Draft Indicative Business Case

Wellington Bus Priority Programme

A report prepared by Wellington City Council, Greater Wellington Regional Council and RDC Group

29 November 2019

Contents

Appendices

Glossary

ATAP	Australian Transport Assessment and Planning Guidelines
BCR	Benefit cost ratio
CL	Cycle length
DBC	Detailed business case
EEM	NZ Transport Agency's Economic Evaluation Manual
g/CL	Green time to cycle length ratio
GWRC	Greater Wellington Regional Council
HCM	Highway Capacity Manual
HTS	Household Travel Survey
IBC	Indicative business case
MCA	Multi-criteria analysis
PT	Public transport
RTI	Real-time information
RTRB	Road traffic reduction benefit
SCATS	Sydney Coordinated Adaptive Traffic System
TCQOSM	Transport Capacity and Quality of Service Manual
V/C	Volume to capacity ratio
VKT	Vehicle kilometres travelled
VoT	Value of time
WTSM	Wellington Transport Strategy Model

Executive summary

Status of the business case

This business case has been collaboratively developed by Wellington City Council and Greater Wellington Regional Council working with Waka Kotahi NZ Transport Agency. The business case assesses the case for a proposed investment in improving bus journeys on key transport corridors in Wellington City. This document provides the evidence base and analysis to underpin the Bus Priority Action Plan (final draft, dated December 2019).

It is anticipated that this indicative business case (IBC) will form part of a wider business case process for the investment in the Let's Get Wellington Moving (LGWM) City Streets programme. This will be a staged and ongoing process as routes and sections are prioritised and more detailed analysis is undertaken on a corridor-by-corridor basis. As such, some sections of this business case have not been completed.

The case for more reliable and quicker bus journeys

Public transport is a very efficient use of limited space on our constrained road network. It enables more people to move with fewer vehicles. Currently most bus travel times cannot compete with car journey times and travel times are highly unreliable, especially during peak periods.

This business case identifies the locations where bus priority is most warranted, matches issues with appropriate bus priority measures, generates options that will be effective and deliver value for money, and proposes priorities for delivery. There is a strong case for delivering bus priority urgently; not only do passengers experience substantial delays and reliability issues, but bus priority measures are also likely to have substantial benefits and offer value for money.

The strategic case of the IBC presents an investment logic map, reconfirms why bus priority is important for Wellington, and identifies eight corridors where bus priority is urgently needed. It sets out five investment objectives for bus priority in Wellington:

- move more people with fewer vehicles – increase the proportion of people using public transport or biking on key corridors by X percent by 2030
- improve people's perceptions of the reliability of the bus system by X percent by 2030
- increase the reliability of bus travel times on key corridors by X percent by 2030
- reduce the average travel times of buses on key corridors by X percent by 2030
- improve the place quality of the key corridors.

Bus priority is important for Wellington for a number of reasons. The city has an extensive and very highly utilised bus network that provides the primary form of public transport. We have seen steady growth in bus patronage in Wellington City over the past decade and we need to ensure this continues by providing more capacity in the bus system and making bus journeys more attractive. To deliver our goal of moving more people with fewer vehicles, journeys by bus must be more competitive with journeys by car. In recent times, the bus system has had extensive challenges resulting in disruption and considerable public concern about reliability of services. Analysis shows that bus services have substantial speed and reliability issues, and that these issues affect a lot of people.

To identify the priority bus corridors for improvement, three criteria were used:

- high daily passenger volumes
  - this was defined as 2500 or more passengers per direction on an average day
- slow bus operating speeds
  - this was defined as average daily speeds of less than 15km/h
- high levels of bus travel time variability
  - this was defined as variability within the morning (AM) or evening (PM) peak of more than 15 %.

We estimate that almost 70 percent of total AM peak bus trips on the Wellington City network traverse the priority corridors at some point. This shows that improvements on these corridors have the potential to benefit most of the people who use the buses.

For the bus priority programme covered by the remainder of this business case, analysis has been completed for the following eight corridors, ordered by passenger volumes:

- Newtown to city
- Karori to city
- Johnsonville to Ngauranga
- Seatoun to city
- Mt Cook to city
- Kelburn to city
- Kilbirnie to Newtown
- Brooklyn to city.

In the economic case, we identify and assess options for addressing the problems identified in the strategic case; and identify three scenarios that demonstrate the costs and benefits associated with differing levels of bus priority.

For the eight bus priority corridors, we identify and assess options using a staged process.

First, we analyse the existing performance of the eight key corridors to:

- identify locations and time periods where buses are delayed
- identify specific issues that contribute to these delays, which include narrow bus stop spacing, excessive dwell times at bus stops, delays re-entering traffic from bus stops, delays at traffic lights, slow running speeds due to narrow road widths, and queuing and slow running times due to general traffic congestion.

Second, we define a bus priority toolkit, which is a set of specific interventions that can be applied to address delays and other performance issues on bus corridors.

Third, we undertake suitability screening to identify which bus priority measures are applicable to specific parts of the bus corridors. This consists of three screens:

- Appropriateness**:** Is the magnitude of the problem worth fixing?
- Effectiveness**:** Will the tool be effective in addressing the issue?
- Feasibility**:** Is it technically possible to implement?

Fourth, we group these interventions into three potential packages for the purposes of indicative cost benefit analysis. These options vary in terms of how comprehensively they address the documented bus performance issues. The first option focuses on minimal interventions that will improve bus performance while minimising disruption, the second option focuses on fixing the worst problems, and the third option aims to fix everything.

Option 1 (fix everything) is expected to deliver the largest improvement to average travel times. Averaged over all corridors, it is expected to cut AM peak travel time delay by approximately 50 percent. Option 2 (fix the worst problems) also delivers a similar level of benefits, reducing delay by about 40 percent. Option 3 (minimal interventions) only reduces delay by about 6 percent.

Under options 1 and 2, bus travel speeds would become increasingly competitive with peak-period car speeds. Inbound speeds during the AM peak would rise from their current average of under 13km/hr to between 18 and 20km/hr. Faster bus speeds will in turn:

- directly benefit bus passengers by making it easier for them to reach their destinations
- encourage additional public transport use by making buses more useful for more people
- contribute to a reduction in general traffic congestion by enabling some people to shift from driving to public transport.

Fifth, we undertake an indicative cost benefit analysis of the three packages to understand which option gives better value for money. We use this information, combined with estimates of the effectiveness of each option, and wider strategic priorities, to identify a recommended investment programme.

We find that:

- Under central assumptions, option 1 would lead to an increase of almost 1200 peak-hour public transport trips and divert around 400 car trips. Option 2 would lead to roughly 80 percent as much mode shift, while option 3 would lead to less than 10 percent as much mode shift.
- Option 2 would deliver a benefit cost ratio (BCR) above one, indicating that it is likely to deliver value for money. Option 1 is expected to have a BCR near one, while option 3 is expected to have a BCR substantially below one, reflecting the fact that it delivers the smallest improvements to journey times while incurring significant fixed costs for engagement and consultation.
- Option 2 is expected to have the highest BCR, reflecting the fact that it targets interventions to locations where problems are most acute.

Costs and delivery of the programme

In the financial case, we calculate implementation costs, identify funding sources, and outline a preliminary approach to implementation.

Implementation costs include capital costs and operating costs and are expected to total to between $25 and $193 million, with a central estimate of $99 million. Renewal costs and residual value have not been considered at this stage.

It is anticipated that the bus priority measures outlined in this business case will be integrated into the City Streets programme of LGWM. This includes planning, engagement, funding and delivery. City Streets has an indicative budget of around $350 million. This will be funded through the LGWM partnership funding model as this is developed and finalised.

The eight corridors have been broken into 15 segments for prioritisation and delivery. We identify a recommended approach to staging the programme for delivery using a multi-criteria analysis that compares the scale of opportunities on each corridor with the expected difficulty of implementation. These have been prioritised for improvements based on passenger volumes, the size of the problems, and the value of the expected benefits if option 2 improvements are implemented.

Each segment has been assigned a planning priority for both early improvements and longer-term upgrades. An early improvements programme has been identified which has been designed to deliver some meaningful changes as soon as possible.

With regard to delivering longer-term improvements, each segment will go through a further detailed analysis and community engagement phase before draft options are identified as part of the detailed business case phase. Community consultation will inform the selection of the preferred option which will need the City Council’s agreement under a traffic resolution process. Segments will be progressed in parallel as much as possible within the constraints of funding, planning and delivery resources.

The approach to delivering bus priority will be further developed to reflect the implementation approach and integration with the City Streets programme as this is developed in early 2020.

The commercial and management cases will be further developed to reflect the implementation approach and integration with the City Streets programme. These will be informed by the LGWM partnership and funding agreement.

Introduction

1. A case for investment in more reliable and quicker bus trips

This business case has been collaboratively developed by Wellington City Council and Greater Wellington Regional Council working with Waka Kotahi NZ Transport Agency. It assesses the case for a proposed investment in improving bus journeys on key transport corridors in Wellington City. This document provides the evidence base and analysis to underpin the Bus Priority Action Plan (final draft, dated December 2019).

This business case follows the Transport Agency's business case approach. This approach and the structure of the document is based on the Treasury Better Business Cases guidelines, which are organised around the five-case model designed to systematically test whether an investment proposal:

- is supported by a robust case for change – the strategic case
- will deliver optimal value for money – the economic case
- is commercially viable – the commercial case
- is financially affordable – the financial case, and
- is achievable – the management case.

This document is an indicative business case (IBC). Its objectives are to confirm the preferred way forward for the programme and to develop a short-list of options for each corridor for further detailed analysis. It focuses on developing the strategic and economic cases for the programme and includes a high-level outline of the financial, commercial and management cases. It has not been possible to fully complete the commercial and management cases as the programme will be integrated with and delivered through LGWM (see below).

The business case is supported by detailed appendices, including economic evaluation and analysis and evidence base of the issues and opportunities on each route.

2. Integration with Let's Get Wellington Moving (LGWM)

The development of this business case has been in the context of and direction from the LGWM programme business case and recommended programme of investment. This programme includes investment in bus priority measures to and through Wellington City as part of a City Streets programme.

In order to ensure alignment of planning, funding and delivery, the recommended programme in this IBC and the Bus Priority Action Plan will be delivered as part of the City Streets programme of LGWM. This approach has been endorsed by the LGWM Board and both Wellington City Council and Greater Wellington Regional Council.

LGWM is a shared programme between Wellington City Council, Greater Wellington Regional Council and Waka Kotahi NZ Transport Agency. LGWM will create a safer, more people-focused central city, a mass rapid transit route from the central city to the southern and eastern suburbs, and improvements to the state highway corridor.

The City Streets programme aims to make better use of the key urban corridors to optimise the use of road space for:

- people in buses
- people on bikes
- people walking
- safety for all users
- attractiveness of urban centres
- network optimisation.

This IBC and the Bus Priority Action Plan have been developed focusing mainly on bus priority because of the urgent need to improve the speed and reliability of bus journeys. This includes the need to advance a programme of minor, lower-cost and lower-risk early improvements on priority routes as soon as possible. It is also expected that this IBC will release funding for an identified programme of early improvements to be made in a relatively short timeframe.

All work in the LGWM programme will need to take a whole-of-transport-system / multi-modal approach as there is a significant overlap between the bus priority corridors, Wellington City's network of cycling routes, and the proposed LGWM mass rapid transit route.

Where bus priority corridors overlap with LGWM's longer-term planning, bus priority improvements will either be integrated into those plans or delivered as shorter-term improvements in the meantime.

More work is therefore needed to develop a multi-modal, whole-of-street approach along identified corridors where possible. This will be completed as part of subsequent stages of the business case process.

It is anticipated that this IBC will form part of a wider business case for investment in the City Streets programme. This will be a staged and ongoing process as routes and sections are prioritised and more detailed analysis is undertaken on a corridor-by-corridor basis

This further analysis will develop the preferred improvement options for that corridor in detail. This will require corridor-by-corridor engagement to inform the detailed design, as well as detailed consideration of financial, commercial and management aspects.

Strategic case

3. Background

Let's Get Wellington Moving (LGWM) is a joint initiative between Wellington City Council, Greater Wellington Regional Council, and Waka Kotahi NZ Transport Agency. The LGWM programme business case has been endorsed by the partner organisations.

LGWM has defined the problem[1] as:

Wellington is a great place to live, work and visit. However, our transport system is starting to impact on Wellington's liveability, and its economic growth and productivity.

Wellington's transport problems include:

- growing traffic congestion and unreliable journey times
- poor and declining levels of service
- safety issues, especially for cycling and walking
- vulnerability to disruption from unplanned events.

Over the next 30 years it is projected there will be 50,000 to 80,000 more people living in Wellington and 22,000 to 31,000 more jobs in the central city.

That means more people travelling into, out of, and through central Wellington.

Improvements are needed to make our transport system work for everyone, and make the most of what the city has to offer.

Wellington's unique geography, compact city, and small number of transport corridors means transport challenges are complex to solve and trade-offs will be required. However, with the right mix of improvements, big gains can be made for Wellington's future.

This business case focuses on the key transport corridors which lead to and through the central city. They are the primary routes for public transport and the planned cycleway network so integrated multi-modal solutions are required. This business case does not address the mass transit proposal or proposed highway investments but needs to take account of the likely form and timing of these to ensure the investments identified by this programme are compatible with those proposals.

4. Key objectives

The objectives of LGWM are to:

- enhance the liveability of the central city
- provide more efficient and reliable access for users
- reduce reliance on private vehicle travel
- improve safety for all users

[1] LGWM Programme Business Case, draft released 21 June 2019.

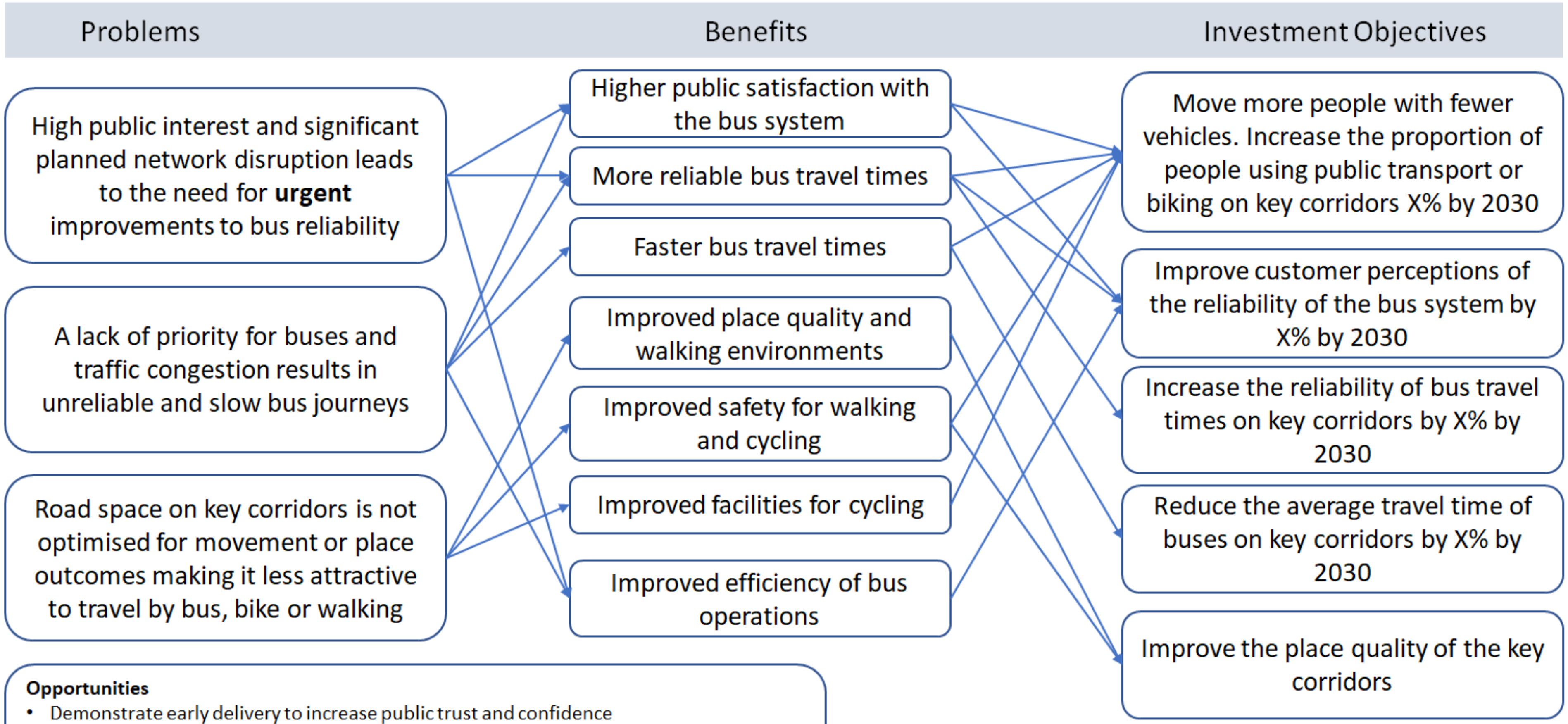
- make the transport system adaptable to disruptions and future uncertainty.

