Methods of measuring mode share and mode shift at different spatial scales and timescales

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Abbreviations and acronyms

AI	Artificial intelligence
AT	Auckland Transport
CDR	Call-detail records
DTP	Department of Transport and Planning (Victoria)
EPOMM	European Platform on Mobility Management
GIS	Geographic information system
GPS	Global positioning system
GUN	Gateway Upgrade North (Queensland)
GWRC	Greater Wellington Regional Council
HCC	Hamilton City Council
HTS	New Zealand Household Travel Survey
LBS	Location-based service
LGA	Local government area
MAC	Media access control
MRWA	Main Roads Western Australia
NSW	New South Wales (Australia)
NTRO	National Transport Research Organisation
NZTA	NZ Transport Agency Waka Kotahi
OD	Origin–destination
PATHS	Perth Area Travel and Household Survey
PKT	Person-kilometres travelled
PMD	Personal mobility devices
POI	Point of interest
QTS	Queensland Travel Survey

RPRL	Redcliffe Peninsula Rail Line (Queensland)
SA	Statistical area (geographic area built from whole meshblocks)
SCATS®	Sydney Coordinated Adaptive Traffic System
SEQ	South East Queensland
TfNSW	Transport for New South Wales
TMR	Transport and Main Roads (Queensland Government department)
TMS	Transportation management system
VEMT	Vehicle Emissions Mapping Tool
VISTA	Victorian Integrated Survey of Travel and Activity
VITM	Victorian Integrated Transport Model
VKT	Vehicle-kilometres travelled
WCC	Wellington City Council

Contents

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Executive summary

In 2023 and 2024, the National Transport Research Organisation investigated ways to measure mode share and mode shift – in person-kilometres travelled (PKT) – at subnational level (regionally and locally), for different spatial scales (that is, measuring mode share for a whole region through to measuring mode share for an individual road segment) and timescales (that is, measuring mode share for a year through to measuring mode share continuously). Our study focuses on three of the main modes of transport in metropolitan areas:

- Active transport (walking and cycling).
- Private transport (all other private vehicles).
- Public transport (bus, rail and ferry).

The New Zealand Household Travel Survey (HTS) and New Zealand Census of Population and Dwellings (the Census) are commonly used to monitor travel behaviour. The HTS is the primary approach of measuring mode share and mode shift; however, its small sample size means that aggregated data from several years is needed to produce meaningful results. The Census has a large sample size but is conducted only once every five years. Also, unlike the HTS, it does not capture detailed travel behaviour.

In this project, we aim to identify and develop other methods of measuring mode share and mode shift, regionally and locally, and incorporate our findings into a toolkit.

We reviewed current practice by engaging with stakeholders in New Zealand, Australia and other countries. Our review identifies current and emerging technologies and practical approaches for measuring mode share at three levels:

- National and regional levels, using a household travel survey.
- Key corridors and city centres, using screenlines.
- Transport networks or regions, using link-based approaches.

Household travel surveys are still commonly used by authorities (this includes regional and local councils, and transport authorities). We observed a general trend towards increasing the frequency of these surveys and making more use of supporting technologies (such as, global positioning system trace recording). Despite these improvements, household travel surveys have limited use because their coverage of rural and remote areas is poor, they use relatively small sample sizes, their results are reported infrequently, and they cannot measure short-term changes in mode share.

Among New Zealand authorities, Auckland Transport (AT) and Greater Wellington Regional Council (GWRC) are using a screenline approach, and Hamilton City Council (HCC) and Wellington City Council (WCC) are developing link-based approaches. The screenline approach measures travel activity by positioning sensors along artificially defined lines (screenlines) at strategic locations, which are crossed by various modes of transport. The link-based approach measures travel activity on individual roads or segments of roads (links), which it aggregates to estimate transport activity across a whole transport network. Many of these initiatives are still in the early stages, and there are not yet consistent guidelines for collecting, analysing and reporting their data.

We developed an assessment framework to analyse different emerging technologies, data sources and approaches to measuring mode share. Our assessment criteria include mode coverage, responsiveness to changes in mode share, data accessibility, data analysis and processing requirements, sample size and indicative cost. We find that several promising and novel data sources (such as, artificial-intelligence–powered sensors, smartphone-based solutions and crowdsourced data) exist that can measure people's active-travel behaviour. However, no single data source can measure all transport modes, spatial scales and

timescales. The only likely path to comprehensively measure mode share and mode shift is fusing data from conventional and emerging sources.

Our assessment shows that using link-based approaches to measure mode share for a transport network offers the most promise for estimating PKT across a city or region. Several New Zealand authorities are making significant progress towards continuously monitoring transport activity. They are currently at different stages of upgrading their data-collection approaches and infrastructure. Given that authorities have different needs, we conducted a pilot study and developed a toolkit that consider screenlines and link-based approaches.

Our pilot study shows it is feasible to develop a framework for measuring and reporting mode share and mode shift consistently. We collected transport data from four authorities (AT, GWRC, HCC and WCC), following defined data specifications. We processed this data in a proof-of-concept dashboard. For the four authorities, the dashboard allows users to visualise mode-share results and mode-shift trends, across links, corridors, screenlines and networks.

The pilot study reveals that data with high spatial and temporal resolution is increasingly available for measuring mode share and mode shift. Many authorities have invested in advanced data infrastructure and capabilities, to continuously monitor transport activity across their networks or at strategic locations. As an authority's data-collection infrastructure and reporting improves, it could use estimated PKT from its link-based approach to aggregate mode-share data for areas or networks and compare or benchmark the data with that from other regions.

By consolidating the lessons from this project, we also developed a toolkit that authorities can use to measure and report mode share and mode shift. The toolkit begins with a scoping exercise. This involves an authority using a decision-making process to determine the purpose and requirements of their mode-share study, including its mode coverage, temporal and spatial resolution and coverage, data availability and gaps, and data-analysis approach. The toolkit provides guidance on the process to measure mode share and mode shift (that is, specifying data; collecting and analysing data; and reporting data, including data visualisation). It also includes guidance for link-based approaches and screenlines, using examples from authorities to illustrate current best practice.

The toolkit provides a solid foundation from which to develop more responsive approaches to measuring mode share across transport networks for different spatial scales and timescales. We recommend that authorities continue to develop and implement their current data systems and use the toolkit to report the results consistently, when that is feasible. This will help improve how mode-share and mode-shift data is applied to project appraisals, before-and-after evaluations, monitoring of long-term trends, sustainability and resilience impact assessments, monitoring of economic well-being and productivity, and business cases.

Abstract

The purpose of this research project was to investigate current methods to measure mode share and mode shift in person-kilometres travelled (PKT) at subnational level (regionally and locally), for different spatial scales and timescales, and for three transport modes: active (walking and cycling), private and public.

The New Zealand Household Travel Survey (HTS) and New Zealand Census of Population and Dwellings (the Census) are the primary means to monitor travel behaviour in New Zealand. The HTS is conducted annually but has a small sample size. This means that data must be aggregated over several years to produce meaningful results, or even longer to get sufficient samples outside major urban areas. The Census has a large sample size but is conducted only once every five years. Unlike the HTS, it captures only simplistic information about travel activity.

This project involved consulting with stakeholders to identify and review current and emerging technologies and approaches for measuring mode share in New Zealand and overseas. The approaches were categorised as national or regional (household travel surveys), key corridors and city centres (screenline approaches) and transport networks or regions (link-based approaches). The project identified that several authorities (this includes regional and local councils, and transport authorities) are making significant progress towards continuously monitoring transport activity, but they are currently at different stages of upgrading their data-collection approaches and infrastructure. The project identified that consistent guidance on measuring and reporting mode share and mode shift is needed.

A pilot study was conducted that involved transport data provided by four authorities. The data was used to develop a proof-of-concept dashboard that demonstrates it is feasible to develop a framework for measuring mode share and mode shift consistently.

The research culminated in a toolkit for measuring mode share and mode shift. It offers guidance on collecting, processing, analysing and reporting data. As authorities continue to improve their data infrastructure, the toolkit will help generate consistent mode-share and mode-shift results that can be used for numerous applications. These include project appraisals, before-and-after evaluations, monitoring of long-term trends, and sustainability and resilience impact assessments.

1 Introduction

1.1 Background

In 2023, NZ Transport Agency Waka Kotahi (NZTA) engaged us – National Transport Research Organisation (NTRO) – to identify which methods are best suited to measuring mode share and mode shift – in person-kilometres travelled (PKT) – at subnational level (regionally and locally), for different spatial scales (that is, measuring mode share for a whole region through to measuring mode share for an individual road segment) and timescales (that is, measuring mode share for a year through to measuring mode share continuously). We carried out this research between November 2023 and June 2024.

'Mode share' is the proportion of travellers who use a particular type (mode) of transport, and 'mode shift' refers to how mode share changes over time (for example, a greater proportion of travellers using public transport instead of private vehicles).

Traditionally, mode share is measured by counting vehicles; however, PKT is a preferred way to measure it. PKT represents the travel of one person over one kilometre, using a defined mode of transport. Unlike a vehicle count, PKT provides the actual distance a person travels, and not simply that a person travelled. For example, a vehicle count would count a bus as a single vehicle, whereas PKT can differentiate the number of people travelling on the bus as well as the distance they each travel.

The New Zealand Household Travel Survey (HTS) and New Zealand Census of Population and Dwellings (the Census) are commonly used to measure mode share, by time, distance and trip for different journey types. However, as the HTS has a relatively small sample size, NZTA typically requires several years of aggregated data to produce meaningful results. NZTA is increasing the HTS sample size, which will mean it needs approximately one year to obtain enough samples to estimate travel behaviour for regional populations. However, despite this enhancement, the HTS will still be inadequate for monitoring local changes associated with increased investment in mode shift.

To respond to this challenge, some authorities in New Zealand have conducted trials or pilots to measure mode share using emerging data sources and innovative technologies that can capture multimodal travel behaviour. NZTA anticipates that there are more cost-effective ways to do this, which could be implemented nationwide. However, to monitor changes in the transport system with improved agility, NZTA needs methods that have high temporal and spatial resolution (that is, they can detect changes in mode share quickly, and for small geographical areas).

1.2 Purpose of the research

Our research objectives are to:

- identify and develop methodologies for measuring mode share and mode shift that respond to regional- and local-scale interventions
- identify and develop methods for measuring mode share and mode shift that can be applied to different spatial scales, timescales, journey types and transport modes
- quantify the uncertainty or confidence intervals associated with these methods
- incorporate the research findings into a toolkit for measuring mode share and mode shift.

These objectives align with NZTA's goal to efficiently move people across New Zealand's transport network (both road and rail), while addressing congestion, managing costs and meeting emissions targets.

1.3 Scope of the research

1.3.1 Transport modes

We focus on three of the main modes of transport in metropolitan areas (see Figure 1-1):

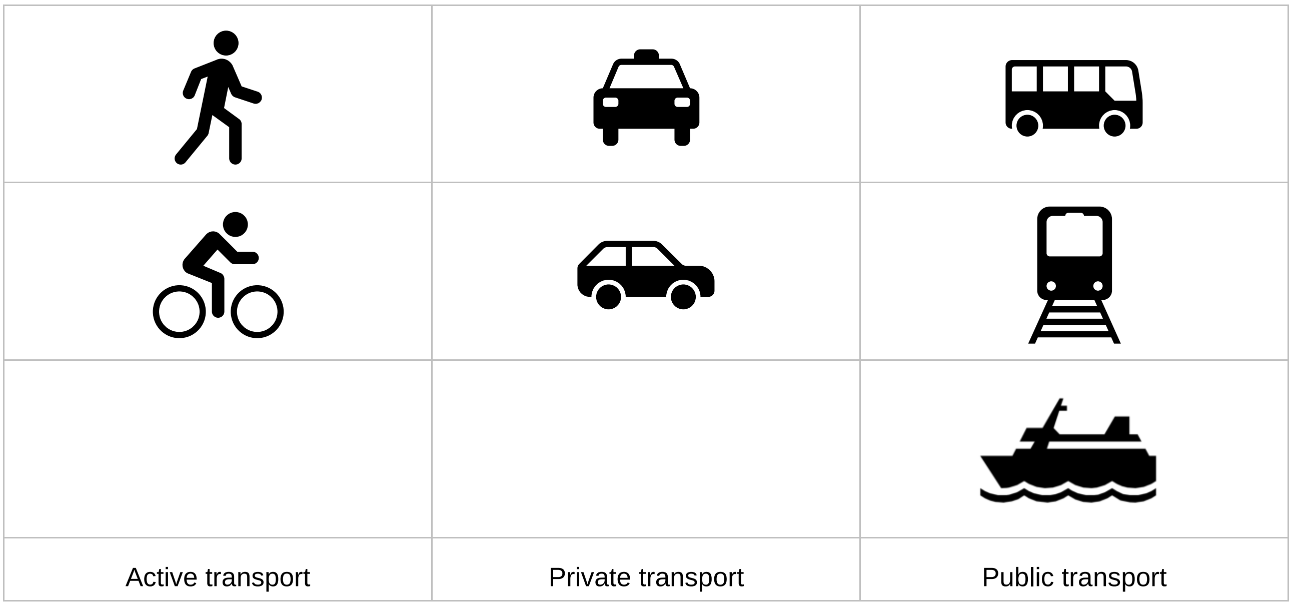
- Active transport (walking and cycling).
- Private transport (all other private vehicles).
- Public transport (bus, rail and ferry).

In other sections of this report, we discuss further classifications of vehicle types and trip purposes.

We exclude emerging transport modes such as different types of personal mobility devices (PMDs), due to their minimal market share. Freight, long-distance trains and air travel are also out of scope.

Using PKT enables us to aggregate data from different sources consistently, to measure major travel modes.

Figure 1-1 Transport modes included in this project



1.3.2 Data and methods

In this project, we focus on developing methods that:

- use open data sources that are easily shareable
- are designed to be repeatable; and suitable for monitoring, evaluation, before-and-after studies, and high-quality impact-evaluation (such as quasi-experimental or controlled comparisons)
- are fit for purpose, right sized and cost-effective for projects, programmes or policy interventions
- complement, and are consistent with, mode-share results from the Census and HTS.

1.3.3 Spatial coverage

The project examines ways to measure mode share at three levels:

- **Macroscopic level** – an entire country or multiple regions (measured by household travel surveys).

- **Mesoscopic level** –strategic locations, such as major roads and key corridors in a region (measured by screenlines or cordons).
- **Microscopic level** – a network of individual road links, or projects covering a restricted area (measured by analysing specific streets or evaluating the performance of projects).

This project emphasises the mesoscopic and microscopic levels, given that the HTS is well established for measuring mode share at the macroscopic level.

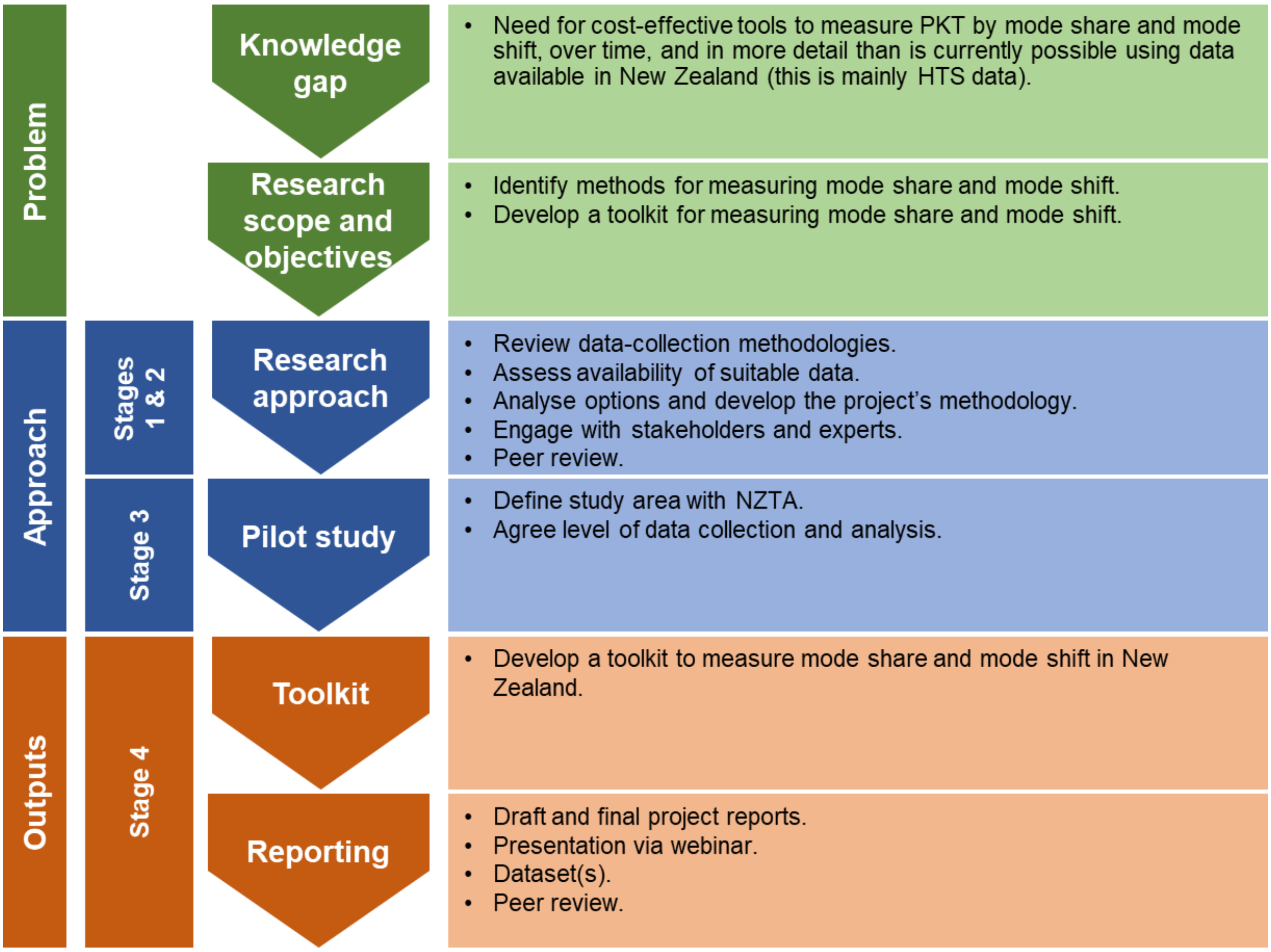
1.4 Stages of the research

We carried out this project in four stages:

- Stage 1 – reviewing current practices and data sources for measuring mode share.
- Stage 2 – analysing options and designing a pilot study.
- Stage 3 – conducting a pilot study to validate our proposed options.
- Stage 4 – creating a toolkit to measure mode share and mode shift and preparing the final project report.

The project included consulting with key stakeholders during the practice review (Stage 1) and options analysis (Stage 2). Our key deliverables were peer reviewed twice. Figure 1-2 shows the entire project flow, from the problem it addresses through to the research approach we used and the outputs we generated.

Figure 1-2 Flow of this project, from problem statement through to research approach and outputs



1.4.1 Stage 1 – reviewing current practices and data sources

During November and December 2023, we reviewed available literature and engaged stakeholders in online interviews, using a semi-structured questionnaire to guide our discussions. The project's stakeholders are experts in household travel surveys in New Zealand and Australia (New South Wales, Queensland, Victoria and Western Australia); and measuring and reporting mode share in New Zealand and overseas. Section 2 summarises the findings of our literature review and practice review. **Error! Reference source not found.** lists the stakeholders we consulted during this stage.

1.4.2 Stage 2 – analysing options and designing a pilot study

During this stage, we further analysed and compared the approaches and data sources for measuring mode share that we identified in Stage 1, using agreed criteria. On 8 February 2024, we held a workshop to communicate the outcome of this assessment to the Project Steering Group and discuss the scope of our proposed toolkit and pilot study. During this stage, our interim report was peer reviewed, and we incorporated the comments into our final report. For more details, see Section 3.

1.4.3 Stage 3 – conducting a pilot study

In Stage 3, we carried out a pilot study to demonstrate the potential to report mode share and mode shift consistently at subnational scales. We collected and reviewed data from four authorities. Each authority uses a different approach, report, and temporal and spatial resolution, so we developed a set of data specifications that could be used to process the data – consistently – from each authority. From this processed data, we developed a proof-of-concept dashboard using Tableau.[2] The dashboard demonstrates the capability to combine the four authorities' data into a framework that reports the data consistently. We presented the results of the pilot study and proof-of-concept dashboard to the Project Steering Group on 22 April 2024. For more details of the pilot study, see Section 4.

1.4.4 Stage 4 – creating a toolkit and preparing the final project report

We used the pilot study to help create a toolkit that provides guidance on how to measure and report mode share and mode shift. The toolkit gives authorities a responsive approach to measuring mode share locally and regionally, so they can detect changes to mode share quickly, and for specific parts of their transport network. The toolkit includes a scoping and decision-making framework that an authority can use to assess whether a particular approach to measuring mode share is feasible and suitable for its needs. It also provides guidelines on specifying, collecting, analysing and reporting on mode-share and mode-shift data. For more details about the toolkit, see Section 5.

[2] For more information about Tableau, see www.tableau.com

2 Reviewing current practices of measuring mode share and mode shift

This section reviews current practice and research on ways to measure mode share and mode shift for the major modes of transport. We have reviewed conventional travel-behaviour surveys, screenline approaches and link-based approaches. We have also examined emerging data sources that are being used to measure mode share and mode shift.

2.1 Household travel surveys

Household travel surveys are the main tool that authorities use to find out about people's travel behaviour and understand how and why people move. These types of surveys are useful for revealing travel-behaviour change over a long period (several years or decades). The data they produce is conventionally used to calibrate strategic transport models, forecast demand and plan infrastructure.

To learn about household travel surveys in New Zealand and Australia, and find out how data is collected, analysed and reported, we consulted experts at NZTA, Transport for New South Wales (TfNSW), the Department of Transport and Planning (DTP) in Victoria, the Department of Transport and Main Roads (TMR) in Queensland and Main Roads Western Australia (MRWA). Our consultations focused on finding out about survey approaches, technologies, data collection, limitations and reporting methods.

From our review, we find that household travel surveys have these features:

- They produce data infrequently, and from only a small number of households each year. Therefore, it can take several years to obtain a representative sample size.
- Many are transitioning towards a continuous survey, which interviews a small number of households every day, and away from a single survey each year (or less frequently).
- They tend to focus on people who live in metropolitan areas, because these areas can generate larger sample sizes than regional areas and budgets limit the number of areas that can be surveyed.
- Their data is not designed to measure mode share in much detail, so it is not responsive enough to track local or regional behaviour changes.
- They typically survey people's travel activity for a few days only, or as little as one day.
- They typically collect data through a face-to-face survey, using a paper or online form. Computer-assisted surveying techniques are increasingly being used to collect data by phone, tablet or webpage, or in person.
- They have started to use global positioning system (GPS) devices or smartphone apps to accurately track trips in detail and use the data to aid interviews or for further analysis.
- Despite introducing new technologies, their costs are still mainly for the labour-intensive fieldwork involved to recruit participants.
- They were significantly disrupted by the COVID-19 pandemic. During the pandemic, some authorities started to use telephone surveys, but survey response rates decreased to single-digit percentages, and it proved difficult to match addresses with mobile-phone numbers.
- They have limited ability to sample active-travel behaviour over a short period, as active-transport modes can vary significantly with the weather or season (Ton et al., 2018).

Table 2.1 summarises household travel surveys conducted in New Zealand and Australia.

Table 2.1 A comparison of household travel surveys in New Zealand and Australia (adapted from Stats NZ, 2023; Australian Bureau of Statistics, 2023)

Criteria	New Zealand	New South Wales, Australia	Perth, Australia	Queensland, Australia	Victoria, Australia
Survey operator	Reach Aotearoa	Ipsos	Ipsos	Roy Morgan Research	Ipsos
Sample size (households) (per year or per survey)	1,700 (plus a 4,000 booster sample paid for by NZTA)	2,000–3,000	6,500	4,000 [a]	3,500
Population (country or state)	5,159,100	8,339,300	2,878,600	5,459,400	6,812,500
Sample of population covered each year [b]	0.033% (0.110% with booster)	0.024–0.036%	0.230%	0.074%	0.052%
Sample period	All travel over 2 days (any day excluding public holidays)	All travel over 1 day (any day including public holidays)	All travel over 1 day (weekdays excluding public holidays)	All travel over 1 day (weekdays in school terms)	All travel over 1 day (any day excluding public holidays)
GPS-tracker sample period	2 days (optional)	7 days (optional)	5 weekdays (optional)	N/A (not offered)	3 days (optional)
Survey frequency	Continuous between 2003 and 2014, and since 2015	Continuous since 1997	Infrequent	Continuous since 2017	Annually since 2008
Reporting interval [c]	Population weighted average of 3 years	Population weighted average of 3 years	Average over sampled period of 4 years	Single year (weighted by Census and housing data)	Aggregated over multiple years or sampling periods
Lowest reporting unit for the public	Local government area (LGA)	Statistical area (SA) 3 [d]	SA3 and SA4 [d]	LGA	LGA

Criteria	New Zealand	New South Wales, Australia	Perth, Australia	Queensland, Australia	Victoria, Australia
Contents of reporting on a public website	Trip statistics (national) Mode share of trip leg by region, travel time or age group Trip by purpose Distance travelled by driver and motorcycle Driver licence	Statistics by region, SA3, LGA Statistics by 6 cities (since 2021) Mode share Trips (number, distance, time) by purpose Trips by mode Total and average distance by mode Average time by mode	Interim internal dashboard By region and LGA: • mode share • travel purpose • trip distance and time (total and average) • travel by time of day	Mode share Travel purpose Trip distance Travel by time of day (weekday) LGA profiles (includes trip origin and destination, and commute details) Vehicle ownership	Mode share Trip by purpose Trip distance Trip travel time Travel by time of day LGA profiles
Method of data collection (travel diary)	Paper form Face-to-face interview	Digital form Face-to-face interview	Paper form Face-to-face and phone interview	Online form Phone interview	Paper form Face-to-face and phone interview
Area covered by survey	New Zealand (all 14 regions)	Greater Sydney metropolitan area (includes 33 LGAs)	Greater Perth metropolitan area and Mandurah (includes 21 LGAs)	South East Queensland (Brisbane, Gold and Sunshine Coasts) (includes 8 LGAs and regional areas)	Greater Melbourne (includes 32 LGAs, Geelong and regional areas)
Regional areas covered by survey	Yes, as part of annual survey	No	No	Yes, major regional centres are surveyed every 5 years	Yes, regional centres are surveyed every 5 years
Modes of active transport reported	2 (cycling, walking)	2 (walking only, walking-linked)	1 (active transport – includes cycling and walking)	2 (cycling, walking)	2 (cycling, walking)
Modes of public transport reported	1 (public transport)	2 (bus, train)	1 (public transport)	1 (public transport)	3 (bus, train, tram)
Modes of private transport reported	3 (car driver, car passenger, motorcycle)	2 (vehicle driver, vehicle passenger)	1 (private car)	3 (taxi/rideshare, vehicle driver, vehicle passenger)	2 (vehicle driver, vehicle passenger)

Criteria	New Zealand	New South Wales, Australia	Perth, Australia	Queensland, Australia	Victoria, Australia
Other modes reported	N/A	1 (other – includes plane, taxi, ferry, bicycle)	N/A	N/A	1 (other)
Categories of travel purposes reported	Accompany Education Employer's business Recreation Shopping or personal business Social visits Work	Commute Education/childcare Personal business Serve passenger Shopping Social/recreation Work-related business Other	Accompany Education Employment Go home Personal business Pick-up/drop-off Shopping Social/recreation Other	Education Pick-up/drop-off/ delivery Shopping/personal Social/recreation Work Other	Accompany or drop-off/pick-up Education Personal business Shopping Social or recreational Work Other

[a] We have estimated this sample size based on the survey approaching approximately 6,000 households and having a reported 65% response rate.

[b] We have calculated the percentages based on the state or country population. Reporting coverage is higher where three-year weighted averages are used. In each state or country, the percentage of the population covered in metropolitan regions is higher, as most or all samples are taken in those regions (that is, major cities in New Zealand; Melbourne and Geelong in Victoria; Sydney, Hunter and Illawarra regions in NSW; South East Queensland; and Perth in Western Australia).

[c] Reporting interval reflects the minimum period needed to collect sufficient data to produce insights.

[d] Statistical areas (SA) are spatial units defined by the Australian Statistical Geography Standard. They provide a way to make statistics geographically comparable (Queensland Government 2023b).

See Appendix B: Section B.1 for a complete account of our review of household travel surveys.

2.2 Screenline approaches

A screenline approach creates an artificial border (‘screenlines’) around multiple traffic-count sites and captures all the traffic passing through the area within the border (Department of Transport and Main Roads, 2016). Screenlines are usually placed along major corridors or at strategic locations within a region. Greater Wellington Regional Council (GWRC) outlines three different screenline approaches:

1. **A corridor**, which comprises of one measuring site for each mode (such as, a rail line, road or highway).
2. **A screenline**, which aggregates data from more than one measuring site (that is, multiple corridors) to capture trips within a particular area (such as, trips from suburbs, or a metropolitan area, to a city centre).
3. **A cordon**, which aggregates data from more than one corridor to capture all trips to or from a particular area (such as, all trips to or from a city centre).

In the past, screenline approaches used traffic data that was counted manually via roadside surveys. However, they now draw on traffic data that is recorded using a range of technologies. These include public-transport data, traffic counters, traffic cameras, the Sydney Coordinated Adaptive Traffic System (SCATS®) and transportation management systems (TMS). Depending on which corridors or areas being monitored, screenlines may not cover every transport mode. For example, screenlines along major highways will generally not capture data about active-transport modes.

We identified three authorities that use a screenline approach: Auckland Transport (AT), GWRC and TMR. Table 2.2 summarises these three approaches.

Table 2.2 A comparison of screenline approaches in New Zealand and Australia

Criteria	AT	GWRC	TMR
Geographical coverage	Auckland city centre	Greater Wellington region	Brisbane northern suburbs and Redcliffe peninsula
Number of screenlines	1 (cordon)	6 (forming 1 cordon)	5 (parallel screenlines)
Number of monitoring sites	17	11	31
Description of monitoring location	Counters/cameras that form a cordon around central Auckland and cover traffic along major routes to and from the central city	Multiple counters for each site or screenline that capture different modes; total counters > 30	Sites on screenlines covering highways, arterial roads, bus routes and train lines
Modes covered	Private vehicles Public transport Cycling Walking	Private vehicles Public transport Cycling	Private vehicles Public transport
Data sources	Private vehicles: SCATS®, [a] TMS Public transport: touch-on/off Cyclists: Eco-Counter sensors	Private vehicles: SCATS®, TMS Public transport: touch-on/off Cyclists: Eco-Counter sensors	Private vehicles: STREAMS highway traffic data, classified traffic counts Public transport: weekday monthly average patronage (based on tap on/off data)

Criteria	AT	GWRC	TMR
Duration of data collection	Started in 2018 Earlier data is available but does not fully align with data from 2018 onwards	Continuous data from VivaCity cameras since 2023 Morning-peak sensor data (city-centre cordon) is available up to 2022	Public-transport data collected for 18 months Private-vehicle data collected for 5 years
Sampling frequency	7am to 9am since 2018 Previously, an annual survey in March	24 hours per day since 2023 7am to 9am up to 2022	One-off (morning peak)
Method of analysing and fusing data	Internal analysis	Internal analysis	Measuring the number of travellers who cross screenlines, based on fusing public-transport data and average private-vehicle-occupancy data
Method of reporting data	Internal dashboard that reports mode share (into the city centre) and analyses capacity at street level Some public monthly summaries	Internal dashboard that reports mode share	None
Frequency of reporting (responsiveness to mode shift)	Daily and monthly summaries Internal capability for more immediate reporting	Quarterly public reporting Internal hourly reports Future capability for immediate reporting	One-off reporting within a few months of collecting data

[a] Volumes recorded at SCATS® sites from inductive loops (New Zealand Government, 2024).

See Appendix B: Section B.2 for a complete account of our review of screenline approaches.

2.3 Link-based approaches

Link-based approaches measure the traffic on individual road sections ('links') or at intersections, using various technologies. These include camera-based approaches; counters for vehicles, cyclists or pedestrians; vehicle data from telematics systems; public-transport fare systems; and crowdsourced data. When it is impractical to directly measure traffic, or there is no data source, traffic is estimated by modelling.

As link-based approaches often use different data sources and estimates (such as, counters and crowdsourced data), they need to be fused. Available data for individual links is aggregated for an area or transport network, to estimate overall traffic and mode share.

When link-based approaches are combined with geographic information system (GIS) information of the road network, they can estimate mode share using PKT. Link-based approaches are suited to providing the detailed information needed to estimate changes in greenhouse gas emissions due to mode shift. They can also provide useful data for spatial tools, such as NZTA's Vehicle Emissions Mapping Tool (VEMT).

We identified that link-based approaches are being used by Hamilton City Council (HCC) and Wellington City Council (WCC), and Zhejiang University, China, has also developed an approach.

Table 2.3 summarises these three approaches.

Table 2.3 A comparison of link-based approaches in New Zealand and China

Criteria	HCC [a]	WCC [a]	Zhejiang University
Geographical coverage of sites and links	Key locations across central Hamilton with additional minor links covered by data fusion	A growing number of sites at key locations across central Wellington	> 245,000 links in Hangzhou region, China
Modes covered	Private vehicles (including freight vehicles) Public transport Cycling Walking Scooters	Private vehicles (cars, motorcycles, freight vehicles) Public transport Cycling Walking Other (data available but not reported)	Private vehicles Public transport Cycling
Data sources	Private vehicles: SCATS®, AddInsight Public transport: Bee Card Cycling and scooters: Strava, Eco-Counter sensors, Lime Walking: Near Other: GIS layer of road network	All modes: VivaCity Public transport: Snapper card Cycling: manual cordon counts, Eco-Counter sensors	All modes: location-based service (LBS) smartphone data Private transport: traffic counters Public transport: taxi, rideshare, bus, metro Cycling: bikeshare Other: GIS layer of the road network and point of interest (POI) data
Sampling frequency	Continuous (24/7)	Continuous (24/7)	Continuous (24/7)
Method of analysing and fusing data	City-wide traffic modelling by fusing measured data at key locations with crowdsourced data, and using estimated data for minor locations	None at this stage. Methods are currently being developed	Travel-mode estimates are linked with GIS data
Method of reporting data	Internal: PowerBI-based dashboards and data visualisation, [b] focused on city-wide mode share External: some data summaries (such as cycling data)	Internal: a VivaCity dashboard that focuses on mode share at key locations	Internal: a dashboard that focuses on estimating carbon emissions by link(s)
Frequency of reporting (responsiveness to mode shift)	Real-time reporting is being developed	Real-time reporting is being developed	Real-time reporting

[a] HCC and WCC are still developing their approaches, so they may change. WCC is working and sharing data with GWRC.

[b] PowerBI is a data visualisation software developed by Microsoft.

See Appendix B: Section B.3 for a complete account of our review of link-based approaches.

2.4 Emerging data sources

Over the years, a range of technologies and data sources have been used to measure the performance of transport networks. Data on public transport is collected through automatic fare-collection systems that are linked to an individual's device or fare card (for example, Bee Card in Hamilton and Snapper in Wellington). These systems work by generating data points when travellers tap their device or card to a reader on a vehicle (bus or light rail) or at a station (rail) at the start or end of their journey. The systems collect data about the transport network (such as stops and routes) that can also be used to estimate occupancy and distance travelled (PKT).

Numerous technologies have been deployed at fixed locations to measure the count or volume of private transport. These include TMS counters, motorway counters, tube counters and manual surveys. These technologies are widely used and well understood, so we do not discuss them further here.

This section presents new and emerging data sources that can be used to measure travel behaviour, including active-transport modes.

2.4.1 Bluetooth data

Bluetooth media access control (MAC) address readers offer a streamlined and cost-effective method to collect travel-time and origin–destination (OD) data. These readers passively capture the MAC addresses of Bluetooth devices in vehicles, which enables them to calculate travel times between sensors and OD estimates.

This approach – known as 'anonymous wireless address matching' – takes advantage of the widespread use of Bluetooth technology. It has proven to be effective in various settings, including urban roads, with results comparable to traditional methods of collecting data (such as, toll tag systems). This technology also addresses privacy concerns, as MAC addresses are not linked to personal information (Blogg et al., 2010; Puckett, 2010).

Studies in the USA (Puckett, 2010); Queensland, Australia (Blogg et al., 2010) and other countries focus on comparing the effectiveness of Bluetooth MAC address readers with traditional methods (such as, automated numberplate recognition). At least one authority in New Zealand has used this technology (see details of HCC's link-based approach in Appendix B: Section B.3.1).

2.4.2 Camera-based technology

Camera-based technologies that use artificial intelligence (AI) to record traffic – by counting vehicles, pedestrians and cyclists – are increasingly available and the technology has been rapidly evolving. These technologies enable data to be analysed in near-real time. We describe the current state for two of the most common camera-based technologies here.

2.4.2.1 Telraam

Telraam (2023)[3] is a small, low-cost traffic counter that can be installed inside premises to monitor traffic on a street. Using onboard AI, the device recognises images and classifies objects on the local device. For each mode, it aggregates counts for 15-minute periods and sends them to the Telraam servers. All counts are publicly available on the Telraam website.

[3] To find out more about Telraam, visit https://telraam.net

The latest Telraam device can detect 10 transport classes: bicycle, bus, car, light truck, motorcycle, pedestrian, stroller, tractor, trailer and truck. According to the Telraam website, the device is 90 to 95% accurate at classifying objects in the daytime. It is currently unable to classify objects in the nighttime, but this functionality is being developed.

In the past, Telraam devices were typically used only for 'citizen science' (informal monitoring), but increasingly local and regional organisations are using them.

The device costs approximately €400 excluding value-added tax. Telraam also offers a network subscription that costs an extra €25 per month. This subscription provides users with additional analytics (such as, mode split) and tools to oversee devices being rolled out and access their data.

Some Telraam devices are being used in New Zealand, including by NZTA. NZTA's trial is due to end in September 2024.

2.4.2.2 VivaCity

VivaCity Labs[4] is a UK-based technology company. It produces a series of onboard AI-powered cameras (these are known as VivaCity sensors) that can be installed onto a light pole, or similar structure, to continuously monitor traffic. The camera feed is analysed on the local device, to detect and classify all users and provide additional insights. The system can identify 32 different transport classes, including bicycle, bus, car, cargo bicycle, e-scooter, heavy vehicle, motorcycle, pedestrian, taxi and van. The cameras record traffic volumes, paths and speeds, as the classified objects pass over count lines and zones that are pre-defined by users.

VivaCity sensors collect anonymised traffic data and blur the output video frames, to prevent people and vehicles being identifiable. The cameras delete footage immediately after the data is processed, although small amounts of data can be temporarily stored, to be validated and tested (VivaCity Labs, 2023).

The data is accessed from an application program interface (API) endpoint or an online dashboard. From the dashboard, users can access various analysis outputs. These include classified counts; road-user tracks; journey times between two sensors (this is available for vehicles with numberplates); turning counts between user-defined zones and count lines; zonal speeds, occupancy and dwell times; and sensor images (images of people are blurred for privacy reasons) to assess abnormal behaviour in near-real time. Our description of WCC's approach (see Appendix B, Section B.3.2) includes an example of typical data visualisations available on a dashboard.

According to VivaCity Labs, its processed data is independently verified by authorities (these include Transport for London) and is at least 97% accurate (VivaCity Labs, 2021). Although we did not find any published independent studies to verify this accuracy, we expect that VivaCity Labs validates its data by obtaining sample videos from their cameras and performing manual counts.

VivaCity sensors have been used in several places around the world. In New Zealand, they are being used by WCC (see Appendix B, Section B.3.2) and NZTA. NZTA is trialling the cameras to identify near-miss incidents on temporary traffic-management sites.

