New Zealand and therefore focused largely on countries with land use and transportation networks similar to New Zealand. Further research should also ensure review is not limited by assuming New Zealand does not have lessons to learn from places that are different from New Zealand in terms of size, geography or demography.
- Given the frequency with which it was cited as a contributing factor to outcomes across the case studies, the **role of parking in supporting mode shift** and associated GHG reductions is noted as warranting further investigation.
- **Staging for maximum impact within programmes.** Several case studies discuss the role of additional components, such as outreach. Developing understanding, likely through qualitative research with staff involved with programme intervention, of any observed benefits of particular staging strategies may aide programme development in New Zealand.
- A further research stream could include investigation of the potential for **New Zealand pilot programmes based on examples highlighted in this research**.
- The research analysed within this programme mostly reflects urban examples, but further research into **other emissions reduction programmes –** such as fuel price increases, rural and intercity transport management programmes, pay-as-you-drive vehicle costs (such as taxes and insurance rates), electric vehicle incentives, aviation transport management and further freight transport examples – would all contribute to the wider transport GHG emissions reduction research programme.
- Further research should **identify the types of data currently used to evaluate transport programmes in New Zealand**. This may include the identification of household travel surveys, traffic models, and business commute travel surveys. Such research will help identify any gaps in current data collection for land transport programmes in New Zealand.
- There may be benefit in investigating the role that removal of **fringe benefit tax on employer-provided public transport passes** could play in influencing VKT and emissions.
- **Induced vehicle travel.** This research primarily focused on the GHG emissions reductions from land transport programmes but did not look in detail at the impacts that general traffic capacity has on inducing additional driving and emissions. More work is needed to estimate the increased GHG emissions that could be expected with traffic capacity increases and/or how reducing capacity in some locations could reduce emissions. For example:
    - A review of general traffic capacity reduction programmes to understand the scale of VKT and emissions reductions from these programmes and whether they have resulted in increased traffic congestion on the network. If they are found to have emissions benefits without broader network impacts, this could help provide further evidence to support reallocating traffic capacity to public transport, walking or cycling infrastructure. This work could review projects completed in New Zealand and international examples such as the Cheonggye Freeway in South Korea (2003), the Embarcadero Freeway in San Francisco (2003) and Prospect Park in New York (2018).
    - A review of recently completed large roading programmes in New Zealand to understand if modelled congestion reductions eventuated. Waka Kotahi conducts benefit realisation reviews (formerly post-implementation reviews) every year on a small sample of completed projects or packages that it has invested in. It would be useful to review a sample of these reports from the perspective of understanding increased demand. Further work could include expanding the review from the

individual corridors to understand the impacts on the wider network. This would help inform future modelling of benefits for business cases of transport programmes.

  - A review of recent large-scale works in New Zealand that have reduced traffic capacity for extended periods of time to identify if, and how, the traffic network comes to a new equilibrium that produces fewer VKT and emissions.
  - The development of a New Zealand-specific induced travel calculator using the methodology behind the National Center for Sustainable Transportation's (2019) Induced Travel Calculator, which estimates incremental vehicle travel induced by adding general-purpose or high-occupancy-vehicle lane miles to roadways. This could help planners and decision makers produce a quick estimate of the impacts of potential projects.

- **Identification of local programmes** relevant for measurement of effects on emissions would be a valuable exercise. Examples may include Auckland's Access for Everyone strategy.
- **Analysis of the role that smaller programmes in combination play** towards overall GHG emissions reduction goals would provide an understanding of the cumulative benefits of a range of interventions.
- **Identification of the cost of abatement** per tonne for different interventions would help to inform investment decisions.
- **Understanding the co-benefits of interventions that specifically reduce vehicle travel** is important. Identifying the secondary impacts of policy and development decisions should be used to guide the type of project data that is collected and how the evaluation feeds into investment and policy decisions.
- **Alignment of a measurement framework with Waka Kotahi's Investment Decision-Making Framework**, including the importance of qualitative and quantitative benefits as well as those that can be expressed in dollar terms (monetised), will further support streamlined investment decision making.

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