The bus priority programme is expected to contribute to achieving these objectives to some extent, but has a specific focus on providing more efficient and reliable access and reducing people's reliance on private vehicle travel.

Specific bus-focused investment objectives will allow the programme to identify the best-performing solutions. The investment logic map for bus priority is shown on the next page.

This investment logic map will be reviewed and updated as part of the development of the City Streets business case. This process will provide the investment objectives (including key performance indicators), priorities and trade-off criteria to guide the prioritisation and delivery of this wider City Streets programme.

Wellington City bus priority business case Investment Logic Map



Opportunities

- Demonstrate early delivery to increase public trust and confidence
- Help mitigate impacts of travel disruption from major LGWM projects
- Trial road space changes to enable future LGWM projects e.g. Mass Transit
- Improve place outcomes to enable social and economic outcomes
- Align with wider bus system improvements through the Bus Network Review

4.1. Programme partners

This programme development has been undertaken collaboratively by the partners, Wellington City Council and Greater Wellington Regional Council working with Waka Kotahi NZ Transport Agency as outlined in Table 1 and described in more detail in the following subchapters.

Table 1: Programme partners

PARTNERS	KNOWLEDGE AREAS / RESPONSIBILITIES
Wellington City Council	Planning land use and managing urban growth. Provision and operation of walking network, cycling network, and local road network (including bus priority measures).
Greater Wellington Regional Council	Strategic transport planning for the region. Provision of public transport services (buses and passenger rail).
Waka Kotahi New Zealand Transport Agency	Investor in land transport system through allocating the National Land Transport Fund. Provision and operation of the state highway network. Regulator of access to and use of the land transport system.

The process to develop this IBC involved:

- direction from the project steering group with executive leadership representatives from all partners
- oversight from the project control group with representatives from all partners, including connections to LGWM
- establishment workshops involving representatives of all partners on 12 April and 10 May 2019 to confirm the direction and scope of the work. These included executive leadership representatives from both councils
- forming a joint team of staff from both councils to extract, analyse and map data, review corridor provisions, complete indicative cost benefit analysis and document the findings. This team worked together to develop the IBC and Bus Priority Action Plan
- collating and analysing data and evidence to identify the priority corridors and the issues and opportunities on each corridor
- undertaking and documenting corridor analysis with charts / descriptions from travel time / delay analysis and opportunities
- developing an intervention logic process and toolkit of standard interventions to inform potential solutions for the issues identified
- workshops with a range of technical experts to test and refine the analysis of evidence and identification of opportunities
- identifying other contextual, modal and safety issues on each corridor to ensure a multi-modal approach is adopted

- identifying potential interventions, including early improvements, on each corridor
- developing network maps showing the key routes, issues and opportunities on each route
- team workshops to test findings and develop thinking, including for the multi-criteria analysis framework that was used to guide the prioritisation of routes
- talking with bus drivers to identify journey pain points
- providing updates to the Regional Council's PT users group and meeting with bus operators and the Tramways Union
- bus trips to experience travel conditions and issues, and site visits to verify and validate particular issues
- auditing the condition and quality of bus stops on the priority routes against expected standards and level of service for passengers
- a study trip to Auckland to visit sites and talk with colleagues in Auckland Transport, which has been implementing bus priority improvements over the last five years and is now developing a new Connected Communities programme for future investment
- testing the process, issues and opportunities with the bus network review project team at Greater Wellington Regional Council to ensure that passenger insights and experiences were helping to shape the programme
- ongoing discussions with City Council staff involved in other related work programmes to align activities, including LGWM, Planning for Growth, parking policy review, and the cycling programme
- discussions on how the implementation of the bus priority programme can be resourced, including opportunities to integrate it with LGWM and the city's cycling programme
- meetings with the Transport Agency about business case requirements
- testing and feedback on approaches to early improvements and trials with the Transport Agency's Innovating Streets for People programme
- identifying the challenges and opportunities of expediting the implementation of early improvements and minor works (such as bus stop improvements).

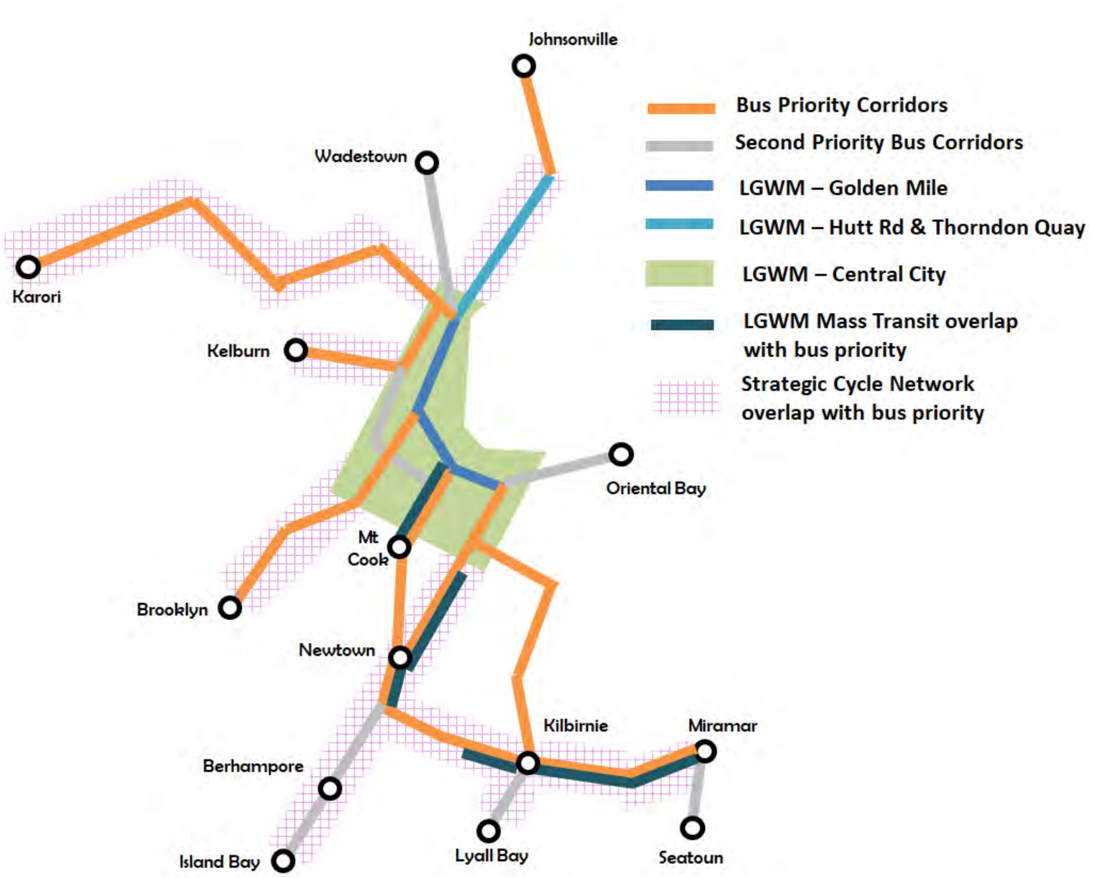
In June 2019 both councils endorsed the work being undertaken jointly and supported the development of a joint action plan. Both councils also received progress updates in August and November

The Bus Priority Action Plan was endorsed by the LGWM Board on 20 November, by Wellington City Council on 11 December, and by Greater Wellington Regional Council on 12 December 2019. This work will now be integrated into the City Streets programme.

5. Strategic and geographic context

The following map shows the corridors which are the focus of this business case and how they relate to the wider LGWM programme.

Figure 1: Strategic and geographic context



LGWM and the bus priority programme have been developed in the context of, and in alignment with:

- the Government Policy Statement on Land Transport Funding and the priority of supporting mode shift in urban areas
- Wellington City's strategic vision, Towards 2040
- the Regional Public Transport Policy
- the Regional Land Transport Plan.

It is integrated with:

- the Regional Council's bus network review
- LGWM's mass transit spine and early delivery programme
- the City Council's cycling programme, including Newtown Connections, Planning for Growth, Transport Strategy and parking policy review.

6. Reconfirming the programme

6.1. Why bus priority is important for Wellington

The vision for Wellington is to have the core characteristics of a globally competitive city and region. It will have a diverse knowledge economy, high amenity and liveability, high housing density and diversity, and a compact central city with strong regional connections.

We want our city and region to continue to grow and prosper, but increasing traffic volumes will detract from the city's amenity and liveability, eroding the things about Wellington that make it a great place to be.

Through the LGWM programme we plan to deliver an integrated transport system with high-quality walking, cycling, and public transport that supports efficient journeys and an attractive and compact city that's more sustainable, accessible and safe. This approach is aligned to the City Council's sustainable transport hierarchy, Urban Growth Plan, Te Atakura – First to Zero plan, and the strategic direction of the Regional Land Transport Plan and Regional Public Transport Plan. Public transport plays a critical role by providing access to jobs, education, and leisure activities, ensuring people have good travel choice and enabling the movement of more people with fewer vehicles.

While a mass transit system proposed by LGWM will provide another public transport option, we will still rely on our bus network to move many people. In the shorter term this is across the city, and in the medium to long term for those areas not served by the mass transit spine.

Wellington has an extensive and very highly utilised bus network that provides the primary form of public transport in the city. This includes:

- 70,000 boardings per day (average weekday)
- 18 million boardings per annum
- 15 to 20 percent of people working in the central city go by bus
- 75 percent of people live within one kilometre (a 10-minute walk) of a high frequency bus route.

Wellington's population is forecast to continue to grow by 50,000 to 80,000 people in the next 30 years, significantly increasing demand for travel. It's important that as many of those new trips as possible are by walking, cycling and public transport to support the city's vision.

There has been steady growth in bus patronage in Wellington City over the past decade and we need to ensure this continues by providing more capacity in the bus system and making bus journeys more attractive. Patronage growth has also been experienced right across the network, including rail and bus beyond Wellington City. A successful regional public transport network is critical for a successful functioning central city.

The bus network plays a vital role in the success of Wellington's transport system. The city's physically constrained urban street network (which cannot be completely served by rail) and the need for more sustainable and efficient forms of transport mean buses will continue to play a role in moving people around. Giving priority to buses over private vehicles is a more efficient use of Wellington's valuable road space and an essential step in being able to move more people with fewer vehicles. Effective bus priority contributes to:

- travel time savings for passengers
- ensuring buses run to schedule and journey times are reliable
- encouraging mode shift from private vehicles to buses
- potential reductions in travel times for private vehicles as a result of reducing the number of cars on the network.

Beyond their individual performance indicators, effective bus priority measures can be beneficial across a range of objectives including the environment, the economy, public health and social inclusion. The typical benefits we might expect to create with effective bus priority include:

- a reduction in greenhouse gases and local pollutant emissions as a result of mode shift to buses (less vehicle kilometres travelled creates fewer emissions)
- improved road safety outcomes as more people use the bus which is the least risky mode of transport
- improved public health outcomes caused by an increase in physical activity due to more people walking to bus stops (improved journey times may also increase peoples' willingness to walk further to bus stops)
- potential improved public health outcomes from reduced exposure to local pollutants such as carbon monoxide and particulates if mode shift occurs
- savings in the operational costs of running a bus service (which could be reinvested to further improve the service or broaden the network)
- a reliable and affordable means of transport which can improve accessibility for everyone, especially those without other transport options, such as older and younger people, or people with disabilities who may have restricted use of other modes.

Like any change to the urban transport network, implementing bus priority may pose challenges. These principally relate to changes in the street corridor, such as removal of on-street parking and the short-term disruption to people and businesses caused by construction. Changes in perceived level of access to the service can also occur, if rationalisation of bus stops is selected as an intervention. This can be challenging for passengers who will perceive that their level of access has been degraded. The extent of these challenges is dependent on the type and scale of interventions combined with the existing complexities in a corridor such as physical constraints or activities that are sensitive to disruption or parking removal, such as residential areas, retail and hospitality businesses.

6.2. The need to improve the reliability and speed of buses

To achieve the goal of moving more people with fewer vehicles we need to make journeys by bus more competitive with journeys by car. Many people who drive into and through central Wellington do so because they find driving quicker and more reliable than public transport. There is also a range of other factors that will need to be considered and which influence travel choices, including cost, convenience and comfort levels.

In recent times, the bus system in Wellington has had extensive challenges resulting in disruption and considerable public concern about reliability of services. This has particularly been the case since July 2018 when several significant changes were implemented, including the public transport operating model, new bus hubs, meal break legislation, and changes to routes and timetables. If buses are able to move through the network more efficiently, this will lead to better services overall – it will mean we can provide more services with the scarce resources of buses and drivers we have available.

There is strong public interest in the speed and reliability of bus journeys. This issue is illustrated through Nielsen's 2018 Quality of Life Survey which reported that just 56 percent of those surveyed from Wellington City thought public transport was reliable (this survey was conducted before the bus network changes in mid-2018). Similarly, Metlink's customer satisfaction survey (Gravitas, November 2018) reported just 61 percent of Wellington City respondents were satisfied with bus travel times.

These are not new challenges. Several studies over the years have identified the importance of improving bus reliability and journey times, with bus priority measures identified as a key response. Bus-on-bus congestion has also been recognised as impacting on reliability and journey times. One of the objectives of the new bus network, introduced in July 2018, was to reduce the number of buses on key corridors such as the Golden Mile to improve operational efficiency, improve reliability and provide opportunities to cater for future growth. Evidence to date demonstrates that this has been successfully achieved, although service provision is still less than expected due to driver shortages and other operational issues.

Greater Wellington has made it a priority to continue to improve the network elements of bus reliability and has an extensive programme underway to work through service issues. This includes working with bus operators to address driver shortages and adjust timetables. Wider initiatives will also improve service provision, such as integrated ticketing systems to be rolled out from 2021 and stage two of the bus network review, which is currently underway. The primary focus of this part of the review is to look at the network design and timetables with the community to determine if there are changes that can be made to better meet their needs.

6.3. The problem – evidence base for reliability and speed challenges

To get a high-level understanding of the scale of the problem, real time passenger information data has been analysed for core routes that, in combination, provide coverage along all the key bus corridors. For each section of each corridor, the analysis has been completed to understand:

- the average travel speed
- the range between peak and off-peak average speed
- travel time variability
- passenger volumes.

Reliability

The impact of traffic congestion on slow bus journeys is evident by the substantial variation in bus travel times along a given route at different times of the day and week. Achieving competitive journey times will always be challenging when buses are sitting in the same queue as general traffic.

The bus system needs to be reliable, so that people can be confident that it will arrive when they expect, and can get them to work, school or other places when they need to be there. Reliability therefore has a range of issues including:

- whether a bus service runs at all – addressing this is part of the wider programme of work to address bus service issues. While less than one percent of scheduled services are cancelled on average each day,[2] even this is unacceptable as it undermines the trust and confidence people have in the bus system

[2] https://www.metlink.org.nz/assets/Uploads/Metlink-Monthly-performance-report-Apr-19.pdf

- capacity at peak times to meet demand so that a service can pick up passengers along the route
- variability (or predictability) of bus travel times. Currently travel times are highly variable (unreliable) – they can vary by +/- 20 percent between one day and the next for the same service
- punctuality – whether a service runs to the scheduled time. This is directly impacted by the variability in travel times.

Case study of reliability of issues (March 2019, real-time data):

Route 1 Island Bay to Wellington Station is scheduled to take 40 minutes during the AM peak period, equivalent to an average speed of 12km/h for the eight kilometre route.

While observations show that peak-period journeys do take around 40 minutes on average, there is considerable variability in travel times and speeds from one day to the next.

Data shows a range of 16 minutes so the journey can take between 32 and 48 minutes (between the 15th percentile travel time of 32 minutes / 16km/h and 85th percentile travel time of 48 minutes / 10km/h).