2.4.3 Eco-Counter

Eco-Counter is a multinational French company that develops traffic counting solutions, especially those that count active-transport modes. Eco-Counter has a range of products employing different technologies that

[4] To find out more about VivaCity Labs, visit https://vivacitylabs.com

can count pedestrians, cyclists, scooters and vehicles, across paths in one or two directions of travel. Users can tag data (tags include 'quiet streets', 'cycle lane', 'cycle path', 'shared path' and 'mixed-user road').

Eco-Counter collects data using different methods. Most methods involve cellular transmission; some methods involve local networks and manual data collection. Eco-Counter's data platform – Eco-Visio – gives users access to its data, analytics and dashboards, with daily and hourly breakdowns and weekday and weekend statistics.

NZTA currently has access to data from 533 counting sites across New Zealand. Depending on sensor type and location, these sites count cars, cyclists, heavy vehicles, motorcycles and pedestrians, travelling in one and two directions. The sites cover many areas, including Auckland, Hamilton and Wellington (see Appendix B: Section B.3.1). NZTA is developing the ability to ingest Eco-Counter data into its own database. However, there are some issues to resolve with collecting data and maintaining devices (for example, it is difficult to arrange to replace batteries in a timely manner).

2.4.4 Smartphone-sensor data

Modern smartphones contain several sensors – GPS, accelerometers, gyroscopes and magnetometers – that can be used to monitor travel behaviour. In general, this approach involves using the smartphone sensors – individually or in some combination – and a supplementary GIS layer that contains information about the transportation network (Chen et al., 2016; Nitsche et al., 2014; Sadeghian et al., 2022).

Smartphone sensors can also be used to obtain other data, such as call-detail records (CDR) (see Section 2.4.6). The built-in sensors can provide valuable data which can replace, or supplement, conventional paper-based surveys about travel behaviour.

The spatial and temporal resolution of the data from these sensors is more accurate than that from CDR; however, the data sample sizes are far more limited (Burkhard et al., 2020). Another potential innovation is imputing travel mode using smartphone-sensor data. This is known to be difficult to achieve and is the subject of much research (Brändle, 2021). The various approaches and algorithms for imputing travel modes are out of this study's scope. However, we do describe commercial and open-source smartphone apps that perform this function (see Section 2.4.5).

2.4.5 Smartphone applications

Several smartphone apps have been developed that can measure travel behaviour; in some cases, they can impute travel mode. In many countries, using GPS or app-tracking technologies to measure travel behaviour is becoming increasingly common, and is often supplemented with a questionnaire. GPS-only surveys are less common; they cannot record information such as trip purpose or mode.

We have reviewed many, but not all, of the available apps, refining our selection by reviewing international literature (academic and non-academic resources) and engaging with local and international stakeholders.

These are the main findings of our review of smartphone apps:

- Numerous commercial and open-source apps are available.
- Apps commonly feature a travel diary, and continuous data logging with various sampling rates (the sampling rate is the frequency that data is logged).
- Some apps build on existing protocols using smartphone sensors (such as, an accelerometer and gyroscope). The most common protocols are Google Activity Recognition API (Android) and Apple Core Motion API (iOS).
- Some apps use algorithms to detect travel mode. AI and machine learning approaches to this are increasingly common and can supposedly detect travel mode more accurately over time.

- Users usually need to verify their actual travel mode, even when apps can impute travel mode.
- Commercial apps can be expensive to use, as can investing resources in adapting, hosting and maintaining an open-source app.
- Survey operators may find it challenging to get users to install the app to log their travel and validate their journeys, which may lead to a small or insufficient sample size. Stakeholders told us that users are concerned about privacy, and this affects them using such apps to monitor their travel behaviour.
- Survey operators may need to give survey participants a financial incentive to use the app-based survey, which would add to the survey cost. Not offering an incentive may lead to a small or insufficient sample size.

See Appendix B: for a comparison of smartphone apps to monitor travel behaviour.

One study of app-based surveys reports that users find the validation task laborious (Roddis et al., 2019), especially when it is comprehensive (for example, when users are asked for details about boarding and egressing stops). The study concludes by recommending a hybrid survey approach, such as using an app that: 'replaced cumbersome validation in its user interface by an automated interpretation of unstructured narratives for each travel day' (Roddis et al., 2019, p. 11).

The accuracy of apps that impute trip purpose varies between 40% and 90% in different studies. By using rule-based algorithms or machine learning methods, the accuracy can be as high as 90% (Shen et al., 2016).

Another study by the Queensland University of Technology and TMR aims to build an app that can conduct a travel survey by tracking users' movements and interacting with them ('gamification'). The app will record their GPS location at a particular time and estimate their travel mode based on ideas from TravelVu.[5] The app will also allow users to correct their travel mode if the imputed mode is incorrect. Data collection is expected to being in early 2024, and the collected data will be analysed statistically.

2.4.6 Mobile-phone and telecommunications data

Telecommunications ('telco') data (this is notably from mobile phones and CDR) is increasingly important to monitor active transport. Telco provides 'big data' that makes it easier to accurately estimate OD matrices, which improves planning of transport systems. Studies demonstrate a significant correlation between CDR-based outcomes and traditional methods, especially for evaluating the viability of investing in mass transit (Çolac et al., 2014).

Qu et al. (2015) propose a method to estimate mode share in each 'traffic zone' instead of for each trip. This method uses CDR plus geographical information about the transportation network, which are represented as nodes and links. The nodes include the road network (the nodes equal the intersections) and the transit network, covering the subway and bus networks (the nodes equal the bus stops and stations). The links equal road segments. For each trip, this method identifies a person's home or work location, and then uses speed and distance information to estimate the travel mode they used. This method also classifies any ambiguous trips using a logit model, which is based on the most likely mode based on trip time. The results are validated by calculating the correlation value of linear regressions.

Yang et al. (2020) present a data-fusion approach that uses telco data and a conventional travel survey to infer travel activity and purpose. They have demonstrated this approach for Shanghai, China, where it proved to be more than 80% accurate when 50% of data was missing. This approach could be applied to other regions, or similar datasets, depending on the availability of data.

[5] To find out more about TravelVu, visit www.travelvu.app

Telco data does not, however, give insights into what motivates people to travel. It also poses privacy risks, due to the potential for it to be misused (Mehndiretta & Alvim, 2014). Privacy thresholds also make it difficult to get detailed data. Local commercial entities like DSpark[6] are key players in providing this type of data. One significant issue with this data is being able to use it to accurately classify different transport modes. For example, it is difficult to parse out cyclists from motorised vehicles during peak times when traffic is congested, because they are travelling at similar speeds.

2.4.7 Crowdsourced data

Various crowdsourced data sources can help determine mode share, particularly for active-transport modes. These data sources include online social networks for cyclists and runners such as Strava,[7] MapMyRun[8] and MapMyRide.[9] Shared mobility data is another data source, available from docked and dockless rental scooters and bicycles such as Lime.[10] Other sources include point of interest (POI) data, such as from Foursquare[11] or CrowdSpot.[12]

There are several potential issues with using crowdsourced data. First, it tends to be skewed and biased (that is, it does not fully represent the general population) as users self-select. Second, it may not include short trips that users do not record. And third, users may opt out of sharing their data with the company. This means that data samples can be influenced by factors that encourage users to participate (incentives) or discourage them.

Therefore, to work with crowdsourced data, authorities need to understand its potential biases and develop a suitable approach to correct them. This may require more resources and effort to process the data before it can be used. Despite the challenges, crowdsourced data still offers significant potential, especially for estimating the demand and mode share of cycling and walking activities, due to its comprehensive coverage of OD data. Our description of HCC's approach includes an example of how to integrate crowdsourced data into an approach to measure mode share and mode shift (see Appendix B: Section B.3.1).

Data provided by connected vehicles[13] (the data is gathered by platforms like Wejo[14] and Compass[15]) offers real-time insights into diverse transportation patterns, which can enhance traffic management and network efficiency. However, it has a limited impact on analysing active-travel behaviour or PKT, as it primarily focuses on vehicle-based transportation. While connected-vehicle data provides a comprehensive view of various vehicle classes, challenges remain around implementation costs and privacy.

2.4.8 Advantages and disadvantages of emerging data sources

A wide range of technologies and data sources can be used to measure and estimate travel behaviour for different spatial scales and timescales. Technology is evolving quickly as computing power, hardware and

[6] To find out more about DSpark, visit www.dspark.com.au

[7] To find out more about Strava, visit www.strava.com

[8] To find out more about MapMyRun, visit www.mapmyrun.com

[9] To find out more about MapMyRide visit www.mapmyride.com

[10] To find out more about Lime, visit www.li.me

[11] To find out more about Foursquare, visit www.foursquare.com

[12] To find out more about CrowdSpot, visit www.crowdspot.com.au

[13] A connected vehicle is one that has an internet connection and the ability to transmit data.

[14] To find out more about Wejo, visit www.wejo.com

[15] To find out more about Compass, visit www.compassiot.com.au

efficient AI becomes increasing cost effective. In this section, we have discussed the current state for several innovative and emerging data sources.

Bluetooth data uses MAC address readers, to anonymously capture Bluetooth device information from vehicles. This enables travel times to be calculated and OD to be estimated. Compared with traditional methods of collecting travel data, Bluetooth is cost-effective, unintrusive and does not have privacy concerns. Using Bluetooth data has proven to be effective in urban settings. However, it is restricted to vehicles equipped with Bluetooth devices and may not encompass all modes of transportation.

Camera-based systems like Telraam and VivaCity use AI-powered cameras and onboard processing to record and classify road users. This type of technology provides real-time data that is highly accurate (it can detect multiple types of vehicles) and does not have privacy concerns. However, its potential drawbacks are hardware costs, limited nighttime functionality, and inability to measure PKT (this is primarily due to privacy concerns and the difficulty of tracking individuals).

Smartphone-sensor data and smartphone apps can monitor travel behaviour and measure PKT for limited sample sizes; however, they often rely on user verification. Telco data (such as from mobile phones and CDR) provides valuable information (such as precise OD matrices) for transportation planning. However, using telco data is hindered by privacy issues. It is also difficult to use it to categorise travel modes.

Crowdsourced data (such as, Strava and shared mobility data) offers insights into mode share for active-transport modes. However, the data can be biased, incomplete and have privacy issues. Processing the data may also require a substantial effort.

Finally, Eco-Counter has a range of solutions for counting traffic, and collecting and analysing count data, that focuses on active-transport modes. The solutions are limited by having to maintain devices and replace the batteries.

Table 2.4 summarises these emerging data sources and their suitability for measuring mode share.

Table 2.4 A comparison of emerging data sources for measuring mode share

Criteria	Bluetooth	Camera-based technology	Eco-Counter	Smartphone-sensor data	Smartphone applications	Mobile-phone and telco data	Crowdsourced data
Vehicle counts [a]	A sample only, as not all vehicles will have the technology	Yes	Yes	A sample only, as not all vehicles will have the technology	No	A sample only, as not all vehicles will have the technology	Yes (if applicable)
Person counts [b]	No	Yes	Yes	No	No	No	Yes
VKT measurement	Estimate	Estimate	No	Yes	Yes	Yes	Yes
VKT measurement method	Bluetooth device tracking	Numberplate recognition	N/A	Assumptions or data about travel mode	Assumptions about travel mode, and feedback from users	Assumptions or data about travel mode	Measurements from vehicles (if applicable)
PKT measurement	No	No	No	Yes	Yes	No	Yes
PKT measurement method	N/A	N/A	N/A	Tracking individuals' movements and routes	Tracking individuals' movements and routes, and travel diaries	N/A	Tracking individuals' movements and routes
Route tracking	Estimate	Estimate	No	Yes	Yes	Estimate	Yes
Travel-mode detection and estimation	Possible via imputation	Yes	Yes	Possible via imputation	Possible via imputation or user entry	Possible via imputation	Yes (if known)
Other trip data	No	No	No	No	Possible via user feedback	No	No

[a] The number of vehicles that pass the counting location.

[b] The number of travellers. For cyclists or pedestrians, the person count is 1.

2.5 Modelling approaches

Modelling techniques are another way to estimate mode share. The key difference, between modelling approaches and other approaches, is that modelling approaches use collected data to calibrate a model that is then used to estimate mode share. We have identified two potential modelling techniques.

2.5.1 Discrete-choice models

The first technique is discrete-choice models (Beeramoole et al., 2023; Paz et al., 2019; Vij et al., 2013; Vij & Walker, 2016). In one example, Beeramoole et al. (2023) analyse the mode choices of 435 Swiss travellers, based on their stated preferences in a survey in 1999.

Discrete-choice models can include various factors related to the intricate process of making decisions. For example, Vij et al. (2013) and Vij and Walker (2016) discuss including latent behavioural aspects (such as habit and indifference) in their choice models, by using a six-week travel diary completed by 317 participants from 139 households. They hypothesise that a relatively long survey period is important to infer such behavioural aspects.

2.5.2 Traffic-assignment models

The second technique is based on traffic-assignment models. Shafiei et al. (2018) outline a method that can estimate time-dependent OD demand for car trips within Greater Melbourne during a typical weekday morning-peak period (6–10 am). This method uses:

- network data from the Victorian Integrated Transport Model (VITM), which consists of 2,974 traffic zones, 55,719 links and 24,502 nodes
- SCATS® traffic data
- historical data on travel time, based on GPS trajectories that map service providers (such as, Google Maps) collect
- data on static OD demand from the VITM
- data from the Victorian Integrated Survey of Travel and Activity (VISTA).

This method recalibrates the VITM's static-OD-demand matrix, by using the other data sources to generate multiple OD matrices at 15-minute intervals. While Shafiei et al. apply this method only to car trips, a similar approach for pedestrian traffic in Sydney has been proposed (Lilasathapornkit & Saberi, 2022). In another study, transit assignment methodology and smartcard data are used together, to estimate ridership of new public-transport lines (Lee et al., 2022). By combining results of these three travel modes (cars, pedestrians, and public transport), it is possible to estimate the overall mode share.

Although these modelling approaches demonstrate potential merits for measuring mode share, they have never been developed to estimate mode share in practice.

2.6 Summary

By engaging with stakeholders and reviewing literature, we have identified technologies and approaches that can measure mode share at three levels:

- National and regional levels, using a household travel survey.
- Key corridors and city centres, using screenlines.
- Transport networks or regions, using link-based approaches.

Household travel surveys are the main tool that authorities use to find out about people's travel behaviour and understand why their behaviour changes in the long term. However, due to budget constraints, they are limited to small sample sizes. It is difficult to reduce their costs by adopting technology, because the main driver of cost is the fieldwork to recruit the participants. Processing GPS data and using other technologies adds to the cost, as they require significant effort and resources. The small sample sizes mean that authorities commonly aggregate data from multiple years in their reporting, making household travel surveys less effective at measuring short-term changes in mode share. The small sample sizes also make it challenging to assess change within an LGA, so some LGAs invest in additional samples to make their data more reliable.

Screenline approaches involve measuring travel activity through data collected from sensors that are positioned along artificial screenlines. They typically assess a simplified network, major corridors into and out of cities, or strategic locations. They often exclude local roads, even when they are along the screenlines. Screenline approaches use information from traffic counters (historically, they used data from manual surveys). They account for all modes of travel, including private vehicles, public transport and active transport. In New Zealand, screenline approaches are used in Auckland and Wellington.

Unlike screenlines, link-based approaches measure travel activity on individual roads or segments. They can aggregate this data to estimate travel activity for whole areas or transport networks. Link-based approaches source data from sensors, traffic counters, cameras or crowdsourced data. These approaches also provide a suitable platform for monitoring broader transport outcomes, such as sustainability.

In New Zealand, Hamilton has a comprehensive framework for measuring mode share that covers all roads in its network. Internationally, Hangzhou, China, uses a link-based approach to estimate carbon emissions from transport. This approach has demonstrated significant advantages of combining data from location-based services (LBS) in smartphone apps with other data sources. However, despite the potential that LBS data offers, it is still impractical in New Zealand, given limited availability, coverage and accessibility of LBS-data infrastructure.

Innovative technologies and emerging data sources are significantly influencing how accurately and comprehensively screenline and link-based approaches can measure mode share. We have reviewed various emerging data sources, including Bluetooth data, camera-based technology, smartphone-sensor data, smartphone apps, mobile-phone and telco data, and crowdsourced data. Camera-based technologies that use AI and machine learning to process feeds can offer a robust way to continuously monitor active modes of transport. Some can detect all modes of transport without needing multiple sensors. Smartphone-based technologies are also proving effective for collecting diverse data. Depending on their adoption rates, they can provide data for substantial portions of the population. Large-scale data sources (such as CDR and crowdsourced data) can also provide data for large samples of the population, at the expense of spatial accuracy, although any bias in the datasets needs to be well understood and accounted for.

Our review finds that several New Zealand LGAs have developed approaches to measure mode share responsively that do not rely on household travel surveys. Three Tier 1 local authorities[16] (AT, HCC and WCC) are at varying stages of implementing screenline and link-based approaches, which include a mix of existing and new technologies to measure travel activities.

Despite these developments, it is still challenging to measure PKT by modes of active transport. Many initiatives to do this are still in the early stages, and we find that consistent guidelines for collecting, analysing and reporting data need to be developed.

[16] The *National policy statement on urban development capacity 2020* defines local authorities as 'Tier 1', 'Tier 2' and 'Tier 3', depending on their urban environment.

3 Analysing options to measure mode share and mode shift

By consulting with stakeholders and reviewing practice, we have identified several approaches – and their associated data sources and technologies – for users (such as, authorities) to measure mode share and mode shift. We used the results of our review to develop assessment criteria to analyse the data sources and approaches (the options). We presented an assessment framework and our assessment criteria to the Project Steering Group, for its feedback and agreement.

In this section, we present the assessment framework and criteria that we use in this project, and the results of applying them to different data sources and approaches (the options analysis). We conclude this section by explaining how we used the options analysis to determine the scope for a toolkit and pilot study.

3.1 Assessment framework and criteria

To assess the options to measure mode share and mode shift, we used the Australian Transport Assessment and Planning framework (Australian Transport Assessment and Planning Steering Committee, 2021). We used the framework's multiple filters to refine the long list of options in Section 2.4 and identify the most suitable option or combination of options. One or more of these options are currently being applied in each of the mode-share approaches presented in Sections 2.1 and 2.3.

We developed eight assessment criteria (see Table 3.1) to analyse the data sources and approaches and compare them with each other. The description of each criterion comprises one or more questions we used to analyse the option. This structured approach enabled us to examine the options thoroughly and determine if they suit their intended purpose.

Table 3.1 Criteria to analyse data sources and approaches to measure mode share and mode shift

Criteria		Description (key questions)
1	Mode coverage	Which travel modes are covered by the data source? How well can the technology identify the travel mode, directly or by inferring the mode?
2	Responsiveness/ reporting frequency	How often is data collected (for example, continuously, monthly or annually)? How responsive can reporting be to mode shift (based on how frequently data is collected)?
3	Kilometres travelled (PKT)	How accurately can PKT be measured, calculated or estimated?
4	Data accessibility [a]	How easily can data be accessed and shared (for example, government data, council data and proprietary data)?
5	Data analysis and processing	What data-cleansing and data-analysis efforts are needed to use the data? How easily can the data be integrated with other data sources? Does the data source provide raw data, or processed data (such as data in a dashboard)?
6	Sample size [a]	What sample size is achievable? How representative is the sample?
7	Coverage granularity	How well can coverage of a defined area (that is, subnational) be achieved? Is the coverage suitable for individual projects and defined subnational areas?

Criteria		Description (key questions)
8	Cost [b]	What capital and operating costs are involved? For example, does the data source involve a (costly) subscription or use of proprietary technology or a platform? What does the data processing cost?

[a] Privacy concerns may limit access to data, the ability to share data and the sample size.

[b] The value derived from the costs of a data source and technology is likely to increase if the same data can be used for other purposes. The potential to use the data more broadly can also influence which method of measuring mode share is chosen.

3.2 Options analysis

As it is not possible to directly compare the different data sources, we analysed each of them against the relevant assessment criteria (see Table 3.1) using a short qualitative description instead of a score or ranking. See **Error! Reference source not found.** for the results of this assessment.

We analysed the approaches against criteria 1 to 4 and 7 to 8 (see Table 3.2). We included the HTS as a benchmark to measure the other options against. We excluded criteria 5 and 6, as they focus on the data sources rather than the approaches (see **Error! Reference source not found.**). For the remaining criteria, we assigned a score of 1 (best) to 3 (worst) to each option, to indicate their performance. From these scores, we calculated the average, to identify which options are the most promising or suitable for measuring mode share and mode shift responsively.

We presented the results of this analysis to the Project Steering Group and used its minor feedback to update and refine the results.

Table 3.2 Analysis of approaches to measure mode share and mode shift

Approach	Approach and data source	Criterion 1: Mode coverage	Criterion 2: Responsiveness/reporting frequency	Criterion 3: Kilometres travelled (PKT)	Criterion 4: Data accessibility	Criterion 7: Coverage granularity	Criterion 8: Cost	Average score
HTS	**Approach:** Household travel survey **Data:** Survey data, GPS data **Locations:** National	1 All modes	3 Annual reporting at best, but usually requires many years of data	1 Yes, through a questionnaire and GPS tracker	1 Excellent (government-owned)	3 National only. Regional is possible with booster samples	3 Expensive	**2.0**
AT	**Approach:** Screenlines **Data:** Survey data, counters **Locations:** Auckland city-centre cordon (17 sites)	2 All road-transport modes (no pedestrians, trains or ferries)	1 Immediate changes noticeable in data, depending on the type of intervention	2 Possible for public transport, but not done currently	2 Good (authority-owned data collected from existing available sources)	2 Travel in and out of the city centre only	2 Cost-effective, but coverage is limited	**1.8**
GWRC	**Approach:** Screenlines **Data:** Public-transport fare data (combined with other WCC data) **Locations:** Wellington city-centre cordon (11 sites), plus 4 regional sites	2 All except pedestrians and ferries	1 Immediate changes noticeable in data, depending on the type of intervention	2 Possible for public transport, but not done currently	2 Good (council-owned data collected from existing available sources)	2 Travel in and out of key regional corridors	2 Using council data is cost-effective, but cost will depend on data-fusion method, which is yet to be finalised	**1.8**

Approach	Approach and data source	Criterion 1: Mode coverage	Criterion 2: Responsiveness/reporting frequency	Criterion 3: Kilometres travelled (PKT)	Criterion 4: Data accessibility	Criterion 7: Coverage granularity	Criterion 8: Cost	Average score
Hangzhou, China [a]	**Approach:** Link-based **Data:** LBS data, smartphone data **Locations:** City-wide coverage through location-based devices and crowdsourced data	1 All road-transport modes, public transport and active modes (bikeshare)	1 Immediate changes noticeable in data	2 Possible to measure or infer	3 Primary LBS data is proprietary and difficult to access	1 Good (coverage can scale from link-level up to city or region)	3 Cost depends on accessibility of LBS data	**1.8**
HCC	**Approach:** Link-based **Data:** Cameras, counters, SCATS®, Bluetooth, public-transport fare data, crowdsourced data **Locations:** City-wide coverage through location-based devices and crowdsourced data	1 All road-transport modes including goods vehicles and trucks (no trains or ferries)	1 Immediate changes noticeable in data, depending on the type of intervention	2 Possible to measure VKT and PKT (via numberplate recognition and vehicle occupancy) for some modes, and public transport, but not done currently	2 Good (council-owned data collected from existing available sources, including third-party providers)	1 Good, coverage can scale from link-level up to city or region	1 Reasonable, using council data and third-party data (methodology is validated and tested, and is suitable for other locations)	**1.3**

Approach	Approach and data source	Criterion 1: Mode coverage	Criterion 2: Responsivenes s/reporting frequency	Criterion 3: Kilometres travelled (PKT)	Criterion 4: Data accessibility	Criterion 7: Coverage granularity	Criterion 8: Cost	Average score
TMR	**Approach:** Screenlines **Data:** Counters, public-transport fare data **Locations:** 5 screenlines (31 sites along major corridors)	2 Private cars, buses and trains	3 One-off reports within a few months of collecting data	2 Vehicle counts and estimates of vehicle occupancy at screenlines. Possible to estimate PKT, but not covered in study	2 Reasonable (TMR oversees data collected by local councils)	2 Selected area (travel in/out)	2 Cost-effective, but coverage is limited, and projects are one-offs	**2.2**
WCC	**Approach:** Link-based **Data:** Cameras (VivaCity). Previously counters combined with GWRC public-transport data **Locations:** Wellington city-centre cordon (11 sites) plus other city-centre locations	2 All road-transport modes (no ferries)	1 Immediate changes noticeable in data, depending on the type of intervention	2 Not done currently, Possible to measure VKT and PKT (via numberplate recognition and vehicle occupancy) for some modes	2 Good (council-owned data collected from existing available sources, including third-party providers)	1 Good (coverage can be from links through to cities or regions)	2 Using council data is cost-effective, but cost will depend on data-fusion method, which is yet to be finalised	**1.7**

Note: Qualitative rating scale uses 1 (best) to 3 (worst) (see Section 3.1).

[a] This option is not suited to New Zealand, as LBS-data infrastructure is unavailable.

Our analysis of the different data sources indicates that:

- data from household travel surveys covers all transport modes, but it is costly to collect and has limited capability to responsively measure mode share and mode shift
- traditional data sources (like SCATS® and TMS), tube counters and fare data measure private and public transport effectively, but it is difficult to adapt them to measuring active-travel behaviour
- emerging data sources and new technologies (such as crowdsourced data, AI-powered cameras and smartphone-based solutions) show promise for measuring active-travel behaviour. Smartphone-based solutions offer potential to measure PKT for all transport modes, but they are constrained by the cost to develop them and difficulty recruiting participants (similar to the problem faced by household travel surveys).

Currently, no single data source can cover all transport modes and provide the required spatial and temporal resolution. Any proposed approach to measuring mode share and mode shift (this includes measuring active transport) will need to fuse data from various conventional and new sources.

Our analysis of the options used by different authorities reveals these findings:

- HCC (scores 1.3), WCC (scores 1.7), GWRC (scores 1.8) and AT (scores 1.8) have the most feasible options. However, while the best score (that is, the lowest number) indicates the option is highly suited to this research project, it may not use the latest technology.
- Authorities generally measure VKT, but do not consistently prioritise PKT, or use consistent methods to measure it for all transport modes.
- Screenline approaches can be useful for specific corridors or strategic locations, but they are limited to count data. The sensor locations need to be carefully considered, to ensure they create a representative picture of travel behaviour. Screenline approaches are often confined to a specific area of interest (such as around a city centre). AT and GWRC have developed ways to measure travel activity using screenlines at different locations, or for different spatial scales and timescales.
- Link-based approaches are useful for comprehensively measuring mode share in a city or region. Currently, HCC's approach offers the best coverage of different transport modes; its data is the most detailed, responsive and easy to access; and its approach is the most cost-effective. WCC has begun rolling out smart sensors and developing a methodology for fusing and analysing data.

The top four options (HCC, WCC, GWRC and AT) demonstrate that New Zealand authorities have made significant progress in measuring mode share and mode shift. Given that data infrastructure and technology are at different levels of maturity across New Zealand, we conclude that our toolkit, of guidance on how to measure and report mode share and mode shift, should consider both link-based and screenline approaches.

4 Conducting a pilot study

This section describes the pilot study we undertook to measure mode share and mode shift responsively. Considering that several New Zealand authorities have already made advanced progress in this area, we decided to carry out a synthetic pilot study that involved collecting data that they had already processed. We developed consistent specifications for the data, processed the data using the specifications, and created a proof-of-concept dashboard to provide examples of report outputs at different spatial and temporal scales. We used the lessons from the pilot study to inform the toolkit we developed.

4.1 Scope of the pilot study

We limited the scope of this study to a synthetic pilot, using data from four participating New Zealand authorities (see Table 4.1).

Table 4.1 Pilot-study participants: approach to measuring mode share and mode shift and area covered

Authority	Study area/coverage	Approach
AT	Auckland city centre	Screenline, with a single cordon
GWRC	North of Wellington city centre	Three screenlines along key corridors
HCC	Hamilton city centre	Link-based approach
WCC	Wellington city centre	Link-based approach [a]

[a] WCC's approach is being developed; it is rolling out new sensors and infrastructure across the city.

4.2 Data for the pilot study

To collect data for the pilot study, we consulted with each participating authority twice (see **Error! Reference source not found.**). During the first consultation, we updated the authorities on this project and asked them to take part in the pilot study. We also talked about what data authorities have available and how to access it; which locations and sites they measure; and what methods they use to measure mode share and mode shift. We consolidated the results of this consultation to further develop and define our formal request for data and supporting data and documentation.

During the second consultation, we presented our data request to each authority (followed up by email after the meeting) and clarified any additional items or assumptions.

4.2.1 Data request

We asked each participating authority to provide us with this data:

- Processed mode-share data for six months, or more, for each transport mode and the finest temporal resolution available.
- GIS base layer with the coordinates of links, screenlines, and count locations or sites.

We also asked the participating authorities to provide us with this information:

- A data dictionary.
- Assumptions they apply to their methodology and calculations (such as, vehicle occupancy).
- Methods they use to differentiate private vehicles from other vehicles (such as freight vehicles or buses).
- Methods they use to process, aggregate and fuse data.

Given authorities use different approaches and infrastructure, and have different end-use requirements, we needed to further process their data before we could develop a proof-of-concept dashboard.

4.2.2 Data review and verification

We comprehensively reviewed the data from each authority to ensure it was accurate, complete and high quality. To explore and examine the data, we used Python, QGIS and Microsoft Excel. As we expected from reviewing current practice, each authority uses a different format and structure to present its data, which reflects the different approaches that authorities use, and their different data requirements. We present our review of each authority's data in Sections 4.2.2.1 (AT), 4.2.2.2 (GWRC), 4.2.2.3 (HCC) and 4.2.2.4 (WCC). An overall summary of the authority data collected is presented in Table 4.2.

4.2.2.1 Auckland Transport

AT provided its data in a single CSV file. This dataset contains the total number of people who entered the city-centre cordon during the morning peak (7am to 9am) each month, from August 2022 to December 2023. The dataset includes the monthly total of cyclists, pedestrians, public-transport vehicles (buses, ferries and trains) and private vehicles (all types). AT's data is unidirectional and considers only inbound journeys.

AT explained that, due to technical issues, it does not have data on cyclists and pedestrians from May to December 2023.

4.2.2.2 Greater Wellington Regional Council

GWRC provided its data in a single CSV file. This dataset covers three screenlines north of Wellington city centre (Ngaio Gorge, Ngauranga Gorge and Petone–Ngauranga) for two months (September and November 2023). The dataset covers bus passengers, car occupants (all private vehicles), cyclists and rail passengers. GWRC's data is bidirectional, covering inbound and outbound journeys. It includes hourly weekday and weekend averages that are taken during the first week of each reported month. The weekday average takes the average of the five weekdays; the weekend average is the average of the two weekend days.[17]

GWRC also provided us with a map of its screenline locations and individual monitoring sites, and details of the methods it uses to produce the data.

GWRC noted that some of its cyclist data is missing or is incorrectly reported as zero.

4.2.2.3 Hamilton City Council

HCC provided its data in a single CSV file. This dataset covers selected road links across Hamilton city centre from July to December 2023. The dataset includes the average daily mode-share measurements for each month. The dataset covers bus passengers, cyclists, pedestrians and private vehicles (all types).

HCC also provided us with a shapefile containing the corresponding GIS road links.

As HCC is still transitioning towards continuously monitoring and estimating mode share across the city centre, its data has some limitations. First, it was able to provide data for only a small subset of its transport network (nine links). Second, we were provided with monthly estimates, although HCC expects higher-resolution estimates (daily and hourly) will be available in future.

[17] GWRC uses data from weeks that do not include public holidays.

4.2.2.4 Wellington City Council

WCC provided its data in CSV files grouped by count lines or sensors. This dataset covers actual hourly traffic counts (raw data) from November 2023 to February 2024, taken from VivaCity sensors that WCC has recently installed on various roads around the city. The dataset includes different transport modes to those of the other authorities (see Appendix B, Section B.3.2.2), so we chose to use a subset of the data for our proof-of-concept dashboard.

WCC gave us information about the locations of installed sensors and count lines – by transport mode and direction of travel at intersections – that can be used to generate link-based mode-share measurements. To calculate mode share and mode shift, we needed to further process this data (see Section 4.2.3). WCC also gave us data and information related to its previous method of measuring mode share (cordon vehicle-occupancy surveys) and geospatial data for various carriageway sections.

As WCC's VivaCity sensors have been only recently installed, a complete dataset is not available for every sensor.

Table 4.2 Data collected during the pilot study

	AT	GWRC	HCC	WCC
Approach	Screenline	Screenline	Link-based	Link-based
Duration of data (reporting frequency)	17 months – Aug 2022 to Dec 2023 (monthly)	2 months – Sep and Nov 2023 (quarterly)	6 months – Jul to Dec 2023 (monthly)	Up to 4 months – Nov 2023 to Feb 2024 (N/A) [a]
Spatial coverage	Auckland city-centre cordon (17 monitoring sites)	3 screenlines (22 monitoring sites) north of Wellington city centre	9 links in Hamilton city centre	6 links around Wellington city
Direction coverage	Inbound	Inbound and outbound	Inbound and outbound	Inbound and outbound
Temporal coverage	Morning peak (7–9am)	Hourly (24 hours)	Monthly	Hourly (24 hours)
Aggregation	Monthly total people count	Average weekday (5-day average) and weekend (2-day average) during first week of each month	Daily average for each month	Hourly average for weekdays and weekends for each month
Modes covered [b]				
• Buses	Yes	Yes	Yes	Yes
• Cyclists	Yes	Yes	Yes	Yes
• Ferries	Yes	N/A	N/A	N/A
• Pedestrians	Yes	N/A	Yes	Yes
• Private vehicles [c]	Yes	Yes	Yes	Yes
• Trains	Yes	Yes	N/A	N/A

[a] For some links, WCC has less than four months of data as it is still installing the infrastructure.

[b] Modes covered means that the authority has provided data by number of people that use different modes (for example, the number of passengers per car or bus).

[c] Only WCC provides subcategories of private vehicles (such as cars and heavy vehicles).

4.2.3 Data analysis and processing

After we reviewed each authority's data, we processed it into a common format before combining it. To do this, we developed comprehensive mode-share data specifications for mode types (active, public and private) and individual modes (such as cyclist, bus and ferry) share (see **Error! Reference source not found.**). We mapped each authority's data to the data specifications' consistent structure, whose hierarchy enables data to be reported across all temporal scales (annual to sub-hourly) and spatial scales (macroscopic to microscopic). The data specifications cater for the different mode-share approaches (screenline and link-based) and can estimate PKT for link-based approaches.

The data formats of AT, GWRC and HCC are relatively straightforward to process into the common format. However, WCC provided only raw counts, so its data needed additional processing. This involved identifying the links from the sensors that correspond with the direction of travel, and then calculating the averages for each month to identify typical weekdays and weekends. From the available transport modes, subsets were selected (such as, car, bus, cyclist or pedestrian) and processed, to estimate the number of people in vehicles. See Table 4.3 for more details of these issues and how we resolved them.

We used the geospatial data and information from the authorities to generate common files for the corresponding road links and screenlines, to link them with the mode-share data (see **Error! Reference source not found.**). These new datasets form the basis of our proof-of-concept dashboard, which we created to demonstrate mode share and mode shift for different spatial scales and timescales in New Zealand.

Table 4.3 Issues with data collected during the pilot study

Authority	Issue	Solution
AT	No data is available on cyclists and pedestrians between May and December 2023, due to technical issues	We assumed that the number of people who use active transport did not change much in the past 20 months. So, we filled the gaps using cyclist and pedestrian data from August 2022 to March 2023
GWRC	Some data on cyclists is missing from the Ngaio Gorge screenline for November 2023 weekend (inbound and outbound)	We assumed that the number of cyclists did not change much between September and November 2023. So, we filled the gaps using cyclist data from September 2023
WCC	No data is available on the number of people in vehicles, only the number of vehicles	We estimated the number of people in vehicles, using WCC's assumed rate of 1.3 people per vehicle
	No data is available on the number of people in buses, only the number of buses	We assumed there were 10 people per bus

Note: Many of our assumptions are not accurate estimates. We have used them purely to illustrate the proof-of-concept dashboard.

4.3 Proof-of-concept dashboard

In this section, we present the features and functions of the proof-of-concept dashboard we developed using Tableau, and the insights that can be obtained from it. The dashboard reports on, and visually represents, mode share and mode shift for the four participating authorities in our pilot study (see Figure 4-1 and Figure 4-2).

The dashboard has the capability to filter data by authority, date (year, month and day) and time (weekday and weekend); it can also aggregate data for links or screenlines. On the centre of the dashboard's mode-share page, there is an interactive map of screenlines and links that users can select and view data from. Depending on approach and data availability, users can select and view the data by counts, estimated PKT and mode share.

The dashboard offers users several options to visualise the data. These include pie charts to see how mode-share data is broken up by mode types (active, public and private) and individual modes (such as bicycle, bus or ferry).

Figure 4-1 Proof-of-concept dashboard: Mode share for people entering Auckland city centre (Aug 2022 to Dec 2023)

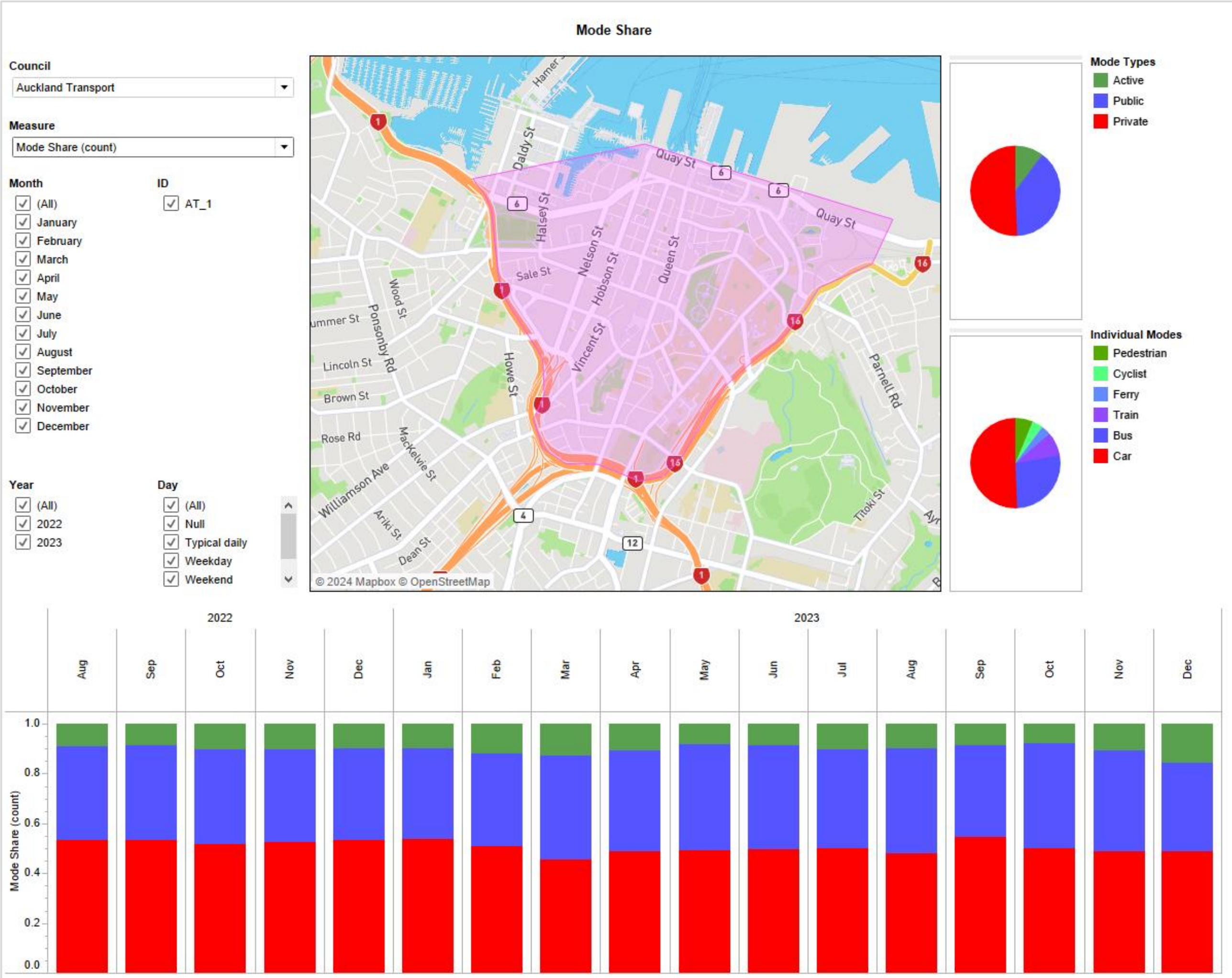
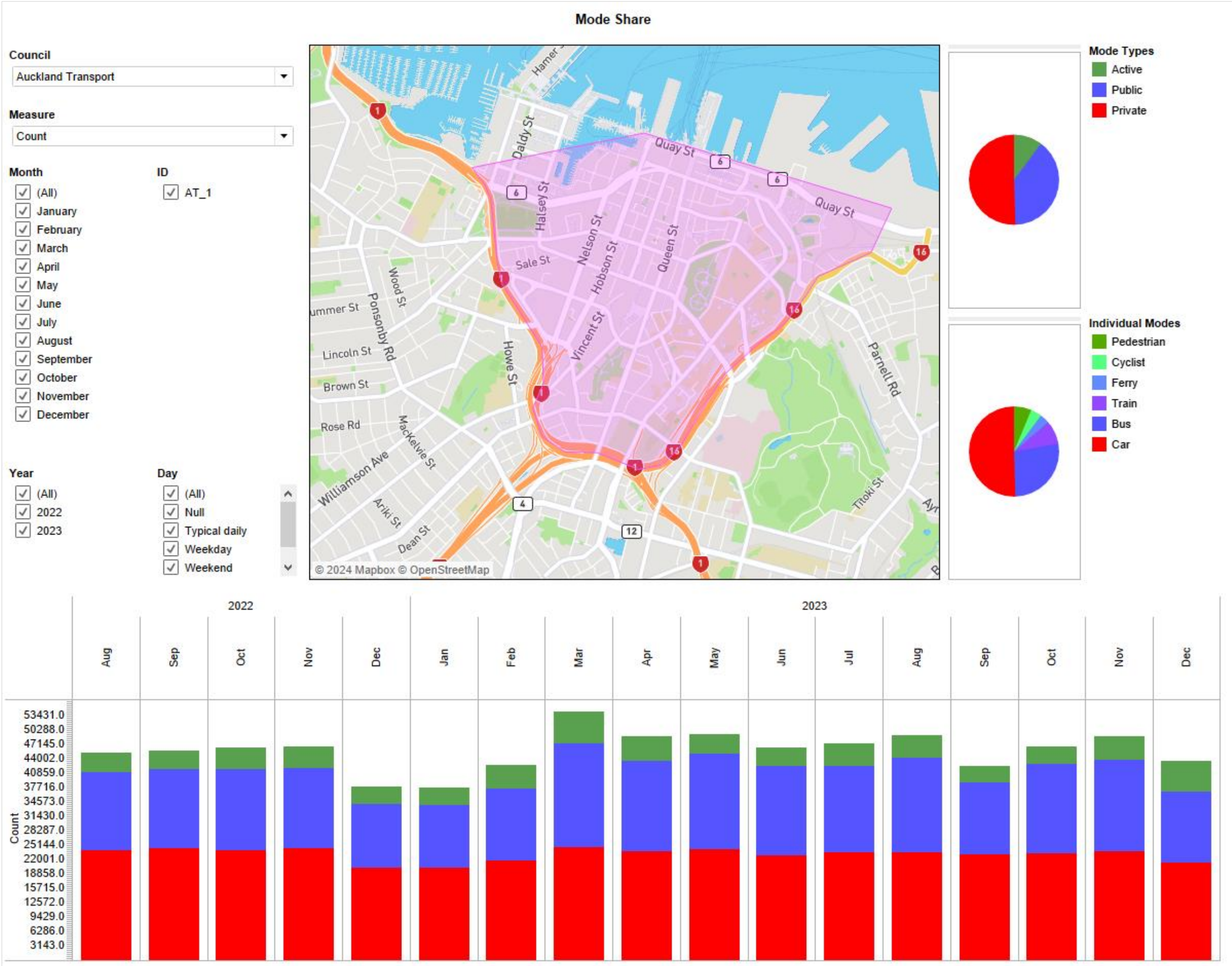


Figure 4-2 Proof-of-concept dashboard: Traffic counts for Auckland city centre (Aug 2022 to Dec 2023)



4.3.1 Examples of reporting and data visualisation on mode share and mode shift

In this section, we present examples of how the dashboard can report on mode share and mode shift for different spatial scales and timescales. The examples are explained using screenshots of the proof-of-concept dashboard and case studies of the four participating authorities.

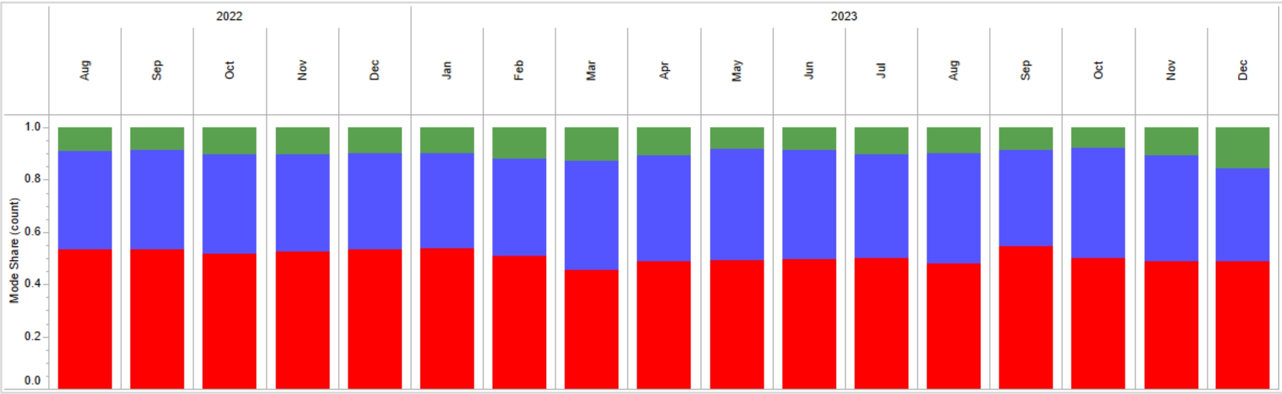
4.3.1.1 Auckland Transport

AT data comprises monthly totals of people entering Auckland city centre during the morning-peak period. It includes comprehensive coverage of mode share by active transport (cyclists and pedestrians), public transport (bus, rail and ferry passengers) and private transport (all vehicles). The dashboard shows the AT cordon (see Figure 4-1 and Figure 4-2).

Figure 4-3 shows the monthly mode share, using the data provided by AT. Over the measured period, it shows the largest proportion of people travelling into Auckland city centre consistently do so using private transport. This is followed by people using public transport and active transport.

Figure 4-4 is a visualisation of mode shift (mode share over time). Such a visualisation can be used to monitor long-term trends. It can also be helpful in a before-and-after study (for example, to see the effect of new infrastructure). A visualisation helps identify changes in mode share or changes in total transport activity (counts or estimated PKT). As the quality and accuracy of data improves over time, it can be used to further analyse mode shift for the AT cordon (such as the percentage increase or decrease of different modes).

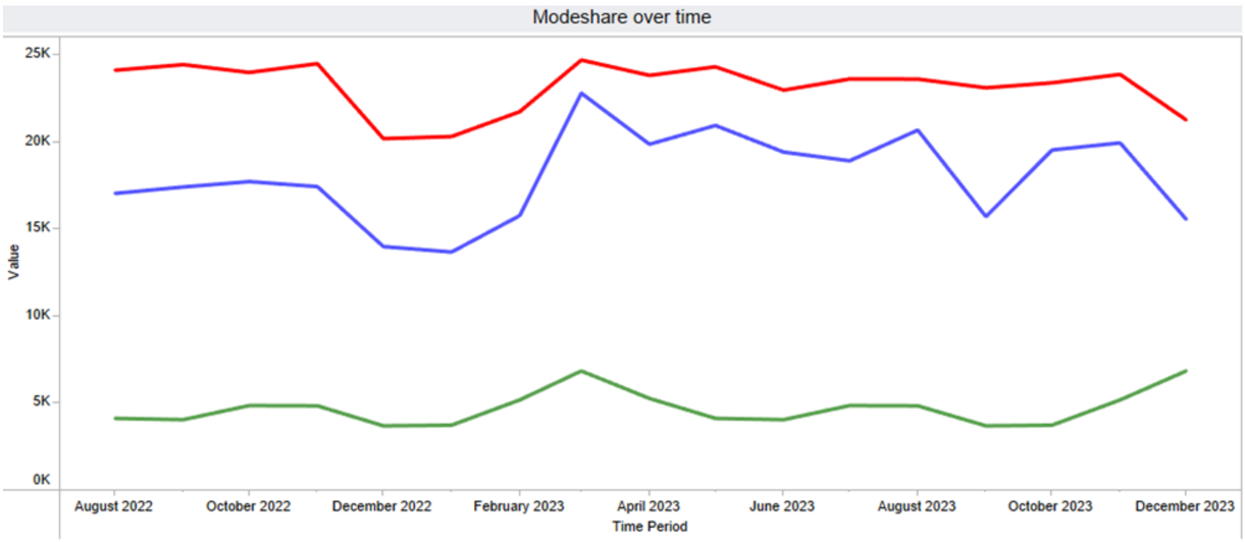
Figure 4-3 Proof-of-concept dashboard: Mode share for people entering Auckland city centre during the morning peak (Aug 2022 to Dec 2023)



Note: Green = active transport; blue = public transport; red = private transport.

Figure 4-4 Proof-of-concept dashboard: Mode shift for people entering Auckland city centre during the morning peak

(a) Mode share (Aug 2022 to Dec 2023)



Note: Green = active transport; blue = public transport; red = private transport.

(b) Month-to-month mode shift (Aug 2022 to Dec 2023)

	Month																
	2022					2023											
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% Change in Active Transport mode share		-3%	18%	-1%	-6%	1%	23%	4%	-15%	-22%	4%	18%	-4%	-12%	-8%	32%	48%
% Change in Private Transport mode share		1%	0%	-2%	-1%	-2%	2%	14%	-3%	5%	-1%	-5%	5%	-12%	13%	-3%	-12%
% Change in Public Transport mode share		0%	-3%	2%	2%	1%	-5%	-11%	7%	1%	0%	1%	-4%	13%	-8%	-3%	0%

(c) Mode shift between August 2022 and August 2023

	Month	
	2022	2023
	Aug	Aug
% Change in Active Transport mode share		8%
% Change in Private Transport mode share		12%
% Change in Public Transport mode share		-10%

4.3.1.2 Greater Wellington Regional Council

GWRC data comprises hourly mode share for three screenlines (see Figure 4-5) for weekdays and weekends. For each screenline, the dashboard can display the hourly counts (see Figure 4-6) and mode share report on a weekday (see Figure 4-7) and at a weekend (see Figure 4-8).

Compared with AT's monthly totals, GWRC's hourly average data gives better insights into mode share and travel behaviour for the screenlines. For example, weekday data in Figure 4-7 clearly shows morning and evening commuting peaks, when use of public transport significantly increases between 6am and 9am, reduces somewhat during the day and increases again between 3pm and 7pm. In contrast, the use of public transport does not change considerably during the weekend. Use of active transport is noticeably more during the weekday morning commute, but not the evening commute out of the city. It is also present only on some screenlines. This may reflect issues with some of the sensors (noted in Section 4.2.2.2). In general, the mode-share results from these three screenlines also demonstrate relatively consistent patterns for hourly counts and mode-share percentages on weekdays and weekends.

Figure 4-5 Proof-of-concept dashboard: Map of three GWRC screenlines north of Wellington city

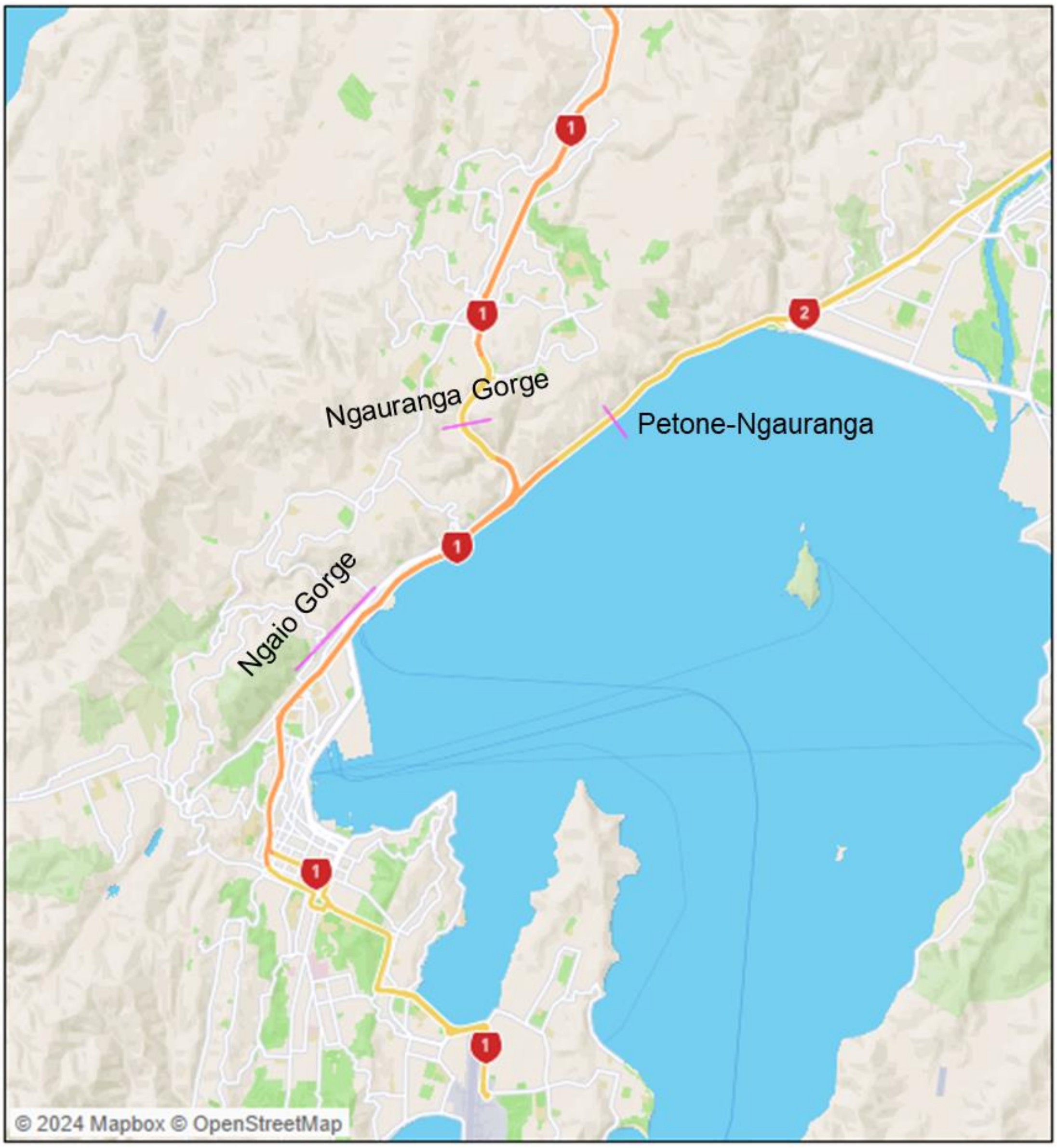
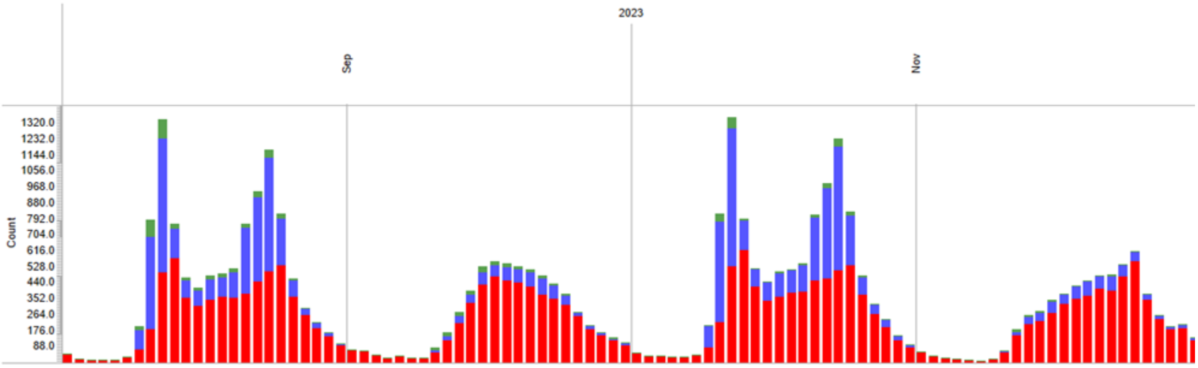
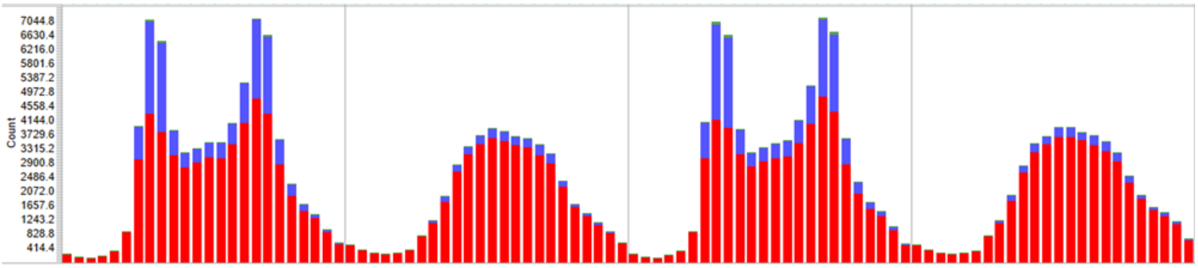


Figure 4-6 Proof-of-concept dashboard: Weekday and weekend hourly counts on three GWRC screenlines (September and November 2023)

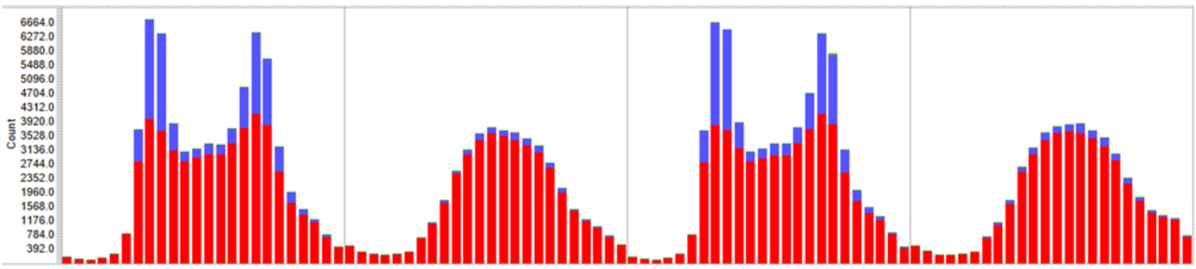
(a) Ngaio Gorge screenline



(b) Ngauranga Gorge screenline



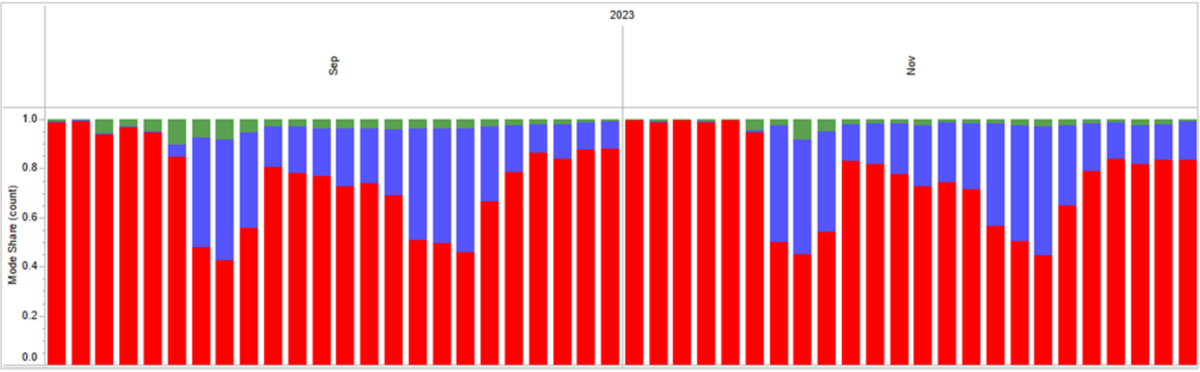
(c) Petone–Ngauranga screenline



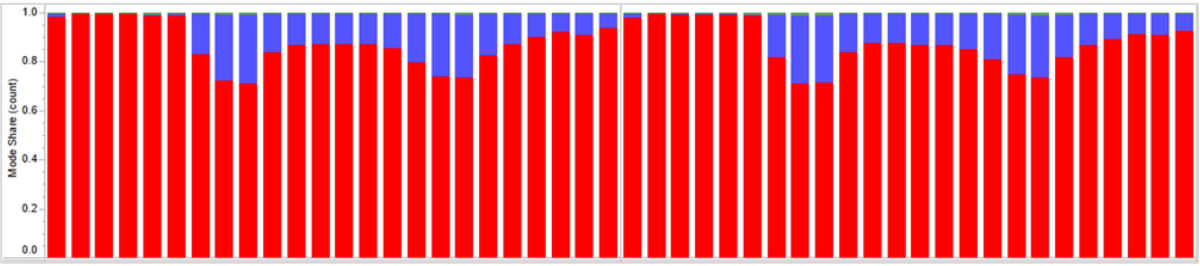
Note: Green = active transport; blue = public transport; red = private transport. Each bar represents one hour, from midnight to midnight.

Figure 4-7 Proof-of-concept dashboard: Hourly weekday mode share on three GWRC screenlines (September and November 2023)

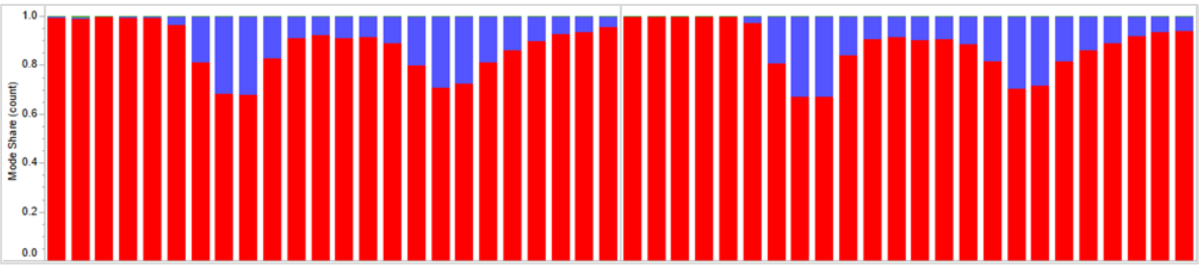
(a) Ngaio Gorge screenline



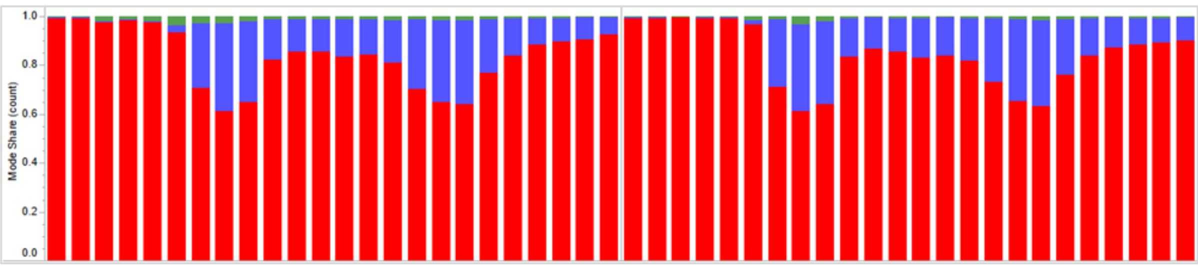
(b) Ngauranga Gorge screenline



(c) Petone–Ngauranga screenline



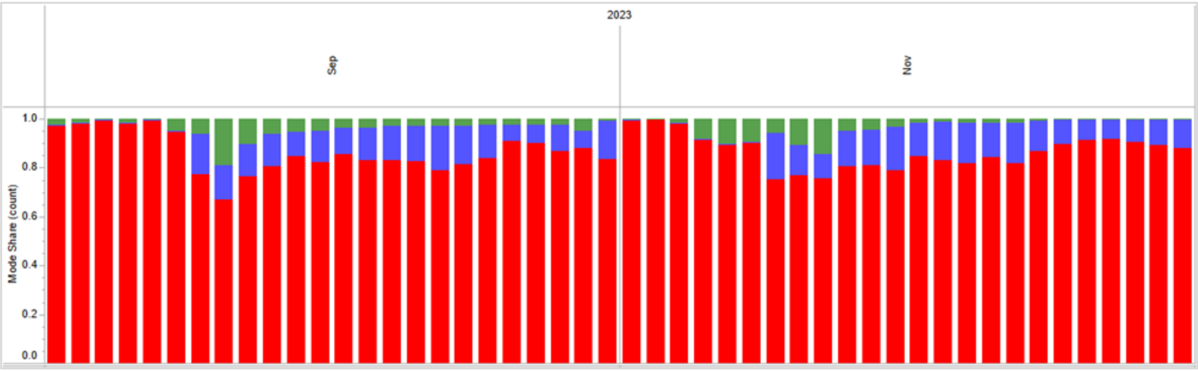
(c) All screenlines combined



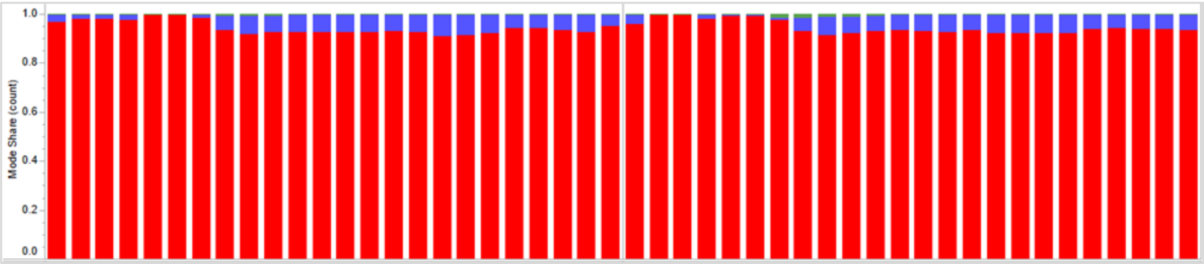
Note: Green = active transport; blue = public transport; red = private transport. Each bar represents one hour, from midnight to midnight.

Figure 4-8 Proof-of-concept dashboard: Hourly weekend mode share on three GWRC screenlines (September and November 2023)

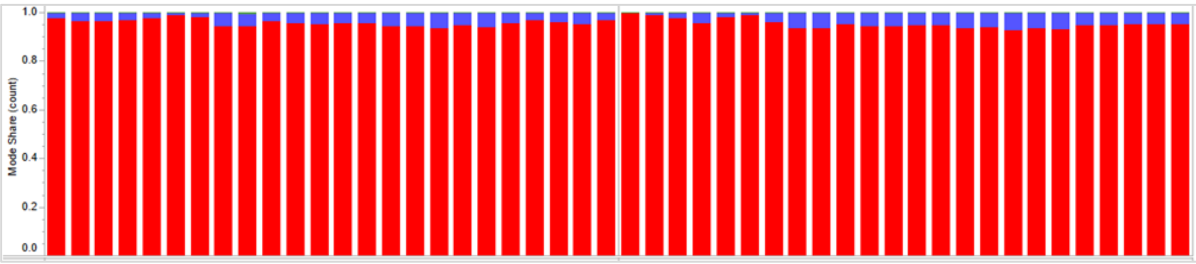
(a) Ngaio Gorge screenline



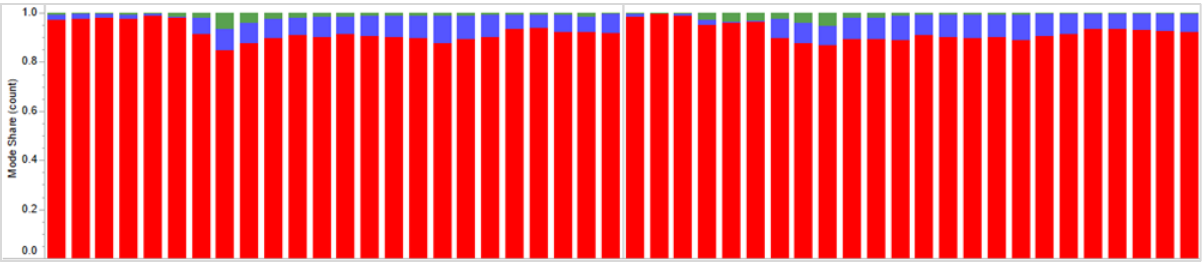
(b) Ngauranga Gorge screenline



(c) Petone–Ngauranga screenline



(c) All screenlines combined



Note: Green = active transport; blue = public transport; red = private transport. Each bar represents one hour, from midnight to midnight.

4.3.1.3 Hamilton City Council

Figure 4-9 shows how the dashboard displays HCC's available link coverage. On the dashboard, users can view the counts, PKT and mode share for individual links (see

Figure 4-10 for an example) or all links aggregated. This data shows that private vehicles are consistently the dominant mode used on these links; mode share does not significantly fluctuate between months.

This data does not demonstrate HCC's full mode-share reporting capabilities, as it is currently transitioning towards continuously monitoring mode share across the entire city-centre network (approximately 40 links).

Figure 4-9 Proof-of-concept dashboard: Map of links with data in Hamilton city centre

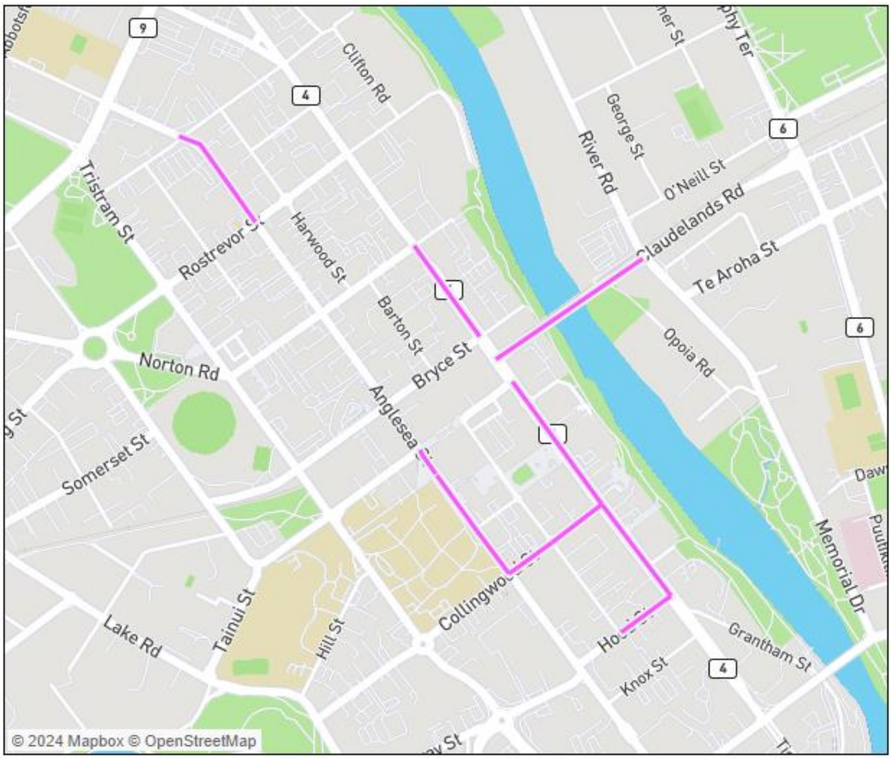
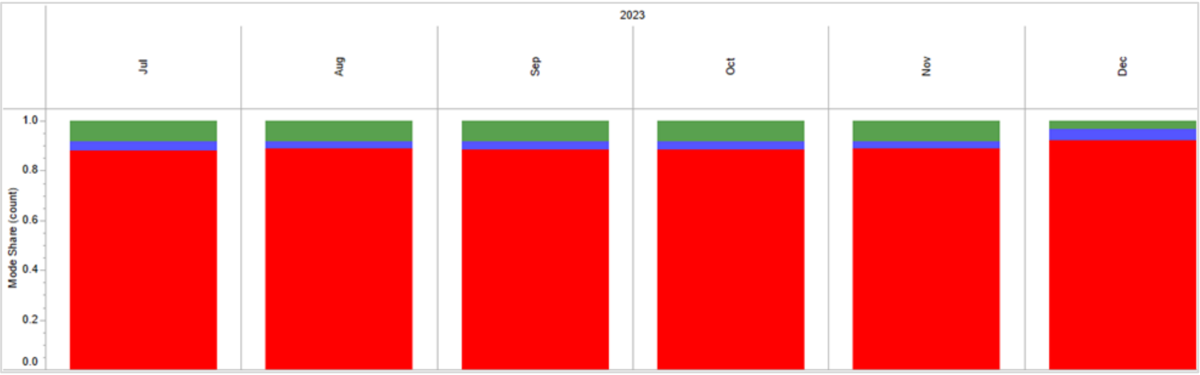
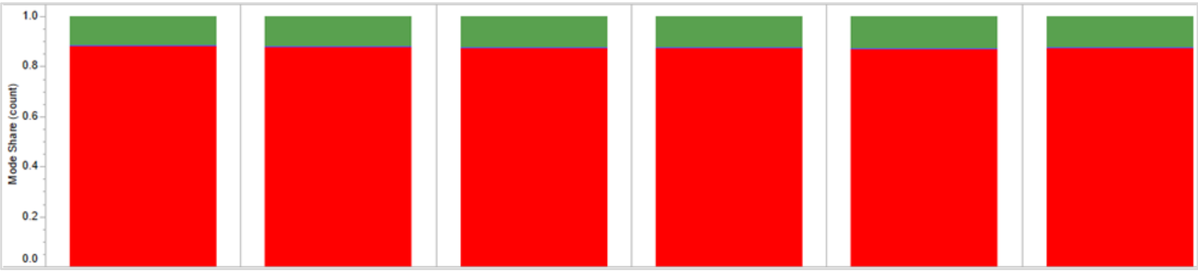


Figure 4-10 Proof-of-concept dashboard: Monthly mode share on two HCC links (July to December 2023)

(a) Victoria Street (segment 3 link)



(b) Victoria Street (segment 5 link)



Note: Green = active transport; blue = public transport; red = private transport.

Using the dashboard data for the HCC network (all links aggregated), we have compared mode share calculated using estimated PKT with mode share calculated by counts (see Table 4.4). Despite the data covering only a small area, there is a noticeable difference in mode share between the two approaches. This difference is likely to increase as the coverage area increases and highlights the care that should be taken when comparing results using counts and PKT.

Table 4.4 Comparison of mode share calculated by link-based counts and estimated PKT for the HCC network

Date	Active transport		Public transport		Private transport	
	PKT	Count	PKT	Count	PKT	Count
July 2023	10.65%	11.75%	1.07%	1.02%	88.28%	87.23%
September 2023	11.01%	11.92%	0.93%	0.88%	88.06%	87.20%
November 2023	10.73%	11.70%	0.87%	0.83%	88.40%	87.47%

Note: This table illustrates the difference between mode share calculated by the two methods, but with a small number of links (HCC provided us with data for nine links), these differences cannot be relied on.

4.3.1.4 Wellington City Council

WCC is currently setting up a comprehensive sensor network across the city. However, in our pilot study, we examined only a subset of links, to demonstrate the key features of the dashboard. The six links we examined are shown in Figure 4-11.

Figure 4-12 presents an example of hourly reporting of traffic counts and mode share for an individual link, for a typical (that is, average) weekday and weekend. From this data, we can easily see the weekday commuting peaks in the morning (7am to 9am) and afternoon to evening (4pm to 6pm). Once the morning peak starts, the share of public transport increases significantly and remains relatively consistent throughout the day.

At weekends, WCC's data shows that travel behaviour in the city centre follows a similar trend to areas north of Wellington city (GWRC data), although public transport has a greater mode share in the city centre. WCC's data shows that use of active transport on weekdays and weekends is less than private and public transport, but its use remains relatively consistent throughout the day, with a peak around midday.

WCC's data gives us a comprehensive view of hourly transport activity and enables us to observe typical weekday and weekend patterns at each link covered.