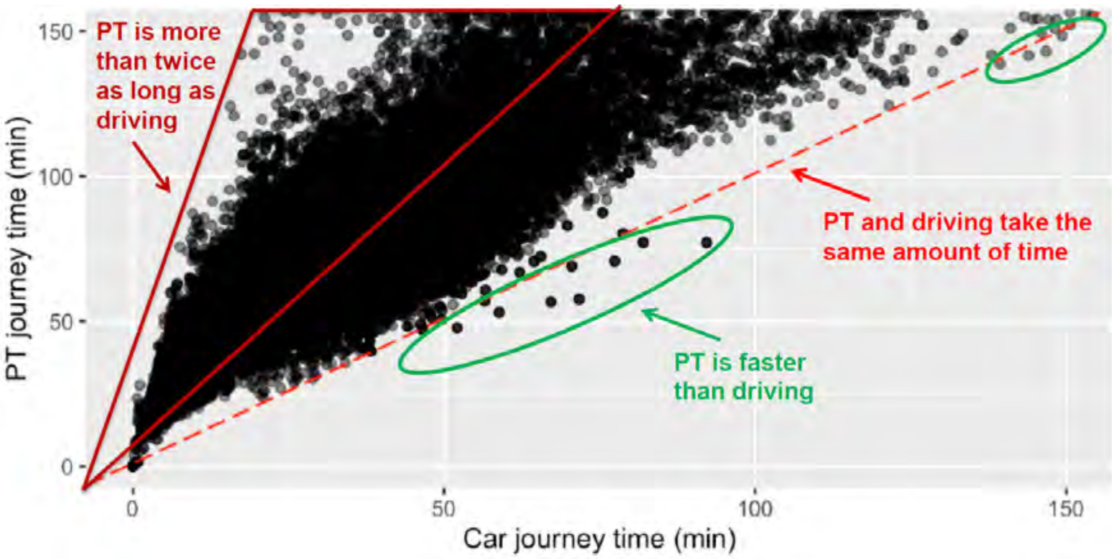
Travel times and speed

In terms of bus speeds, the average speed on studied routes during peak periods are 15 to 20km/h, with typical speeds not much higher in the off-peak. On certain parts of the network such as the Golden Mile or between Wellington Hospital and the central city, average speeds for some services drop below 10km/h. As a result, the bus service is not time competitive with driving. A target speed that is comparable with international best practice is 22km/h – a 10 to 30 percent increase on current performance.

This is illustrated in Figure 2 below which shows travel times by public transport in relation to driving for origin / destination pairs across the region. This highlights that:

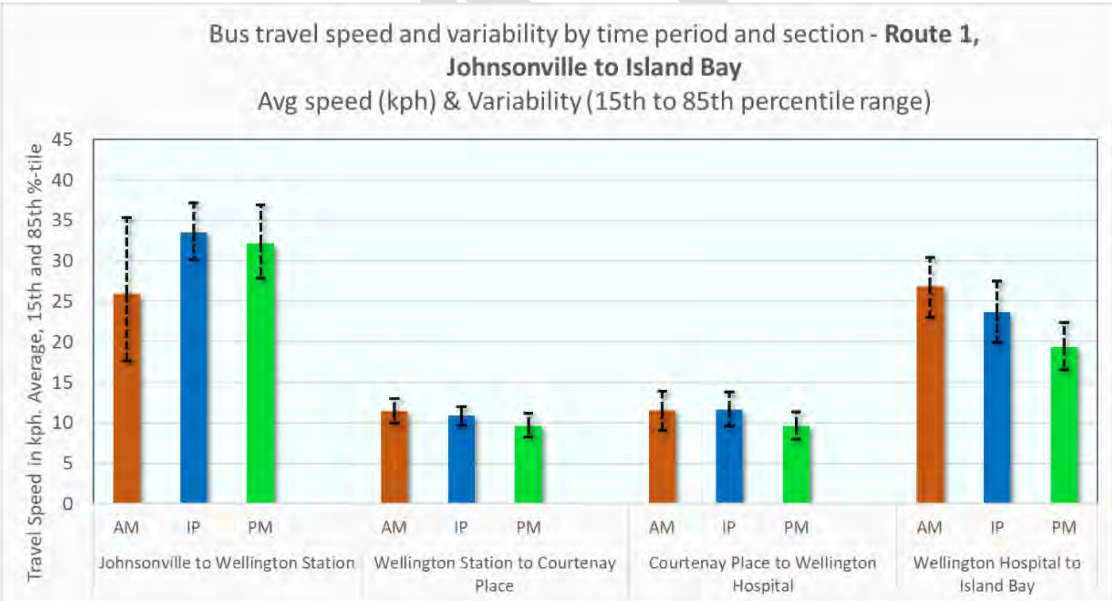
- in a very few instances taking public transport is slightly faster than driving or takes about the same amount of time. However, in all these instances, this is by train rather than bus
- for nearly all journeys, taking the bus is slower than driving
- for around 50 percent of journeys, taking the bus is at least twice as slow as driving.

Figure 2: PT journey times relative to driving (source data Wellington Transport Strategic Model outputs 2013)



Reliability and speeds are interrelated. Figure 3 below provides an example of analysis of the variability and speed issues for route 1 from Johnsonville to Island Bay.

Figure 3: Bus travel speed and variability (March 2019, real-time data)



The analysis of this route shows:

- Johnsonville to Wellington Station – moderate speed but highly variable during the AM peak
- Wellington Station to Courtenay Place – slow throughout the day (average ~10km/h), worst in the PM peak
- Courtenay Place to Wellington Hospital – slow and variable, worst in the PM peak
- Wellington Hospital to Island Bay – reasonable speeds in the AM peak and inter-peak (noon–2pm), slower in PM peak, highly variable throughout the day.

6.4. Route identification process

To identify the priority bus corridors for improvement, three criteria were used:

- high daily passenger volumes
    - this was defined as 2500 or more passengers per direction on an average day
- slow bus operating speeds
    - this was defined as average daily speeds of less than 15km/h
- high levels of bus travel time variability
    - this was defined as variability within the AM or PM peak of more than 15 percent.

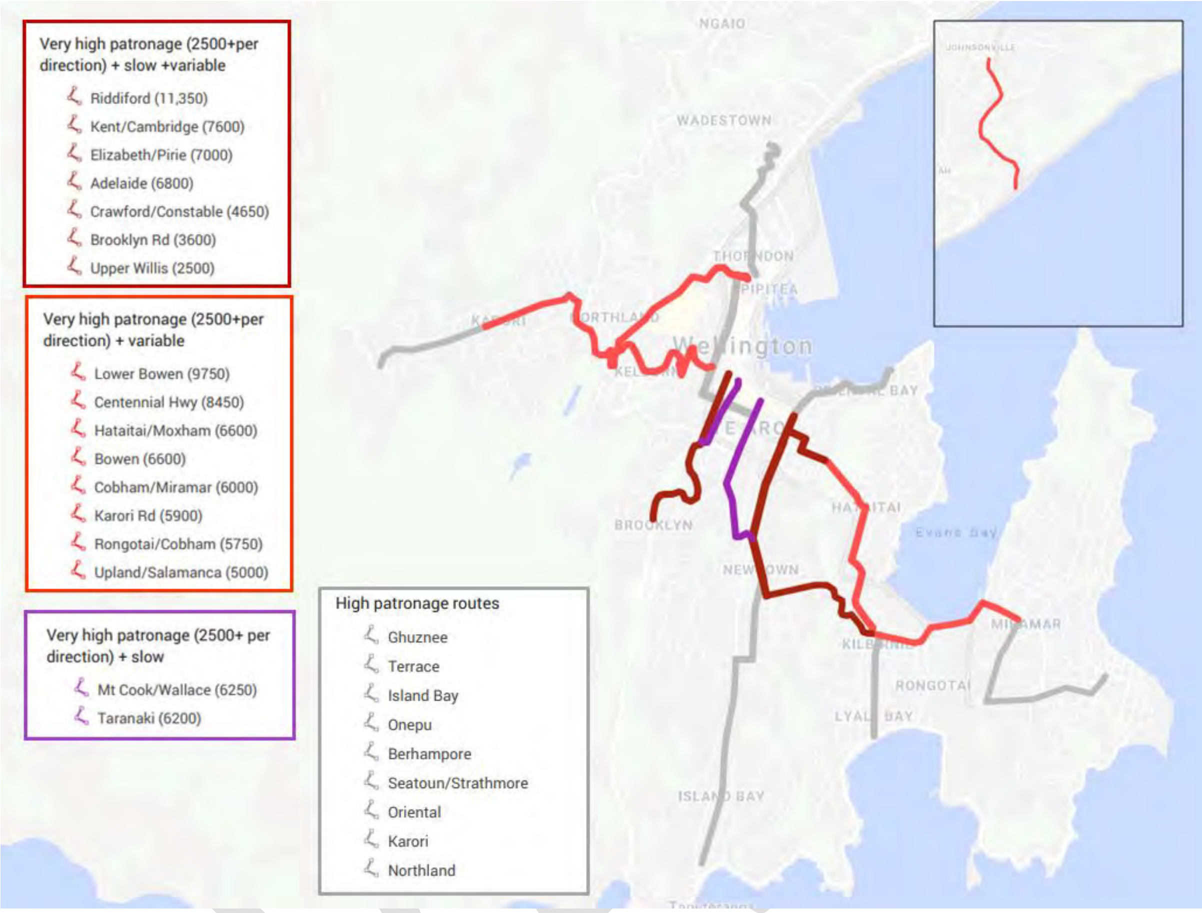
Figure 4 shows daily bus passenger volumes on the main routes entering and exiting the central city. It shows that the busiest bus corridor is the Golden Mile, followed by the corridors connecting the Golden Mile to the northern, southern, eastern and western suburbs. The Golden Mile and Thorndon Quay-Hutt Road are excluded from this bus priority programme as they are already being considered under the LGWM early delivery programme.

Figure 4: Daily bus passenger volumes

Figure 5 and Figure 6 show average bus speeds and travel time variability for the main corridors during the PM peak. Analysis was also completed for the AM peak and noon to 2pm periods. This showed that the PM peak was the worst-performing period.

Combining passenger volumes, bus speed and variability produced a composite view of the areas of the network where bus performance issues are affecting the most people (shown in Figure 5).

Figure 5: Busy, slow and variable bus corridors



Bus corridors were ordered for the purposes of prioritising a work programme for conducting more detailed analysis. Bus corridors were sorted into a list:

- Firstly, the routes with the highest travel time variability and slow speeds, ordered by passenger volumes were considered.
- Secondly, the busiest corridors with either a speed or variability problem were considered. Adjacent corridor segments were grouped together to form logical corridors for analysis. This produced a list of seven priority corridors for analysis as shown in Figure 6.

Figure 6: Priority corridors for analysis

For the short-listing process, bus travel time data was analysed for relatively long corridor sections to determine average speeds and travel time variability. This analysis was used to identify the short-list corridor priorities for analysis. The analysis looked at three time periods: AM peak (7–9am), inter-peak (noon–2pm), evening peak (4–6pm) for both inbound and outbound directions. Results were plotted on the 12 maps shown in Appendix 1. These have been summarised into a table below, which shows:

- slow bus operating speeds of less than 15km/h in orange and less than 10km/h in red
- high levels of bus travel time variability of more than 15 percent in orange and more than 20 percent in red.

Table 2: Priority corridors for analysis

Route and section	Daily passengers per direction	Inbound						Outbound					
		Slow			Variable			Slow			Variable		
		AM	IP	PM	AM	IP	PM	AM	IP	PM	AM	IP	PM
1. Newtown to city													
Riddiford	11,350												
Kent/Cambridge	7600												
Adelaide	6800												
2. Karori to city													
Lower Bowen	9750												
Bowen/Glenmore	6600												
Tunnel to Karori shops	5900												
3. Seatoun to city													
Elizabeth/Pirie	7000												
Hataitai/Moxham	6600												
Cobham/Miramar	6000												
Rongotai/Cobham	5750												
Broadway	3250												
4. Mt Cook to city													
Mt Cook/Wallace	6250												
Taranaki	6200												
5. Kelburn to city													
Upland/Salamanca	5000												
Bowen to Salamanca	3300												
6. Kilbirnie to Newtown													
Crawford/Constable	4650												
7. Brooklyn to city													
Brooklyn	3600												
Upper Willis	2600												
Victoria	2600												
8. Johnsonville to Ngauranga													
Centennial Hwy	8450	Not included in initial analysis											

The Johnsonville to Ngauranga corridor was not included in the initial analysis but was added to the shortlist due to its high usage. For the bus priority programme covered by the remainder of this business case, analysis has been completed for the following eight corridors, ordered by passenger volumes:

- Newtown to city
- Karori to city
- Johnsonville to Ngauranga

- Seatoun to city
- Mt Cook to city
- Kelburn to city
- Kilbirnie to Newtown
- Brooklyn to city.

7. Planned cycling network

City Councillors approved the Wellington Cycleways Programme Master Plan in September 2015. It is a companion document to the cycleways business case which was accepted by the Transport Agency.

The cycle network is currently envisaged to be developed in four stages over a period of some 20 years, largely dependent on the availability of funding. The timing and sequencing of individual components of stages 2–4 are subject to ongoing refinement.

Stage 1 2015–2019

Stage 1 (the purple and green lines are the existing routes) shows how we are beginning to develop a network by gradually improving and adding connections to the north, east and south of the city, including the Island Bay end of the southern connection, a safer link between Ngauranga and Thorndon, around Evans Bay from Miramar to the city, and between Kilbirnie and Newtown. All the upgrades and projects that will provide these connections either already exist, are underway, or have been approved for development in 2018–2019.

Figure 7: Cycle network stage 1

Stage 2 2019–2021

Stage 2 (pink lines) of the cycle network will connect more suburbs to the south and east of Wellington. Suburbs including Newtown, Mt Cook, Berhampore, Island Bay, Kilbirnie and Miramar will all be connected to safer routes for people on bikes.

Figure 8: Cycle network stage 2

Improved central city connections are expected to be developed as part of LGWM.

Stage 3 2021–2028

Stage 3 (orange lines) of the cycle network is likely to see connections developed to the outer eastern suburbs, including more of Miramar, Seatoun and Strathmore Park. The Transport Agency is expected to develop a connection to the Hutt Valley.

Karori, Highbury, Kelburn and Brooklyn should all become part of the network. Safer connections from Johnsonville, Paparangi, Newlands, Churton Park and Tawa will be added from the north, and Thorndon will be improved as part of LGWM.

Figure 9: Cycle network stage 3

Stage 4 Beyond 2028

In the future, we will add more suburbs to the network (blue routes), including a north to west connection from Wilton through to Johnsonville and beyond, via Crofton Downs, Ngaio, Khandallah and Broadmeadows. Also included is a link down through Ngaio Gorge; safer facilities from Highbury down through Aro Valley; and through Northland and Wadestown to Thorndon.

Better connections around Miramar Peninsula, the south coast to Owhiro Bay, and then a loop back through Brooklyn will complete the cycle network. These connections are key to the region's goal to develop the Great Harbour Way / Te Aranui o Pōneke, a walking and cycling route around Te Whanganui-a-tara, Wellington Harbour from Fitzroy Bay in the east to Sinclair Head in the west. They could be progressed earlier with the right mix of local, regional and national support.

Figure 10: Cycle network stage 4

7.1. Bicycle level of service analysis

Wellington City Council has previously commissioned assessments of the existing levels of service for people on bikes using the city's main transport routes. The original assessment was carried out by Opus International Consultants in 2013 and used the Danish level of service tool to determine the mid-block level of service for each section of the routes studied. The tool primarily takes account of the type of cycling facility provided and the volume and speed of traffic adjacent to that facility.

As part of more recent work on the Newtown Connections project, Tonkin and Taylor used the same methodology to identify the current levels of service between Mt Cook and the central city.

We have summarised the more detailed bicycle level of service assessments to form a summary view for each corridor using the following rating system.

Table 3: Bicycle levels of service

Rating	Bicycle level of service
Poor	Large sections with poor levels of service rated E or F.
Average	Large sections with average levels of service rated C or D.
Good	Good levels of service rated A or B.

The summary results are shown below. All corridors have large sections with poor levels of service for people on bikes which suggests two things:

- the needs of people who cycle must be considered as part of intervention planning for all corridors
- bicycle level of service is not a differentiator for determining which corridors should be improved first.

Table 4: Current bicycle levels of service

Corridor	Bicycle LoS
Newtown to city	LoS E-F
Johnsonville to Ngauranga	LoS C-F
Kelburn to city	LoS E-F
Mt Cook to city	LoS E-F
Karori to city	LoS E-F
Seatoun to city	LoS E-F
Kilbirnie to Newtown	LoS E-F
Brooklyn to city	LoS E-F

8. Road safety issues

We have undertaken a high-level review of the current road safety performance of the corridors.