Figure 4-11 Proof-of-concept dashboard: Map of links with data in Wellington city

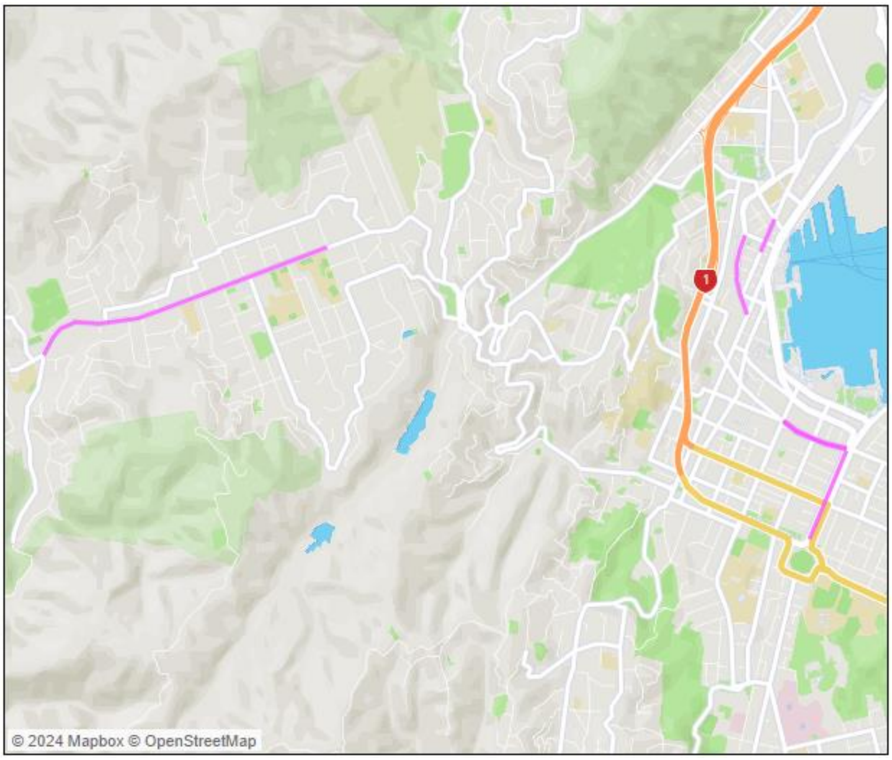
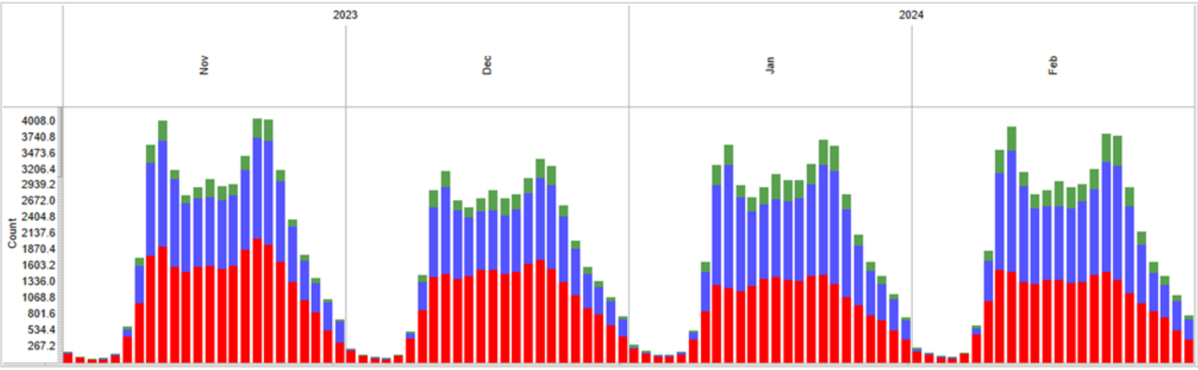
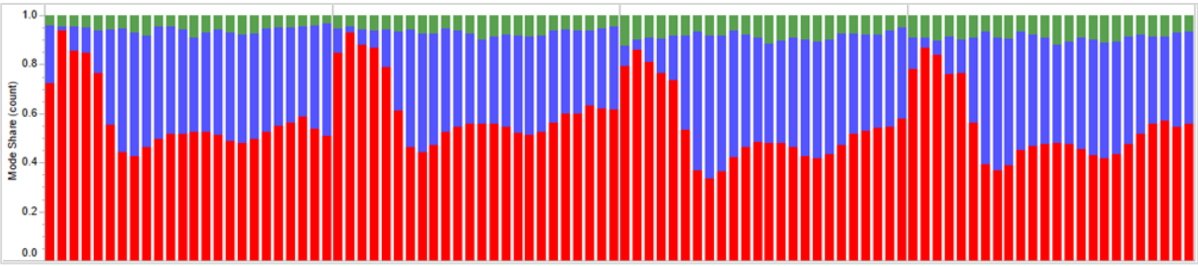


Figure 4-12 Proof-of-concept dashboard: Hourly traffic behaviour on Lambton Quay link (November 2023 to February 2024)

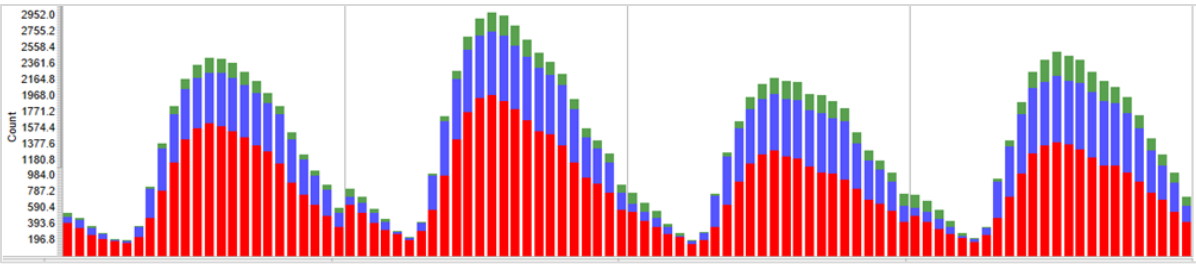
(a) Weekday traffic count



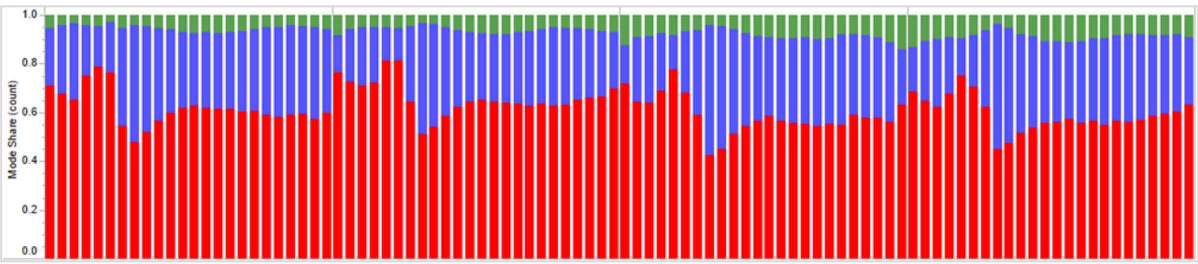
(b) Weekday mode share



(c) Weekend traffic count



(d) Weekend mode share



Note: Green = active transport; blue = public transport; red = private transport. Each bar represents one hour, from midnight to midnight.

4.4 Validation and benchmarking of results

We validated the mode-share data from the four authorities that participated in the pilot study in three ways:

1. Using technology to validate via quality control.
2. Using results from other similar mode-share studies.
3. Using regional or national benchmarks.

4.4.1 Using technology

In general, the authorities validate their data through their own quality-control processes. This gives them confidence that their data, technology and analysis approaches are available, reliable, accurate and comprehensive (that is, they have the required spatial and temporal coverage). It also allows them to identify and document any issues, so they can be improved in future.

4.4.2 Using results from similar studies

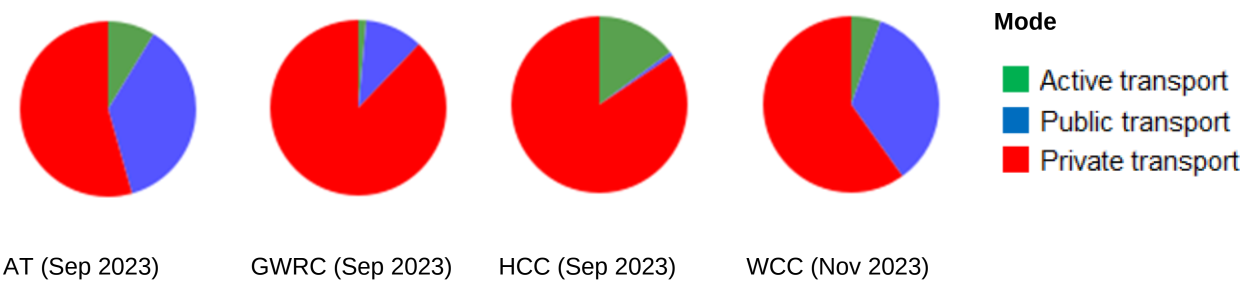
The second method involves comparing authorities' mode-share measurements with data from other studies with similar coverage and resolution – the 'ground truth'. Ground-truth data is usually representative samples collected by manual surveys or video recordings. Ground-truth data is not always available, due to limited budget, time or technology.

4.4.3 Using regional or national benchmarks

The third method involves comparing mode-share measurements from other regions, to understand similarities and differences. However, it is currently difficult to compare measurements between regions, because authorities' data collection, aggregation and analysis approaches vary significantly.

Figure 4-13 illustrates the aggregated mode share of each participating authority for a typical weekday (where possible) in September or November 2023. The data shows that Auckland and Wellington (the two large urban areas) have a similar split of active, public and private transport. In contrast, active-transport mode share in GWRC's coverage area (this comprises cyclists only) is much smaller than it is in other authorities' coverage areas. We would expect this, as GWRC's coverage area is major corridors into Wellington, which are less conducive to cycling. HCC data shows that only a very small proportion (~1%) of people use buses. However, the data we have covers only a small subset of links; other data shows the mode share for buses in 2021 was 4% (see Appendix B:, Section B.3.1.2).

Figure 4-13 Aggregated mode share for four authorities in New Zealand



Note: AT and GWRC data is from screenlines or cordons, while HCC and WCC data is from a link-based approach. Data from AT and GWRC is from counts, while data from HCC and WCC is from PKT. GWRC and WCC data is from a weekday, selected to align best with AT and HCC data.

It is valuable to cross-reference mode-share data from the four authorities against data from the latest HTS, to determine how consistent they are. The HTS and New Zealand Census have several limitations (see Section 2 and Appendix B:). Therefore, comparing high-resolution data collected from continuous monitoring technology with data from the HTS or Census should be done cautiously and the findings used solely for reference purposes.

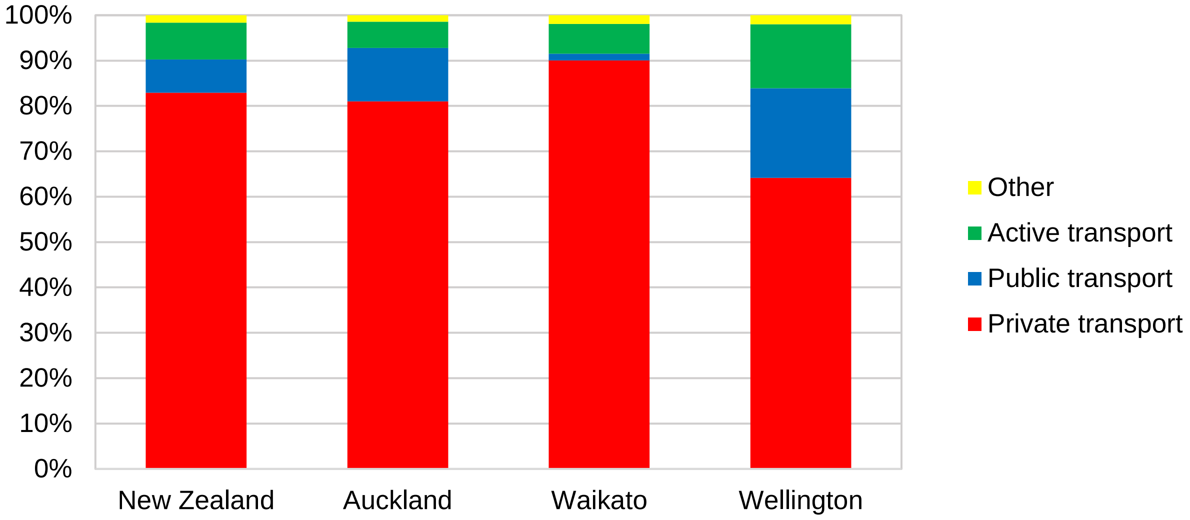
The most recent HTS took data collected during a two-day survey period and averaged it over two years (2021 to 2023). The best possible HTS match to PKT is the distance travelled by mode (the HTS uses the unit 'million km per year'). Figure 4-14 shows relevant national and regional mode share from HTS data, which we have re-categorised to align with the transport modes in our pilot study.

The Census provides people counts for the main means of travel for work and education (that is, the mode of transport they use most often). Figure 4-15 shows the main means of travel to work from the 2018 Census, which we have re-categorised to align with the transport modes in our pilot study.

Figure 4-14 Mode share by distance, measured by the HTS 2021–2023 (adapted from Ministry of Transport, 2024b)

Note: Mode share by distance equals PKT per year. Private transport includes car and van drivers and passengers. Public transport includes all relevant modes but is limited to trips of less than 100 km. Active transport includes cycling and walking. 'Other' includes motorcycles and other household travel.

Figure 4-15 Mode share by main means of travel to work, measured by the 2018 Census (adapted from Stats NZ, 2022)



Note: Mode share by main means of travel is calculated from people count and does not include distance travelled. Private transport includes all drivers and passengers of cars, vans, trucks and company buses. Public transport includes buses, trains and ferries. Active transport includes cycling, walking and jogging. 'Other' covers all other transport, including motorcycles and taxis.

In Table 4.5, we compare the authorities' mode-share measurements from the pilot study with the most recent available mode-share data from the HTS and Census. These are our main observations:

- The mode-share measurements from the pilot study (people counts and estimated PKT), HTS (PKT) and Census (people counts) are from different years (due to survey frequency), are calculated differently and use completely different sampling approaches. Therefore, it is not feasible to directly compare them.
- The HTS results correlate reasonably well with the pilot-study data, in that private vehicles have the highest mode share. However, the HTS attributes a much higher mode share to private vehicles in all pilot-study areas, except the area covered by GWRC.
- The measurements from the HTS and Census for the Waikato region are similar to HCC's sensor data; however, the data that HCC reports using its link-based approach reveals significantly larger mode shares for active and public transport.
- The measurements from the HTS and Census for active transport in Auckland are considerably different to AT's data from the pilot study. AT's screenline approach captures a much larger share of public and active transport, because it focuses on commuters travelling into the city centre during the morning.
- The pilot study shows large differences between travel behaviour in GWRC and WCC. The pilot-study data for WCC (a link-based approach) aligns reasonably well with the HTS and Census data for Wellington region. However, the pilot-study data for GWRC (a screenline approach) gives mode share by private vehicles a much larger proportion than the HTS and Census data for Wellington region. This is expected, given that GWRC screenlines capture travel activity on a strategic travel corridor into Wellington city.

Table 4.5 A comparison of mode-share data from the pilot study, HTS and Census (adapted from Ministry of Transport, 2024b; Stats NZ, 2022)

Authority and region [a]	Mode	Pilot study [b]	HTS 2021–23 [c] Data based on million km travelled per year	Census 2018 [d] Data based on main means of travel to work
AT Auckland	Private transport	54.3%	90.4%	82.9%
	Public transport	37.0%	6.6%	7.3%
	Active transport	8.7%	2.8%	8.2%
	Other	N/A	0.2%	1.6%
GWRC Wellington	Private transport	87.9%	78.8%	64.1%
	Public transport	10.6%	5.9%	19.8%
	Active transport	1.5%	14.3%	14.1%
	Other	N/A	1.0%	2.0%
HCC [e] Waikato	Private transport	78.0%	94.9%	90.0%
	Public transport	4.0%	1.6%	1.5%
	Active transport	18.0%	3.3%	6.6%
	Other	N/A	0.2%	1.9%
WCC Wellington	Private transport	59.9%	78.8%	64.1%
	Public transport	34.7%	5.9%	19.8%
	Active transport	5.4%	14.3%	14.1%
	Other	N/A	1.0%	2.0%

[a] We compare authorities' data (the pilot study) with regional data (HTS and Census).

[b] Mode-share data for the pilot study is either based on counts (AT and GWRC) or PKT (WCC), except for HCC.

[c] The HTS calculates mode share using PKT per year (million km per year).

[d] The Census calculates mode share from people counts (main means of travel) and does not include the distance travelled.

[e] HCC data comes from its mode-share results in 2021, which cover a larger part of the transport network than the data available for our pilot study.

4.5 Summary

We conducted this synthetic pilot study to demonstrate how mode-share and mode-shift data can be collected, analysed, visualised and reported using consistent data specifications and guidelines. We developed data specifications that would give us a common framework to report mode-share and mode-shift data, even when that data is measured using different approaches, and has different spatial scales and timescales. We processed the data to fit the data specifications and then presented it in a proof-of-concept dashboard. We used Tableau to develop the dashboard, as it has the flexibility to accommodate data from different authorities consistently. Finally, we used sample data from the four authorities' links or screenlines, to test the data specifications and dashboard functions.

These are the key findings from the pilot study:

- Highly detailed mode-share and mode-shift measurements are becoming increasingly available. Many authorities now have the data infrastructure and capabilities to monitor major transport modes, at all links or strategic locations, via continuous data flowing in from counting stations or smart detectors. The data received is usually high quality and continuously improved.
- Mode-share information and mode-shift trends can be displayed visually for different links, corridors and networks in New Zealand. Given that mode-share measurement technologies, and data-fusion and data-

aggregation approaches vary between authorities, it is currently less feasible to aggregate or compare measurements from different authorities.

- PKT has the potential to estimate mode share consistently for a network and be used to compare or benchmark mode share measurements with those from different regions. PKT is not, however, feasible for some approaches to measuring mode share (such as screenlines or small numbers of links). Therefore, we used PKT *and* counts in the pilot study to measure mode share.

We use the results and insights from this pilot study to inform the toolkit for measuring and reporting mode share and mode shift.

5 Creating a mode-share and mode-shift toolkit

We consolidated the lessons and insights we gained from reviewing current practice and data sources, analysing options and conducting a pilot study, to develop an integrated toolkit for mode share and mode shift.

The toolkit is designed to give users nationally consistent guidance on how to measure mode share and mode shift locally and regionally.

We designed the toolkit for government practitioners (such as those working for NZTA, local and regional councils, and transport authorities). It will also suit others with an interest in planning and managing transport infrastructure, and those who measure mode share and mode shift sub-nationally.

5.1 Scope of the toolkit

The toolkit contains:

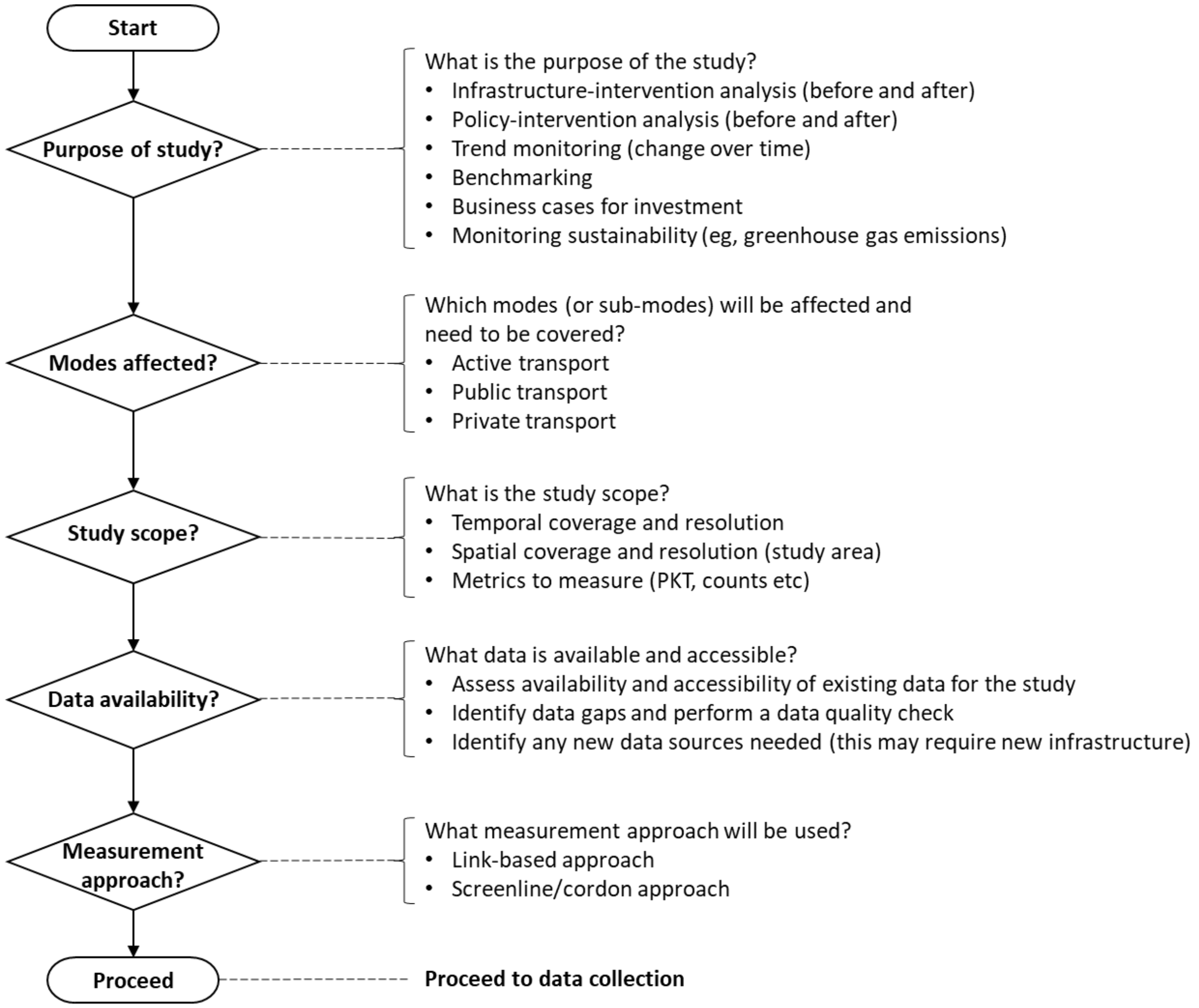
- a decision-making process to use when scoping a study related to mode share and mode shift, to determine the study's purpose and whether to use a screenline or link-based approach (see Section 5.2)
- guidance on how to specify the data to collect (see Section 5.3.1)
- guidance on how to collect data, what data-collection technologies to use and what to consider when placing sensors (see Section 5.3.2)
- guidance on how to process, analyse and validate data (see Section 5.3.3)
- guidance on how to report mode share and mode shift, including how to display data visually (see Section 5.3.4).

5.2 Decision-making process

Before starting to measure mode share or mode shift, a scoping study is needed. The purpose of a scoping study is to assess the most suitable and feasible approach to measure mode share and mode shift. To assist with this, we have developed a decision-making process (see Figure 5-1). The process consists of five questions that cover these areas:

1. The study's purpose.
2. The transport modes affected by the study.
3. The study's temporal and spatial scope.
4. The data that is available and the study can access.
5. The study's approach to measuring mode share.

Figure 5-1 Decision-making process to determine the most suitable approach to measure mode share and mode shift



Box 1 lists some intervention categories. Each intervention category leads to a different set of answers to the five questions in the decision-making process; practitioners can use the answers to determine how to measure mode share and mode shift.

Box 2 outlines the two main approaches that can be used to monitor mode shift and gives examples of how authorities in New Zealand are using them. The choice of approach depends on what data is currently available, or will be in future, and the purpose of the study. This toolkit is technology agnostic. It does not recommend preferred sensors or technologies for screenline or link-based approaches.

Box 1 Intervention categories and examples for different transport modes

Intervention categories

- Infrastructure, capacity or schedule/route changes
- Pricing and policy/regulations changes
- Long-term performance monitoring
- Benchmarking or comparative analysis
- Business cases for investment
- Monitoring sustainability (such as, changes in greenhouse gas emissions) and resilience

Active transport	Public transport	Private transport
Examples of infrastructure and capacity: • New footpath/bike lane • New bike/scooter rental service • Safety measures for vulnerable road users • Infrastructure or capacity changes that have an impact on active transport, and therefore on air quality or greenhouse gas emissions	Examples of infrastructure and capacity: • Additional bus/rail/ferry capacity • New/additional bus/rail/ferry route • New park-and-ride facilities • Infrastructure or capacity changes that have an impact on public transport, and therefore on air quality or greenhouse gas emissions	Examples of infrastructure and capacity: • New road link/section • Wider/narrower road • New/changed parking capacity • Road-safety improvements
Examples of pricing and policy/regulations: • Change to PMD regulations (such as use of e-scooters)	Examples of pricing and policy/regulations: • Fare-system/price changes • Incentives to encourage use of public transport	Examples of pricing and policy/regulations: • New road-user charges, congestion charges or toll roads • Changed parking fees

Box 2 Approaches to measuring mode share, and examples of how they are used

Current best practice to measure mode share is using a link-based or screenline approach. This toolkit is technology agnostic. It does not recommend a preferred approach or technologies to use.

Link-based approaches

Link-based approaches focus on mode share within an area or network. They monitor travel activity at as many individual links (or roads) as possible.

A linked-based approach can be scaled up to a larger urban or regional network, as the supporting infrastructure and estimation methods are developed.

Link-based approaches can measure counts or estimate PKT.

Example: Hamilton city centre

HCC is developing a link-based approach to continuously monitor mode share across the city centre. HCC's network currently comprises around 40 links and uses measurements and estimates to monitor mode share.

Example: Wellington city centre

WCC is upgrading its infrastructure to enable it to continuously monitor mode share across the city centre. It has committed to installing 80 AI-powered camera sensors, to cover the city's strategic network.

Screenline or cordon approaches

Screenline or cordon approaches aggregate data from several monitoring sites at key locations, to capture mode share along an artificial line.

Screenline or cordon approaches are limited to measuring counts.

Example: Auckland city-centre cordon

AT wants to capture the morning peak (7am to 9am) traffic entering Auckland city centre. To achieve this, it has set up sensors at 17 locations that cover the primary entry points. These locations form a cordon around the city centre.

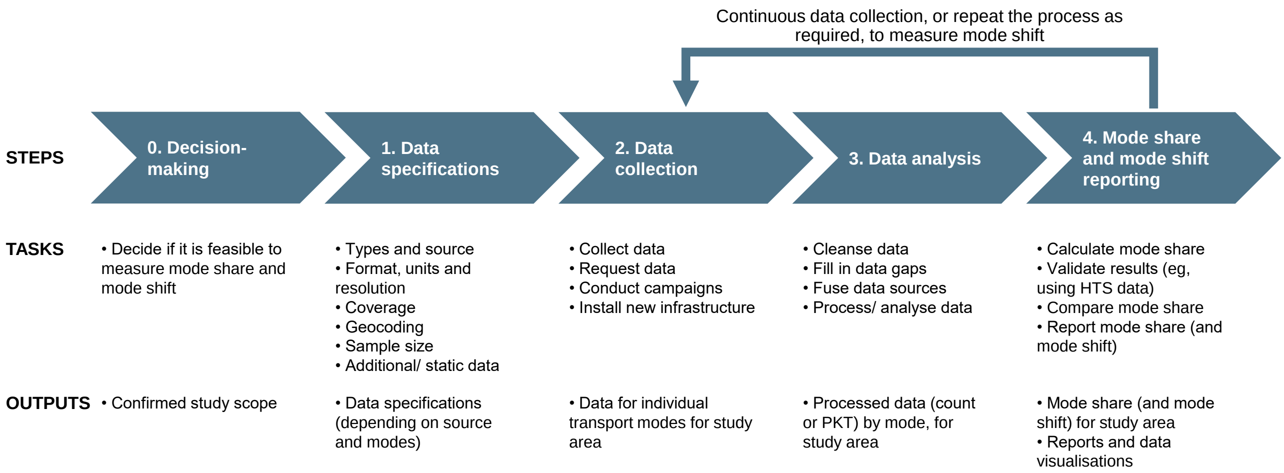
Example: Greater Wellington screenlines

GWRC monitors inbound and outbound travel from various regional centres into Wellington. It has set up several screenlines around Wellington city, which each comprise of multiple monitoring sites.

5.3 Guidelines on collecting, analysing and reporting data

After using the decision-making process to define the study's requirements and approach, the toolkit takes users through four steps to measure mode share and mode shift (see Figure 5-2). In this section, we describe each step, providing guidelines and examples, and explaining important considerations.

Figure 5-2 Four-step process to measuring mode share and mode shift



5.3.1 Step 1: Data specifications

A study that measures mode share must have clear data specifications. The specifications should state the data types, sources, formats, units and sample size, and what the temporal and spatial coverage and resolution are. To support the chosen approach to measure mode share, other data may be required (such as, GIS transport layers, with link-length data for estimating PKT, and POI data).

An important part of specifying data is ensuring that the sample size of collected data is statistically meaningful and has an acceptable level of uncertainty. Collecting data continuously typically gives sufficiently large samples to achieve this. For more guidance on this, see Austroads (2020).

The different approaches to measuring and reporting mode share have some different requirements. Practitioners must take care to ensure their data specifications are consistent and appropriate. Box 3 outlines what to consider. As an example, the data specifications we developed for the pilot study are outlined in **Error! Reference source not found.**.

Box 3 Data specifications: what to consider

Data types and sources

The type of the data that will be needed to measure mode share and mode shift, and the corresponding data sources, will be based on what approach is selected and what data-collection technologies are available. In general, count data can be acquired from various means (such as, camera footage, tube counters and smartcard data). Alternative data types may also be used (such as, GPS trajectory data, telco data and crowdsourced data).

Data formats and units

The specification for the file format will depend on what software is being used. CSV and XLSX files are accepted by most software. The data units (such as kilometres) will depend on the type of data being collected. Data units can easily be converted into other units (such as metres to kilometres). For clarity, the data unit must be specified in the dataset or associated metadata.

Temporal coverage and resolution

The study's purpose will determine what time periods should be covered (temporal coverage) and the detail to which the data will be aggregated (the resolution). For example, if the study intends to investigate peak periods, it should be sufficient to aggregate data hourly during peak times. However, if the study intends to investigate day-to-day changes, it should be sufficient to aggregate data daily. Aggregating data achieves a coarser granularity. For example, aggregating hourly data to produce a daily dataset. It is important to consider differentiating weekdays, weekends and public holidays, as they affect mode share differently.

Data sample size

It is important to ensure that sample sizes are sufficient for data to be statistically meaningful. To calculate the minimum sample size for a traffic survey or before-and-after study, refer to Austroads (2020), Section 3.3. The methods we use to collect continuous data in this project generally give sufficiently large samples to form statistically meaningful estimates.

The study's purpose will also determine the sample size. For before-and-after studies, the study period should start at least three months before the relevant infrastructure or policy intervention takes place, and end at least three months after the intervention is complete. To monitor long-term mode-shift trends, the study period should be at least 6 to12 months. When analysing shifts towards active and public transport, seasonal changes must be accounted for (for example, people tend to use these modes less in colder and wetter seasons).

Spatial coverage and resolution

The geographical area that a study should cover (spatial coverage) is limited only by the cost of collecting data in a larger area. With a link-based approach, the spatial coverage can be as little as a few links in an area (although such a small number of links will be less relevant to studying mode share and mode shift for a whole transport network). With a screenline approach, the spatial coverage will typically focus on meaningful areas or corridors (for example, inbound or outbound routes to a city centre or key transport corridors).

GIS transport-layer data

GIS transport-layer data is useful to visualise mode-share data on a map, using GIS software, as the geocoding is usually calibrated to particular GIS data. This data usually comes as a shapefile. A shapefile usually contains link-length information, which is needed to analyse PKT for links.

Geocoding

If GIS transport-layer data is unavailable, geocoding (that is, latitude and longitude or a shapefile) for each data point, or text descriptions (for example, Bowen Street), can be included in the data specifications. Geocoding enables data to be visualised on a map.

5.3.2 Step 2: Data collection

Collecting data may entail preparing data requests, designing and implementing questionnaires for roadside-trip surveys or installing new sensors to collect data. It is important to consider what current and emerging data sources and technologies are available, and their respective advantages. It may be helpful to compare the cost-effectiveness of feasible data-collection approaches, while also considering their long-term benefits. For example, to collect data at strategic locations, surveys may require little upfront investment. However, they give only a snapshot of mode share at the time(s) when they are carried out. In contrast, installing new, permanent data-collection infrastructure (such as, permanent roadside sensors) has a significant upfront cost, but could collect data continuously.

When collecting data involves installing new sensors, it is important to devise a location placement strategy, to ensure the area of interest is covered optimally. To capture relevant data effectively, the location placement strategy must consider factors like transportation infrastructure, population density and key travel corridors. If the study is interested in active-travel behaviour, it may be relevant to include links or routes that have low motorised-vehicle traffic. Box 4 provides examples of sensor placement across New Zealand.

Data must then be collected for the identified area(s) of interest. As it is not always possible to collect data at every location, it may be necessary to interpolate or estimate data, using a data-fusion method (this is required for link-based approaches).

Box 5 Example of how Hamilton City Council collects data

What types of data HCC uses

There are many possible data sources, and the choice depends on the transport mode being monitored. HCC uses the services and technology in Figure **5-6** to monitor different transport modes.

Figure 5-6 **Data sources used by HCC (adapted from Hamilton City Council**, **personal communication, 2023)**

Mode	Walking	Cycling	Scooter riding	Public transport	Freight	Car travel
Count	bellwether opito BriefCam	opito BriefCam BE COUNTED TECHNOLOGY	opito	Waikato Regional Council Te Kaunihera ā Rohe o Waikato	COLAB RATA opito	scats opito COLAB RATA addinsight
Pathing [a]	near	STRAVA	Lime	Waikato Regional Council Te Kaunihera ā Rohe o Waikato	EROAD	addinsight

[a] Pathing refers to data sources that have the capacity to follow a user's full travel path.

How HCC fuses crowdsourced data with other data

For every mode of transport it monitors, at some locations with counters HCC uses fixed sensors to count all traffic (this is known as 'all as some locations'). And at every location with counters, HCC uses crowdsourced data to count some traffic (this is known as 'some at all locations'). Using this approach, at the locations with counters, HCC can see the relationship between crowdsourced data and total traffic counts.

HCC uses two types of crowdsourced data:

- Strava, which counts trips by OpenStreetMap edge, for cyclists who record their trips on the Strava app.
- Lime, which collects GPS data from Lime scooters.

HCC uses AddInsight physical sensors. Installed at intersections, these sensors detect nearby Bluetooth devices. The sample rate of this data is relatively consistent, although increasing over time, but varies between intersections.

HCC also uses data from Waikato Regional Council Bee Cards, which record where and when people get on and off buses, what type of ticket they have and what route they take.

How HCC procured active-mode counters

The choice of which technology and services to use depends on the costs to procure them. These costs can include ongoing subscriptions, and service and maintenance fees. In 2020, HCC procured active-mode counters from two local companies. As the scale of collecting data on active modes increased, HCC found it was not cost-effective to expand the data-collection infrastructure provided by these companies. Instead, HCC contracted another company that uses CCTV analytics to record the volume of active-mode transport.

Box 5 gives examples of data sources that support data fusion.

Data must be collected for long enough to obtain the minimum specified sample size, with sufficient temporal and spatial coverage (see Box 3). When a study collects data from sensors, data collection would, ideally, be integrated into an ongoing campaign or routine practice, to maximise the return on investing in the sensors and to support long-term planning for transport and infrastructure. This will also ensure that the data collected remains relevant for future analysis and decisions.

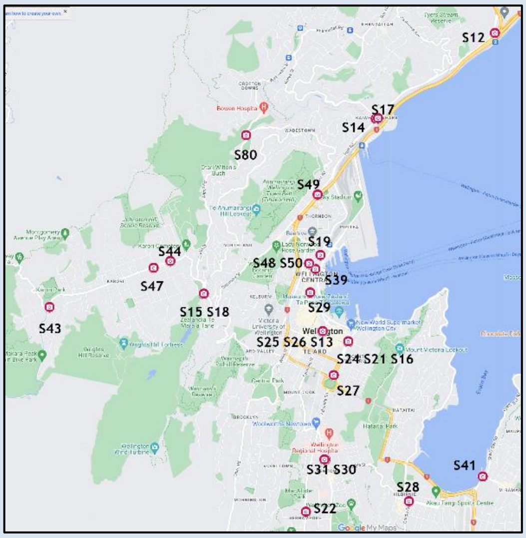
If data is collected for a limited period only (such as for a before-and-after study), it is important to consider when the data is collected. This is because mode share is influenced by seasonal variations (such as, weather and public holidays) and temporary changes (such as infrastructure closures due to construction or maintenance).

Box 4 Examples of where to place sensors for link-based and screenline approaches

Link-based approaches

There is some flexibility with where to place sensors for link-based approaches. Sensors are often placed on major road links. On minor road links (that is, links classified by low traffic volumes), the count can be estimated from sensor measurements on the nearby major road links. However, it is important to consider that the volume of active transport may be high on minor road links. Figure 5-3 shows the locations of sensors in Wellington city and the surrounding area.

Figure 5-3 Sensor locations in Wellington (reprinted from Wellington City Council, personal communication, 2024)

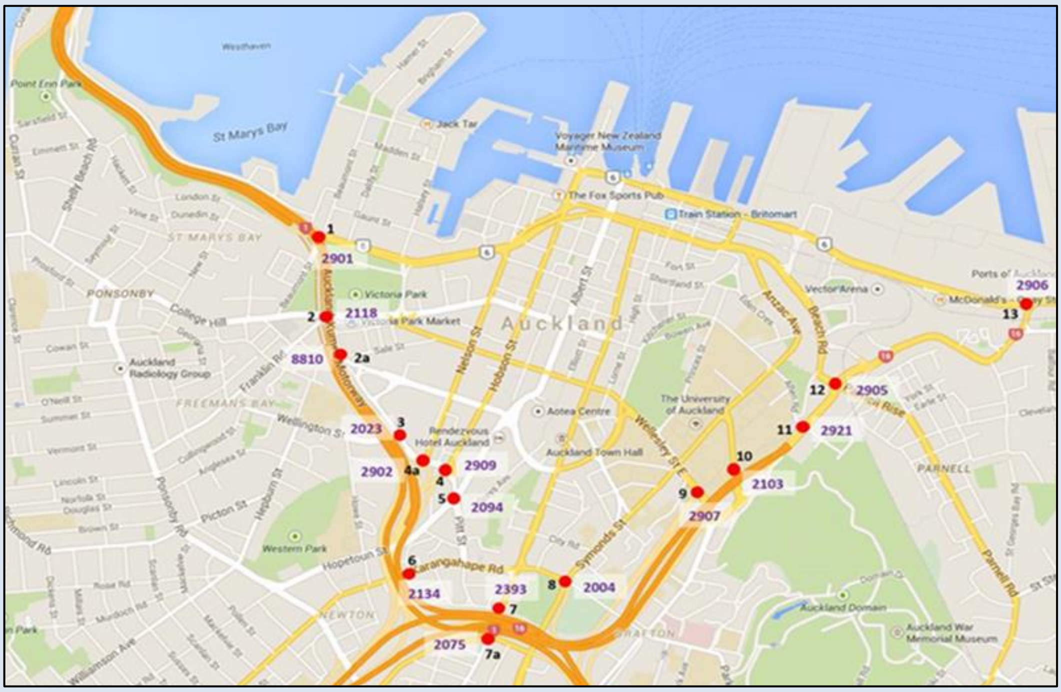


Screenline approaches

Screenline approaches involve collecting data at strategic locations across the study area, to capture the main flow of traffic that is of interest to the study. With these approaches, key locations to consider placing sensors are major corridors into urban areas and strategic corridors that handle significant traffic volumes. For example, AT has set up a cordon around Auckland city centre, with monitoring locations at 17 sites that capture all inbound traffic (see Figure 5-4).

Box 4 Examples of where to place sensors for link-based and screenline approaches

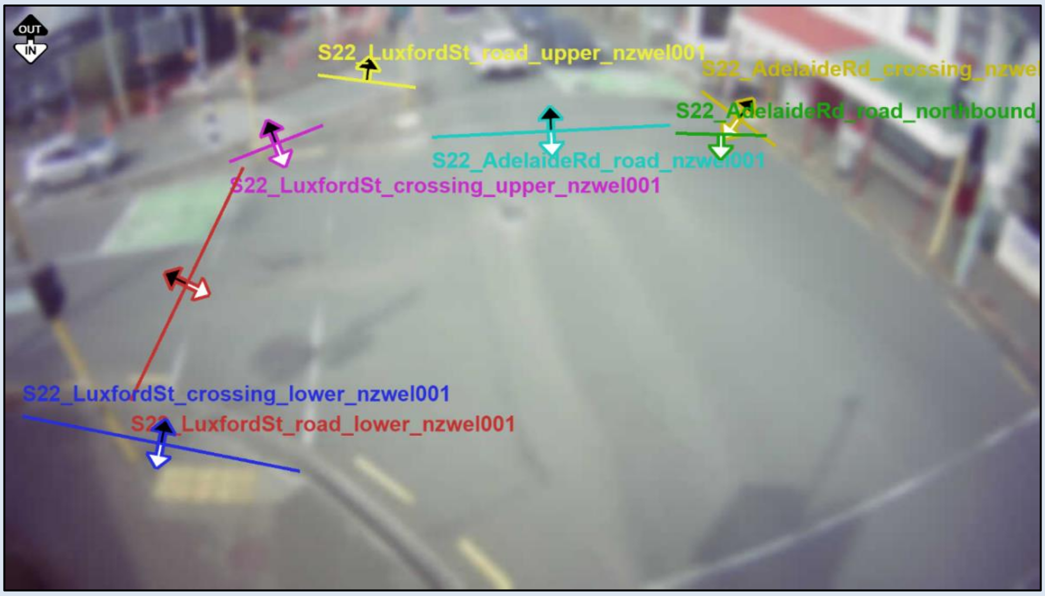
Figure 5-4 Sensor locations in Auckland (reprinted from Auckland Transport, personal communication, 2023)



Note: The map shows sensors at 16 locations, but AT confirms it collects data from sensors at 17 locations. The sites shown on the map indicate the sensors' approximate locations.