The reported road safety rating is based on personal risk as presented on the Transport Agency's MegaMaps tool. Personal risk is defined as the risk of deaths or serious injuries per 100 million vehicle kilometres travelled. Using the tool, personal risk is mapped onto each road using five categories: high, medium-high, medium, low-medium, and low. These were recorded in a spreadsheet for each section of each of the eight bus priority corridors. An average score was then deduced for each corridor, presented in Table 6.

Broadly speaking, each of the corridors has a moderate average personal risk rating. Corridor 1 (Newtown to city) and corridor 4 (Mt Cook to city) have the highest personal risk ratings. Corridor 2 (Karori to city) and corridor 8 (Johnsonville to Ngauranga)[3] have the lowest average personal risk ratings. However, this does hide the fact that there are sections on some corridors that are high risk. Corridors that include high-risk sections are corridor 1 (Newtown to city), corridor 2 (Karori to city), corridor 3 (Seatoun to city), and corridor 4 (Mt Cook to city).

In addition, crash data was retrieved from the Transport Agency's Crash Analysis System (CAS). Crashes which resulted in death or serious injury (DSI) from the 10-year period from 2009–2018 were recorded. Corridor 1 (Newtown to city), corridor 4 (Mt Cook to city) and corridor 7 (Brooklyn to city) had the highest number of DSIs per kilometre over the 2009–2018 period.

All data was retrieved in September 2019.

[3] Not including the SH1 part of the Johnsonville corridor.

We have summarised the more detailed crash outcomes assessments to form a summary view for each corridor using the following rating system.

Table 5: Personal risk ratings

Rating	Crashes – personal risk
Poor	High personal risk
Average	Medium personal risk
Good	Low personal risk

Results for the average personal risk ratings by corridor are shown in Table 6 below.

Table 6: Personal risk ratings by corridor (2009–2018)

Corridor	Fatal	Serious	Minor	DSI per km	Personal risk average score
Newtown to city	0	28	152	12	2.2
Johnsonville to Ngauranga	0	7	38	2	1.3
Kelburn to city	0	5	27	2	2.0
Mt Cook to city	2	14	98	8	2.3
Karori to city	1	24	111	4	1.6
Seatoun to city	1	20	129	2	2.0
Kilbirnie to Newtown	0	6	36	3	2.0
Brooklyn to city	3	21	101	9	2.0
Total	**7**	**125**	**692**	**4**	

The results suggest safety performance is generally average and opportunities for improving safety must be considered as part of intervention planning for all corridors.

9. Strategic case conclusions

Eight major corridors have been identified as carrying high volumes of bus passengers. All these corridors suffer from varying degrees of very slow and unreliable travel times.

Interventions to improve bus priority provisions should be developed to address these issues but improvements must be integrated with the LGWM programme, and changes should address issues and opportunities for improving walking, cycling and safety outcomes.

All corridors have large sections with poor levels of service for people on bikes. This means the needs of people who cycle must be considered as part of intervention planning for all corridors.

The review of safety showed generally average performance and opportunities for improving safety must be considered as part of intervention planning for all corridors.

Improvements to these corridors will provide substantial benefits to a large number of users.

Economic case

10. Process for identifying and assessing options

In the economic case we identify and assess options for addressing the problems identified in the strategic case; and identify three scenarios that demonstrate the costs and benefits associated with differing levels of bus priority. The investment programme for bus priority will need to be developed further through corridor-specific investigations, including community engagement, and taking account of other modes and desired outcomes.

This assessment focuses on the eight bus corridors that were identified in the strategic case. These corridors have documented issues with slow and unreliable travel times that affect a large number of passengers.

We identify and assess options using a staged process.

- First, we analyse the existing performance of the eight corridors to:
  - identify locations and time periods where buses are delayed
  - identify specific issues that are causing these delays, which include narrow bus stop spacing, excessive dwell times at bus stops, delays re-entering traffic from bus stops, delays at traffic lights, slow running speeds due to narrow road widths, and slow running times due to general traffic congestion.
- Second, we define a bus priority toolkit – a set of specific interventions that can be applied to address delays and other performance issues on bus corridors.
- Third, we undertake suitability screening to identify which bus priority measures can be applied to specific parts of the bus corridors. This consists of three screens:
  - Appropriateness**:** Is the magnitude of the problem worth fixing?
  - Effectiveness**:** Will the tool be effective in addressing the issue?
  - Feasibility**:** Is it technically possible to implement?
- Fourth, we group these interventions into three potential packages for the purposes of indicative cost benefit analysis. These options vary in terms of how comprehensively they address the documented bus performance issues. The first option focuses on minimal interventions that will improve bus performance while minimising disruption, the second option focuses on fixing the worst problems, and the third option aims to fix everything.
- Fifth, we undertake an indicative cost benefit analysis of the three packages to understand which option delivers better value for money. We use this information, combined with estimates of the effectiveness of each option, to identify a recommended investment programme.

- Sixth, we identify a recommended approach to staging the programme for implementation. This employs a multi-criteria analysis using three types of criteria: the scale and impact of the bus problem, the opportunity for wider improvements, and the potential effectiveness of bus priority interventions.

11. Analysing the performance of bus corridors

For each of the eight priority corridors, a detailed analysis of bus patronage, operating speeds and conditions, and sources of delay by hour of day was undertaken.

Six causes of delay were quantified at the bus stop to bus stop level.

- **Short bus stop spacing**: When bus stops are close together, this reduces the time that buses spend travelling at full running speeds and increases the time spent decelerating into bus stops, positioning at bus stops, and accelerating out of bus stops.
- **Long dwell times at bus stops**: Lengthy dwell times increase journey times for the passengers already on the bus. However, it may be difficult to reduce dwell times as they reflect the time it takes for passengers to get on and off, which tends to scale with passenger volumes.
- **Re-entry delay**: Buses exiting off-line bus stops into heavy traffic may be delayed while waiting for a gap in traffic.
- **Traffic light delays**: A share of buses must stop at traffic lights or signalised pedestrian crossings while waiting for the green phase. In addition to average wait times, this adds deceleration and acceleration time.
- **Queue service delays at traffic lights**: Signalised intersections with heavy traffic volumes typically build up queues that take a while to clear. If bus lanes are not available at these intersections then buses will be delayed.
- **Road layout**: Narrow traffic lanes and narrow shoulders may make it difficult for buses to travel at the posted speed limits.

All other sources of delay are combined into a seventh 'other' category. This includes mid-block traffic congestion, un-signalised intersections, hills and corners, roundabouts, and 'side friction' from parking (such as cars not parked well, car doors opening, people manoeuvring into parking places). The analysis of sources of delay along bus corridors is based on a comparison of observed bus speeds and dwell times from real-time information (RTI) and estimated optimal bus speeds based on formulas in the Transit Capacity and Quality of Service Manual (TCQOSM) and Highway Capacity Manual (HCM).

Detailed results by corridor are outlined in Appendices 5 to 11. High-level results for each corridor are outlined in Table 7.

Table 7: Summary patronage and travel time statistics by corridor

INBOUND	Newtown to city	Karori to city	Miramar to city	Mt Cook to city	Kelburn to city	Kilbirnie to Newtown	Brooklyn to city	Johnsonville to Ngauranga
Daily passengers	5479	2744	2624	3469	2492	1972	1549	3700
Average speed (km/h)	13.1	22.6	19.3	12.5	19.7	14.0	15.3	24.5
Average travel time (mins)	11	17	27.1	10.1	6.7	8.6	10.2	8.8
Minimum travel time (mins)	7.2	12.5	22.1	6.1	5.3	5.4	6.7	6.7
Maximum travel time (mins)	14.9	29.6	35.1	14.7	8.9	11	13.9	1.3
Length (km)	2.4	6.4	8.7	2.1	2.2	2	2.6	3.6
No. of stops	8	21	30	8	5	7	10	4
Slowest weekday hour	4-5pm	8-9am	8-9am	4-5pm	8-9am	8-9am	8-9am	8-9am
OUTBOUND	**Newtown to city**	**Karori to city**	**Miramar to city**	**Mt Cook to city**	**Kelburn to city**	**Kilbirnie to Newtown**	**Brooklyn to city**	**Johnsonville to Ngauranga**
Daily passengers	5329	3024	2838	3119	4158	2101	2025	4000
Average speed (km/h)	12.2	21.5	19.6	13.0	20.3	16.8	14.7	34.8
Average travel time (mins)	11.8	17.3	27.2	9.7	6.5	6.8	10.6	6.2
Minimum travel time (mins)	8.9	14	23.4	6.3	4.9	4.9	7.4	5.2
Maximum travel time (mins)	15.1	23.8	32.7	13.3	8.4	8.6	15.4	8.9
Length (km)	2.4	6.2	8.9	2.1	2.2	1.9	2.6	3.6
No. of stops	7	20	30	7	5	7	10	5
Slowest weekday hour	5-6pm	5-6pm	3-4pm / 5-6pm	5-6pm	5-6pm	5-6pm	5-6pm	5-6pm

12. Bus priority toolkit

An appropriate mix of bus priority measures can reduce travel times and improve reliability resulting in bus services becoming more attractive and efficient.

Bus priority encompasses a variety of techniques used to improve bus service performance by reducing journey times and improving reliability. Bus priority measures are particularly effective when bus journey times and service reliability are being affected by traffic congestion. Like all high-quality urban transport, effective bus priority can have a positive effect on people's quality of life, health, safety and productivity.

The bus priority toolkit includes the following kinds of interventions:

- segregation of buses from general traffic in bus or bus only lanes operating full-time or part-time
- traffic signal control and other intelligent transportation system elements which give priority to buses over other vehicles at intersections
- improvements to bus stop capacity, function and frequency, which may include improvements to bus stop layout, the use of in-line stops or rationalisation of bus stops
- changes to street layout including intersection changes and widening or narrowing road corridors
- improvements to ticketing, bus operations (all-door boarding) and scheduling to enable efficient boarding and alighting.

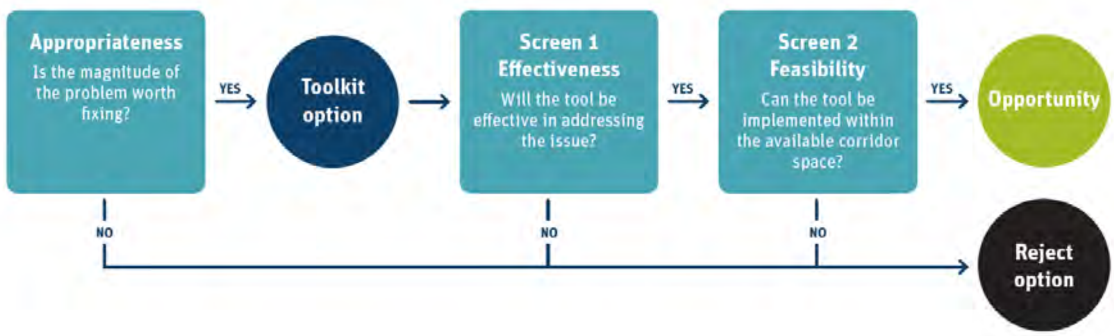
A full description of the bus priority measures under consideration, how they work, and when they are useful is outlined in Appendix 2, Section 5.

Not all priority corridors have the same travel demand or physical street conditions and so there is no one-size-fits-all bus priority package of interventions, as not all measures will be suitable for every part of a corridor.

13. Approach to screening opportunities on bus corridors

For each of the eight priority corridors, we have identified opportunities that would improve bus operations. These opportunities would address the documented problems along the corridors to decrease bus delay. We used a three-stage screening process to move from issue identification to opportunity to selection, as outlined in Figure 11.

Figure 11: Approach to screening opportunities



13.1. Identifying issues on priority corridors

To identify opportunities, we first needed to understand the causes of the documented problems along the corridors. We used the results from the performance analysis to determine specific locations where delays occur, the source of the delays, and the severity of the delays. For each location, we then had a documented list of issues that are causing delays for buses. Summaries of the issues on each corridor are outlined in Appendices 3 to 10.

13.2. Appropriateness of intervention

The first step of the screening process was to apply an appropriateness screen. Interventions were only considered if there was a sufficient magnitude of delay to buses to justify intervention. For each of the three options outlined in section 13.5, a different magnitude of delay was used to determine if intervention was necessary.

13.3. Screening the effectiveness of the bus priority interventions

The next step of the screening process was to identify which bus priority interventions would be effective in addressing the problems on each corridor. For every location, we considered the list of problems and then identified a list of potential interventions that would effectively address the sources of delay. The resulting list of interventions that were considered effective was then carried through to the next stage of screening.

Table 8 provides a summary of the types of problems we identified on the corridors and the corresponding interventions that we considered to address the problems.

Table 8: Effectiveness screening

Cause of delay	Interventions to consider
Closely spaced bus stops	• Rationalise bus stops
Dwell time delay	• Consider other interventions outside the scope of this project: ○ increase bus frequency ○ operational improvements
Re-entry delay	• In-line bus stops
Traffic signal delay	• Bus phase • Increased green phase • Minor intersection re-design • Major intersection re-design
Queue service delay	• Queue jump • Bus phase • Increased green phase • Minor intersection re-design • Major intersection re-design
Road layout delay	• Widen traffic lanes
Mid-block congestion and on-street parking delay	• Transit lanes, including: ○ full-time bus lanes ○ part-time bus lanes ○ peak-hour clearways
Missing entry and / or exit tapers	• Provide entry and exit tapers
Short bus box	• Lengthen the bus box

13.4. Screening the feasibility of the bus priority interventions

Once interventions were identified, their space requirements were checked against the particular corridor street layout to see if the interventions could be physically accommodated within the available space. If corridor widening would be required, it was assumed that this would be undertaken if it could be achieved by acquiring four or less properties and through retaining wall construction. If corridor widening required the acquisition of more than four properties or required earthworks above and beyond retaining wall construction, the intervention was removed as an option.

13.5. Defining packages for assessment

We defined three levels of packages to provide infrastructure and bus priority interventions on the corridors. Assessing three options allowed us to understand the value for money relative to the level of intervention and help to select the preferred interventions on each corridor.

The three options for upgrading the bus corridors are defined as follows:

- **Option 1: fix everything**
  This option would:
  - address all problems identified on the corridor
  - implement any of the possible interventions that:
    - are effective at addressing all of the problems that have been identified on the corridor
    - are feasible to implement within the available corridor space.
- **Option 2: fix the worst problems**
  This option would:
  - address only the most severe problems identified on the corridor
  - implement interventions that:
    - are effective at addressing the most severe problems that have been identified on the corridor
    - are feasible to implement.
- **Option 3: minimal interventions**
  This option would:
  - address only the most severe problems identified on the corridor
  - implement interventions that:
    - are effective at addressing the most severe problems that have been identified on each corridor
    - are feasible to implement
    - involve only minimal reconfiguration of corridor space.

Each of these options is assessed against a base case scenario, in which no improvements are made to these bus corridors and bus journey times do not improve relative to current observed levels.

13.6. Key characteristics of options

Table 9 summarises some key characteristics of these options. It provides a high-level overview of the amount of change on each corridor under the two options.

Table 9: Key characteristics of options

Category	Intervention	Unit	Option 1	Option 2	Option 3
Signal improvements	Green phase extension	Intersection	8	11	11
	Queue jump	Intersection	4	4	2
	Bus phase	Intersection	4	4	3
	Intersection re-design - minor	Intersection	34	23	29
	Intersection re-design - major	Intersection	29	6	-
Lane priority	In-line bus stops	Bus stop	41	43	80
	Bus lanes	Kilometre	46	30	-
Corridor	Clearways	Kilometre	1	0	-
	Widen traffic lane	Kilometre	30	20	-
Bus stops	Bus stop optimisation	Bus stop	59	43	19
	Entry / exit tapers	Bus stop	1	17	52
	Lengthening bus stop	Bus stop	1	18	48

14. Indicative cost benefit analysis of alternative bus priority packages

An indicative cost benefit analysis has been undertaken on the alternative packages defined above. The purpose of this exercise is to:

- understand the value for money offered by the bus priority programme
- help select a preferred option to take forward to detailed business cases.

Appendix 2 provides a detailed description of how programme benefits have been assessed. Current (May 2019) data on bus performance and passenger volumes is used to measure outcomes under the base case scenario. We model and value the resulting outcomes for increased public transport patronage and reduced traffic congestion using methods and parameters outlined in the Transport Agency's Economic Evaluation Manual.

We have developed indicative cost estimates based on the quantity of work expected to be required for each option, unit cost rates drawn from quantity surveying estimates, and estimated or actual costs for previous projects. These estimates are indicative and do not necessarily take into account all potential for site-specific cost escalation (such as the need to relocate underground utilities). They include an allowance for planning, engagement, and consultation.

14.1. Outcomes for average travel times along corridors

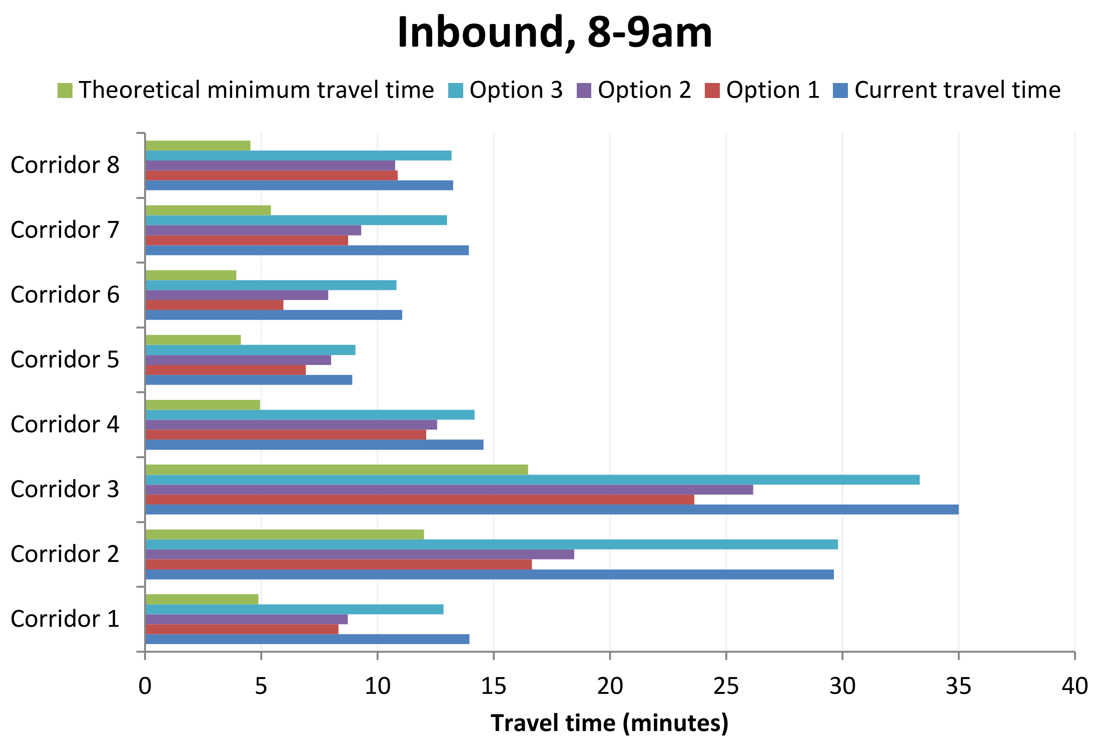
Figure 12 illustrates the outcomes for average travel times along these corridors that are expected to arise from each option. Each of the three options reduces travel times relative to current performance but the level of improvement varies across the three options.

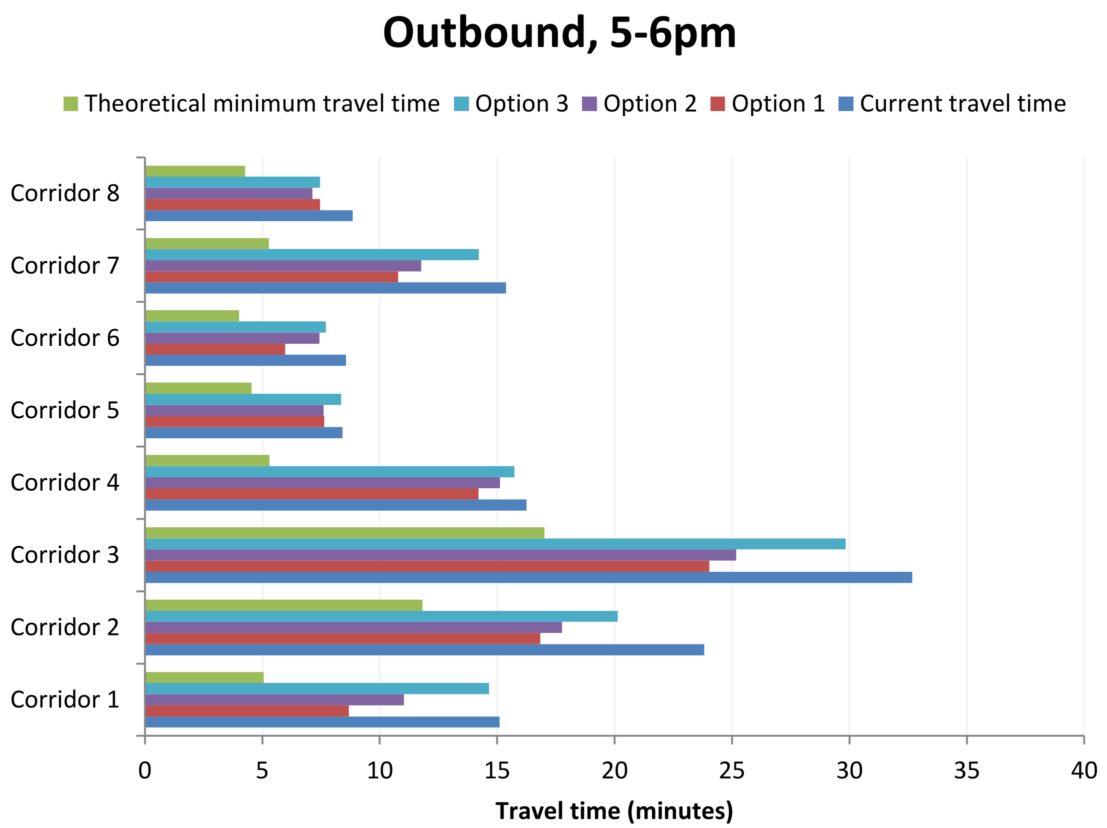
Option 1 is expected to deliver the largest improvement to average travel times. Averaged over all corridors, it is expected to cut AM peak travel time delay by approximately 50 percent. Option 2 also delivers a similar magnitude of benefits, reducing delay by 40 percent. Option 3 only reduces delay by 6 percent.

Under options 1 and 2, bus travel speeds would become increasingly competitive with peak-period car speeds. Inbound speeds during the AM peak would rise from their current average of under 13km/hr to between 18 and 20km/hr. Faster bus speeds will in turn:

- directly benefit bus passengers by making it easier for them to reach their destinations
- encourage more people to use public transport
- contribute to a reduction in general traffic congestion by enabling some people to shift from driving to public transport

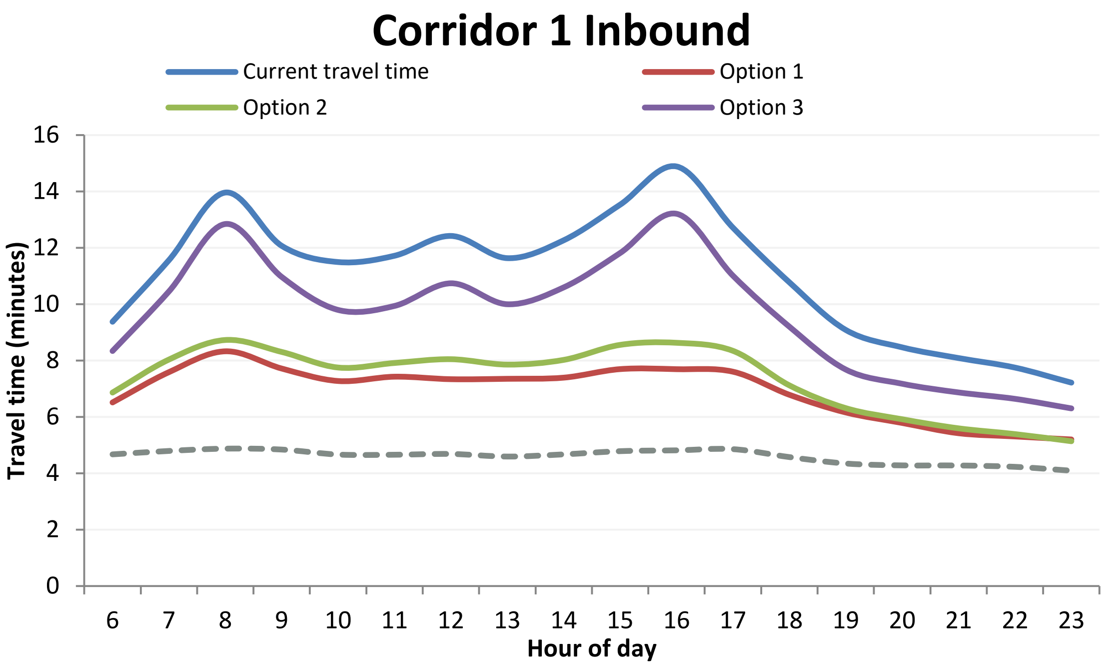
Figure 12: Outcomes for average travel times under each option

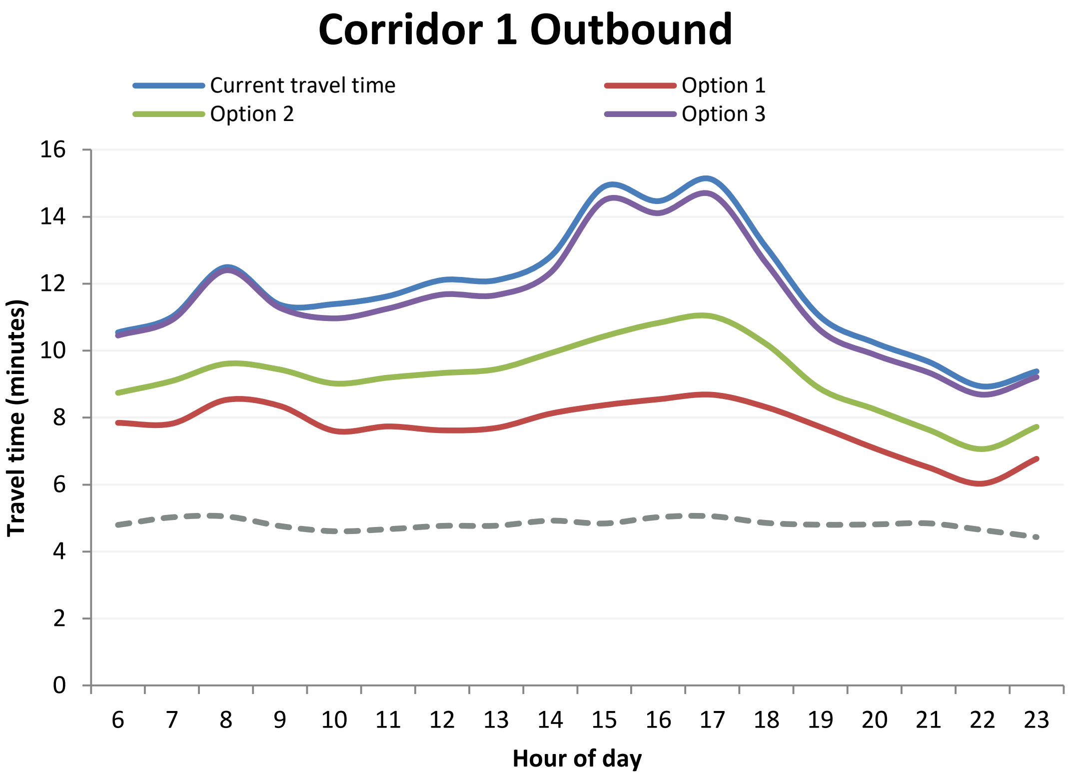




These options result in faster and more consistent bus travel times throughout the day. Figure 13 illustrates this based on data for corridor 1 (Newtown to city). Option 3 is expected to have modest benefits for journey times throughout the day. Options 1 and 2 achieve larger reductions in journey times, with additional improvements in peak travel times due to transit lanes and clearways that reduce the likelihood of buses being delayed by peak congestion. There is a similar pattern for other corridors.

Figure 13: Outcomes for travel times by time of day, corridor 1 (Newtown to city)





14.2. Cost benefit analysis results

The following table summarises key results from a cost benefit analysis of three alternative options for the bus priority programme under central valuation assumptions.[4]

The programme is likely to have some additional benefits, plus some minor traffic disbenefits, in addition to what we have assessed. These may be assessed at future stages.

We find that:

- Under central assumptions, option 1 would lead to an increase of almost 1200 peak-hour public transport trips and divert around 400 car trips. Option 2 would lead to roughly 80 percent as much mode shift, while option 3 would lead to less than 10 percent as much mode shift.
- Option 2 would deliver a BCR above one, indicating that it is likely to deliver value for money. Option 1 is expected to have a BCR near one, while option 3 is expected to have a BCR significantly below one, reflecting the fact that it delivers the smallest improvements to journey times while incurring significant fixed costs for engagement and consultation.
- Option 2 is expected to have the highest BCR, reflecting the fact that it targets interventions to locations where problems are most acute.

[4] Per baseline guidance in the EEM, we use a 40-year evaluation period, 6 percent discount rate, value of travel time savings parameter of $12.16, and a road traffic reduction benefit rate of $1.21 per kilometre. Benefits in future years are increased in line with projected Wellington City population growth, projected growth in PT demand relative to population growth, and projected increases in traffic congestion, which will degrade bus performance in the absence of intervention.

Table 10: Summary of indicative cost benefit analysis of bus priority programme options

Option	Option 1 – fix everything	Option 2 – fix worst	Option 3 – minimal works
Change in PT trips (AM peak hour)	1180	950	70
Avoided car trips (AM peak hour)	440	360	20
Costs (present value, $m)			
Construction costs	$185.44m	$91.63m	$24.22m
Land purchase costs	$12.38m	$6.88m	NA
Operation costs	-$4.84m	$0.68m	$1.23m
Renewal costs	NA	NA	NA
Total	$192.97m	$99.19m	$25.44m
Benefits (present value, $m)			
Public transport user benefits	$105.62m	$87.14m	$6.85m
Public transport reliability benefits	NA	NA	NA
Decongestion benefits	$55.89m	$45.37m	$3.26m
Added traffic delay	NA	NA	NA
Safety benefits	NA	NA	NA
Walking and cycling user benefits	NA	NA	NA
Health benefits of added walking to PT	$22.54m	$18.17m	$1.27m
Wider economic benefits	NA	NA	NA
Total	$184.05m	$150.68m	$11.37m
Benefits relative to costs			
Net benefits (benefits minus costs)	-$8.92m	$51.49m	-$14.07m
BCR	0.95	1.52	0.45

The following table summarises the results of an incremental BCR calculation undertaken following guidance in the Economic Evaluation Manual (EEM), Appendix A12.4. This indicates that the additional expenditure incurred for option 1 is unlikely to provide value for money relative to option 2.

Table 11: Incremental cost benefit analysis of bus priority programme options

Options ranked by cost	Option 3 – minimal works	Option 2 – fix worst	Option 1 – fix everything
Total costs	$25.44m	$99.19m	$192.97m
Total benefits	$11.37m	$150.68m	$184.05m
Incremental costs	$25.44m	$99.19m	$93.78m
Incremental benefits	$11.37m	$150.68m	$33.37m
Target incremental BCR (min = 1)	1.00	1.00	1.00
Incremental BCR	0.45	1.52	0.36

14.3. Sensitivity testing

To ensure that these findings are robust to changes in assumptions, a number of sensitivity tests have been conducted on modelling assumptions, valuation parameters, and construction costs.

Key sensitivity tests are reported in the following table. We find that:

- Our key conclusion that option 2 is likely to provide value for money is robust to changes in any individual assumption.
- The incremental BCR of additional investment under option 2 provides improved value for money is also robust to changes in any individual assumption.
- Option 1 provides value for money under most individual sensitivity tests.
- Extreme bounds testing shows that the plausible range for BCRs falls between 0.4 (reflecting pessimistic assumptions for all parameters) and 5.8 (reflecting optimistic assumptions for all parameters) for option 2, and between 0.3 and 3.8 for option 1.

In addition, we have added an indicative allowance for three unquantified impacts (PT reliability benefits, traffic delay disbenefits, and wider economic benefits) based on an analysis of travel time variability on these routes and past experience evaluating other public transport projects. This increases BCRs for all three options by around 30 percent.