It is important to place sensors strategically, so they count traffic at multiple roads and links. This will minimise costs. For example, Figure 5-5 shows how WCC has placed a camera at an intersection that can count traffic volumes across multiple links.

Figure 5-5 A single sensor in Wellington counts traffic across multiple links (reprinted from Wellington City Council, personal communication, 2024)



Box 5 Example of how Hamilton City Council collects data

What types of data HCC uses

There are many possible data sources, and the choice depends on the transport mode being monitored. HCC uses the services and technology in Figure **5-6** to monitor different transport modes.

Figure 5-6 **Data sources used by HCC (adapted from Hamilton City Council**, **personal communication, 2023)**

Mode	Walking	Cycling	Scooter riding	Public transport	Freight	Car travel
Count	bellwether opito BriefCam	opito BriefCam Be Counted Technology	opito	Waikato Regional Council Te Kaunihera ā Rohe o Waikato	CoLab RATA opito	scats opito CoLab RATA addinsight
Pathing [a]	near	STRAVA	lime	Waikato Regional Council Te Kaunihera ā Rohe o Waikato	EROAD	addinsight

[a] Pathing refers to data sources that have the capacity to follow a user's full travel path.

How HCC fuses crowdsourced data with other data

For every mode of transport it monitors, at some locations with counters HCC uses fixed sensors to count all traffic (this is known as 'all as some locations'). And at every location with counters, HCC uses crowdsourced data to count some traffic (this is known as 'some at all locations'). Using this approach, at the locations with counters, HCC can see the relationship between crowdsourced data and total traffic counts.

HCC uses two types of crowdsourced data:

- Strava, which counts trips by OpenStreetMap edge, for cyclists who record their trips on the Strava app.
- Lime, which collects GPS data from Lime scooters.

HCC uses AddInsight physical sensors. Installed at intersections, these sensors detect nearby Bluetooth devices. The sample rate of this data is relatively consistent, although increasing over time, but varies between intersections.

HCC also uses data from Waikato Regional Council Bee Cards, which record where and when people get on and off buses, what type of ticket they have and what route they take.

How HCC procured active-mode counters

The choice of which technology and services to use depends on the costs to procure them. These costs can include ongoing subscriptions, and service and maintenance fees. In 2020, HCC procured active-mode counters from two local companies. As the scale of collecting data on active modes increased, HCC found it was not cost-effective to expand the data-collection infrastructure provided by these companies. Instead, HCC contracted another company that uses CCTV analytics to record the volume of active-mode transport.

5.3.3 Step 3: Data analysis

Data analysis generally involves a combination of these tasks:

- Cleansing data and filling gaps.

- Fusing data, including map-matching.
- Aggregating and analysing data.
- Validating data.

5.3.3.1 Cleansing data and filling gaps

Cleansing data and filling gaps is the first data-analysis task. It addresses the quality, consistency and completeness of data that is being collected. A general data-quality check should reveal any gaps, abnormal values or inconsistencies. Data gaps occur for many reasons. These include sensor outages, problems with where sensors are placed (for example, covered by grass), insufficient samples (for example, from crowdsourced data) and erroneous data (for example, instances of accidental ‘touch-on’ events on public transport, or people forgetting to ‘touch off’).

A suitable method should be identified to fill the gaps. The frequency of implementing this method will depend on how often data is reported. For example, when HCC prepares quarterly mode-share reports, it fills data gaps by taking the median value of days with complete data and excluding the days with data gaps. As HCC progresses to measuring mode share hourly, to fill data gaps it is putting effort into applying an algorithm that detects anomalies and imputes data.

5.3.3.2 Fusing data, including map-matching

The second data-analysis task is processing data. This involves extracting common insights from multiple datasets, and estimating where data coverage is limited (such as, for minor roads).

Many authorities have data that comes from various sources and vendors. These datasets are unlikely to align with each other (that is, they will have spatial discrepancies). It is important to process this data, so that it is consistent. Processing data, therefore, usually involves developing a data-fusion model, to incorporate all available data on different transport modes into a consistent view. The type of model will depend on which data sources and types are involved, and their different resolutions and coverage.

For example, when HCC developed aggregated datasets, it had to clean and join datasets to form a single base spatial layer. The elements in this spatial layer include lines, edges and points (points include counts, and GPS or POI data). As traffic data from multiple modes is not consistently geocoded, HCC developed a method to map and integrate them into a single model with consistent map layers.

Authorities should consider, and consult their stakeholders about, these factors when they are planning how to fuse data.

Converting vehicle counts to people counts

Vehicle counts need to be converted to people counts. This is usually done using vehicle-occupancy data or profiles obtained from manual counts, surveys or national data (HTS or Census). Vehicle occupancy can vary significantly, depending on the trip purpose and location, so care is needed when converting VKT to PKT.

Covering all transport modes and links

To expand its coverage data to minor roads, HCC has developed a model to estimate the number of cyclists on every road. The model involves scaling the Strava count based on its relationship with the total count. To mitigate bias in Strava data, HCC adds attributes such as dedicated sporting facilities. During the model training process, counters are randomly left out of the dataset. The model’s predictions are tested against these counters to validate their accuracy.

HCC's models for estimating cyclists, freight, pedestrians, private vehicles and scooters all use some form of correlation modelling against sample data. The only transport mode in Hamilton that is truly 'counted' across the city is public transport. HCC uses tap on/off data (Bee Card) to route the most likely journeys from OD pairs.

Differentiating private vehicles

Freight and heavy vehicles are currently part of the private transport mode. This may affect mode-share results, depending on which road, corridor or screenline is being examined. However, it is not a critical factor in before-and-after studies, if the proportion of heavy vehicles stays the same. To better align with national data categories, measuring or estimating heavy-vehicle counts should be considered.

5.3.3.3 Aggregating and analysing data

The next step is to aggregate and analyse the data to calculate the mode share. Table 5.1 shows the available mode-share outputs and geographical coverage of the two approaches to calculating mode share. After the baseline mode share is established for a road, it is possible to evaluate mode shift, over time, while a particular project or programme is being implemented.

Table 5.1 Mode-share outputs and geographical coverage for screenline and link-based approaches

Approach	Mode-share output	Geographical coverage
Screenline	People counts	People crossing a screenline or cordon only (both directions of travel)
Link-based	PKT or people counts	People travelling through a corridor or small network area, up to people travelling through a large urban area or regional network (both directions of travel)

The data can be aggregated to achieve the resolution defined in the data specifications. When aggregating data, it is important to consider spatial domains (such as, multiple zones and the travel direction) and temporal domains (such as, hourly, daily, quarterly, monthly and peak/off-peak). The period that mode share is measured for can affect the aggregated results, as seasonal variations and other factors (such as temporary road closures) can influence mode share. For more details of aggregation methods that follow the general practice of traffic studies and experimental design methods, see Austroads (2020).

5.3.3.4 Validating data

Data can be validated in three ways:

1. Using technology.
2. Using results from similar studies.
3. Using regional or national benchmarks.

Using technology

Authorities use technology to validate their mode-share data through their own quality-control process. This gives them confidence that their data, technology and analysis approaches are available, reliable, accurate and comprehensive (that is they have the required spatial and temporal coverage). Authorities should identify and document any issues, so they can be improved in future.

Using results from similar studies

This method involves comparing authorities' mode-share measurements with data from other studies whose data has similar coverage and resolution – the 'ground truth'. Ground-truth data is usually representative samples collected by manual surveys or video recordings. Ground-truth data is not always available, due to limited budget, time or technology.

Using regional or national benchmarks

This method involves comparing mode-share measurements from other regions, to understand similarities and differences. Measurements can also be compared against national benchmarks, by using the HTS or Census. However, care is needed when comparing data from the HTS with high-resolution data obtained from technology-based continuous monitoring.

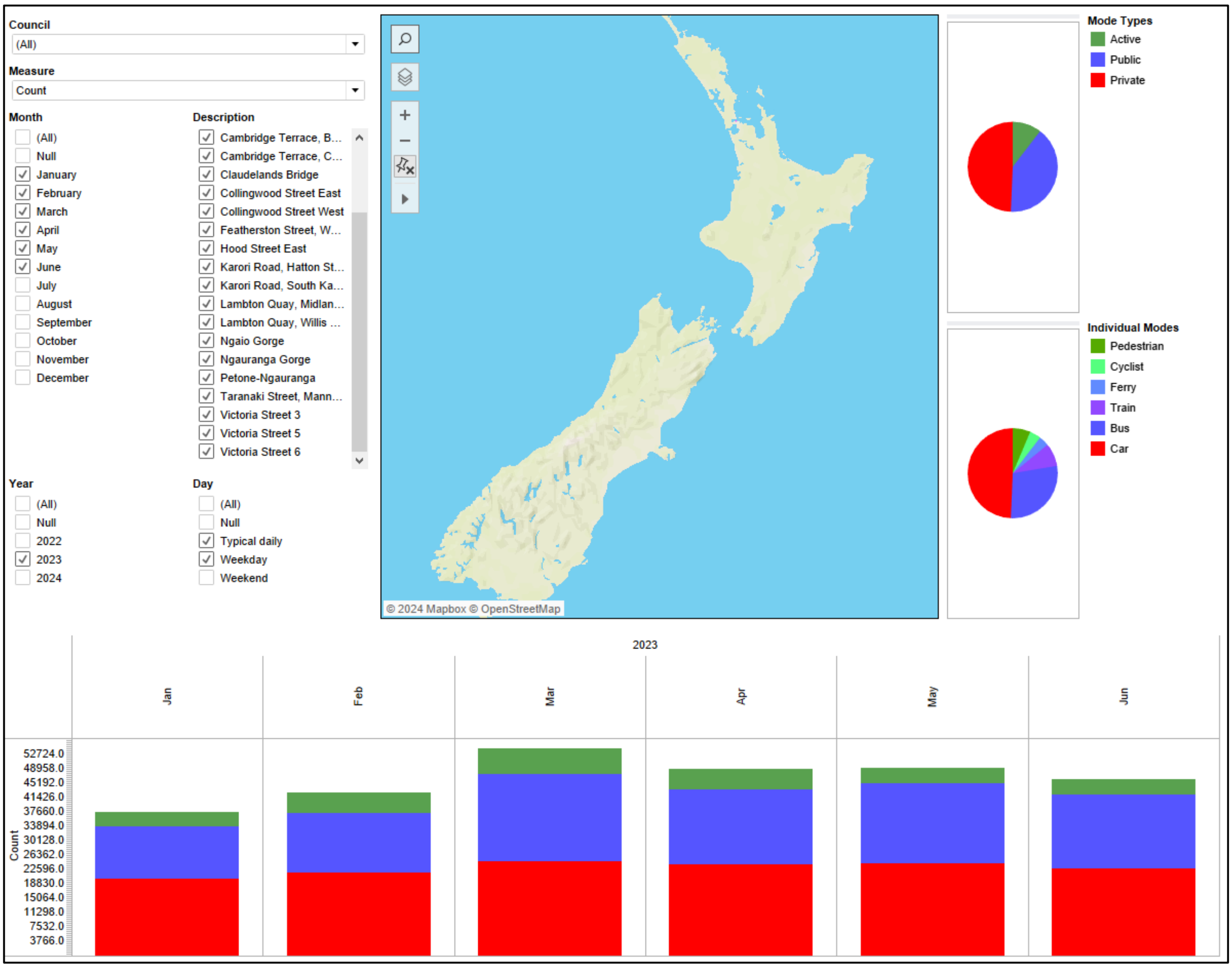
5.3.4 Step 4: Mode-share and mode-shift reporting

Mode-share and mode-shift outputs can be reported on and displayed visually in tables, charts or dashboards. It is important to use consistent methods of reporting and data visualisation. Section 4.3.1 gives examples of how different approaches to measuring mode share and mode shift are reported on, for various temporal and spatial scales.

Data visualisation generally includes two components (see Figure 5-7):

1. A map that shows the geographical location and scope of the data.
2. A pie or bar chart that shows the mode share – as counts, PKT or percentages – for various points in time.

Figure 5-7 Example of how aggregated data can be reported visually



It may be possible to break down the data further. If this is done, it should align with the study's purpose, or, where possible or feasible, with the HTS.

Any platform that authorities use to create national reports should make it simple to analyse shifts in travel patterns from data gathered at project sites. It should enable data to be joined to a single base layer, reducing the need to traverse datasets across several sources. It should also make it easy to extract data for a given area. Authorities can provide consultants or the public access to the platform, so they can download data themselves or analyse patterns in mode volumes over a given time or area. People can use the mode-share data for the types of studies listed in Box 1, or for wider applications (such as, monitoring economic productivity and well-being, or the performance, sustainability and resilience of transport networks).

5.4 Guidelines for interpreting study results

Practitioners should exercise care when interpreting the results of mode-share and mode-shift studies. They should always refer to the study's context and potential constraints. Here are some examples of what to consider:

- **The effects of certain interventions or infrastructure investments may not be visible for all transport modes.** It is important to consider the scale of the intervention, and the minimum change in mode share and mode shift that can be detected. For example, extra bus stops might affect commuting time and the uptake of public transport, but they may have a limited impact on mode share for the area.

- **PKT is the preferred way to measure mode shift, but is not always feasible**, due to limited data or the measurement approach. For example, if a screenline or cordon approach is used, mode share is often measured by passenger counts, as it is difficult to estimate travel distances.
- **The toolkit's approaches to measuring mode share and mode shift overcome issues of uncertainty and confidence intervals that household travel surveys experience**. The toolkit's approaches involve large volumes of data, whereas conventional household travel surveys often have poor sample sizes and no detailed coverage.
- **When using PKT to report mode share and mode shift, care is needed to understand the underlying causes**. Mode shift can result in total PKT changes, such as when people replace a long car trip with a short walk or cycle.
- **Measuring mode share may detect changes resulting from factors that authorities or NZTA cannot influence**. This could include new mobility options (such as, electric PMDs) becoming available, or improved predictive routing and navigation services due to more advanced AI tools. In these cases, authorities need to make proper assumptions and ensure they understand the underlying cause of mode shift, to justify the outcomes of their mode-share assessment.
- **People take time to change their behaviour**. The timeframe for collecting data on mode share and mode shift should be carefully defined at the beginning of a study. However, to validate a study's short-term results, it is prudent to monitor mode share and shift over a longer period.

5.5 Considerations for scaling up the toolkit

The toolkit outlines an approach to measure and report on mode share and mode shift consistently, and guidance on how to use it. In this section, we briefly outline the conceptual requirements for a robust, scalable system that could complement the toolkit.

Delivering a robust, scalable system has three broad requirements.

5.5.1 Data from multiple authorities

The first requirement is for authorities to provide their mode-share data to the system. The system operator would need two separate agreements with each authority. The first is an ongoing agreement to supply data; the second is an agreement that specifies the method and frequency for delivering data (such as, using an API). The agreements should specify what data cleansing, gap filling and validation is necessary to achieve consistent data.

5.5.2 Data management

The second requirement is for the authorities' mode-share data to be managed. Their data would need to be open and accessible via a central location. It could use existing infrastructure, such as the NZTA Open Data Hub.[18]

The spatial properties of the data would also need to be carefully maintained, to ensure they accurately represent the area covered (that is, the links or screenlines). To achieve this, the data should follow consistent data specifications (such as those in **Error! Reference source not found.**, which we developed for the pilot study) and align with a single spatial base layer of New Zealand's transport network and authority or regional zones.

[18] To find out more about the NZTA Open Data Hub, visit https://opendata-nzta.opendata.arcgis.com

5.5.3 Data reporting and end use

The final requirement is for the data to be available in a form that can be used. This will require a public GIS-based tool, like the proof-of-concept dashboard in Section 4.3. This tool would display all New Zealand's available mode-share data. It should have the ability to perform some data analysis, and be able to generate data reports, or other outputs, that users can view or export to use in other applications.

6 Conclusions

In this project we identified and developed suitable methods for measuring mode share (using PKT) and mode shift, locally and regionally for short timescales, with a focus on measuring active-transport modes.

Household travel surveys are the main way to measure travel behaviour. To develop more continuous sampling, authorities are surveying more frequently and using supportive technologies (such as, GPS trace recording). Despite these improvements, the ability of household travel surveys to measure short-term changes in mode share is still limited by their poor coverage of a region or area, relatively small sample sizes and infrequent reporting.

Several New Zealand authorities have developed other ways to measure mode share that are more responsive than conventional household travel surveys. Three Tier 1 authorities (AT, HCC and WCC) are at varying stages of implementing a screenline or link-based approach, using a mix of existing and new technologies to measure travel activities. They are making good progress towards being able to responsively measure mode share, but their approaches to collecting, analysing and reporting data are inconsistent with each other.

We developed a proof-of-concept dashboard to demonstrate that a harmonised platform can be used to combine mode-share and mode-shift data from various authorities and be used for reports and data visualisation. The dashboard needs to report data consistently, while being flexible enough to accommodate the authorities' different needs and different approaches to collecting data. We used the authorities' screenline and link-based data to test our project's data specifications and the dashboard's functions. We also developed a toolkit to give authorities guidance on how to consistently measure mode share and mode shift.

We observe that high-resolution (temporal and spatial) data is increasingly available to measure mode share and mode shift. Advanced data infrastructure and capabilities to continuously monitor major transport modes at links or strategic locations, with data inflow from counting stations or smart detectors, are also becoming widely available. These sources of continuous data overcome the uncertainty associated with data from household travel surveys, due to their relatively small sample sizes and lack of detailed coverage of a region or area. Our review shows it is necessary to fuse data from conventional and emerging data sources to comprehensively measure mode share and mode shift.

PKT offers authorities the opportunity to estimate mode share for a whole transport network and compare, or benchmark, their results against those from other regions. However, despite recent developments to methodologies and measurement technologies, it is still difficult to measure PKT for active transport. Our assessment of viable approaches to measure mode share reveals that link-based approaches (such as HCC's approach) are the most promising way to estimate PKT across a city or region.

Capitalising on the progress that several authorities have made, we identified the need to develop a toolkit and guidelines for collecting, analysing and reporting mode share and mode shift consistently, using screenline and link-based approaches.

In future, the toolkit could be scaled up to contain all mode-share data in New Zealand. It could be linked to, or integrated with, the NZTA Open Data Hub, to provide open and accessible data. Having consistent, and increasingly high-resolution, mode-share data could support investment plans and decisions; or be used to continuously monitor economic productivity and well-being, emissions of air pollutants and greenhouse gases (for example, building on the VEMT) or the sustainability and resilience of transport networks.

Finally, we recommend that consideration be given to refining transport modes, particularly private vehicles. Currently, passenger and freight transport are both considered as private vehicles, but they need to be consistently separated. Although freight makes a significant contribution to transport movements, measuring the effect of transport interventions on mode share and mode shift does not always focus on freight transport as well as passenger transport. In addition, as newer modes of transport (such as PMDs) are increasingly used, authorities should consider how best to categorise and measure them.

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Appendix A: Consultations with stakeholders

This appendix summarises our consultations with stakeholders for the review of current practice and data sources (see Table A.1) and pilot study (see Table A.2).

Table A.1 Summary of consultations with stakeholders for the review of current practice and data sources

Organisation	Expertise of primary contact	Format	Date	Duration
NZTA	Performance and analytics	Online interview, email consultation as required	14 November 2023	1 hour
NZTA	Urban mobility, including active transport	Online interviews, email consultation as required	14 November 2023 26 November 2023	1 hour
NZTA	New Zealand Household Travel Survey	Online interview, email consultation as required	14 November 2023	1 hour
Zhejiang University	Transport systems and environment	Online presentation, email consultation as required	14 November 2023	1 hour
VivaCity	Multimodal measurement	Online interview, email consultation as required	15 November 2023	0.5 hour
National Transport Research Organisation	Various	Hybrid workshop, follow-up consultations as required	17 November 2023	1 hour
Department of Transport and Planning (Victoria)	Victorian Integrated Survey of Travel and Activity	Online interview, email consultation as required	21 November 2023	1 hour
Hamilton City Council	City-wide multimodal transport project with data fusion	Online interview, email consultation as required	28 November 2023	1 hour
Greater Wellington Regional Council	Multimodal screenline projects	Online interview, email consultation as required	28 November 2023	1 hour
Department of Transport and Main Roads (Queensland Government)	Queensland household travel survey	Online interview, email consultation as required	28 November 2023	1 hour
Auckland Transport	Screenline (cordon) multimodal transport project	Online interview, email consultation as required	30 November 2023	1 hour

Organisation	Expertise of primary contact	Format	Date	Duration
Transport for New South Wales	New South Wales household travel survey	Online interview, email consultation as required	30 November 2023	1 hour
Queensland University of Technology	Urban transport systems	Online interview, email consultation as required	30 November 2023	1 hour
Main Roads Western Australia	Transport modelling and Perth household travel survey	Online interview, email consultation as required	6 December 2023	1 hour
Wellington City Council	New multimodal traffic-monitoring infrastructure	Online interview, email consultation as required	11 December 2023 13 December 2023	1 hour

Table A.2 Summary of consultations with stakeholders for the pilot study (anonymised)

Authority	Role of primary contact	Format	Dates	Duration
Greater Wellington Regional Council	Transport data analyst	Online meetings, email follow-up as required	19 February 2024 29 February 2024	1 hour each
Hamilton City Council	Transport data analyst	Online meetings, email follow-up as required	20 February 2024 29 February 2024	1 hour each
Wellington City Council	Transport data analyst	Online meetings, email follow-up as required	21 February 2024 29 February 2024	1 hour each
Auckland Transport	Transport engineer	Online meetings, email follow-up as required	22 February 2024 1 March 2024	1 hour each

Appendix B: Review of current practices and data sources

This appendix provides the details of our review of current practices to measure mode share and mode shift, and the technologies used to collect data. These details are summarised in Section 2.

B.1 Household travel surveys

B.1.1 New Zealand Household Travel Survey

The New Zealand Household Travel Survey (HTS) is currently conducted by Reach Aotearoa for the Ministry of Transport. Table B.1 summarises what the HTS covers.

Table B.1 Summary of what the HTS covers

Survey item	Description of item
Transport modes	All travel modes: bicycle, car driver, car passenger, motorcycle, other (this includes long-distance transport), public transport (bus, train and ferry) and walk
Travel purposes	Accompany (this includes drop-off and pick-up), education, employer's business, recreation, shopping or personal business, social visits and work
Locations covered	New Zealand, including North Island, South Island and Waiheke Island
Sampling	Approximately 1,700 households per year plus a 4,000-household booster by NZTA. The survey was paused between March and June 2020, due to COVID-19
Survey frequency	Annually

B.1.1.1 Data-collection method

The survey takes place every year between July and June. It involves a face-to-face survey and paper-based travel diary, which participants use to record their travel over two days (between 2015 and 2018 the survey covered travel over seven days).

Participants are offered an optional GPS logger that records their location every 20 seconds. This data is processed using a stop-detection algorithm that identifies their trips. The GPS traces are used to prepopulate the travel diary, which is shown to participants to help them recall their travel behaviour.

The HTS surveys people in 14 regions. Individual LGAs can fund an expanded sample size in their regions (Ministry of Transport, 2020a).

B.1.1.2 Data reporting and data use

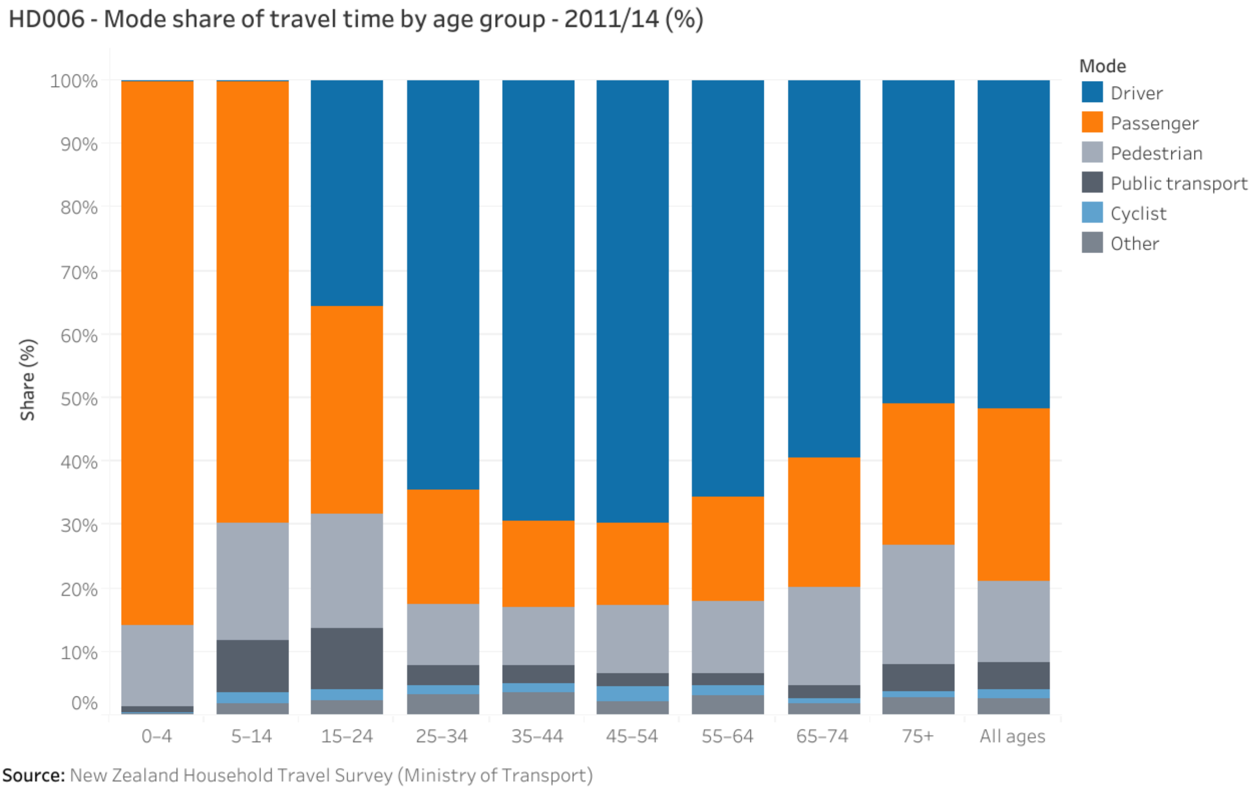
The Ministry of Transport presents key facts from HTS data on its website, using Tableau-powered visualisations (Ministry of Transport, 2024a). It usually publishes survey results about four months after the data collection is complete. As the HTS has a relatively small sample size, national reports are based on average data over three years.

HTS data is categorised by transport modes (see Table B.1) and demographic characteristics (age and gender). The data includes:

- summary statistics for the time and distance of trip legs (a trip leg is an individual journey with no stops or changes to travel mode)
- travel purpose
- use of public transport by geographical area
- cycling frequency over the past year
- health information and difficulty using transport.

Figure B.1 is an example of the type of mode-share output reported by the Ministry of Transport. Public-transport modes are aggregated. The data shows that cycling makes up around 2% of travel time. This highlights that the HTS samples relatively few households that use active transport, and that trips by active transport are typically shorter (distance and time) compared with trips by public and private transport.

Figure B.1 Breakdown of mode share by age group in New Zealand (2011/14) (reprinted from Ministry of Transport, 2024a, 'Household travel, te karore ā-whānau, how')



B.1.1.3 Survey limitations

Since the COVID-19 pandemic, NZTA has been unable to achieve the target 4,000 households for a booster survey, as face-to-face surveys were not possible between March and June 2020. It collected an extra 800 samples in 2020–21 and 2,500 in 2021–22. NZTA was on track to collect the full 4,000 household samples to complete the booster in 2022–23.

Despite the booster survey, the HTS sample size remains small. This makes it difficult to analyse data in fine detail, which delays detecting changes in travel activity over time. It also makes it difficult to get a sufficient sample of trips by active transport, as they represent a small proportion of the total trips (this is one reason why NZTA funds the booster survey).

Uptake of the optional GPS loggers is low, particularly since the COVID-19 pandemic. And, as with other surveys, participants that do accept a GPS logger sometimes forget to carry the device with them to record their trips during the sampling period.

B.1.1.4 New Zealand Census of Population and Dwellings

Every five years the New Zealand Government undertakes the national Census, which aims to capture information from everyone in the country on one night (Stats NZ, 2022). For transport, the 2018 Census captured information on the primary mode of travel to work and education. It did not capture information about travel unrelated to work or education. The Census covers these transport modes: private vehicle (driver or passenger), public transport (school bus, public bus, train or ferry), active transport (bicycle or walk/jog) and other. The Census data gives an overview of mode share for a large sample, but is less frequent than the HTS.

B.1.2 Victorian Integrated Survey of Travel and Activity

The VISTA is a household travel survey that covers Melbourne and the state of Victoria, Australia. VISTA is the primary dataset that Victoria's DTP uses to measure mode share and calculate mode shift. It is vital for calibrating DTP's transport modelling, which it uses to support its infrastructure-investment decisions.

VISTA is currently conducted by Ipsos for DTP. Table B.2 summarises what VISTA covers.

Table B.2 Summary of what VISTA covers

Survey item	Description of item
Transport modes	All travel modes: bicycle, bus, other, train, tram, vehicle driver, vehicle passenger and walk
Travel purposes	Accompany or drop-off/pick-up, education, other, personal business, shopping, social or recreational, and work
Locations covered	Greater Melbourne metropolitan area and Geelong regional area. Each regional centre (such as, Ballarat, Bendigo, Shepparton and Latrobe).is surveyed every five years
Sampling	Approximately 2,000 to 3,000 households per year
Survey frequency	Annually. Before 2020, the survey was conducted every two years and covered 4,500 households

B.1.2.1 Data-collection method

VISTA is conducted over the course of a year that starts in July and ends in June. The survey involves face-to-face and telephone interviews, and a paper travel diary that participants complete for one travel day. Participants are offered an optional GPS tracker, which approximately 2,000 households accept. In practice, however, less than 50% of households always carry the device with them. The GPS tracker records location data in 5-second intervals (this is downsampled to 30-second intervals for analysis) and other data, such as temperature. DTP also has access to people's raw location data. This comprises of latitude and longitude coordinates that are randomised within 100 metres of home locations, for privacy reasons.

DTP allocates around 10% of its annual budget to trialling new or alternative technologies and methodologies. If the trials are successful, they are integrated into future VISTA cycles. For example, in the past, DTP trialled the RMOVE smartphone app. The app was able to streamline significant parts of the survey; however, its uptake was low – users found its interface was unintuitive and difficult to use, particularly when they were modifying trip modes.

B.1.2.2 Data reporting and data use

DTP publishes summary-level VISTA data online, using Tableau-powered dashboards (Department of Transport and Planning, n. d.). Its dashboards (see Figure B.2 for an example) cover various years and modes of transport. They include:

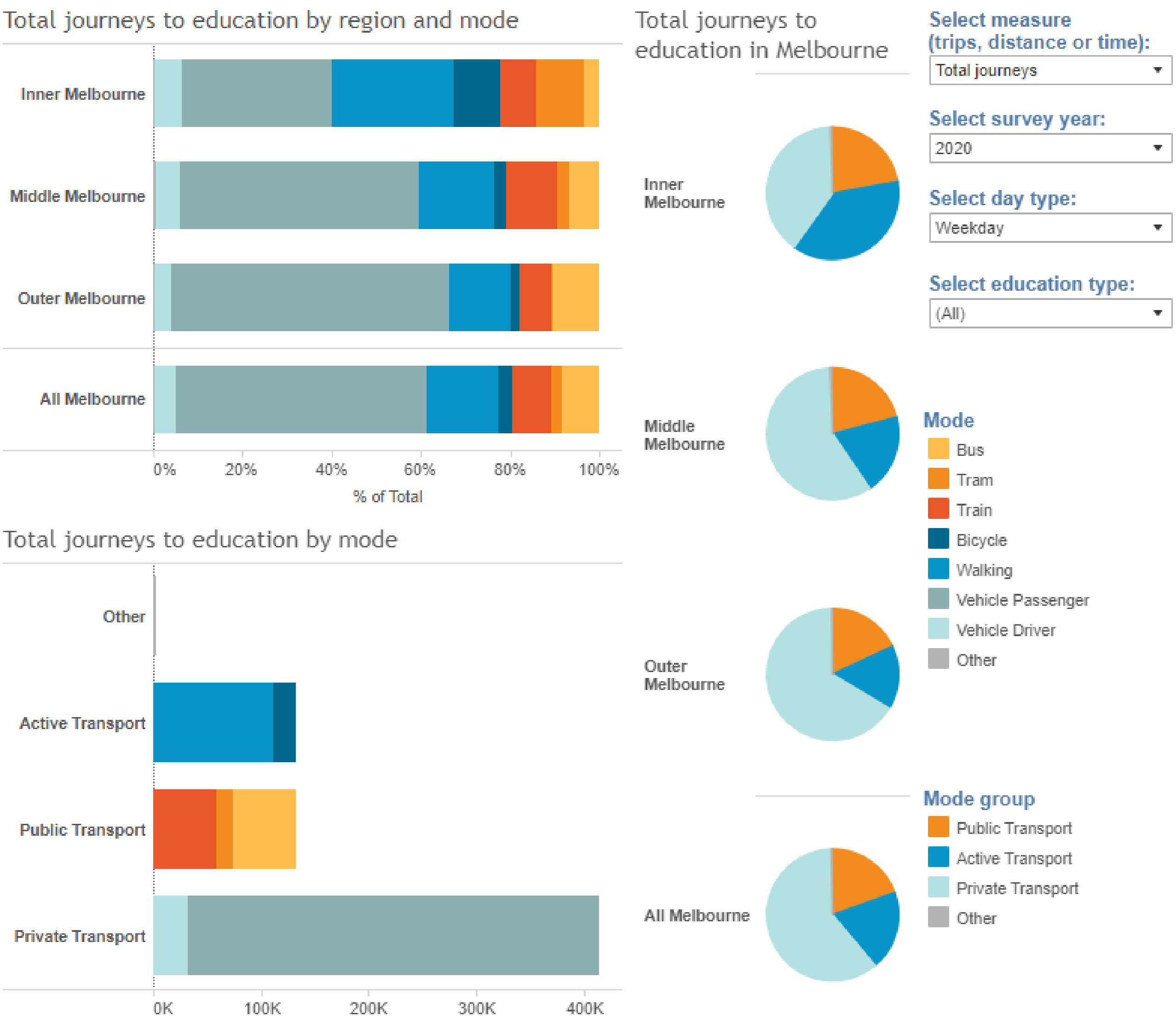
- summaries by state and LGA for each survey year. The summaries cover the number of trips taken, and the time and distance by modes (bicycle, bus, train, tram, vehicle driver/passenger, walking or other)
- journeys to education and work
- travel time of day (aggregated to 30-minute bins) by mode groups (active, public, private or other), travel purpose and demographics (age and sex) for weekdays and weekends
- walking and cycling (1 to 2% of trips are cycling). The surveys reveal little interest so far in micro-mobility modes (such as, scooters), as people's use of them is an even smaller fraction of active transport.

Five councils in inner-city Melbourne regularly use VISTA data, but other LGAs rarely use it. This is probably because travel-activity data for individual LGAs is unreliable, due to the low sample sizes, and because DTP does not release many public reports or case studies that use the data and illustrate its benefits.

In our consultation with DTP, representatives mentioned these insights from the 2023 VISTA, whose results have not yet been published:

- Travel time is generally accurate to the nearest five minutes.
- Travel patterns do not change much over time, but some changes have happened since the COVID-19 pandemic (for example, more people now work from home).

Figure B.2 VISTA data visualisation showing travel behaviour for education for Melbourne (2020) (reprinted from Department of Transport and Planning, n. d.)



B.1.2.3 Survey limitations

Ipsos needs to call back many participating households to clarify items in their travel diary, which causes delays and adds to the survey cost. COVID-19 also affected the sample size, which dropped to 2,800 households during the pandemic. The survey frequency and sample sizes in regional areas are low, but this is not expected to change. Another limitation is that DTP has only one full-time-equivalent staff member working on VISTA's contracting, project management, reporting and some of its analysis.

B.1.3 New South Wales household travel survey

Ipsos currently conducts the New South Wales (NSW) household travel survey (Transport for New South Wales, 2024a) on behalf of TfNSW. Table B.3 summarises what this household travel survey covers.

Table B.3 Summary of what the NSW household travel survey covers

Survey item	Description of item
Transport modes	All travel modes: bus, other (this includes plane, taxi, ferry and bicycle), train, vehicle driver, vehicle passenger, walk linked and walk only
Travel purposes	Commute, education/childcare, personal business, serve passenger, shopping, social/recreation, other and work-related business
Locations covered	Greater Sydney metropolitan area (this includes Sydney, Illawarra and Greater Hunter regions). Regional areas are not covered
Sampling	Approximately 2,000 to 3,000 households per year
Survey frequency	Continuous

B.1.3.1 Data-collection method

The NSW household travel survey has been a continuous survey since 1997. Rather than sample households periodically, it aims to cover a small number of households every day throughout the year.

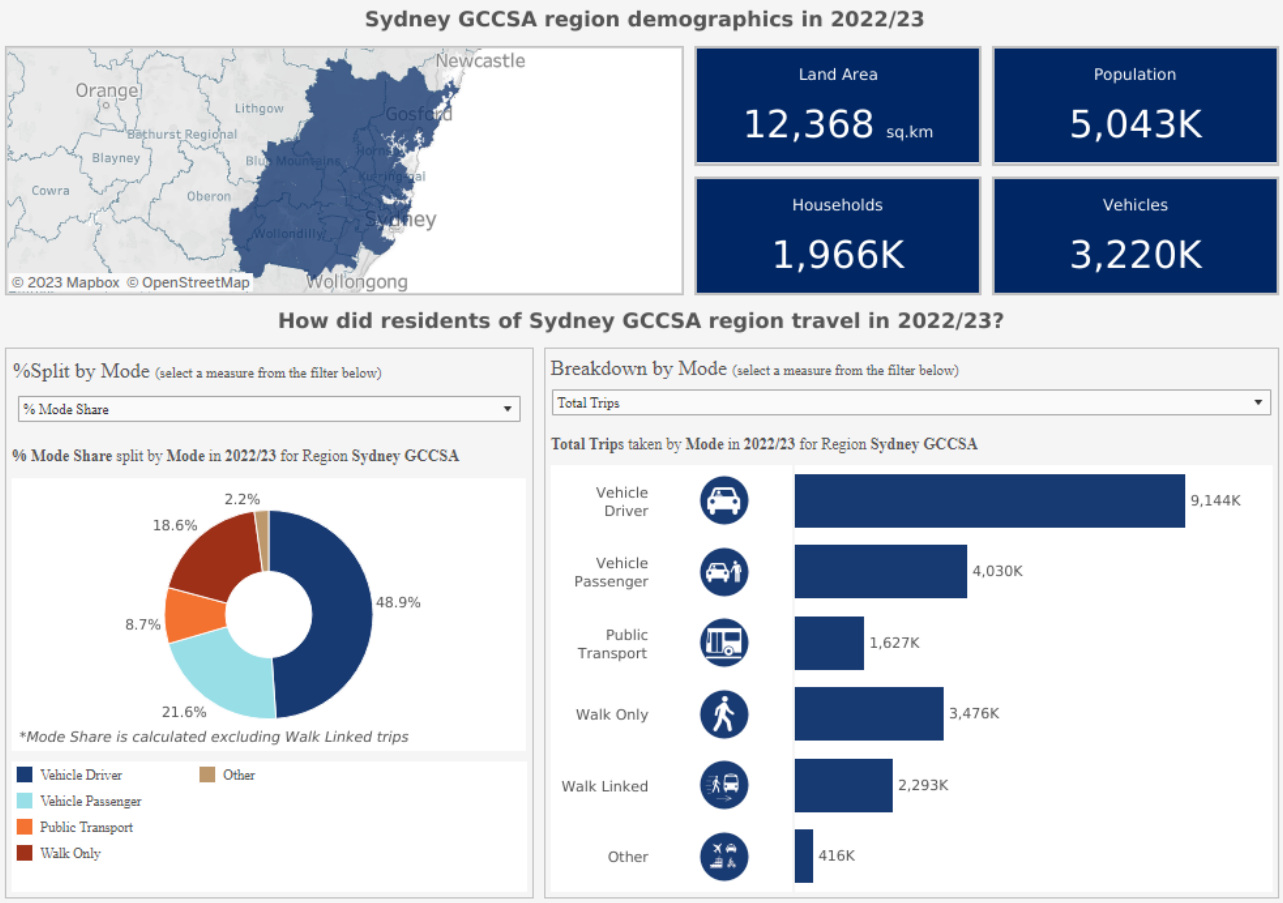
Survey participants record their travel activity over a single day of the week. Since 2015, data has been collected face-to-face or by computer-assisted interviews (online or using tablets). TfNSW has recently given participants the option of a GPS tracker that monitors their travel behaviour over seven days, in addition to the single day. Over 50% of participants have taken up this option, which is high uptake. As GPS tracking is a recent initiative, TfNSW has limited experience of its performance so far.

Participants record their trip distance and duration, by mode and purpose. Travel mode and duration are cross-tabulated, due to the small sample size and potential for a large sampling error. The survey data is weighted, using Australian Bureau of Statistics population data from the same year that survey data is collected (Transport for New South Wales, 2024a). Trip data from Sydney's public-transport ticketing system is used to validate the survey data on public-transport trips.

B.1.3.2 Data reporting and data use

TfNSW presents data from the household travel survey in a series of Tableau-powered dashboards, which typically report on SA3. In some cases, data is aggregated to address privacy concerns (such as for small LGAs that have a low sample size). Figure B.3 gives an example of how TfNSW presents its data. Users can filter the data by the number of trips, total distance travelled, average distance travelled and average trip duration. Reporting on active-transport modes is limited to walking and linked-walking trips. Cycling is included in the 'other' category.

Figure B.3 NSW household travel survey data visualisation showing mode share for Sydney GCCSA region (2022/23) (reprinted from Transport for New South Wales, 2024b)



B.1.3.3 Survey limitations

The cost of conducting the NSW household travel survey is approximately A$2 million per year (this includes the cost of GPS tracking), which is higher than other surveys. The main cost item is recruiting survey participants.

Using the GPS trace data has some limitations. The data requires significant cleansing and processing before it is presented to participants to validate it. There are also issues with the devices' performance. These include their battery capacity, and their accuracy when travelling in tunnels and around high-rise buildings. The GPS data does not always represent a household's travel behaviour, if, for example, only one person in the household opts to use the device, as this severs the connections between travel-behaviour data for the household.

In the long term, TfNSW is considering using app-based (smartphone) tracking, such as the Mobile Market Monitor.[19] Trialled in Singapore, this is considered a better solution than standalone GPS devices. In 2022, TfNSW trialled smartphone apps for four to six weeks, with around 100 households (see Section 2.4.5). The trial cost around A$100,000 more than the typical cost of field work.

[19] To find out more about Mobile Market Monitor, visit www.mobilemarketmonitor.com

Globally, GPS, smartphones and computer-assisted surveying techniques are increasingly being used to collect data. However, the cost of using these technologies for household travel surveys is similar to the cost of traditional survey methods, which is around US$500 to 700 per household.

From March to October 2020 and July to October 2021, the household travel survey was suspended, due to the COVID-19 pandemic. When possible, some data was collected in Sydney, but not the wider metropolitan region, and face-to-face surveys were temporarily replaced by phone interviews. The pre-COVID and post-COVID data have very different sample sizes and reflect very different travel patterns, so they cannot be joined for reporting purposes. Consequently, 2021 reporting is based on only one year of data and 2022 reporting is based on only two years of data. Reporting for 2023 is based on three years of data, which is how data is normally aggregated.

B.1.4 Queensland Travel Survey

The Queensland Travel Survey (QTS) is conducted by the Queensland Government's Department of Transport and Main Roads (TMR), with fieldwork assistance from Roy Morgan Research (Department of Transport and Main Roads, 2023). Table B.4 summarises what the QTS covers.

Table B.4 Summary of what the QTS covers

Survey item	Description of item
Transport modes	All travel modes: bicycle, public transport, taxi/rideshare, vehicle driver, vehicle passenger and walk
Travel purposes	Education, other, pick-up/drop-off/delivery, shopping/personal, social/recreation and work
Locations covered	South East Queensland. Regional centres are surveyed every five years, or when major infrastructure changes
Sampling	Approximately 4,000 households per year
Survey frequency	Continuous

B.1.4.1 Data-collection method

The QTS is conducted continuously throughout the year, using an online self-completion questionnaire that is supplemented by face-to-face and phone interviews (paper surveys were used up to 2017). The QTS covers travel activity over a single weekday during school terms (weekends, public holidays and school holidays are excluded).

Each year, around 6,000 households in South East Queensland (SEQ) are invited to take part in the survey. The typical response rate is 65%. The QTS sample size does not scale linearly with the population; therefore, smaller councils need a larger sample to get meaningful data or overcome privacy issues. Consequently, some LGAs contribute extra funding, to increase the sample size for their area.

TMR does not use GPS devices, due to the resources needed to cleanse and process the data, the likely low uptake by participants, and the devices' limited accuracy in urban areas.

B.1.4.2 Data reporting and data use

TMR reports on three years of aggregated QTS data, and its latest dataset is calibrated to 2022. Due to the QTS low sample size, TMR reports data only down to LGA level.

QTS data is used in the Queensland Transport Snapshot (Translink, 2023) and a Tableau data portal (see Figure B.4). The Queensland Government also provides insights from the data in its Open Data Portal (Queensland Government, 2023a).

TMR reports on private transport, public transport, taxi or rideshare, and active transport (this covers walking and cycling). Due to the small sample sizes for types of active transport, 'cycling' includes scooters, skateboards and e-bicycles. Figure B.5 shows an example of its reports on active transport.

Figure B.4 QTS data visualisation showing trip purpose, distance and duration by mode for South East Queensland (2018) (reprinted from Department of Transport and Main Roads, 2022)

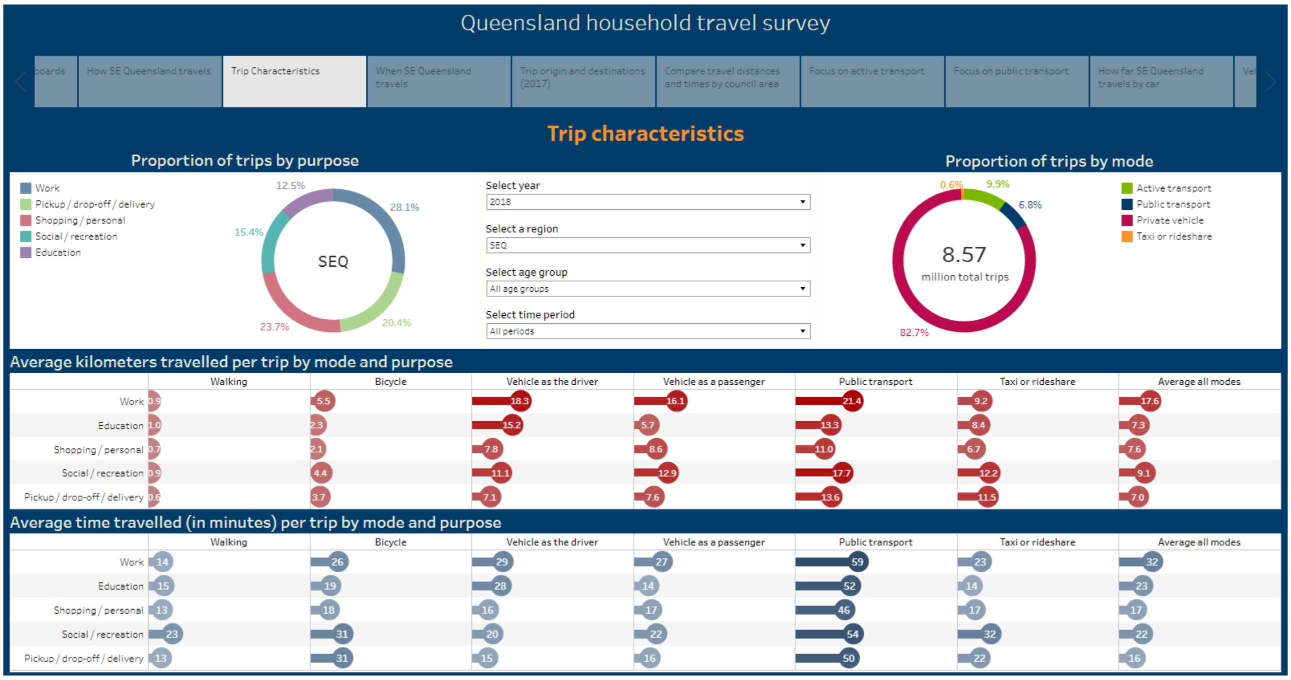
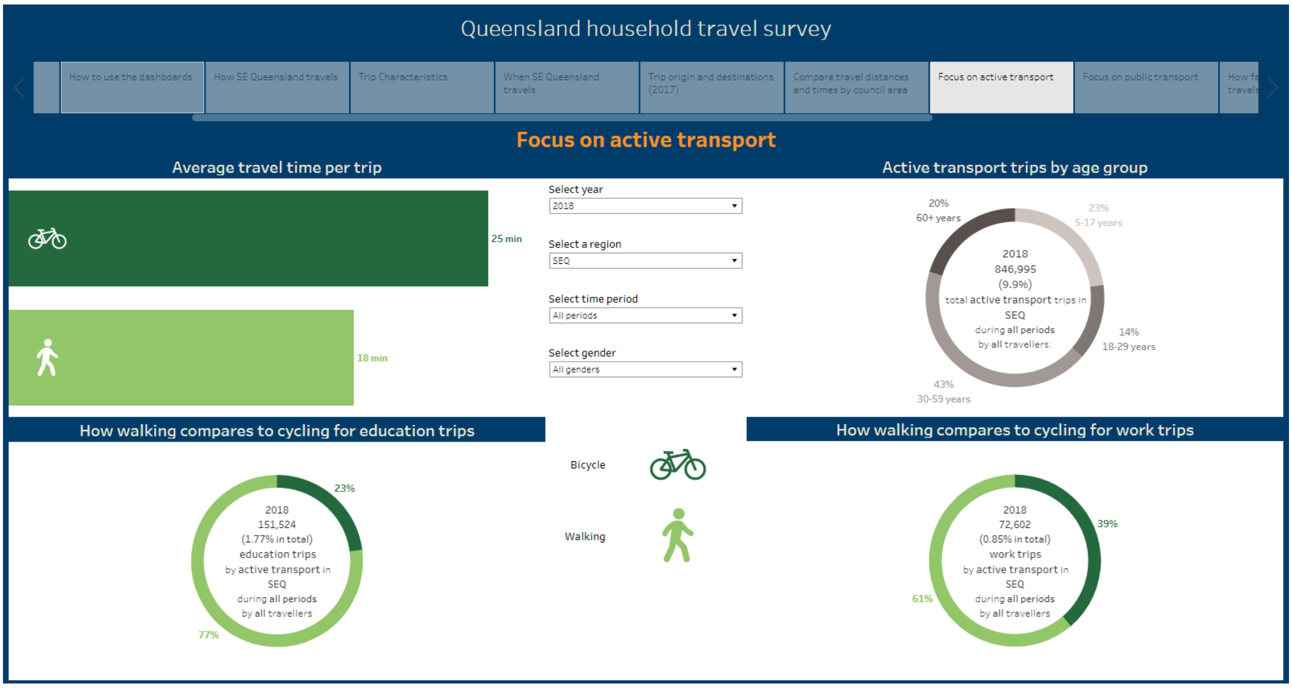


Figure B.5 QTS data visualisation showing active-travel (walking and cycling) behaviour for South East Queensland (2018) (reprinted from Department of Transport and Main Roads, 2022)



B.1.4.3 Survey limitations

As with other household travel surveys, the QTS has a relatively small sample size. This means that TMR is required to aggregate three years of data, and does not recommend that the data is used to estimate trip information for small spatial areas, such as SA1. TMR has had problems recruiting participants, and with participants omitting short trips. In common with the experience of other authorities, the COVID-19 pandemic caused a break in the continuous dataset, resulting in lower coverage in 2020 and 2021.

The annual cost to conduct the QTS in SEQ is approximately A$700,000. Of this, A$550,000 is for fieldwork and A$150,000 is for 'backend' and infrastructure costs. The cost to undertake the survey in regional centres is slightly less than the cost for SEQ.

B.1.5 Perth Area Travel and Household Survey

The Perth Area Travel and Household Survey (PATHS) is the main household travel survey conducted in Western Australia. It was last conducted by Ipsos between 2018 and 2022, on behalf of MRWA (Main Roads Western Australia, 2021). Table B.4 summarises what PATHS covers.

Table B.5 Summary of what PATHS covers

Survey item	Description of item
Transport modes	All travel modes: active transport, private car and public transport
Travel purposes	Accompany, education, employment, go home, other, personal business, pick-up/drop-off, shopping and social/recreation
Locations covered	Greater Perth metropolitan area (this includes Mandurah). No regional locations are surveyed
Sampling	Approximately 6,500 households over four years
Survey frequency	Infrequent. The previous survey was conducted between 2002 and 2005

B.1.5.1 Data-collection method

PATHS records participants' travel behaviour over one day, using a paper travel diary and an optional GPS tracker (approximately 80% of participants take up this option). Ipsos also conducts choice experiments with participants, to gather supplementary information about their choice of transport modes. MRWA acknowledges that its approach is labour intensive; it involves considerable face-to-face interaction with participants during recruitment, interviews and recall surveys.

While the diary records travel behaviour over one day, the GPS trackers measure participants' movements over five days. PATHS is one of the first surveys in Australia to collect this amount of GPS trace data and, unlike other authorities' surveys, use it to calibrate strategic transport models.

PATHS is conducted infrequently due to budget constraints. The previous survey was conducted between 2002 and 2005; the next survey will be undertaken in the next eight to ten years.

B.1.5.2 Data reporting and data use

MRWA uses PATHS data, particularly GPS traces, to calibrate its transport models. It processes GPS traces to identify people's trips by their stops. In future, it may use GPS traces for other purposes, such as analysing route choices.

Currently, MRWA does not have a public reporting dashboard that summarises PATHS results. MRWA gave us an interim PowerBI dashboard to review, and Figure B.6 shows what it can report. In general, MRWA's public reporting is at SA3 or SA4 level only, and for three travel modes only: car, public transport and active transport. Figure B.7 breaks down active transport into walking and cycling. It shows that walking is the second most common transport mode, while cycling makes up about 2% of trips.

Figure B.6 PATHS interim data visualisation showing the estimated number and proportion of trips by private vehicles (2018–2022) (reprinted from Main Roads Western Australia, 2023)

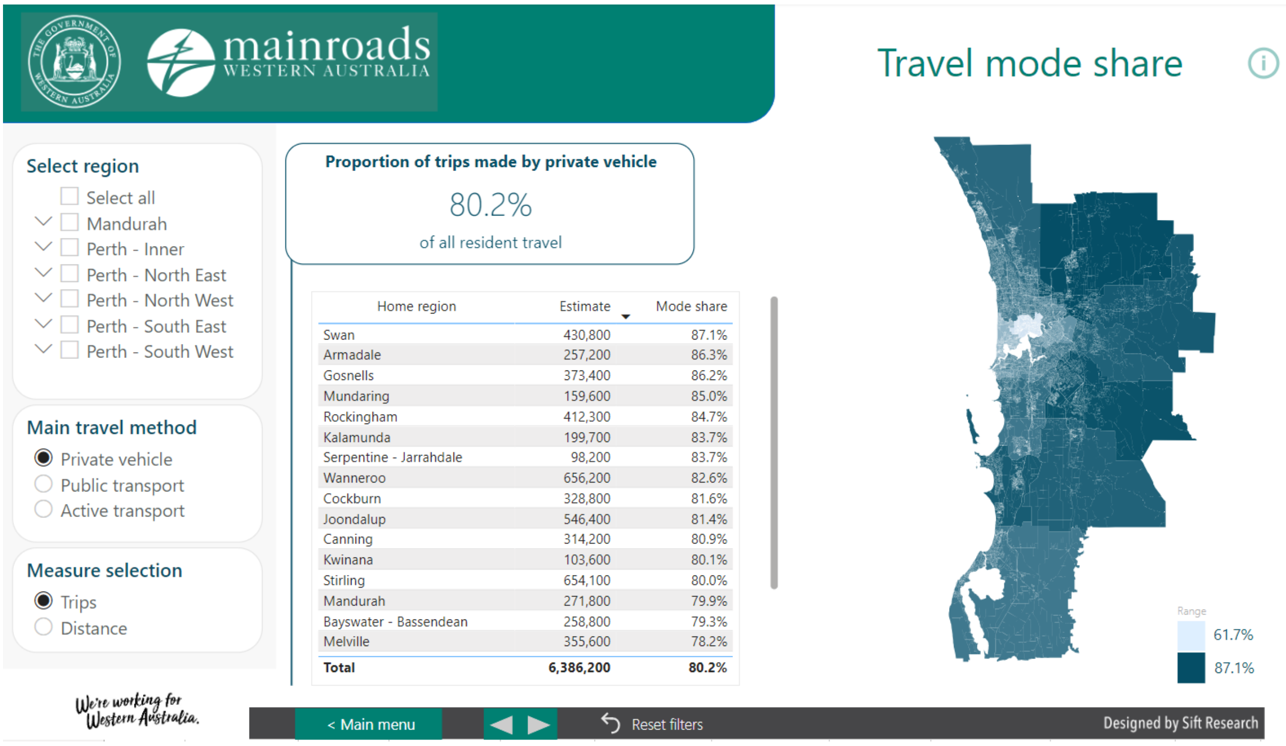
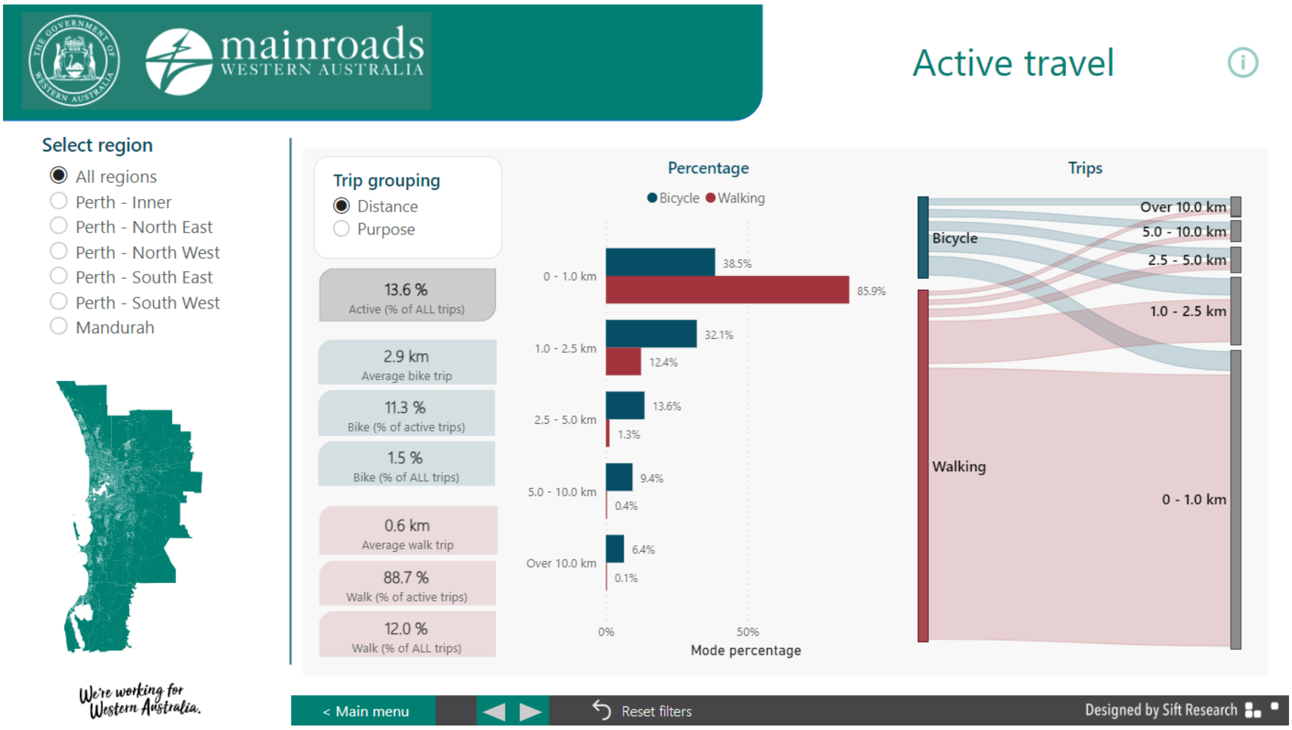


Figure B.7 PATHS interim data visualisation showing active-travel behaviour for all Perth regions (2018–2022) (reprinted from Main Roads Western Australia, 2023)



B.1.5.3 Survey limitations

Due to budget constraints, PATHS is run infrequently – the previous survey was conducted 20 years ago. The survey is labour intensive, as in involves significant face-to-face contact with participants. During the survey period, Ipsos approached 15,000 households and around 30 to 40% agreed to take part. When it was last run, PATHS costs around A$7 million over its four-year period. Some of this cost was to buy GPS devices and process GPS trace data.

MRWA put considerable effort into collecting a lot of GPS trace data. This was time consuming, as it was MRWA's first experience of doing it. MRWA found it challenging to set correct 'stop-detection' thresholds, to identify destinations. To overcome this challenge, it needed to incorporate GIS layers (POI, such as shopping centres) into the transportation network, to identify actual destinations and eliminate incorrect detections (such as a person stopping at traffic lights).

PATHS was halted during COVID-19 lockdowns. MRWA collected data for two years prior to the lockdowns and two years afterwards.

The sample sizes for public transport are low, which reflects low usage of public transport in Perth. This finding has been confirmed, as the public-transport data is supplemented with actual touch-on/off data from the public-transport ticketing system.

B.1.6 International surveys

Many authorities across the world conduct household travel surveys. In the US, household data was collected every 10 years. However, in recent years the trend is to collect data more frequently and use technology to collect and aggregate data (Lawson et al., 2023).

Svaboe et al. (2024) compare national travel surveys in Denmark, England, France, Germany, Norway and Sweden. While these countries have different approaches and survey designs, they all experience similar challenges: participants not responding or underreporting their trips, and samples not being representative of the population (Svaboe et al., 2024).

A recent literature review by Strommer et al. (2023) provides an overview of the methods that 17 EU countries use to measure mode share, the frequency that they measure and the modes they measure. These are the key findings from this review:

- The most common methods to collect data are statistical surveys of passengers (this is similar to household travel surveys in Australia and New Zealand) and technologies that track vehicles and count passengers.
- Statistics are published at least annually, but more often quarterly. The literature does not examine sample sizes and coverage closely.
- Transport modes cover public and private transport and include aviation and rail. They do not include active-transport modes like cycling and walking.
- Most countries measure individual travel using PKT.

According to Strommer et al. (2023), these are the surveys' top two limitations:

- Data sources are unreliable, regardless of the level to which data is analysed (that is, national, regional or local). Each country uses its own measurement strategy, and outsiders are unaware of how reliable their methods are and how accurate their data sources are.
- Countries have inconsistent survey scope, and their terminology and approaches to measuring mode share are also inconsistent (Strommer et al., 2023).

B.2 Screenline approaches

B.2.1 Auckland Transport

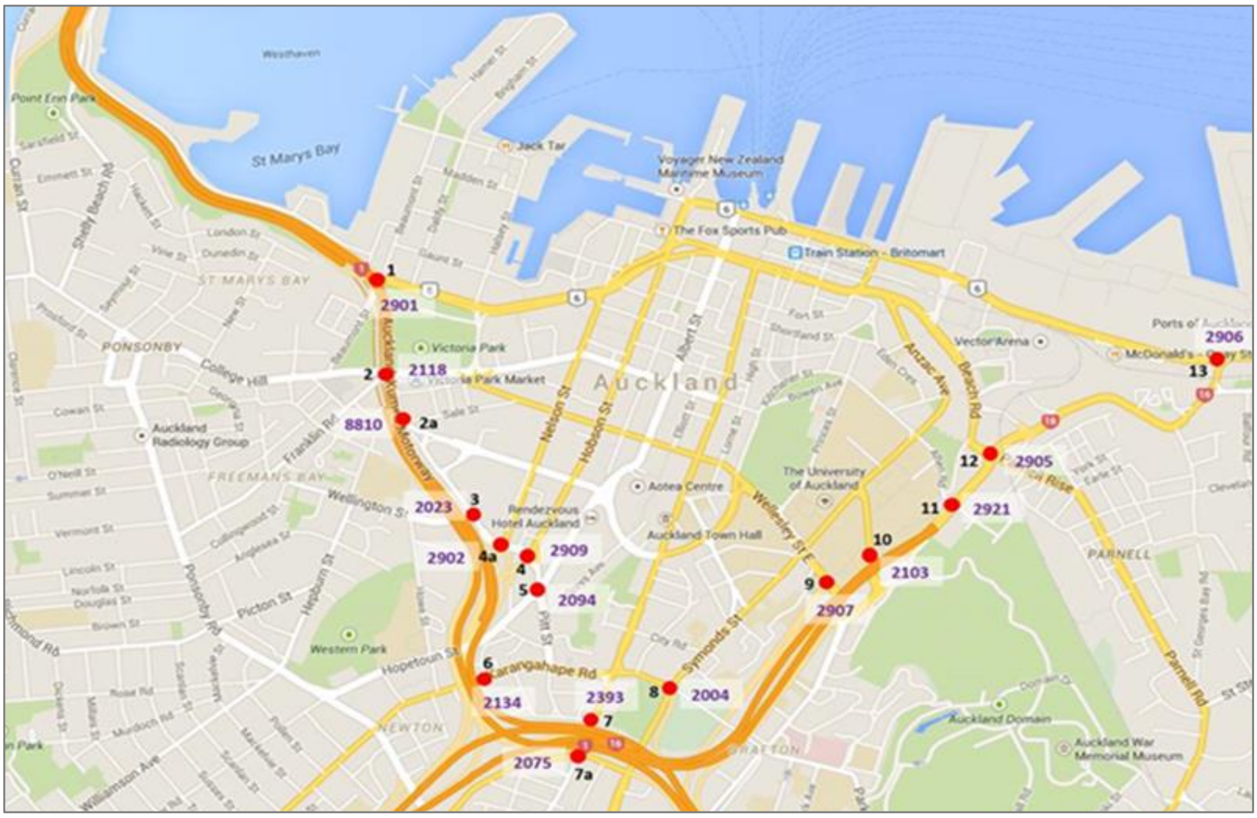
AT needs a transport system that provides genuine choice and enables people to shift from private vehicles to public transport and active modes of transport (walking and cycling) (Auckland Transport Alignment Project, 2019).

AT has developed a cordon (see Figure B.8) consisting of sensors at 17 locations around the city centre. AT uses this cordon to monitor all traffic on primary routes entering and exiting the city centre, which enables it to assess the effectiveness of its transport interventions.

The counters along the cordon measure three transport modes:

1. **Private vehicles**. AT has had access to count data from car-traffic counters since 2018. Automatic numberplate recognition can get vehicle classification information and assign vehicle occupancies using averages.
2. **Public transport**. AT has been collecting data using touch-on/off events from smartcards or the AT HOP card,[20] since 2018.
3. **Cyclists**: AT has used annual surveys to count cyclists manually. However, it is now rolling out cameras as a permanent solution to collecting continuous data. These cameras only count active transport; they do not capture PKT. Eco-Counter sensors (see Section 2.4.3) also collect data in Auckland.

Figure B.8 Locations of sensors that form a cordon around Auckland and collect data about multiple transport modes (reprinted from Auckland Transport, personal communication, 2023)



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20 For further information about the AT HOP card, visit https://at.govt.nz/bus-train-ferry/at-hop-card

Note: The map shows sensors at 16 locations, but AT confirms it collects data from sensors at 17 locations. The sites shown on the map indicate the sensors' approximate locations.

B.2.1.1 Data-collection method

Including the cordon, around 70 locations in Auckland have counters installed that measure active transport. All locations count cyclists and around half also count pedestrians. AT uses 26 key locations to track its performance against measures published in its *Statement of intent* (Auckland Transport, 2023a). The measures include the number of cyclists, the number of people who board public transport and the average number of people moving per hour during the morning peak ('arterial productivity').

Before it introduced automatic counters, AT used manual surveys to count active-transport users at the 17 locations in Figure B.8. It conducted manual surveys every three months, which cost approximately NZ$10,000 each. AT still uses some of the adjusted historical data from these surveys in its cycling-count reporting (Auckland Transport, 2024). It has recently installed CCTV cameras at each of its screenline locations (see Figure B.8) and is currently setting up the data feed and daily data reports from the camera footage.

B.2.1.2 Data reporting and data use

AT publishes some cycling data in a monthly cycling monitoring report (Auckland Transport, n. d.), and provides free access to more detailed daily data from many of the counters that record cyclists (this data is available in an XLSX file). It also reported key insights about cycling-count trends from April 2017 to April 2023 (Auckland Transport, 2023b). About 8% of all traffic entering the city during the morning peak is active transport.

Recent data shows that fewer people are travelling into Auckland city compared with periods before the COVID-19 pandemic. Within that decreased demand, public transport has maintained its market share and active transport has been relatively stable, and slightly increased (Auckland Transport, n. d.).

AT uses a dashboard to analyse and present the data it collects from various monitoring locations. Figure B.9 shows AT's analysis of capacity on Queen Street (vehicle numbers per hour). Figure B.10 is an example of a dashboard that analyses the performance of Auckland's city-centre transport network.

Figure B.11 is an example of a dashboard that analyses mode share (cars, cyclists, pedestrians and public transport) during the morning peak. And Figure B.12 shows the impact that COVID-19 lockdowns and working-from-home arrangements have had on traffic volumes since March 2020.

AT tells us that data visualisations can enable it to more immediately assess the effects of infrastructure projects (for example, the effect that introducing a new bus lane has on public transport patronage).

Figure B.9 Analysis of capacity on Queen Street (reprinted from Auckland Transport, personal communication, 2023)

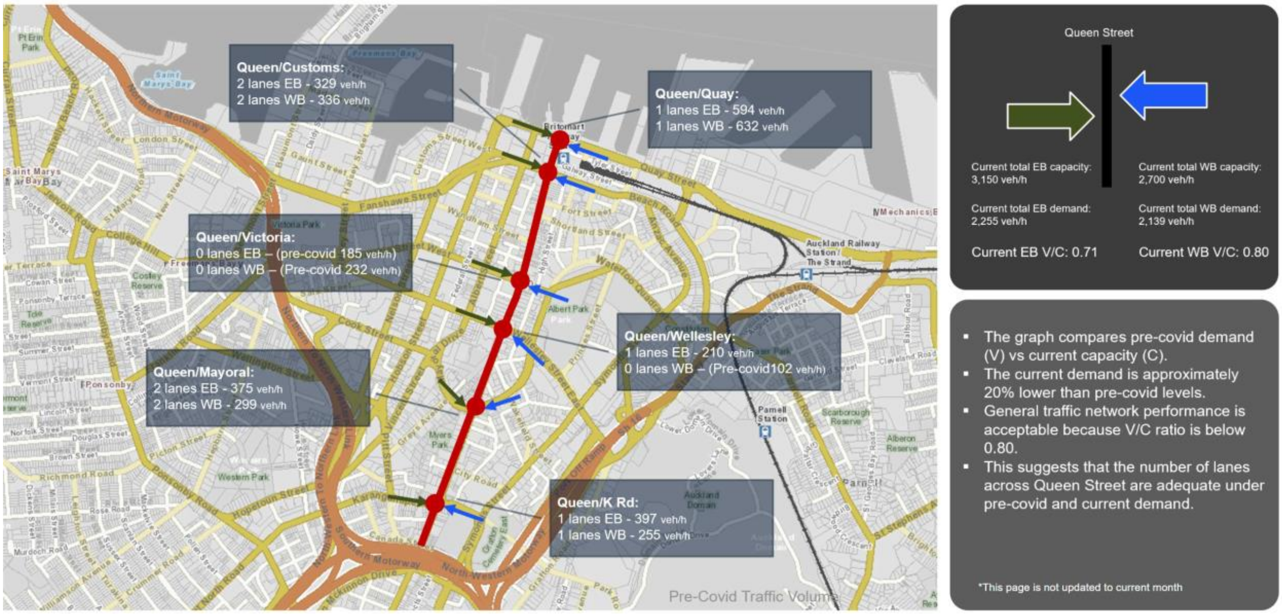


Figure B.10 Analysis of performance of Auckland's city-centre transport network (March 2023) (reprinted from Auckland Transport, personal communication, 2023)

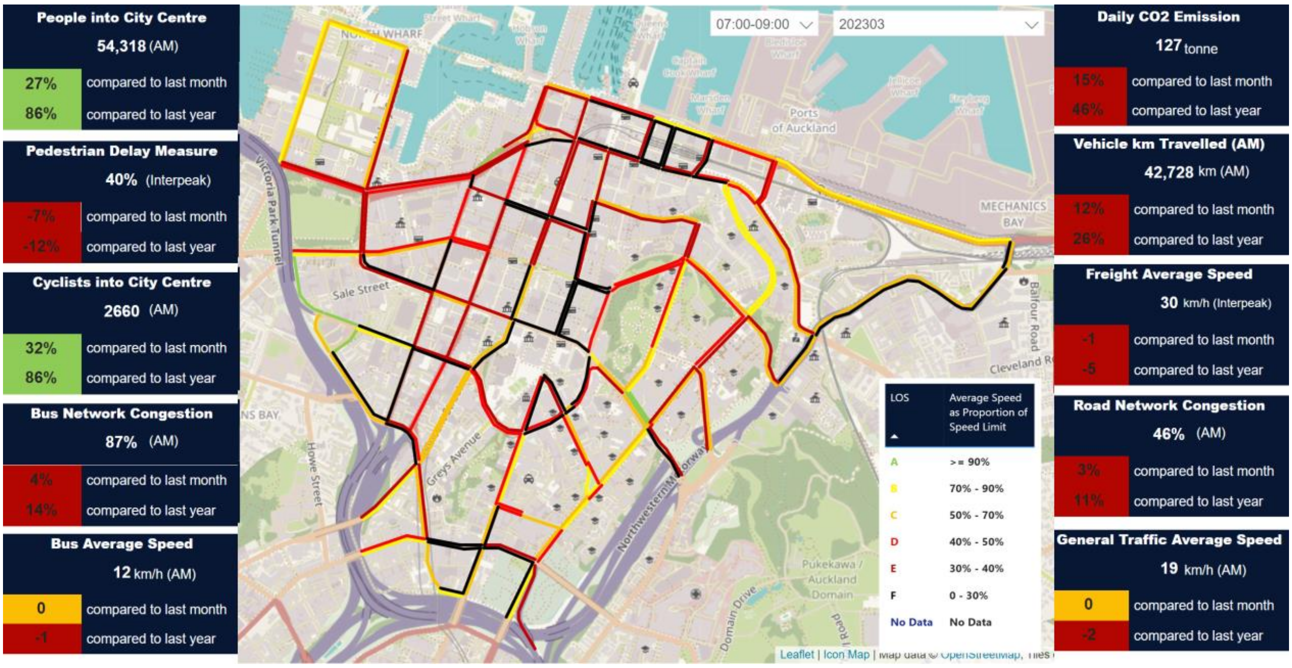


Figure B.11 Mode share during morning-peak travel into central Auckland (Jun 2019–Mar 2023) (reprinted from NZTA, personal communication, 2023)

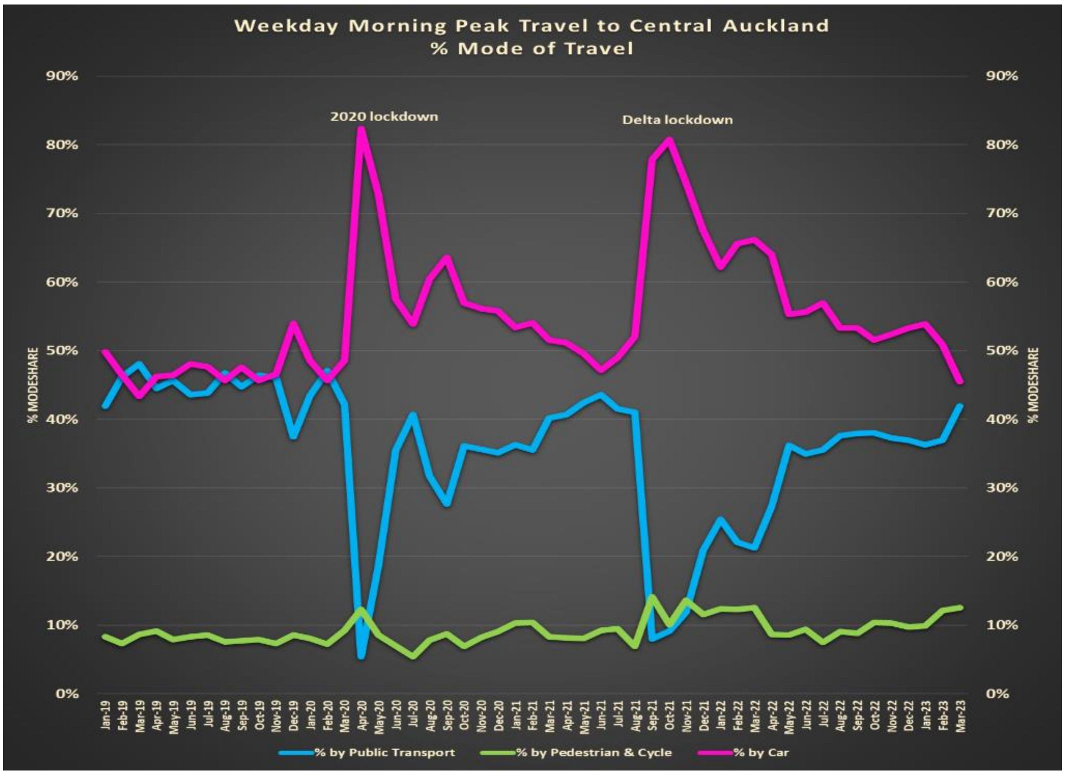
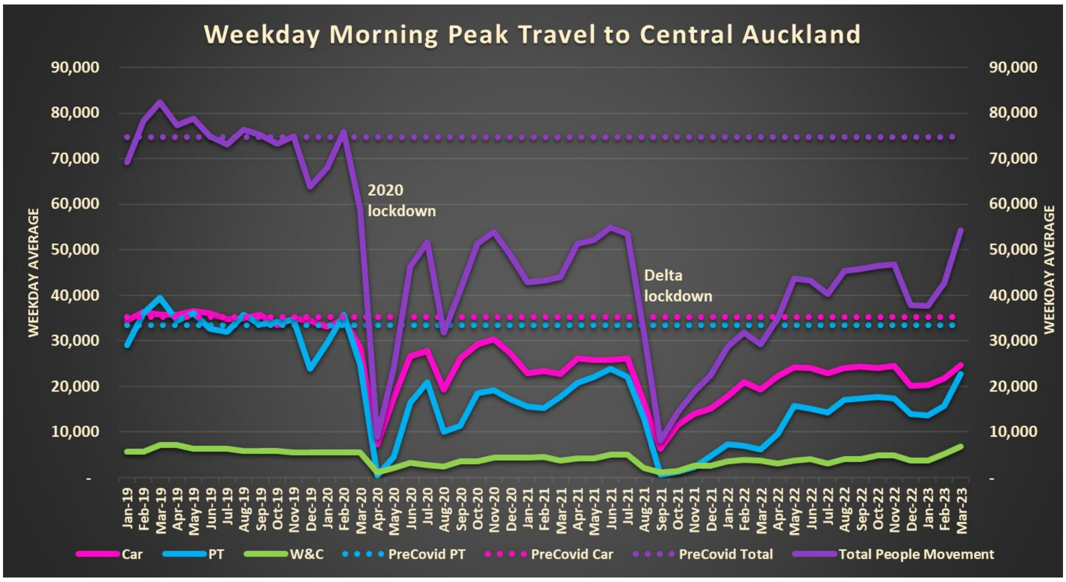


Figure B.12 Effects of COVID-19 lockdowns and post-COVID work arrangements on morning-peak travel into central Auckland (Jun 2019–Mar 2023) (reprinted from NTZA, personal communication, 2023)



B.2.1.3 Limitations of this approach

AT acknowledge that collecting data to monitor active transport is the most difficult. For example, because PKT is not known, it is hard, or sometimes impossible, to detect route changes or mode shift. In comparison, public-transport data shows where passengers get on and off, which enables AT to estimate route changes and mode shift. Despite this challenge, compared with other survey methods, AT can rapidly track changes (even during the COVID-19 lockdowns) in travel activity from the continuous data supplied by the counters.