Table 12: Sensitivity tests of project BCRs

Sensitivity test	Option 1 BCR	Option 2 BCR	Option 3 BCR
Central assumptions	0.95	1.52	0.45
Low discount rate (4%)	1.30	2.05	0.60
High discount rate (8%); shorter evaluation period (30 years)	0.67	1.07	0.32
Larger demand response to faster PT journeys (elasticity = -2.0)	1.30	2.03	0.55
Smaller demand response to faster PT journeys (elasticity = -0.8)	0.74	1.20	0.37
Slower increase in PT demand and PT delay in future years	0.84	1.33	0.39
Larger increase in PT demand and PT delay in future years	1.09	1.73	0.51
Higher value of travel time savings ($17.33/hr)	1.19	1.89	0.56
Lower diversion rate from car to PT (20%) and road traffic reduction benefit ($0.60/km)	0.69	1.10	0.33
Low construction costs (-10%)	1.06	1.67	0.49
High construction costs (+45%)	0.67	1.09	0.28
Extreme bounds analysis: Low discount rate (4%); larger growth in PT demand and delay; higher demand response (E=-2.0); higher VOT ($17.33/hr); higher diversion rate from car to PT (70%); low construction costs (-10%)	3.75	5.77	1.54
Extreme bounds analysis: Higher discount rate (8%); shorter evaluation period (30 years); slower growth in PT demand and delay; lower demand response (E=-0.8); lower diversion rate (20%); low road traffic reduction benefit ($0.60/km); high construction costs (+45%)	0.26	0.43	0.12
Add indicative allowance for PT reliability benefits (25% of PT user benefits); traffic delay disbenefits (-50% of decongestion benefits); wider economic benefits (25% of direct transport user benefits)	1.24	1.98	0.59

15. Progressing economic analysis to detailed business cases

Appendix 2 provides a detailed description of the approach to assessing programme benefits and how this may differ between the indicative and detailed business case stages. Cost estimates will also be revised once detailed designs for proposed interventions are available.

Once the preferred interventions, timing and sequencing of works have been determined, a revised economic analysis can be produced for each of the corridors as a component of the detailed business case.

Financial case

16. Implementation costs

Capital and operating costs have been estimated at an indicative level. Capital costs were estimated on a per corridor basis using two main inputs: estimated overhead costs per corridor which are not intervention specific and estimated costs per intervention for proposed changes. Appendix 2 provides a detailed description of the approach to assessing capital costs.

The bus priority programme can be expected to influence operating costs through two main pathways. Firstly, faster journeys reduce operating costs directly by reducing the time it takes to operate a given service. Secondly, faster journeys can be expected to result in an increase in patronage. At this stage, an indicative assessment of the impact of the programme on operating costs has been conducted, using a number of simplifications for calculation purposes. At the detailed business case stage, more analysis that takes into account actual bus operating patterns will be required.

This analysis also excludes a detailed consideration of renewal costs and residual value at the end of the evaluation period for new or changed transport facilities. This is appropriate for indicative analysis, as assessing renewal costs and residual value requires more detailed cost estimation than is expected to be available at this stage.

The time profile of capital costs has been estimated at a high level based on construction times. Construction time is likely to vary by length of the corridor as well as the scale of interventions that are applied. For option 1 (minimal interventions), a one-year construction time is expected for each corridor. For option 2 (fix the worst problems), a two-year construction time is expected for each corridor, and for option 3 (fix everything), a three-year construction time is expected for each corridor. This variation in construction times across options has been assumed based on varying levels of intersection re-designs, bus lanes, and corridor widening across the three options, as these interventions are likely to be associated with long construction times.

Cost uncertainty has been accounted for in two ways. Firstly, broad ranges for cost estimates have been produced to reflect the uncertainty regarding delivery costs in the absence of detailed design. Secondly, the potential impact of higher than anticipated construction costs on project BCRs has been investigated through sensitivity testing.

17. Funding sources

It is anticipated that the bus priority measures outlined in this business case will be integrated into the LGWM City Streets programme. This includes planning, engagement, funding and implementation.

City Streets has an indicative budget of around $350 million. This will be funded through the LGWM partnership model.

In support of this, other programmes and budgets can be aligned to help achieve the measures and outcomes recommended by this business case. These include:

- funding through LGWM of other packages, including mass transit and state highway works

- the Transport Agency's maintenance and operations budgets
- Greater Wellington Regional Council's operational expenditure and changes implemented following the bus network review
- Wellington City Council budgets, including for minor works and maintenance and operations, as well as for implementation of the cycling programme. The City Council currently has funding for bus priority works in the 10-year Long-term Plan, however this will need to be reviewed and updated in line with the emergent funding requirements for LGWM and City Streets.

18. Current funding status

Currently, funding is not confirmed for subsequent business case, pre-implementation or implementation phases.

The funding model, funding streams, costs and programme budget will be developed as part of scoping and early planning for the City Streets programme. This will require alignment with the LGWM funding and partnership model and opportunities to align with and leverage off other funding streams as outlined above.

Implementing the programme

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME AS THIS IS DEVELOPED IN EARLY 2020

This part of the business case outlines how the preferred programme will be successfully implemented.

It contains the following four sections:

Prioritisation, staging and sequencing – this outlines the criteria and approach for the potential prioritisation, staging and sequencing of implementation as part of the City Streets programme.

Early improvements – this sets out the case for making lower-cost and/or lower-risk improvements to provide early benefits. It is proposed that these would be scoped further and advanced alongside the development of the City Streets programme.

Commercial case – this presents a range of approaches to the procurement of the preferred programme, sets out the pros and cons of each, and provides an indicative assessment of the most suitable options. It presents evidence on risk allocation and transfers as well as details of responsibilities for implementing different aspects of the programme.

Management case – this addresses the achievability of the programme and planning arrangements required to ensure successful implementation and to manage project risks.

Prioritising, staging and sequencing

19. Staging and sequencing

It is anticipated that implementation of the full programme recommended in this business case as part of City Streets will take seven to ten years. This needs to be planned, coordinated and implemented in the context of the wider LGWM programme which will take 15 to 20 years or more to implement.

The risks, challenges and complexities of planning and implementing a programme of the scale of LGWM are beyond anything previously attempted in Wellington. These are well documented in the LGWM report 'Staging and sequencing considerations, options and next steps' from November 2018.[5] This report notes:

"The scale of these challenges should not be underestimated, and the risks are high if this work is not undertaken effectively as an ongoing process as part of the planning, design and delivery of the programme. It needs to be considered a core accountability and an ongoing process. It will need to be resourced accordingly as part of the delivery agency responsible for LGWM.

The risks of not doing this work well include failure to deliver key programme elements, unacceptable social and economic impacts, cost escalations, project delays, failure to realise the programme benefits and loss of social licence."

While the works envisaged in this business case are not as significant as other LGWM components from a construction perspective, they will be disruptive and have considerable local interest in relation to the reallocation of road space, removal of car parking and changes to bus facilities and services.

This means that while it is possible to apply a range of criteria to prioritise the relative importance of each section of the bus priority programme, this will also need to be overlaid with and assessed in relation to a range of other criteria and inputs to inform the optimal staging and sequencing for planning and implementation. These considerations include:

- opportunities to implement early improvements through other programmes and funding
- feedback from public engagement on City Streets or other aspects of the LGWM programme
- ongoing feedback and stakeholder positions on each corridor as this is planned and engagement occurs
- critical interdependencies with other projects, such as:
    - work or projects that must be completed before another project can be started because they are in the same location (such as on the quays)
    - enabling works to relocate services or facilities
    - enabling works or projects to create behaviour change, or network capacity before another project can get underway (such as travel demand management), as the programme will significantly reduce network capacity during construction

[5] Refer to: https://lgwm.nz/resources/documents/technical-documents/

    - lead times, including detailed business case development, design, consenting, engagement, property and enabling works (in some cases these will be very significant such as for mass rapid transit)
    - construction times, including enabling works, service relocations and mitigation works
- recommendations and changes resulting from the bus network review or other related projects
- optimising value for money (doing the right things, in the right way, at the right time, at the right price) to ensure overall programme benefits
- enabling and facilitating bus passenger behaviour change and positive experiences of the bus system as it improves
- equity and distribution of benefits for different communities and user groups
- minimising the system disruption to the communities of Wellington over the life of construction projects
- programming constraints such as market capacity to deliver, consenting and approvals processes, and social and environmental impacts how these are balanced and weighted will require careful and ongoing consideration.

Other factors include funding availability and cash flows. These are all legitimate things to consider in the staging and sequencing of the programme, and the importance of different factors will change over time.

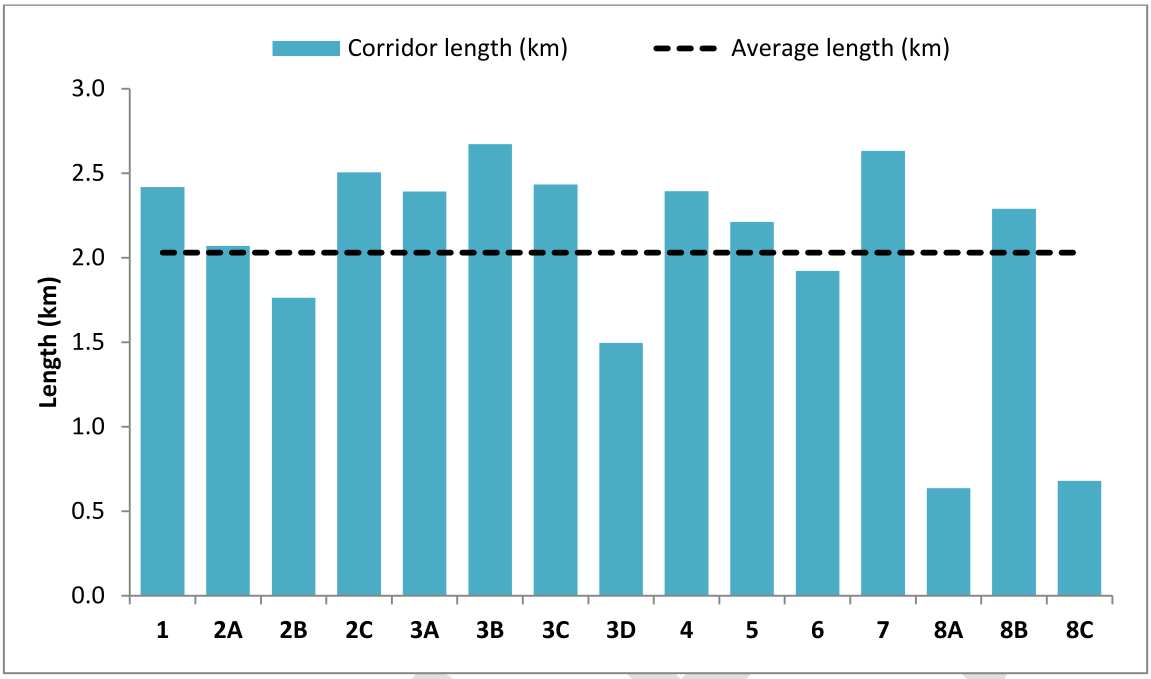
It is important that staging and sequencing is therefore considered as an ongoing process of refinement as the programme moves forward

20. Multi-criteria analysis for prioritising corridors

Noting the staging and sequencing challenges outlined above, a multi-criteria analysis (MCA) was used to prioritise the corridors in terms of informing how the implementation is sequenced.

For the purposes of prioritising and sequencing, the longer corridors were divided into sections as there is a lot of similarity between them. It may be desirable to sequence improvements within a corridor according to the MCA. Corridors were divided into subsections using two criteria: a corridor length of around 1.5 to 2.5 kilometres, and relatively similar conditions with regard to bus operating conditions and surrounding land use. The corridor subsections are shown in Figure 14.

Figure 14: Corridor subsection lengths



Three broad types of criteria were used to prioritise corridors: the scale and impact of the problems, the opportunities for other improvements, and implementation effectiveness. The criteria metrics and weightings are outlined in Table 13.

Table 13: MCA criteria and weighting for prioritising corridors

Category	Criteria	Metric	Weight
Scale and impact of the problem	Patronage	Weekday average passengers (inbound + outbound)	10%
	Bus travel time performance	Estimated delay (min/km) during worst inbound and outbound hours	10%
	Travel time reliability	Measure using Snapper microdata	10%
Opportunity for wider improvements	Cycle network	Desired level of service improvement / Cycle priority corridor identified by master plan (everywhere except Moxham Avenue) / Timing for cycling improvement over next 3-10 years	15%
	Safety	DSI/km over 10-year period	15%
Implementation effectiveness	Effectiveness of proposed changes	Modelled minutes/km improvement to travel time in the AM peak (inbound) and PM peak (outbound)	10%
	Implementation complexity / ease of change	Constructability / level of disruption / lack of overlap with other projects	30%

Figure 15: MCA results

	Corridor														
Criteria	**1**	**2A**	**2B**	**2C**	**3A**	**3B**	**3C**	**3D**	**4**	**5**	**6**	**7**	**8A**	**8B**	**8C**
	Newtown to city	**Karori Road**	**Chaytor / Glenmore**	**Glenmore at Rigi / Bowen**	**Seatoun to Miramar**	**Miramar to Kilbirnie**	**Kilbirnie to Hataitai**	**Mt Victoria**	**Mt Cook to city**	**Kelburn to city**	**Kilbirnie to Newtown**	**Brooklyn to city**	**Johnsonville triangle**	**Ngauranga Gorge**	**Centennial Highway**
Patronage	7752	5899	6568	3296	1560	3551	5593	6625	6758	4648	3704	3320	4638	6362	7822
Bus travel time performance – inbound	4.42	4.95	1.38	2.09	1.05	1.88	3.08	2.52	4.88	2.20	3.88	3.35	6.52	1.73	1.52
Bus travel time performance – outbound	4.26	1.73	2.70	1.86	2.21	2.67	1.01	0.99	4.59	1.76	2.65	4.07	2.63	0.00	2.59
Travel time reliability – inbound AM peak	1.06	2.88	0.54	0.82	0.55	0.45	0.66	0.80	0.88	0.70	1.08	0.78	2.60	1.13	0.63
Travel time reliability – outbound PM peak	0.68	0.49	0.70	0.36	0.36	0.28	0.55	0.89	1.17	0.68	0.69	0.80	2.04	0.74	0.91
Effectiveness of proposed changes	0.37	0.48	0.11	0.37	0.11	0.34	0.34	0.13	0.14	0.10	0.29	0.33	0.43	0.00	0.11
Cycle network	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes
Safety	11.6	6.8	2.3	3.2	0.8	4.5	0.8	2.7	6.7	2.3	3.1	9.1	7.8	7.9	5.9
Implementation complexity / ease of change	High	Medium	Medium	Low	Medium	High	Medium	Medium	High	Medium	Medium	Medium	Medium	High	Low
Scores and ranking (long-term)															
Total score (normalised to 0-100%)	60%	71%	42%	63%	31%	38%	41%	34%	43%	39%	51%	59%	74%	18%	61%
Option rank	5	2	9	3	14	12	10	13	8	11	7	6	1	15	4
Scores and ranking (early improvements)															
Total score (normalised to 0-100%)	79%	78%	40%	51%	25%	50%	38%	28%	57%	35%	51%	62%	81%	23%	48%
Option rank	2	3	10	7	14	8	11	13	5	12	6	4	1	15	9

21. Identifying early improvements

A programme of early improvements for bus priority is proposed in order to make some meaningful changes as soon as possible. Early improvements can be made before whole corridors are reconfigured because they are less complex.

Early improvements have been defined as activities that meet four criteria. They will:

- provide bus efficiency benefits, and
- can be implemented relatively quickly (within one to two years), and
- are relatively low cost, and
- don't preclude longer-term options.

Examples of activities which meet these criteria include:

- timing changes at traffic lights
- bus phase / queue jumps at traffic lights
- bus stop rationalisation
- bus stop layout improvements such as lengthening bus boxes, adding entry and exit tapers
- implementing in-line bus stops
- changing hours of operation of existing clearways / bus lanes.

The eight corridors were also reviewed to identify the most significant causes of delay. These were assessed against the early improvements criteria (set out above) to identify locations where early improvements are likely to be appropriate. The full screening is shown in Appendix 11. Table 14 shows the locations that are recommended to be prioritised as part of the early improvements programme.