In future, due to budget constraints, AT plans to have fewer counting sites but improve its oversight of conditions at the counting sites, its calculations of correlations between empirical data and its analysis of trends. AT also intends to shift its focus on capturing mode shift away from the city centre and towards areas where it is planning new investments.

B.2.2 Greater Wellington Regional Council

The *Wellington regional land transport plan 2021* outlines GWRC's aim to increase the proportion of people who use active and public transport by 40% between 2018 and 2030 (Greater Wellington Regional Council, 2021). This equates to the proportion of all travel by active transport increasing from 28% in 2018 to 39% in 2030.

GWRC and WCC work together to collect mode-share data. Prior to 2023, GWRC was particularly concerned to monitor peak-time travel activity into (morning peak) and out of (evening peak) Wellington. It collected mode-share data only during the morning peak (7am to 9am) and only for traffic that crossed WCC's cordon around Wellington city centre (this cordon was similar to AT's cordon in Auckland). This approach collected counts of vehicles, cyclists and pedestrians, which GWRC supplemented with data about public transport patronage (the fare system). GWRC did not collect data for the rest of Wellington region.

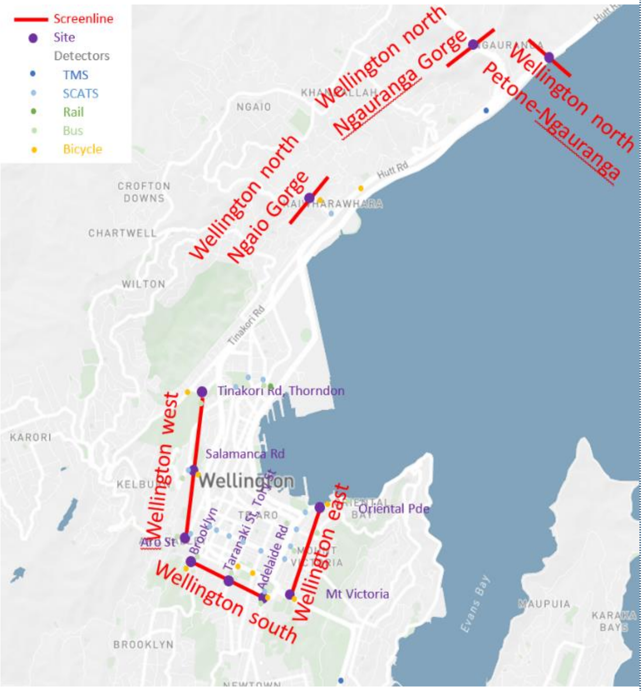
From 2023, GWRC and WCC have undertaken a series of initiatives to improve data collection in the city centre and Wellington region. In the city centre, WCC continues to capture counts of private transport and active transport, and GWRC continues to collect public-transport data. However, as WCC rolls out VivaCity sensors across the city, it will collect more granular data and be able to monitor mode share continuously (see Section B.3.2 for WCC's approach and Section 2.4.2.2 for details of VivaCity sensors).

The Wellington Transport Analytics Unit is leading a project to define screenlines across the Wellington region. The screenlines capture traffic on major or strategic corridors leading into the city, to enable GWRC to understand traffic volumes and mode share at select locations. Six screenlines have been created on major routes into Wellington (three to the north; one to the west; one to the south; and one to the east) (see Figure B.13(a)). The three screenlines to the north capture inbound and outbound traffic from areas north of Wellington city (see Figure B.13(b)). GWRC expects to refine the locations of the screenlines in the first half of 2024.

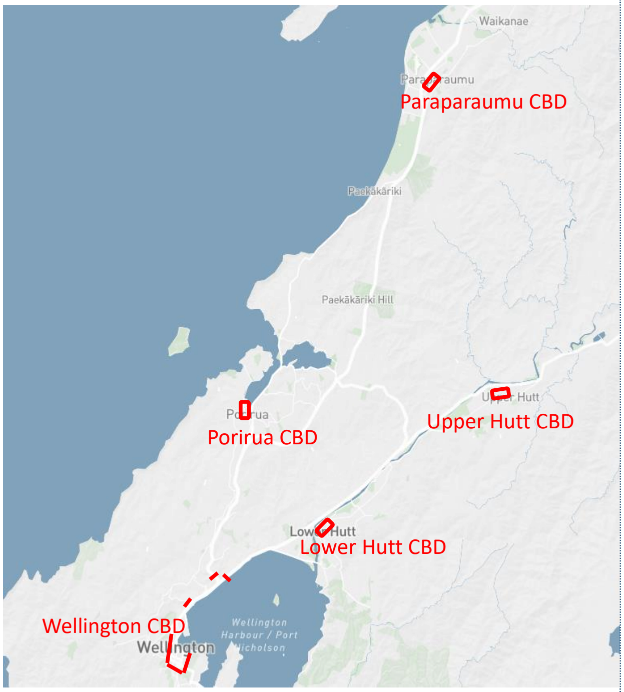
Every screenline collects public-transport data (from the fare system), SCATS® data, TMS data and cycling data (from cycling loop detectors). Ideally, data would be collected throughout the region for every transport mode. However, considering that cars and public transport are the dominant modes used outside the city, some compromises are necessary.

Figure B.13 Indicative locations of screenlines in Wellington city centre and the Wellington region (reprinted from Greater Wellington Regional Council, personal communication, 2023)

(a) Screenlines around Wellington city



(b) Major towns north of Wellington city



Note: The screenlines form a cordon around Wellington city centre, and capture data about traffic travelling into and out of central Wellington.

B.2.2.1 Data-collection method

GWRC validates data it collects from screenlines with HTS data, which includes data for 200 to 300 households in the Wellington region per year. Recently, data from additional samples was collected when GWRC updated its transport model. This led to a total sample size of over 1,000 households, which equates to approximately 0.7% of all households in the region.

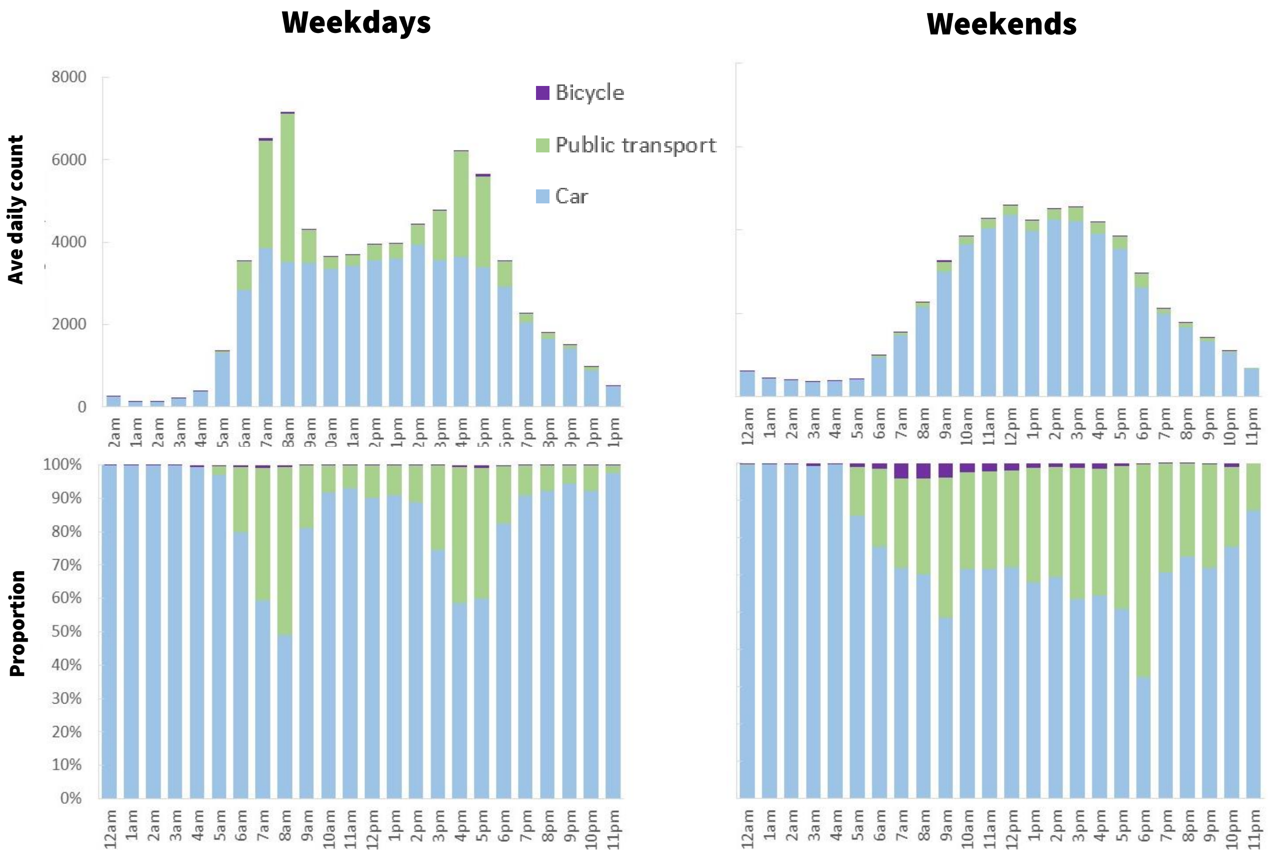
GWRC has also used mobile-phone and telco data to build demand matrices for highways, by inferring mode choice and demand. This data is collected by a third-party provider (Qrious). GWRC intends this data to be its main source for developing detailed matrices for its new traffic-assignment model (Cornelis, 2022). The telco data covered all public-transport modes, active-transport modes and about 40% of vehicle-movement data. However, procuring and analysing the data were relatively expensive (it cost about NZ$200,000 to process one months' data and validate it using screenline data). GWRC has now scaled up the matrices from the telco datasets, to provide movement data for a larger area.

Currently, GWRC does not capture PKT for private transport and active transport. To do this, it could combine traffic counts with VKT collected from other sources (such as, TomTom), to estimate trip lengths for trips that pass counters or screenline locations. This would give GWRC VKT data for a sample, which it could scale up to estimate VKT for the region. Vehicle-occupancy data can also be used to derive PKT. PKT by public transport can be estimated based on converting data from public-transport cards or fares into trip lengths.

B.2.2.2 Data reporting and data use

GWRC's reporting is currently limited to internal users. Figure B.14 shows a typical report on its mode-share data. GWRC captures data from a range of sources (see Section B.2.2.1), including SCATS®, TMS, netBI[21] and cycling counts. This data reveals that public transport has a 40 to 60% mode share during the morning and afternoon peaks, while cars have a 70% or higher mode share during other times. Cycling has a low mode share compared with other modes, although it can reach 12% during the morning peak.

Figure B.14 Bidirectional mode share data for the Petone–Ngauranga screenline (September 2023) (reprinted from Greater Wellington Regional Council, personal communication, 2023)



B.2.2.3 Limitations of this approach

GWRC relies heavily on HTS data (this includes extra samples for the Wellington region) to validate its monitoring data, but HTS data is limited by small sample sizes and infrequent collection.

With its current screenline approach, GWRC finds it difficult to reliably measure pedestrian movements, including trip lengths, so it is not capturing this data yet. Further work is underway (see Section B.2.2.1) to develop multimodal screenlines along key corridors in the region that will collect data continuously. One of GWRC's key future priorities is improving its understanding of PKT and VKT across the region.

[21] To find out more about netBI, visit https://netbi.com.au

B.2.3 Department of Transport and Main Roads

In 2020, NTRO conducted the Benefits Achieved by Major Infrastructure Projects in the Study Area of Bruce Highway project for TMR (Queensland) under its National Asset Centre of Excellence research program (Wu et al., 2020). The project aims were:

- to provide an understanding of the economic cost of traffic congestion on Bruce Highway north of Brisbane
- to evaluate the effectiveness of smart motorway treatments that were implemented in previous years
- to assess the potential impacts of a series of major infrastructure projects on Bruce Highway.

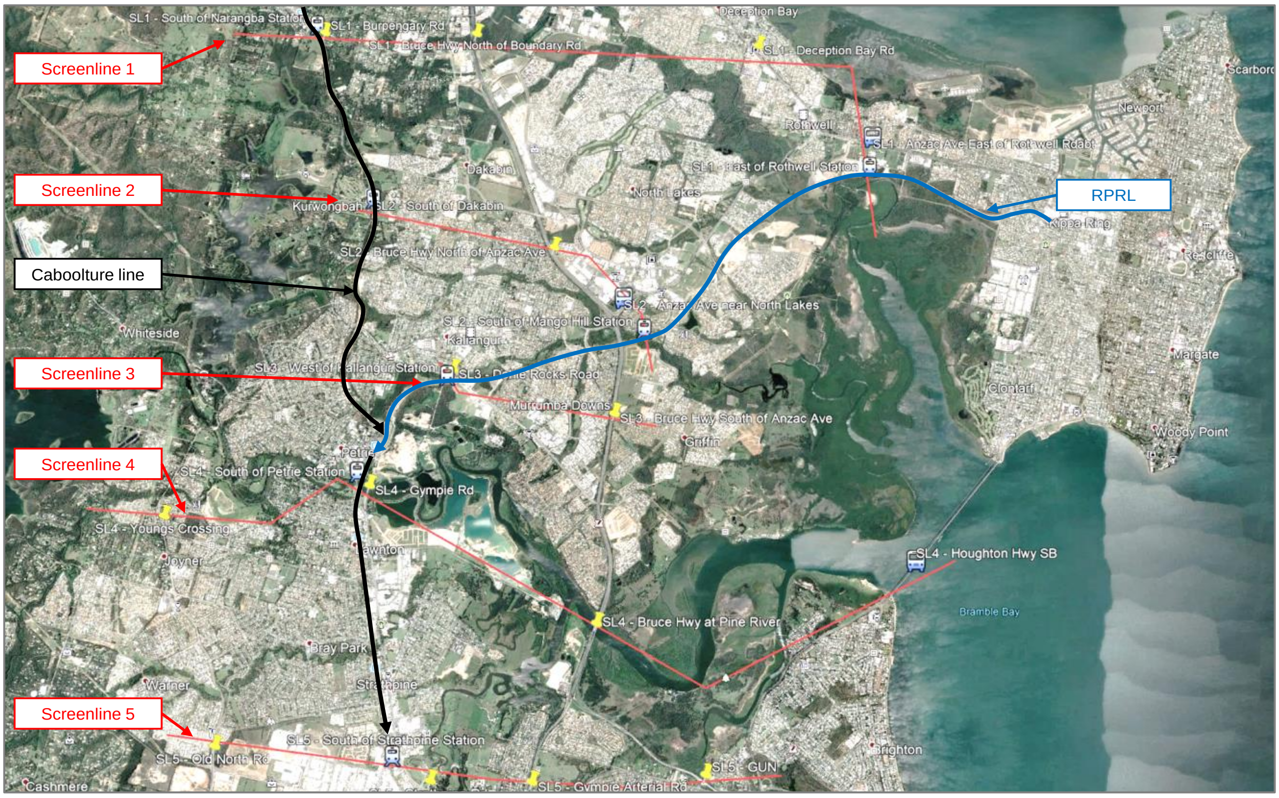
The project focused on understanding how people's travel choice had changed after the local rail network (Redcliffe peninsula line) and Bruce Highway were upgraded. The project involved a screenline approach that used data on highway traffic (STREAMS Intelligent Transport System and classified traffic counts) and data on bus and rail patronage (Queensland's GoCard system). Data on active transport was not included, as it was unavailable during the data-analysis period.

B.2.3.1 Data-collection method

The screenlines (see Table B.6 and Figure B.15) were designed to cross bus and rail routes and major traffic corridors (arterial roads and freeways). This enabled NTRO to create a representative dataset containing most travellers and commuters (it was not possible to capture traffic that crossed the screenlines on small local roads).

The project focused on traffic travelling towards the city during the morning peak (5am to 10am). To identify what impact the infrastructure upgrades were having on mode share, NTRO analysed public-transport data (the monthly average ridership on weekdays) and data on vehicles that crossed the screenlines. The traffic data covered five years (2015 to 2019), and the public-transport data covered 3.5 years (2016 to 2019). Traffic data was reported in 15-minute intervals, while public-transport data was reported for the morning-peak period. TMR aggregated the data for each screenline. It also converted vehicle-volume data to vehicle-occupant numbers, so that vehicle traffic could be compared with public-transport passengers.

Figure B.15 Locations of the study area and screenlines in the Benefits Achieved by Major Infrastructure Projects in the Study Area of Bruce Highway project, north Brisbane (reprinted from Wu et al., 2020, p. 24)



Note: The black line indicates the main north–south rail corridor (Caboolture line). The blue line indicates the new rail corridor introduced in 2016 (Redcliffe Peninsula Rail Line, or RPRL). The red lines represent the project's five screenlines, which cross the north–south travel corridors (arterial roads, freeways and rail lines), predominantly in a horizontal (east–west) direction. Screenline 5 is closest to Brisbane's inner city.

Table B.6 Transport corridors captured by screenlines in the Benefits Achieved by Major Infrastructure Projects in the Study Area of Bruce Highway project, north Brisbane (adapted from Wu et al., 2020, p. 25)

Screenline number	Bus routes	Rail lines	Arterial road links	Motorway links
1	2	2	2	1
2	1	2	2	1
3	1	1	1	1
4	3	1	2	2
5	1	1	2	2

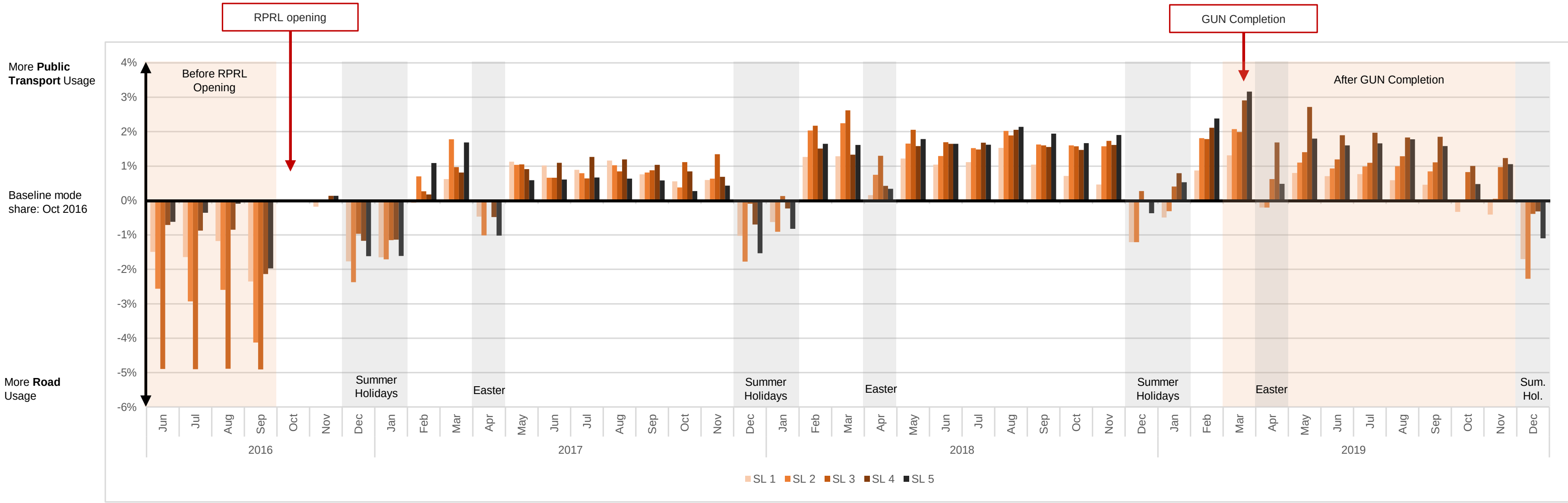
B.2.3.2 Data reporting and data use

The project's results clearly show that the infrastructure investments have affected travel patterns (Wu et al., 2020). After the new rail line (RPRL) opened in late 2016, passenger numbers increased steadily until March 2019, which increased the mode share by public transport. In contrast, when the motorway upgrade (Gateway Upgrade North, or GUN) was completed in March 2019, there was a noticeable shift away from public transport and towards private vehicles, which reflects significantly lower congestion levels during the morning peak.

These trends are visualised in Figure B.16. For each month in the chart, five columns represent data for the five screenlines. Positive percentages indicate a shift towards public transport compared with the baseline data recorded in October 2016. Negative percentages indicate a shift away from public transport compared with the baseline data. Before the RPRL opened, and during summer and Easter holidays, negative percentages are observed. Once GUN was completed in March 2019, a drop in public-transport usage is apparent: the trend of increasing uptake of public transport reverses.

This project's approach enables mode shift to be detected within a few months of implementing infrastructure measures (in this case, the measures were a new rail line and freeway upgrade). However, the project team suggest having a longer period of 'after' data, to allow for more robust detection and analysis of mode-shift trends.

Figure B.16 Mode share and mode shift between public transport and private vehicles, northern Brisbane metropolitan region (2016–2019) (reprinted from Wu et al., 2020, p. 37)



Note: For each month in the chart, five columns represent data for the five screenlines (SL). Holiday periods (summer and Easter) are indicated with grey shading. The RPRL opened in October 2016 and the GUN was completed in March 2019. Before and after periods are indicated with orange shading.

B.2.3.3 Limitations of this approach

Data cleansing and data fusion are a major challenge for this type of project. For this project, filling data gaps and managing inconsistencies within each dataset was especially challenging. It was also difficult to combine PKT with VKT at a granular level. This required TMR to provide average vehicle-occupancy rates for all vehicle types and aggregate daily weekday travel data to monthly data.

B.3 Link-based approaches

B.3.1 Hamilton City Council

HCC has developed a link-based approach to monitoring traffic across the city. It collects data from 12 sources for 6 transport modes (car travel, cycling, freight, scooter riding, public transport and walking) (see Figure B.17). It records vehicle data using tube counters and SCATS®.

HCC uses Briefcam (CCTV analytics) to record the volume of active transport. Eco-Counter (see Section 2.4.3) is also operating in Hamilton. When HCC started collecting data in 2020, it used Be Counted and Bellwether counters, but it has now developed a custom camera-based traffic counter (see Figure B.18) with a private technology company.

HCC also uses these data sources:

- **AddInsight**, which provides data from sensors that are installed at intersections. The sensors detect nearby Bluetooth devices. The sample rate of this data is relatively consistent, although increasing over time, but varies between intersections.
- **Strava**, which counts trips by OpenStreetMap edges, for cyclists who record their trips on the app.
- **Lime**, which collects GPS data from Lime scooters.
- **Bee Card**, which records where and when people get on and off buses, what type of ticket they have and what route they take.
- **EROAD**, which provides freight-vehicle data from telematics systems.

Figure B.17 Data sources used by HCC to count traffic and measure mode share (adapted from Hamilton City Council, personal communication, 2023)

Mode	Walking	Cycling	Scooter riding	Public transport	Freight	Car travel
Count	bellwether opito BriefCam	opito BriefCam Be Counted Technology	opito	Waikato Regional Council Te Kaunihera ā Rohe o Waikato	CoLab RATA opito	scats opito CoLab RATA addinsight
Pathing [a]	near	STRAVA	Lime	Waikato Regional Council Te Kaunihera ā Rohe o Waikato	EROAD	addinsight

[a] Pathing refers to data sources that have the capacity to follow a user's full travel path.

Figure B.18 A custom counter used by HCC to count active transport (reprinted from Hamilton City Council, personal communication, 2023)

B.3.1.1 Data-collection method

HCC collects continuous data from the 12 data sources in Figure B.17. With this approach, HCC combines:

- counts of people using all transport modes, but only at some locations (known as 'all at some locations')
- crowdsourced data collected city-wide, but only for people using some transport modes (known as 'some at all locations').

By fusing the count data with crowdsourced data, HCC can see the relationships between the two data types and estimate city-wide movements. This work involved cleaning the datasets and then fusing them to form a single common output layer. HCC encountered these issues when it fused the datasets:

- Lines or edges from AddInsight, Strava and EROAD are not consistent with each other, so HCC had to develop a method to map and integrate them into a single map layer.
- Points at discrete locations may join to multiple edges around the point and spread out to a threshold met by traffic volume or a change to the road environment.
- GPS points need to be carefully matched to the coordinates of the correct road links (for example, to avoid joining a side road). The periodicity of the data (such as, the sampling rate) also needs to be investigated).

HCC developed a custom base layer of the transport network using OpenStreetMap (this includes roads, cycle paths and so on). It simplified this to a single edge per direction, while maintaining edges such as off-road shared paths. One example of why HCC needs the custom base layer is to estimate the number of cyclists. Estimating the number of cyclists involves using a model that scales the Strava count based on its relationship with the total count. To mitigate bias in Strava data, HCC adds attributes, such as facilities that may support cyclists, like public carparks. During the model training process, counters are randomly left out of the dataset. The model's predictions are tested against the omitted counters to validate their accuracy.

The models that estimate cyclists, freight vehicles, pedestrians, private vehicles and scooters all use some form of modelling correlations against sample data. HCC considers that the only 'true' counts are those of public-transport patrons, which come from the touch-on/off Bee Card. HCC uses this data to calculate people's journeys, along the most probable route from their OD.

Where possible, HCC estimates or measures these metrics for individual roads:

- Number of private vehicles (number of passengers is based on an occupancy survey that shows the average occupants per vehicle is 1.3).
- Number and percentage of heavy vehicles.
- Number of buses, and number of people on buses.
- Total number of vehicles (this is sum of the counts of private vehicles, heavy vehicles and buses).
- Number of cyclists, pedestrians and scooters.

B.3.1.2 Data reporting and data use

HCC publishes PowerBI dashboards that summarise its traffic and cycling data (Hamilton City Council, 2023). However, it is still developing its approach to measuring mode share and has not yet published outputs for this. In the meantime, it has created dashboards and data visualisation for internal use (see Figure B.19, Figure B.20 and Figure B.21).

HCC uses its mode-share data for several purposes:

- **Analysing mode share before and after an intervention**: HCC's data analysis and visualisations allow it to detect changes to mode share after an intervention (such as, upgrading an intersection) and see what effects this has on active and public transport in the surrounding area. HCC's platform makes it much simpler for the council to collect relevant data at a project site to analyse changes in travel patterns. HCC has joined all its available data (this includes counts and mode-share data) into a single base layer, which reduces its need to obtain datasets from several sources.
- **Observing mode-share trends**: After it establishes the baseline mode share for road links, HCC can evaluate mode shift over time, as it implements projects across Hamilton city. It can aggregate data, to analyse how people's mode choice varies by area and time of day.
- **Responding to data requests**: HCC can give consultants or the public access to its platform and dashboards, where they can download data (this includes mode-share data) or analyse patterns in mode volume for a given period or area.

Figure B.19 Proportion of people travelling by bus, bike, car and foot on Hamilton city streets (2021) (reprinted from Hamilton City Council, personal communication, 2023)

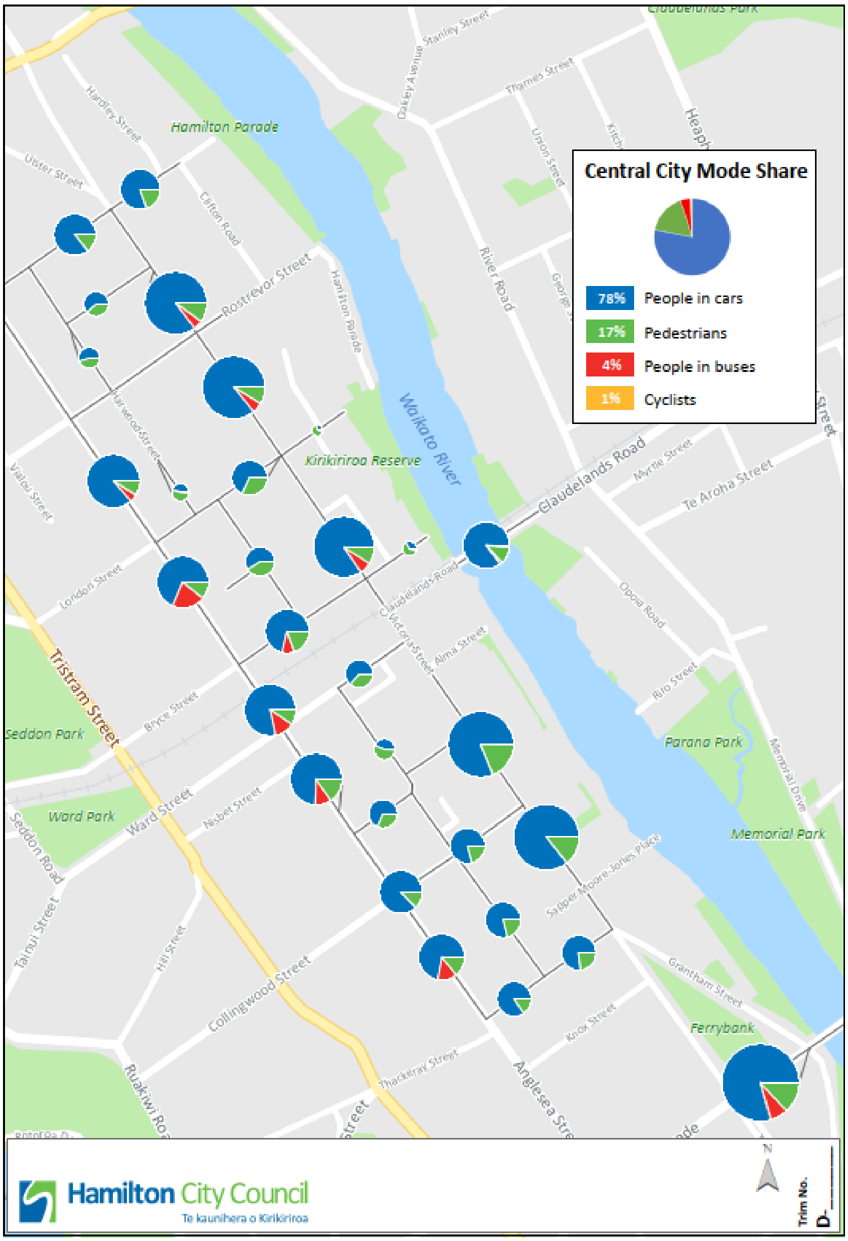
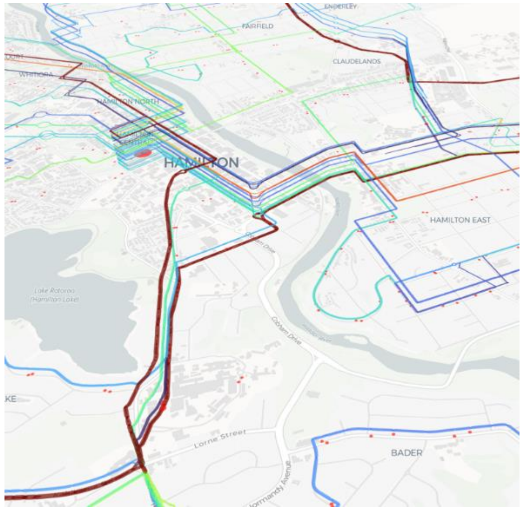


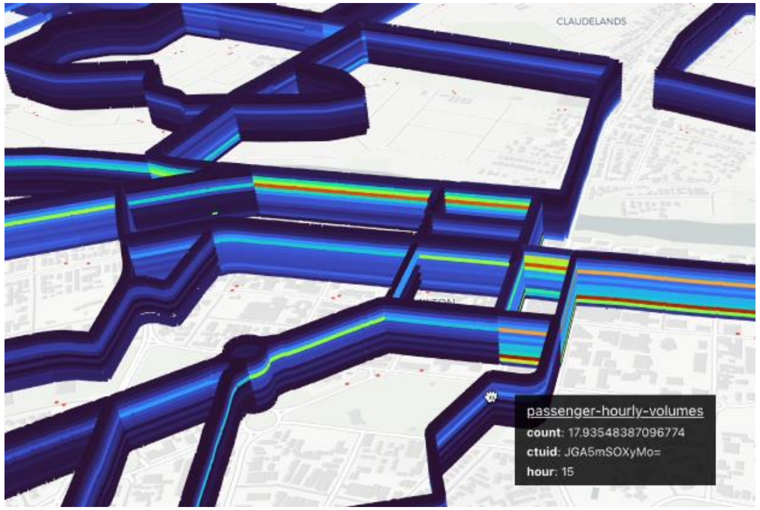
Figure B.20 Examples of visual data on travel by public bus and walking, Hamilton (reprinted from Hamilton City Council, personal communication, 2023)

(a) Number of people using buses, by route



Note: Where there is more than one route running on the same street (such as, through the city centre), these are stacked on top of each other.

(b) Number of people on buses, by road and time of day

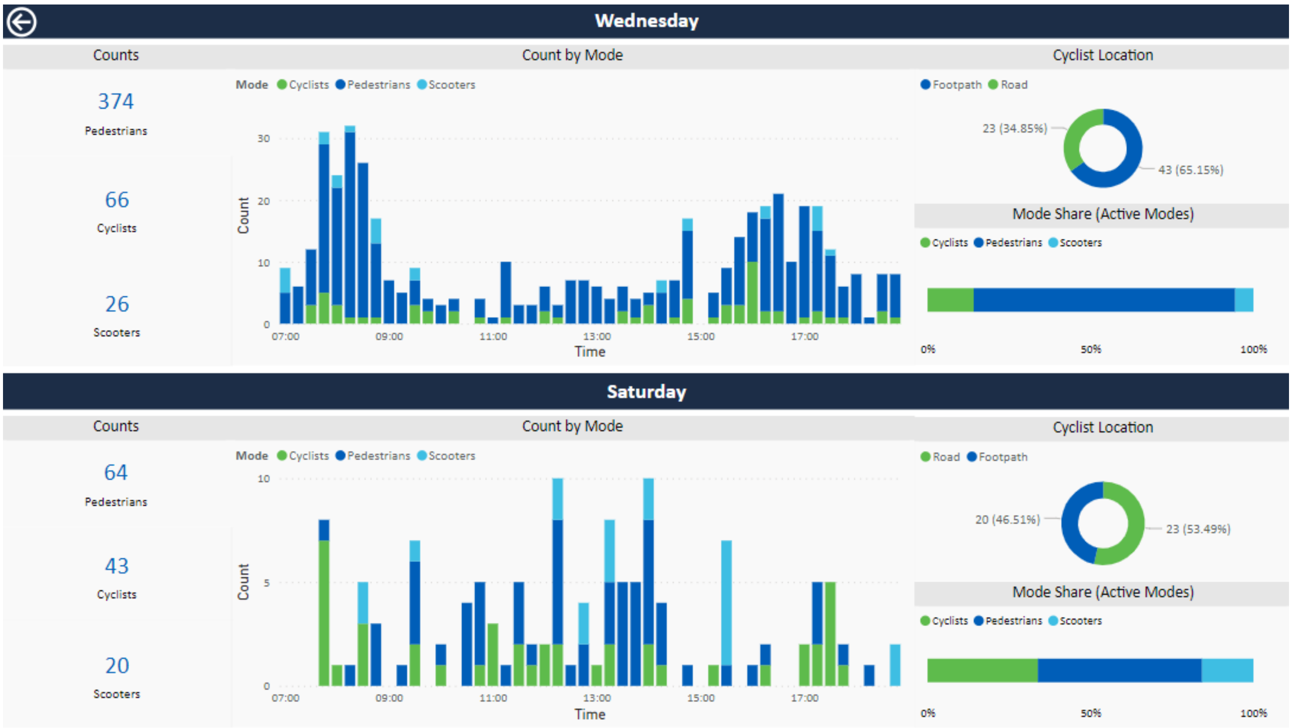


Note: The top of each line represents passenger volume at 6am, through to the bottom of each line representing passenger volume at 8pm. Users can see data for the direction of travel by rotating the map in the visualisation tool.

(c) Estimated volume of pedestrians in the city centre

Note: Lighter colours indicate higher pedestrian volumes.

Figure B.21 Example of visual data on active transport on Rostrevor Street, Hamilton City (reprinted from Hamilton City Council, personal communication, 2023)



B.3.1.3 Limitations of this approach

To develop this approach, HCC had to invest significant resources and effort into developing and validating the data-cleansing and data-fusion methods.

Currently, HCC cannot measure PKT for active-transport modes; it has PKT data only for public transport (via Bee Card) and cars (via numberplate recognition). HCC is not currently prioritising capturing other information, such as OD.

In future, HCC envisages improving these aspects of its approach:

- **Estimating vehicles**: HCC has a large amount of data on the total volume of vehicles, collected from approximately 250 locations. However, it needs do more work on estimating the volumes on local roads. Near[22] (see Figure B.17) has been a valuable source of data on the relative volumes on local roads.
- **Calculating mode share for trip legs**: To do this, HCC needs to model trips from OD data, which is available, in some form, for each mode of transport.

B.3.2 Wellington City Council

WCC has committed to investing NZ$1 million, over the next five years, into installing new monitoring technologies and developing a consistent approach to monitoring travel, so it can better understand how vehicles and people move around the city.

WCC has already started rolling out VivaCity camera-based sensors across the city (see Section 2.4.2.2), to replace the current cordon approach (see Section B.2.2) that has been in place since the late 1990s

[22] Near is now called Azira. To find out more about this product, visit https://azira.com

(Wellington City Council, n. d.-b). These sensors allow WCC to continuously monitor the transport network, whereas the current approach provides only a limited snapshot of morning-peak travel. With its new approach, WCC will be able to perform three types of monitoring:

1. Continuously monitoring travel behaviour throughout the city, for strategic purposes.
2. Monitoring transport projects, from before they start to after they complete (often over three years), to see their effects on travel behaviour and mode share.
3. Monitoring mode share for three to five months before a project is agreed, to assist with planning.

WCC started installing VivaCity sensors in September 2023. By December 2023, it had installed 36 across 24 locations (some locations have two or three sensors). By March 2024, it aims to have 80 installed, covering the city's strategic network. Typically, the sensors are mounted to existing streetlights or traffic-signal poles, with signs indicating their locations.