Table 14: Early improvements to be included in the programme

Corridor	Direction	Period	Location	Issue	Early improvements criteria			
					Effective	Quick	Cheap	Flexible
Newtown to city	Inbound	4-5pm	Adelaide	~60 sec delay due to congestion	Bus lane	Extend bus lane hours	✓	✓
	Inbound	4-5pm	Cambridge	~60 sec delay due to congestion	Bus lane	Extend bus lane hours	✓	✓
	Inbound	8-9am	Cambridge	~60 sec delay due to congestion	Bus lane	Upgrade bus lane	✓	✓
	Outbound	8-9am	Kent @ Courtenay, Elizabeth	~110 sec delay due to congestion	Bus lane	Extend bus lane hours	✓	✓
	Outbound	4-5pm	Kent @ Courtenay, Elizabeth	~70 sec delay at 2 signals	Bus jump	Simple reconfiguration	✓	✓
	Outbound	4-5pm	Courtenay, Kent	~40 sec delay due to congestion	Bus lane	Simple lane reallocation	✓	✓
	Outbound	4-5pm	Kent / Pirie	~40 sec delay at 1 signal	Bus jump	Simple lane reallocation	✓	✓
Karori to city	Inbound	5-6pm	Bowen clearway	~40 sec delay due to congestion	Bus lane	Extend bus lane hours	✓	✓
	Outbound	5-6pm	Glenmore @ Upland roundabout	~90 sec delay due to congestion	Bus lane	Part-time signal on Upland	✓	✓
Seatoun to city	Inbound	8-9am	Kilbirnie Cres @ SH1	~40 sec delay at 1 signal	Bus jump	Reconfigure intersection approach	✓	✓
	Inbound	8-9am	Cambridge	~40 sec delay due to congestion	Bus lane	Upgrade bus lane	✓	✓
	Inbound	8-9am	Elizabeth @ Kent	~40 sec delay at 1 signal	Bus jump	Simple lane reallocation	✓	✓
	Outbound	5-6pm	Kent @ Courtenay, Elizabeth	~60 sec delay at 2 signals	Bus jumps	Simple reconfiguration	✓	✓
Mt Cook to city	Inbound	4-5pm	Taranaki (Wallace–Abel Smith)	~90 sec delay due to congestion	Bus lane	Partial widening on Taranaki	✓	✓
	Outbound	5-6pm	Taranaki (Webb–Wallace)	~60 sec delay due to congestion	Bus lane	Change clearway to bus lane	✓	✓
Newtown to Kilbirnie	Inbound	8-9am	Bay @ Evans Bay, Rongotai	~70 sec delay at 2 signals	Signal changes	Phasing and timing changes	✓	✓
	Outbound	5-6pm	Bay @ Evans Bay, Rongotai	~40 sec delay at 2 signals	Signal changes	Phasing and timing changes	✓	✓
Johnsonville to city	Inbound	8-9am	Centennial Hwy @ Hutt	~30 sec delay at 1 signal	Bus jump	Simple reconfiguration	✓	✓
	Outbound	5-6pm	Broderick @ Gothic	~90 sec delay at 2 signals	Bus jumps	Simple reconfiguration on Broderick	✓	✓

Commercial case

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME.

THIS WILL BE INFORMED BY THE LGWM PARTNERSHIP AND FUNDING AGREEMENT

22. Procurement of the programme

The commercial case presents a range of approaches to the procurement of the preferred programme, sets out the pros and cons of each, and provides an indicative assessment of the most suitable options. It presents evidence on risk allocation and transfers as well as details of responsibilities for implementing different aspects of the programme.

As with the rest of this IBC, the commercial case is focused on procurement of the physical infrastructure interventions on each corridor.

The indicative assessment of procurement options in this section focuses on a number of qualitative factors, particularly:

- cost competitiveness, and the ability of the different models to ensure strong market tension
- the ability of the procurement model to meet deadlines for the detailed business case and implementing changes
- the effectiveness of the procurement model at maximising certainty of costs
- the ability of the model to accommodate and respond to uncertainty
- the procurement model's ability to deliver innovation in DBC development, asset design, construction and management, achieving lower whole-of-life project costs.

23. Procurement strategy

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME

24. Required services and outputs

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME

25. Scope of further business case analysis including key issues to be addressed

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME

26. Early improvements programme

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME

THIS WILL NEED TO INCLUDE THE PROCUREMENT AND DELIVERY MODEL INCLUDING WHO IS THE CONTRACTING ENTITY – THIS WILL BE INFORMED BY THE LGWM PARTNERSHIP AND FUNDING AGREEMENT

27. Risk apportionment

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME

28. Timing / staging – include a diagram

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME

An indicative timeline for the programme is shown in Figure 16. This will be confirmed as part of scoping the City Streets programme. The major work that needs to be done in the first three months of 2020 includes:

- confirming the scope, approach and business case pathway for City Streets
- informing the 'design sprint' for the mass rapid transit and state highways LGWM workstreams by April
- confirming the priorities, packaging, funding, resourcing and procurement model for early improvements to get these underway as soon as possible.

29. Consenting

Consenting requirements will be an important factor for programme delivery, timing, and sequencing. The requirements will vary depending on the type of intervention. Some minor works such as traffic light changes and kerb realignments do not require consents.

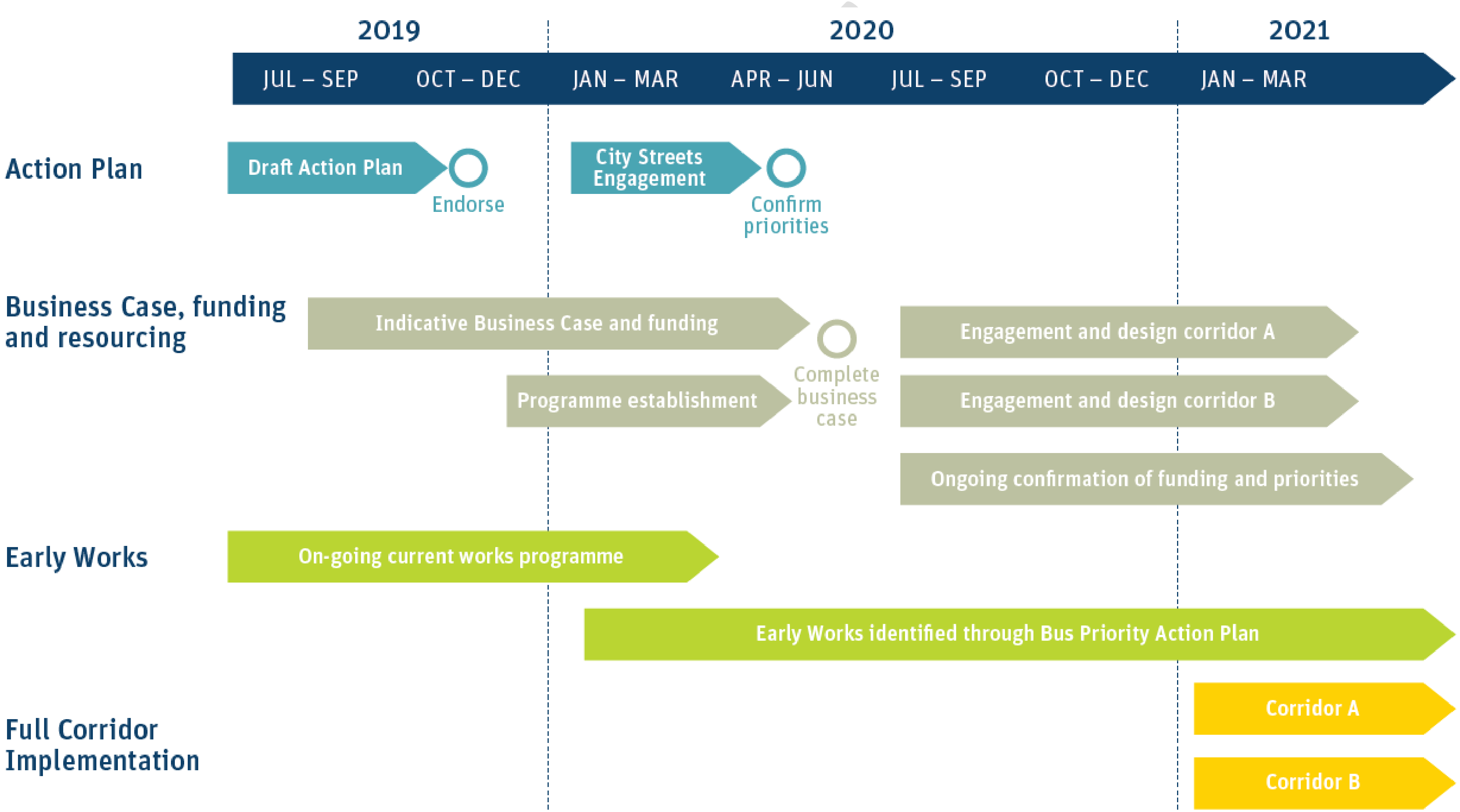
Other changes such as removing or restricting parking, relocating or lengthening bus stops, creating or altering clearways or bus lanes require Wellington City Council's approval following the Traffic Resolution procedures made under the Wellington Consolidated Bylaw 2008, Part 7: Traffic (reflecting the requirements of the Local Government Act 2002, section 151). Final decisions must be made by elected members.

Bus shelters in residential areas require resource consent under the District Plan. Consent is obtained following the statutory planning process administered by the City Council. Affected parties may lodge an objection to a proposed bus shelter location under section 339 (2) of the Local Government Act 1974. If an objection is received it must be heard by the Council. This hearing is covered by delegations to the Regulatory Processes Committee (or its successor).

If it's necessary to widen road corridors, the procedures under the Public Works Act 1981 will be followed.

For the recommended programme, all necessary consents will be applied for when the form and location of works have been determined. This will follow engagement and consultation with local communities and preliminary designs have been completed. Final designs would then reflect any consenting requirements.

Figure 16: Indicative timeline for bus priority and city streets



Management case

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME

30. IBC project management strategy and framework

As noted above, the development of this IBC has included:

- direction from the project steering group with executive leadership representatives from all partners
- management by the project control group with representatives from all partners, including connections to LGWM
- oversight and coordination by an independent programme director
- establishment workshops involving representatives of all partners on 12 April and 10 May 2019 to confirm the direction and scope of the work. These included executive leadership representatives from both councils
- formation of a joint team of staff from both councils to extract, analyse and map data, review corridor provisions, complete indicative cost benefit analysis, and document the findings. This team worked together to develop the IBC and Bus Priority Action Plan.

From here, the planning and implementation of bus priority works will be integrated into the LGWM model. The details of this scope and management model are still being developed but it will include:

- scope and interrelationship with other LGWM workstreams
- governance
- people resources / team design
- procurement – for the core team, business case, design and construction
- funding and costs
- business case requirements and pathway
- engagement and communications approach
- management and implementation model.

Some aspects of this approach have been developed and agreed, including an implementation model where the City Streets programme will:

- be an agile, rolling programme that can make early improvements and respond to changes in context
- be based on a streamlined business case process – 'Tetris model' / chapters in a book, rather than a single IBC or DBC for the whole programme
- have a strong focus on early improvements:
  - for bus priority in particular, we have a good understanding of what these will be but funding and resources need to be put in place to carry out the work (this is likely to be a two- to three-year rolling programme)
- have a strong emphasis on community engagement
- have a core resourcing model that will draw heavily from the partners and require:

  - significant support from external consultants, and
  - RFTs for some elements of the programme.

31. Ongoing programme of governance and commitment from the partners

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME

32. Integration with other projects and activities

City Streets will take a multi-modal approach to the eight corridors which will be further developed at the next stage of the business case process.

Where bus priority corridors and the city's planned cycleway network overlap, the cycleway programme will be integrated with the bus priority works to ensure one consistent conversation is had with local communities and solutions are enduring.

The recommended programme will complement LGWM's planned early delivery investments:

- Thorndon Quay-Hutt Road, which will include cycling and bus improvements
- the Golden Mile, which will include bus improvements.

Implementation of the recommended bus priority programme needs to be appropriately integrated with planning and delivery of the following currently identified projects:

- LGWM mass transit – planned to affect parts of three corridors in the medium term:
  - Seatoun to city (Cobham Drive)
  - Newtown to city (Adelaide Road and Riddiford Street)
  - Mt Cook to city (Taranaki Street).
- LGWM state highway – planned to affect parts of four corridors:
  - Newtown to city (Kent Terrace and the Basin Reserve)
  - Brooklyn to city
  - Mt Cook to city
  - Seatoun to city
- the Regional Council's bus network review.

Therefore initial interventions in these areas may be of a lower cost, temporary nature to enable further changes without undue asset write-offs.

There are opportunities for coordination during implementation planning to align works with planned operations, maintenance and renewal activities, such as street resurfacing, kerb renewals and ongoing minor improvements to bus stops.

33. Project management

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME

The project planning for City Streets will include:

- a project management plan

- a benefits realisation plan
- a risk management plan
- ensuring responsibility is also covered for the management of risk. The risk register is intended to be continuously updated and reviewed throughout the course of the project.

34. Operations and maintenance considerations

Detailed design of physical infrastructure will need to take account of the ongoing impacts on operations and maintenance. Maintenance of new infrastructure will happen in accordance with the asset management plans of both councils.

35. Integration with existing operations

This proposed bus priority programme has two key parts – early improvements consisting of relatively low-cost, low-risk improvements that can be made relatively quickly, and longer-term, higher-cost corridor changes. For efficiency, the early improvements will need to be coordinated with business-as-usual activities. The larger projects will need to be coordinated where possible with planned maintenance and renewal programmes, such as resurfacing and kerb replacement.

35.1. Maintenance challenges

The proposed programme will result in the creation of new physical assets. Once changes are implemented, these assets would be maintained and renewed as part of the City Council's asset management processes. New infrastructure, such as new traffic lights and paved areas would trigger a requirement for extra maintenance and renewal funding in future.

As currently envisaged, there are no factors which might adversely affect the City Councils' ability to operate or maintain the recommended programme over its projected life without major additional costs.

36. Safety in design (not sure if this section fits here or elsewhere)

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME

- Are there any significant hazards associated with the option which may pose a health and safety risk in the design, build and final product? Can safety be developed into the design process to control it?

37. Engagement and communications

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME

At this time, it is planned that there will be a city-wide engagement process on the City Streets programme from March 2020 onwards.

This will help to confirm the priority corridors and issues on each corridor. It will also help to inform the approach and prioritisation of place, walking, safety and network optimisation outcomes when considering appropriate interventions in specific places.

There will be more detailed engagement with local communities on each corridor as part of more detailed analysis and the business case process. Consultation will also be required for any changes through the traffic resolution process. Where appropriate, these engagement and consultation processes may be combined.

38. Project risks

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME

39. Monitoring achievement of benefits

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME

- Benefits
- Key performance indicators
- Measures
- Anticipated level of benefit
- Draw from MCA development

40. Next steps

THIS SECTION WILL BE FURTHER DEVELOPED TO REFLECT THE DELIVERY APPROACH AND INTEGRATION WITH THE CITY STREETS PROGRAMME

The evidence and analysis outlined in this business case will be used to inform and help shape the scope and approach to City Streets, including the business case requirements.

As noted above, the work that needs to occur in the first three months of 2020 includes:

- confirming the scope, approach and business case pathway for City Streets
- informing the 'design sprint' for the mass rapid transit and state highways LGWM work streams by April
- confirming the priorities, packaging, funding, resourcing and procurement model for early improvements to get these underway as soon as possible.

Appendix 1 – Short-listing corridor plots

For the short-listing process, bus travel time data was analysed for relatively long corridor sections to determine average speeds and travel time variability. The analysis looked at three time periods: morning peak (7–9am), inter-peak (noon–2pm), evening peak (4–6pm) for both inbound and outbound directions. Results were plotted on the 12 maps shown on the next pages. These have been summarised into Table 2 in Section 6.4.