B.3.2.1 Data-collection method

The VivaCity camera-based sensors collect data continuously, and report traffic counts every five minutes. The data can be viewed online on the VivaCity dashboard or downloaded for further analysis. WCC is developing its own data-analysis methodology. Currently, it downloads data manually to produce analysis reports and dashboards. However, it plans to set up automatic downloads into its own data warehouse, to which NZTA will have access.

Up until 2022, WCC and GWRC used Eco-Counter technology (Wellington City Council, n. d.-a) to count cyclists and pedestrians (see Section 2.4.3 and Section B.2.2). This approach collected data only during the morning peak (7am to 9am), and only for traffic that crossed the cordon into Wellington city centre. This data on cyclist counts from 2000 to 2021 is available on the WCC website (Wellington City Council, n. d.-c).

WCC is now phasing out the Eco-Counter approach, replacing it with data from the VivaCity sensors in similar locations.

B.3.2.2 Data reporting and data use

The VivaCity dashboard (see Section 2.4.2.2) gives WCC these outputs:

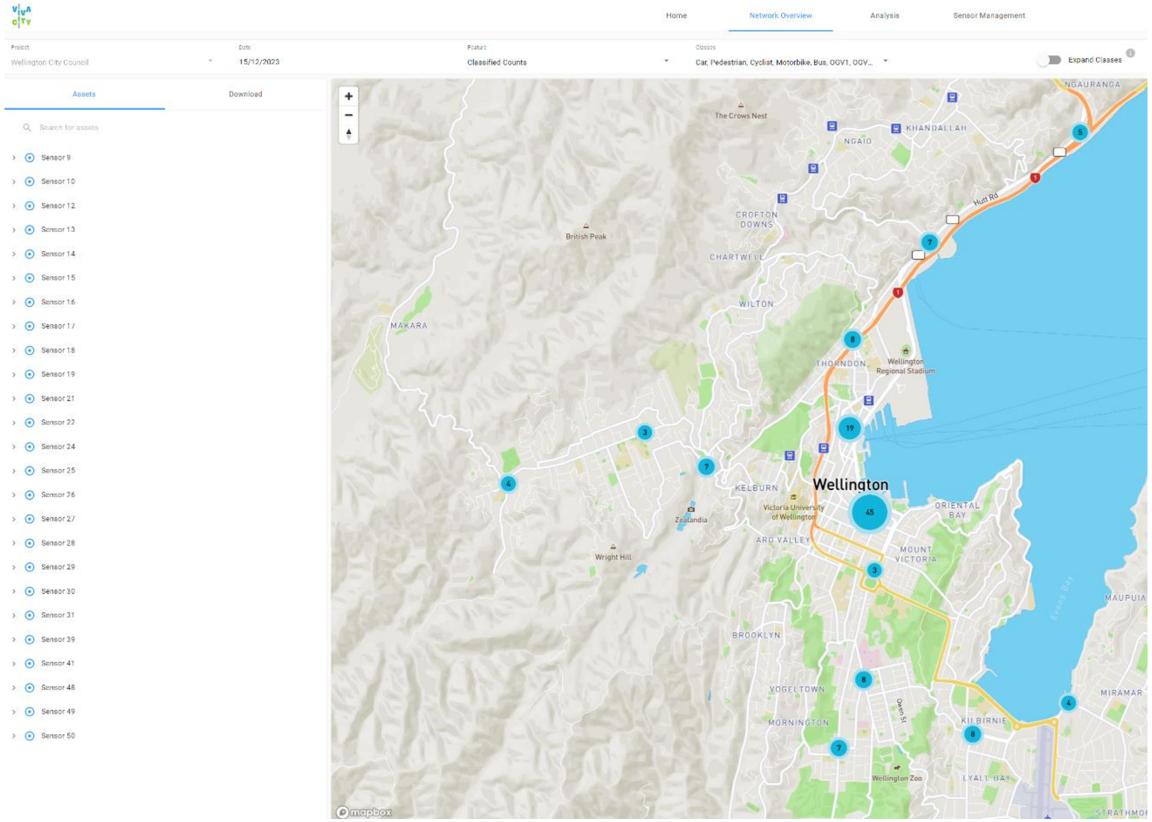
- Data visualisations for each location (camera) by individual days. It is possible to aggregate this data to weeks and months.
- Reporting on up to 32 modes of transport. The primary modes are bicycles, buses, cars, emergency cars, emergency vans, fire engines, minibuses, motorbikes, pedestrians, rigid trucks, taxis, trucks and vans.
- Mode-share reporting, by count, average and percentile.
- Reporting on user-defined 'groups' (for example, a group could be several locations on a cycleway).
- Visuals of turning zones, which include dwell time and occupancy at intersections in those zones. Dwell times can give insights into traffic volume and flow.
- Data on speeds across user-defined count lines, which can be aggregated at different speed intervals.
- A visual 'track view', which summarises the paths that all transport modes take.
- Analysis of journey times (this is based on numberplate recognition) (WCC has not enabled this feature).

Figure B.22 to Figure B.26 give examples of the insights that the VivaCity dashboard gives WCC. While VivaCity is a proprietary tool, these examples show the range of ways that WCC can use the data.

WCC currently uses this data for individual projects only, while it develops the infrastructure for data downloads and methods for data analysis. In future, however, this data will provide broader insights into how people use Wellington's transport network and streets (for example, which bus stops people use, which cycle routes and paths they prefer and which businesses they visit). These insights will help WCC decide its transport strategies and city planning. The data will also help WCC monitor the impact of construction on the city's transport and economy. WCC plans to combine the data with other datasets (such as, weather, retail spend and road closures), which will also help inform decisions (WCC, n. d.-b). Continuously monitoring mode share will also give WCC the ability to analyse how travel is affected by natural disasters (such as, earthquakes and tsunamis).

Figure B.22 Sensors and count lines in Wellington (December 2023) (reprinted from Wellington City Council, personal communication, 2023)

(a) Numbers of sensors across Wellington



(b) Locations of count lines at city-centre intersections, covering multiple directions and transport modes

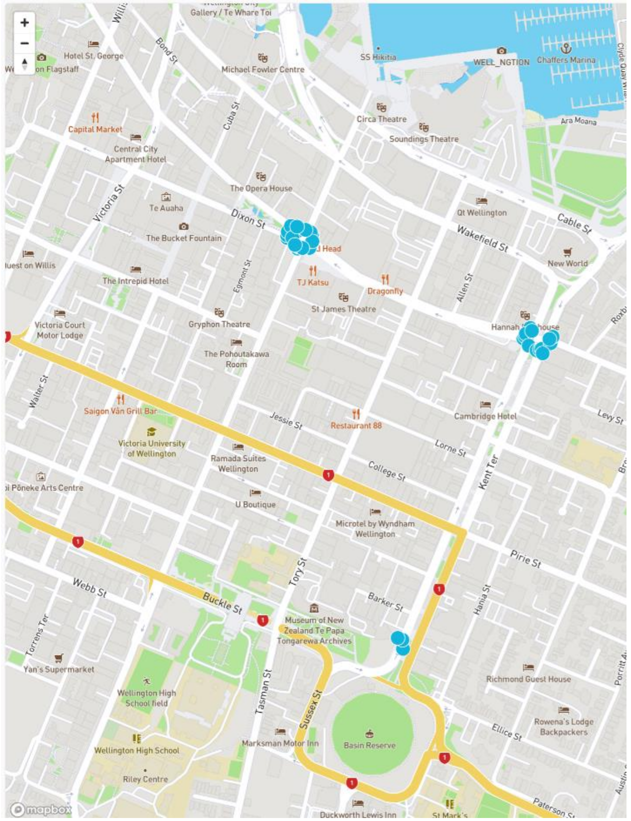
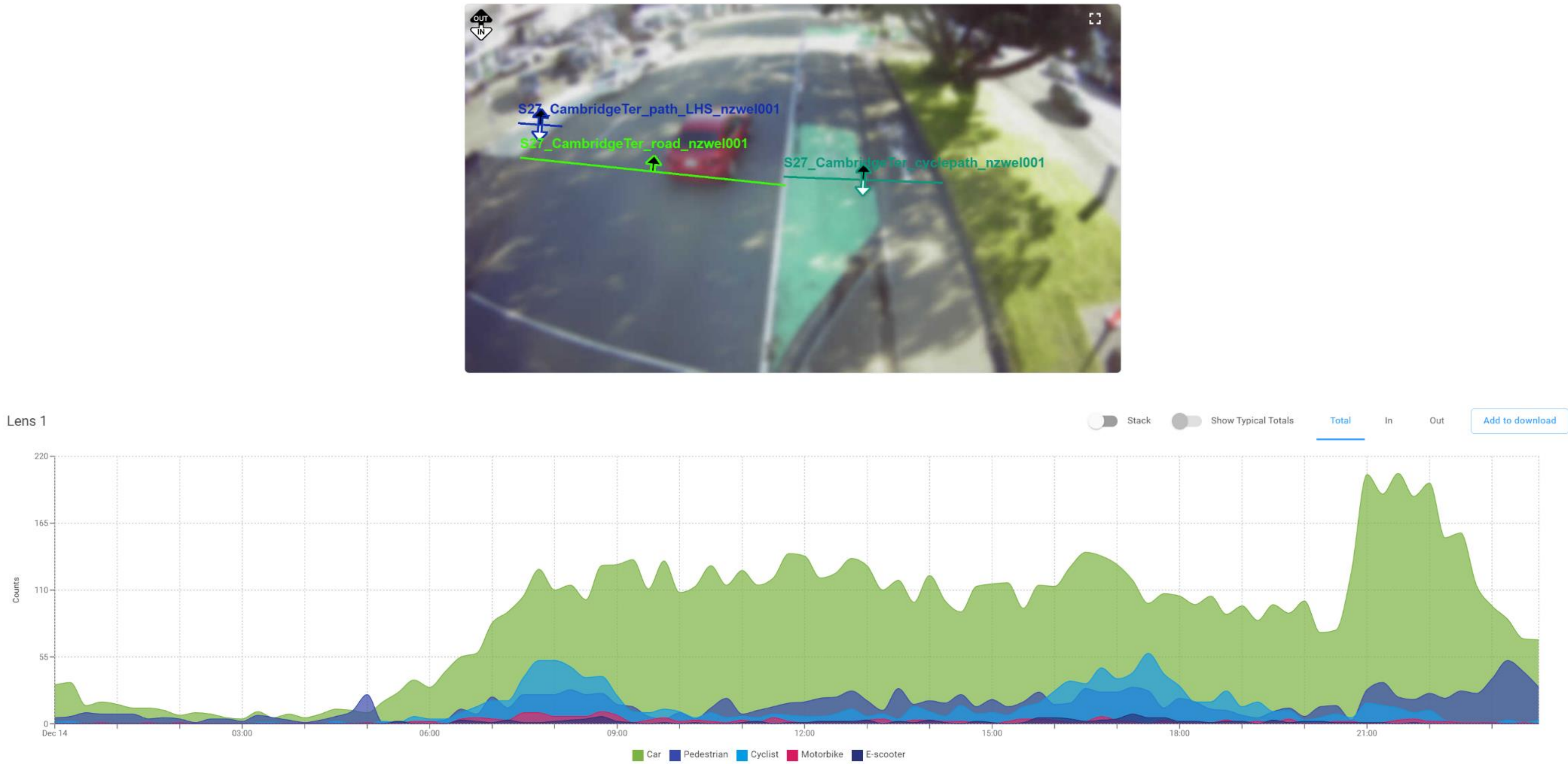
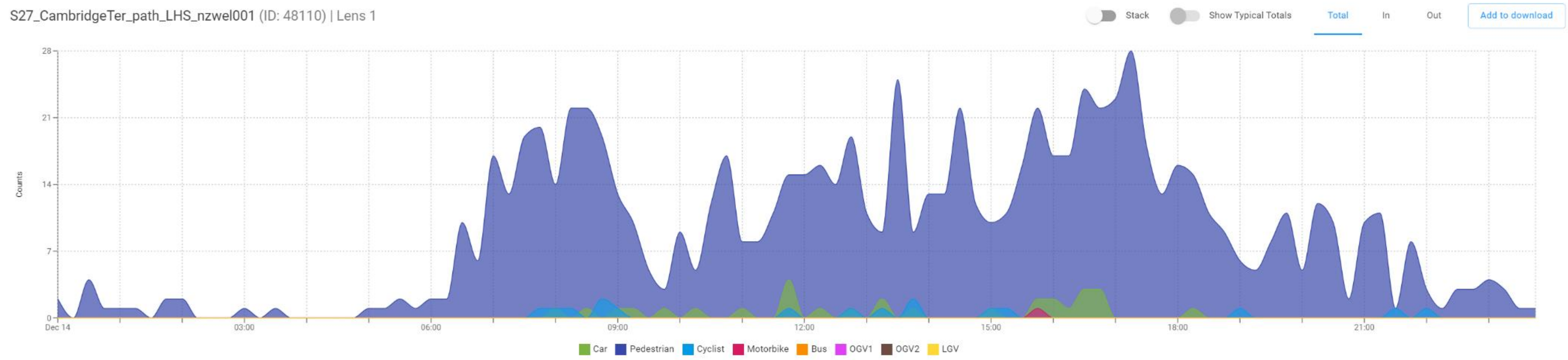


Figure B.23 VivaCity data visualisation for Cambridge Terrace, Wellington (2023) (adapted from images supplied by Wellington City Council)

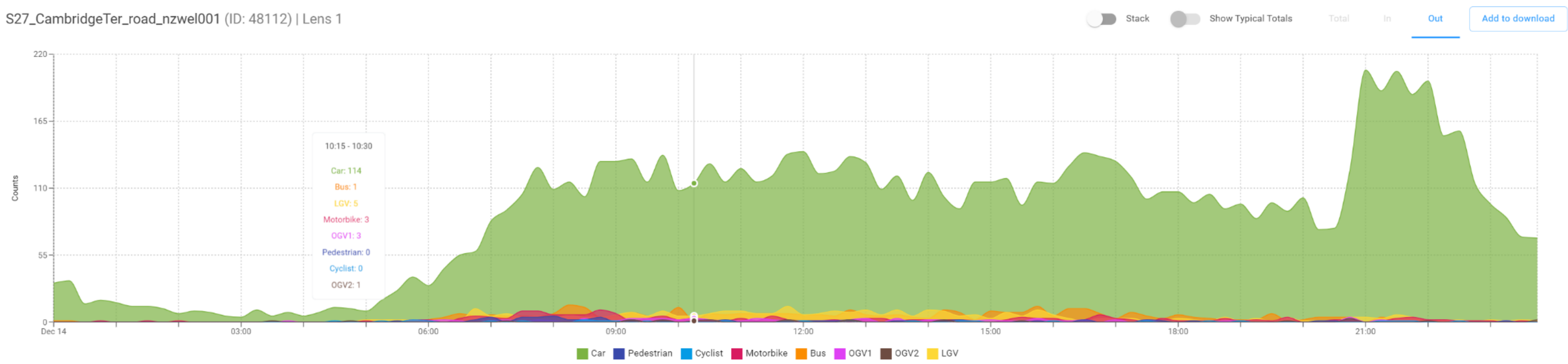
(a) Top: Image from the camera sensor. Bottom: Count of cars, pedestrians, cyclists, motorbikes and e-scooters over 24 hours



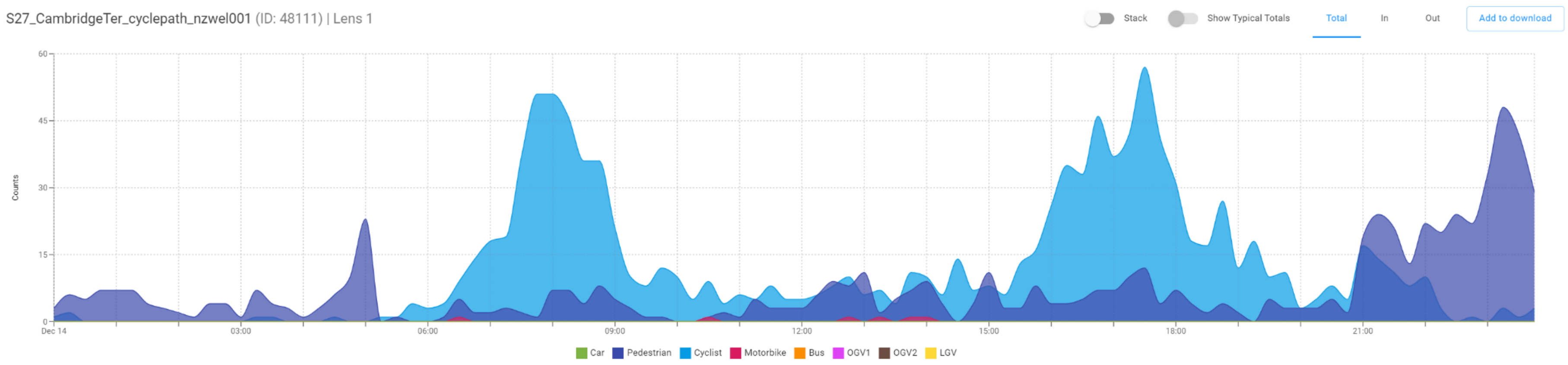
(b) Counts of travel activity for the footpath count line over 24 hours



(c) Counts of travel activity for the road count line over 24 hours

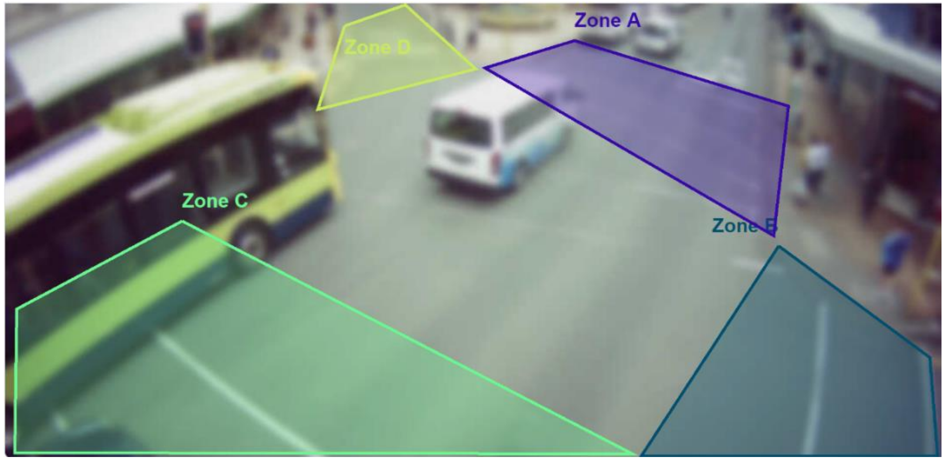


(d) **Counts of travel activity for the cycleway over 24 hours**



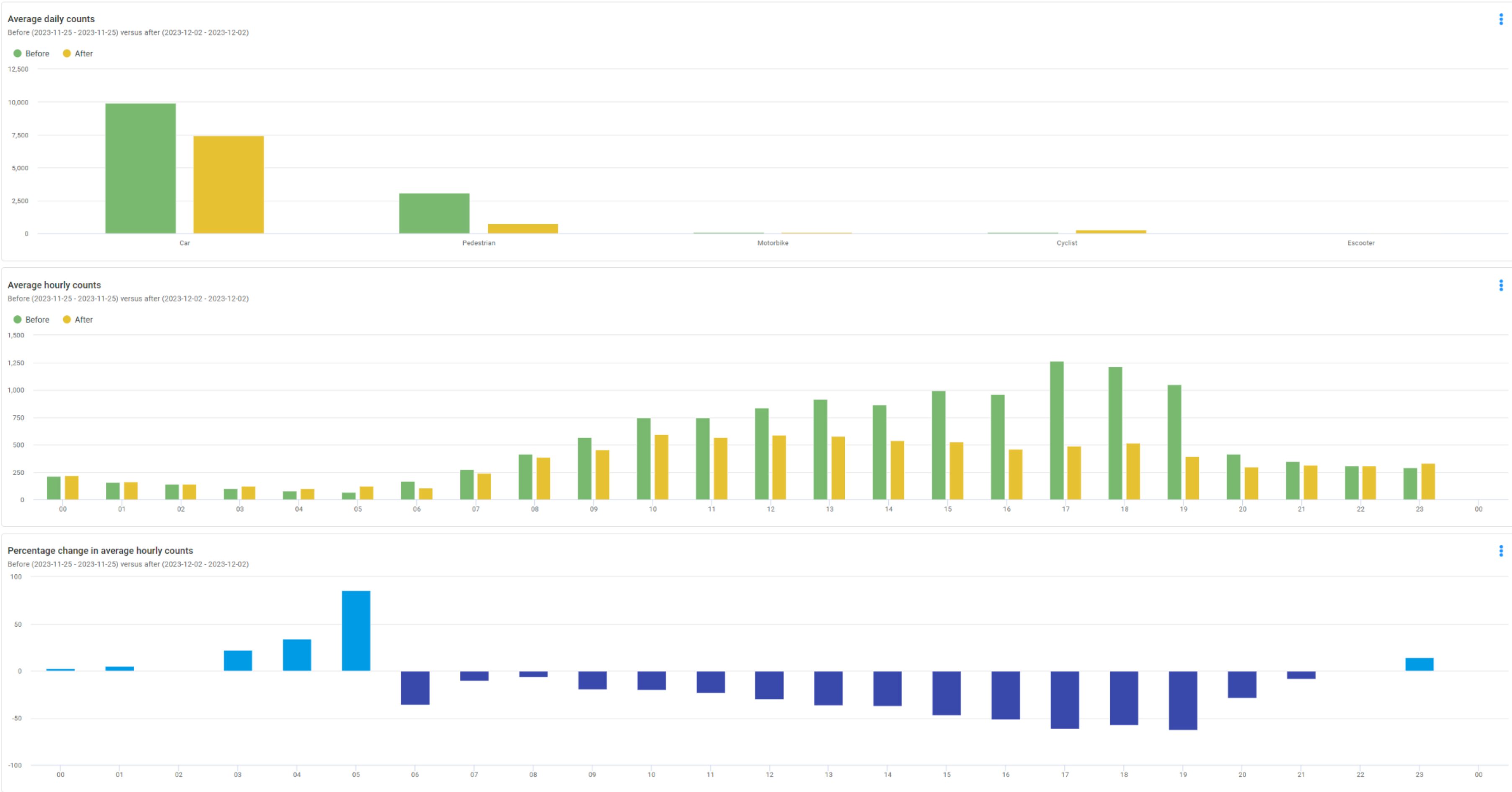
Note: The data visualisations show buses (orange), cars (green), cyclists (blue), light commercial vehicles or LGV (yellow), heavy commercial vehicles, or OGV1 and OGV2 (pink and brown, respectively), motorbikes (red) and pedestrians (purple).

Figure B.24 VivaCity turning zones, Wellington (2023) (adapted from image supplied by Wellington City Council)



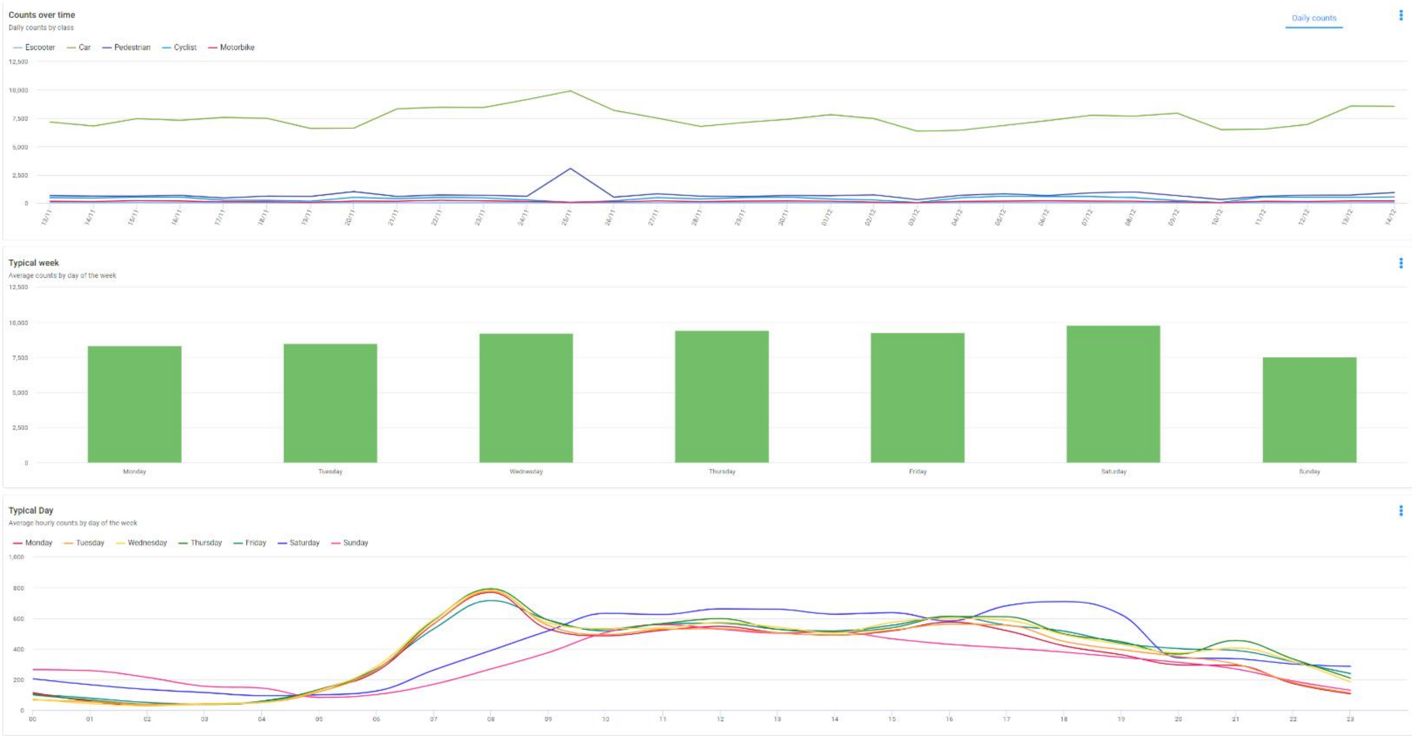
Note: Turning zones track the movements of road users as they move from one zone to another. Tracking is specific to different modes of transport (that is, cyclists, pedestrians and cars are reported separately).

Figure B.25 Example of VivaCity intervention analysis of mode share and mode shift for different time periods, Wellington (2023) (adapted from image supplied by Wellington City Council)



Note: Intervention analysis can be used to compare counts between two periods, to examine the impact of an intervention on mode share. This example compares mode share on a typical Saturday (yellow, ‘after’ data) with a Saturday when an event was held (green, ‘before’ data). The blue and purple bars show the percentage difference in hourly traffic on the typical Saturday, compared with the event Saturday (blue = more traffic; purple = less traffic).

Figure B.26 VivaCity analysis of mode share over one month, Wellington (2023) (adapted from image supplied by Wellington City Council)



Note: Trend analysis allows users to analyse count line data for up to a year and explore typical day and week patterns for all transport modes.

B.3.2.3 Limitations of this approach

WCC's current datasets have established baselines that WCC can use to analyse long-term trends. However, the depth of insights it can obtain are limited by insufficient sample sizes and geographic coverage (VivaCity Labs, 2024). WCC could overcome this problem by carefully selecting monitoring locations and installing more sensors across the region.

The cost of providing a power source to the sensors (in Wellington and Christchurch some sensors cannot easily connect to existing power on streetlights) and managing traffic while they are installed, can be significant. This is a potential barrier to this approach.

B.3.3 International approaches

This section summarises some approaches that are used internationally. It focuses on Europe, where it is common for authorities to collaborate across borders.

Many mode-share studies still rely on volume counters at fixed locations (Xiao et al., 2022). London has traditionally relied on traffic counts and a household travel survey to estimate mode share and mode shift (Transport for London, n. d.). London has introduced infrastructure initiatives aimed at reducing mode share by cars and increasing walking and cycling (this includes Low Traffic Neighbourhoods with modal filters for motorised vehicles). To monitor mode share, it has mostly relied on in-person surveys and traffic counts rather than using innovative techniques (Aldred & Goodman, 2020). However, measuring the shift to active transport, especially walking, is acknowledged to be difficult (London Living Streets, 2021). Bristol has used VivaCity sensors to measure the shift to cycling resulting from new and improved infrastructure (VivaCity Labs, 2022).

In Europe, the non-profit organisation European Platform on Mobility Management (EPOMM) brings together governments from various European countries.[23] EPOMM has developed a modal split tool known as TEMS, which aims to produce information that compares the modal split of all European cities, using data supplied by EPOMM member states and countries. At the time of writing, we found no information about how this data is collected.

Many countries around the world are developing innovative big-data approaches using smartphone data. Liu et al. (2023) present a novel big-data method for estimating carbon emissions that uses LBS data from smartphones in China. This method involves an estimation model that uses residents' inputs about their daily travel behaviours (this includes travel mode, distance and time). The model has been applied to provide real-time monitoring of emissions in Hangzhou, China from over 245,000 road links across the city. The LBS dataset used to develop the model was provided by a large technology company. It contained more than nine million travel records, covering 10 to 20% of all travellers. The LBS data was processed and fused with other data sources (such as data from traffic flows, taxis, rideshare, buses, metros and bikeshare) and base spatial data (that is data on the road network and POI) to create information on trips performed by the users. It also imputed the transport mode for the trips, using five travel modes: bicycle, bus, car, metro and walking. The method to fuse the data uses a density-based spatio-temporal clustering algorithm and random forest algorithm, to identify and match trips to location POI. The results are displayed visually on an interactive dashboard (see Figure B.27) that covers all scales – from road links to the region – and most travellers (from LBS data or estimates). This approach is feasible in China, because only a few apps are available, and a large proportion of the population use them for multiple purposes. However, in other countries, its application is currently limited.

[23] To find out more about EPOMM, visit https://epomm.eu

Figure B.27 Dashboard screenshots of (top left) link-level carbon emissions, (top right) regional carbon emissions, and (bottom) summary statistics for travel and emissions, Hangzhou, China (provided by Dr Simon Hu, Transport Systems & Environment Lab, Zhejiang University)

Appendix C: Smartphone applications

Table C.1 summarises the smartphone applications that are used to measure travel behaviour.

Table C.1 Smartphone applications that measure travel behaviour

Product	Developer (country)	Type	Data			Imputes travel mode	Uses	Estimated cost
			Survey	Location	Other			
ATLAS II	University of Queensland (Australia)	Research	✓	✓		No, user labels trips	HTS and academic studies	Unknown
Avicenna	Avicenna Research (Canada)	Commercial	✓	✓	✓	No	Mainly health-related research	Unknown
Daynamica	Daynamica (US)	Commercial	✓	✓	✓	Yes	Health and travel projects	US$20–50k
Itinerum	Concordia University (Canada)	Open source	✓	✓	✓	Yes, using device activity-recognition frameworks	Studies in Canada	Cost of building own app and setting up server for data
Mobile Market Monitor	Mobile Market Monitor (US)	Commercial	✓	✓	✓	Yes	Numerous studies around the world	Unknown
OpenPATH	NREL (US)	Open source	✓	✓	✓	Yes	Many worldwide, including the NSW travel survey during the COVID-19 pandemic	Free (NREL hosted version) or cost of building own app and setting up server for data
RECORD	MOTIONTAG (Germany)	Commercial	✓	✓	✓	Yes [a]	Several apps in Europe	Initial setup is €3,300 plus cost for 1,000 users is €4,400 per month or 3,000 users is €6,600 per month
RMOVE	RSG Inc. (US)	Commercial	✓	✓	✓	Yes, but also prompts user to verify after trip	Many worldwide	Unknown

Product	Developer (country)	Type	Data			Imputes travel mode	Uses	Estimated cost
			Survey	Location	Other			
Sesamo	Mobidot (Netherlands)	Commercial	✓	✓	✓	Yes, using device activity-recognition frameworks	Local, regional and national mobility panels in Europe	Unknown
TravelVu	Trivector AB (Sweden)	Commercial	✓	✓		Yes, requires user to review and adjust (if needed)	Numerous studies around the world	Unknown

[a] Detects walking, cycling, car, subway, train, regional train, bus, tram, rapid transit railway and airplane.

Appendix D: Assessment of data sources

Table D.1 presents our descriptive assessment of the data sources we reviewed against the criteria in our assessment framework (see Table 3.1). It is not possible to directly compare the data sources, so we give a short qualitative description of their ranking. We did not assess the data sources against criteria 3 and 7, as these criteria are not useful for assessing the data source only.

Table D.1 Descriptive assessment of data sources to measure mode share and mode shift

Data source	Criterion 1 Mode coverage	Criterion 2 Responsiveness/ reporting frequency	Criterion 4 Data accessibility	Criterion 5 Data analysis and processing	Criterion 6 Sample size	Criterion 8 Cost [b]
Household travel surveys	All modes are reported: bicycle, car driver, car passenger, motorcycle, other (this includes long-distance transport), public transport (bus, train and ferry), and walk	Low responsiveness Infrequent data collection (annually or less)	Good (government-owned)	Requires significant data processing	2,000 to 4,000 households per year Multiple years of data are required for a representative sample size	Significant NZ$1–2 million, or > $500 per household
Manual surveys	Any mode can be covered at survey locations	Reasonable responsiveness, depending on how frequently the survey is conducted (monthly or less)	Good (government- or authority-owned)	Requires significant data processing	Limited sample size for a single survey over a few hours up to several days Reasonable coverage is possible with multiple survey sites or frequent data collection	Cost depends on frequency and coverage of data collection. For example, AT's cordon survey cost NZ$10,000 per site and was conducted quarterly
SCATS®/TMS	Two mode groups: private and semi-private transport Requires mode imputation	Good responsiveness, as data is collected continuously Reporting available as required	Good (government- or authority-owned)	Requires significant data processing	All road vehicles in selected locations within an area Focuses on major roads and transport corridors	Significant data-processing costs, due to the high volume of data

Data source	Criterion 1 Mode coverage	Criterion 2 Responsiveness/ reporting frequency	Criterion 4 Data accessibility	Criterion 5 Data analysis and processing	Criterion 6 Sample size	Criterion 8 Cost [b]
Fare data	All public transport This is the only option that accurately captures travel by rail and ferry	Good responsiveness, as data is collected continuously Immediate reporting	Good (government- or authority-owned)	Requires data processing, which can be done by authorities that own or manage fare data	All public-transport users May require adjustment (for example, to manage fare dodgers or paper-ticket users)	No cost for data Processing costs may be significant
Bluetooth	Two mode groups covered: private and semi-private transport Some public transport and active transport may be possible Requires mode imputation	Good responsiveness, as data is collected continuously Continuous reporting available	Good, but data is managed by a third-party provider, which requires a subscription or collaboration	Requires significant data processing Pre-processed or cleansed data may be available from contractors	Most travellers, as it covers anyone with a Bluetooth-enabled phone Possible to cover a reasonable area Focuses on motorised transport	Cost to procure data Cost to process data may be significant
Cameras with AI	All modes except trains and ferries	Good responsiveness, as data is collected continuously Continuous reporting available	Good, but data is managed by a third-party provider, which requires a subscription or collaboration (a subscription is available in some authorities' areas)	Cleansed and processed data is available via a dashboard	All travellers and vehicles at camera locations Possible to cover a large area, depending on the number of cameras	Cost for data or subscription (usually third-party provider)
Eco-Counter	Two modes: active transport – walking and cycling	Good responsiveness, as data is collected continuously Continuous reporting available	Good, but data is managed by a third-party provider, which requires a subscription or collaboration (current subscription is available)	Cleansed and processed data is available via a dashboard	All active transport at data-collection sites Some cover motorised transport Possible to cover a large area	Cost for data or subscription (third-party provider)

Data source	Criterion 1 Mode coverage	Criterion 2 Responsiveness/ reporting frequency	Criterion 4 Data accessibility	Criterion 5 Data analysis and processing	Criterion 6 Sample size	Criterion 8 Cost [b]
Smartphone sensors and applications [a]	All modes	Good responsiveness, as data can be collected continuously Immediate reporting	Reasonable, but privacy issues may be a hurdle or costly to manage	Requires significant data processing Off-the-shelf apps are available that provide processed data	Limited sample size Sample size may be affected by privacy concerns or limited funding	Cost to procure data Cost to process data or subscribe to an off-the-shelf product may be significant
Telco data	All modes Estimates approximate locations only Requires mode imputation	Good responsiveness, as data is collected continuously Immediate reporting	Difficult, as proprietary third-party data can be a hurdle	Requires significant data processing Pre-processed or cleansed data may be available from contractors	Able to capture most travellers within the coverage area	Cost to procure data Cost to process data may be significant
Crowdsourced data	All modes Coverage of public transport is limited, but covered by fare data	Good responsiveness, as data is collected continuously Immediate reporting	Depends on source. Some free and easily accessible data is available	Data may be pre-processed or accessible via a dashboard May require data fusion from multiple data sources	All or some within selected population groups (such as, cyclists, hire-scooter users, rideshare users) Sample is biased	Possible cost to procure data unless it is free to access Cost to process data depends on the data source
Tube counters	Two mode groups covered: private and semi-private transport Counts of bicycles and PMDs may be possible Requires mode imputation	Reasonable responsiveness, as data is collected continuously or at intervals (monthly or annually)	Good (government- or authority-owned)	Requires significant data processing Pre-processed or cleansed data may be available from contractors	All road vehicles at a data-collection site Coverage of an area is possible, depending on the number of data-collection sites	Significant data-processing costs and costs of contractors

[a] Smartphone sensors and applications are considered together, because their technologies overlap.

[b] Cost information is indicative. It is difficult to determine cost, as it depends on several factors (such as, service provider, sample size, area coverage and data-collection frequency).

Appendix E: Data specifications for proof-of-concept dashboard

Table E.1 lists the data specifications we developed for the proof-of-concept dashboard, after reviewing data collected for the pilot study. This data can be used to calculate mode share. Depending on the approach used, mode share can be estimated from counts or PKT (for an area that has multiple links), or both.

To display mode-share data on a map, spatial data is needed. Table E.2 lists the data specifications we developed for the proof-of-concept dashboard's spatial input files. These files use the GeoJSON data format.[24]

Not every authority will need every data field (for example, only Auckland needs ferry data). In these cases, the field is left blank.

It is straightforward to extend the data specifications to additional transport modes in future (such as adding PMDs or categorising private vehicles).

Table E.1 Data specifications for the common input file for the proof-of-concept dashboard

Column	Type	Description
Authority	Text	Name of authority
Type	Categorical	Type of mode-share estimate (screenline or link)
Description	Text	Description of data
ID	Text	Unique identifier for entry (link or screenline) used to link with spatial data
Year	Date	Year of measurement/estimate
Month	Date	Month of measurement/estimate
Day	Date	Weekday or weekend (also supports day of the week)
Hour	Time	Hour of measurement/estimate
Direction	Text	Direction of measurement (inbound, outbound or both)
Aggregation method	Text	Description of how data is aggregated
Cyclist count	Number	Count of cyclists at screenline or link
Pedestrian count	Number	Count of pedestrians at screenline or link
People in buses count	Number	Count of people in buses at screenline or link
People in ferries count	Number	Count of people in ferries at screenline or link
People in trains count	Number	Count of people in trains at screenline or link
People in private vehicles count	Number	Count of people in private vehicles at screenline or link

[24] To find out more about GeoJSON, visit https://geojson.org

Table E.2 Data specifications for the spatial input files for the proof-of-concept dashboard (geoJSON)

Properties	Type	Description
Geometry type	Type	Type of geometry (such as line or multiline)
Coordinates	Number	Coordinate data for geometry of road, screenline or other feature
ID	Text	Unique identifier to link with mode-share data
Name	Text	Description of data (such as, name of road, segment or screenline)
Link length	Number	Road length in kilometres (where applicable)

Note: Multiple files may be required, as Tableau does not currently support different geometry types in a single file.