Figure 17: Inbound AM peak average bus speed and travel time variability maps

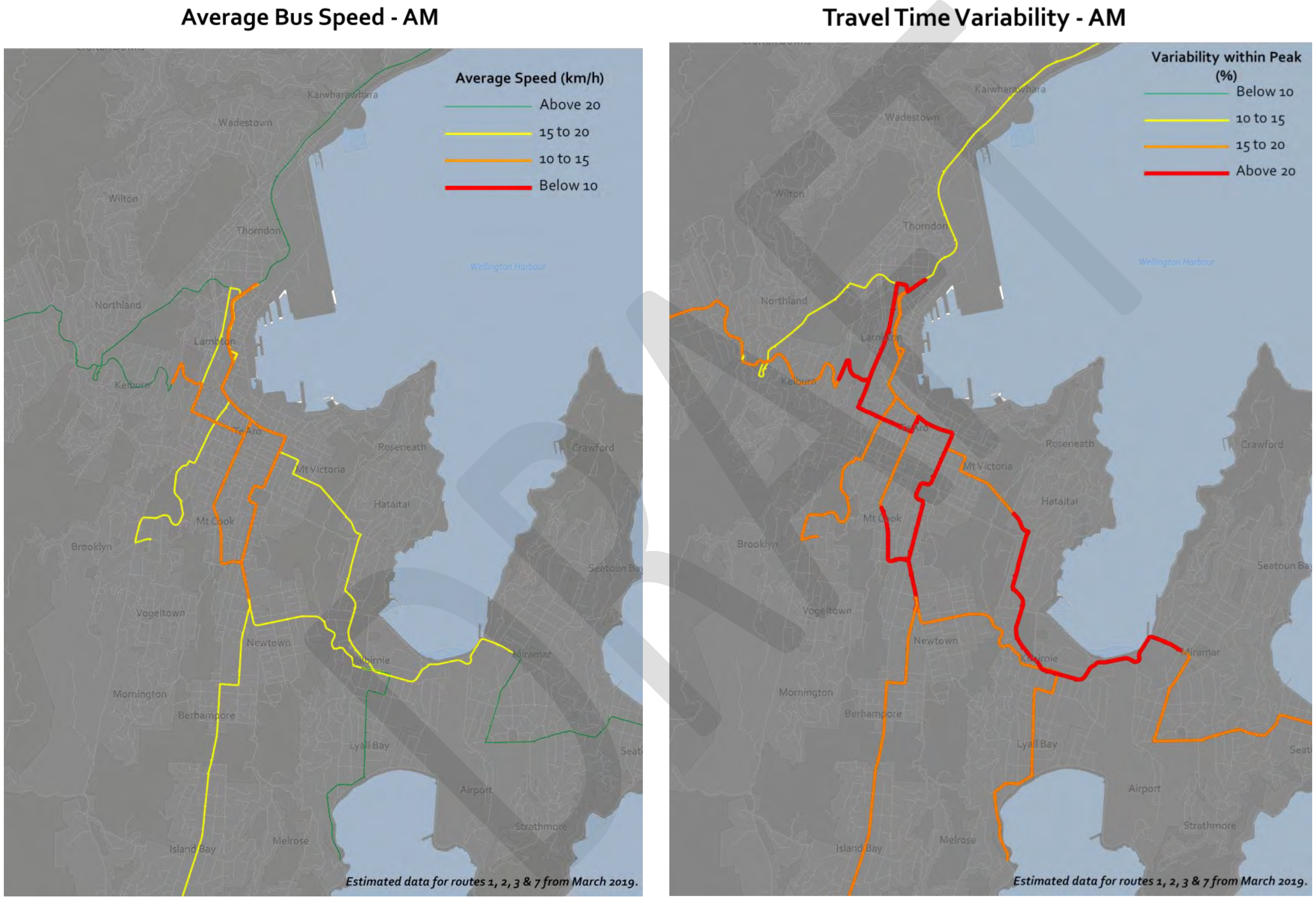


Figure 18: Inbound inter-peak average bus speed and travel time variability maps

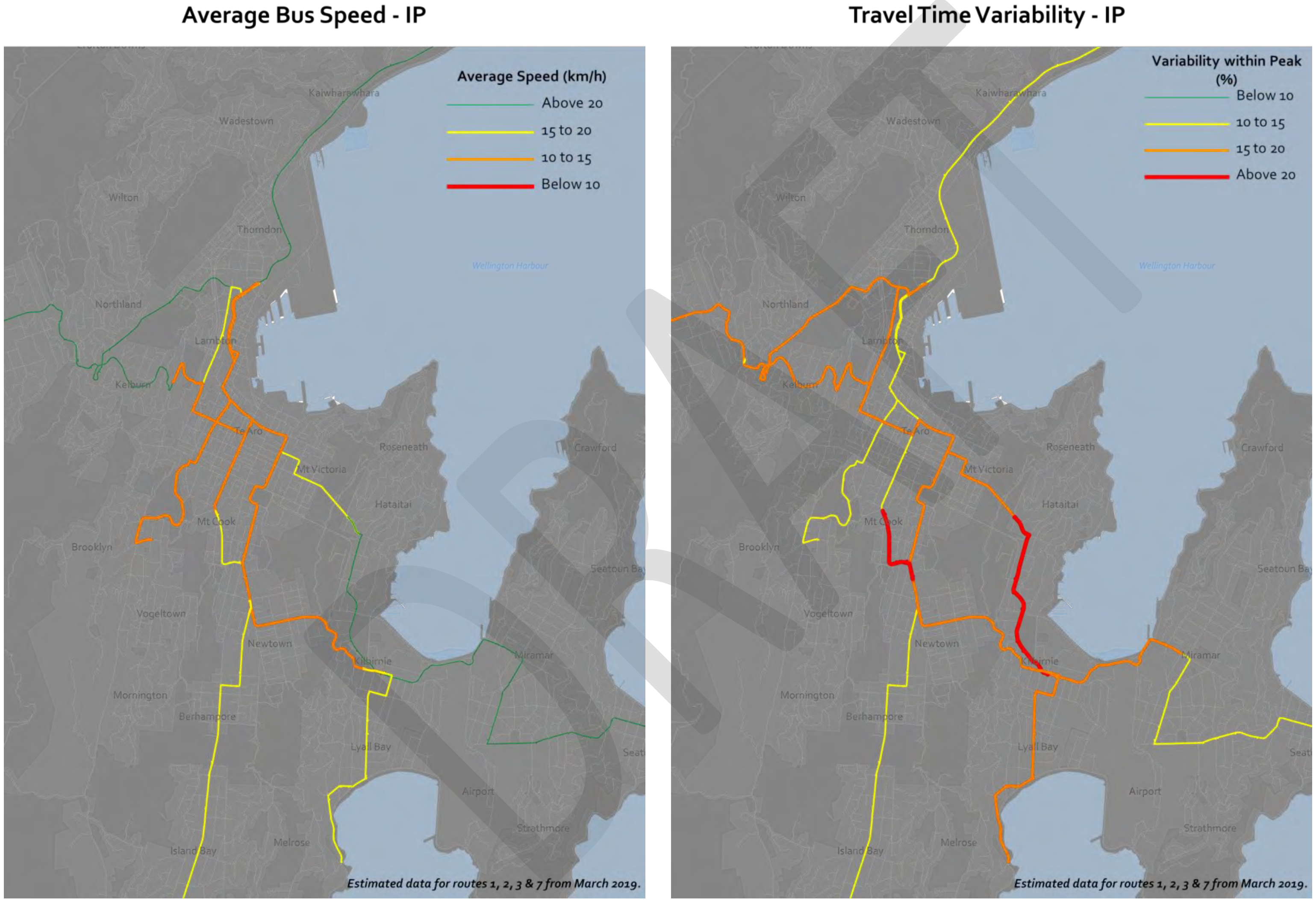


Figure 19: Inbound PM-peak average bus speed and travel time variability maps

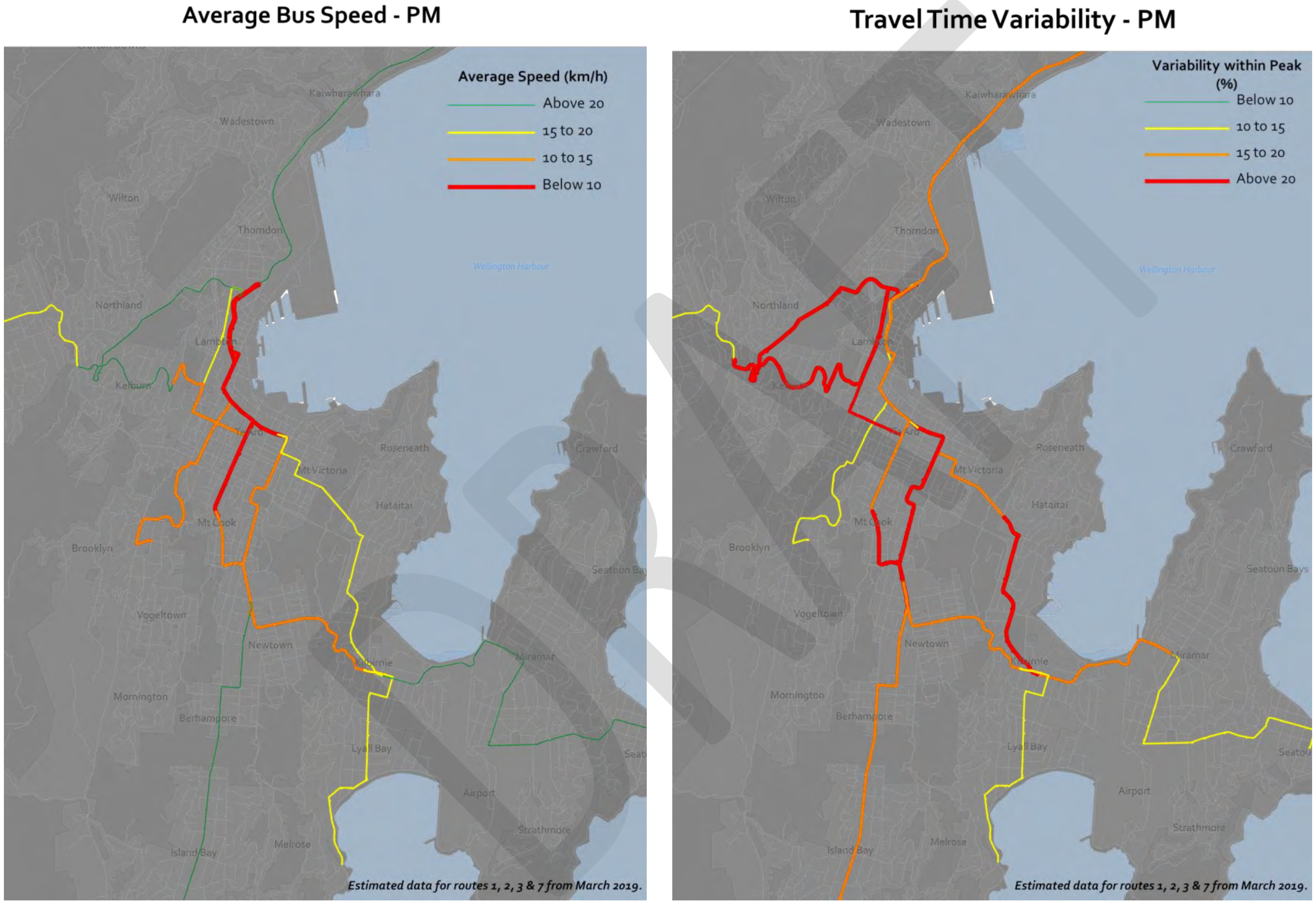


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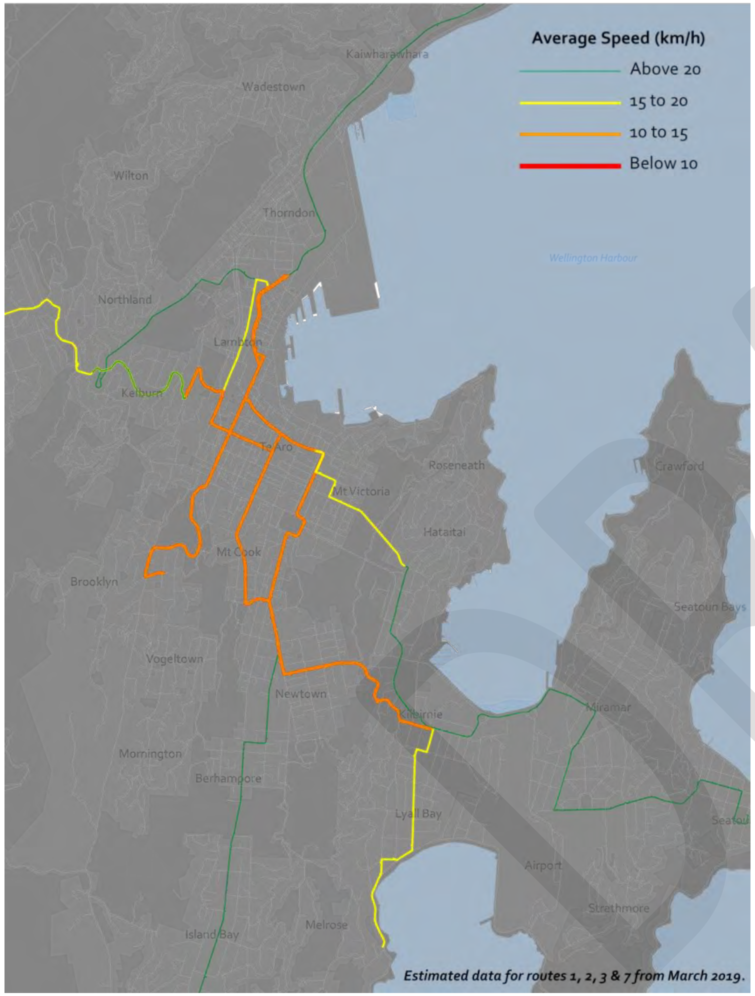
Figure 20: Outbound AM peak average bus speed and travel time variability maps

Average Bus Speed - AM



Travel Time Variability - AM

Figure 21: Outbound inter-peak average bus speed and travel time variability maps

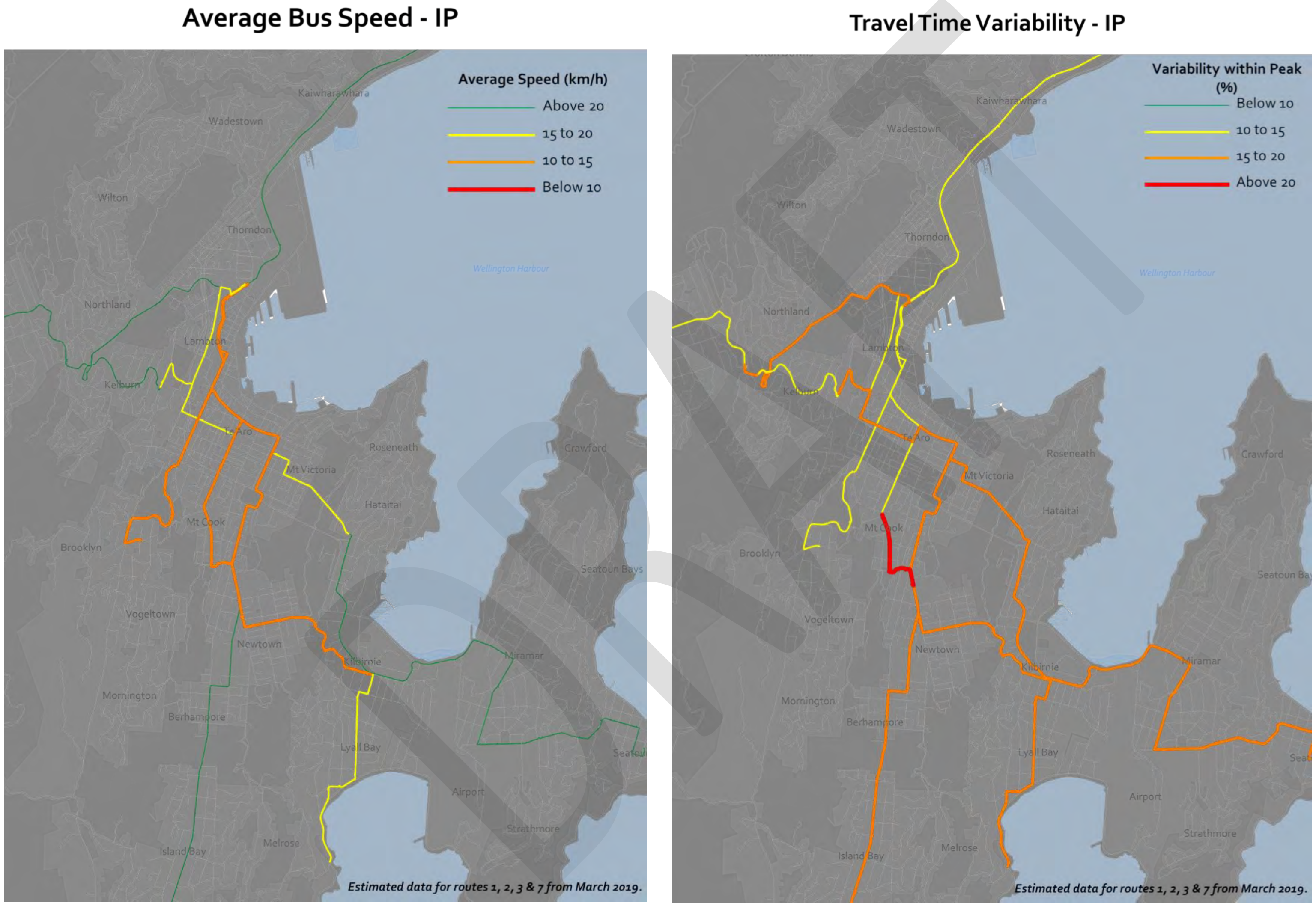


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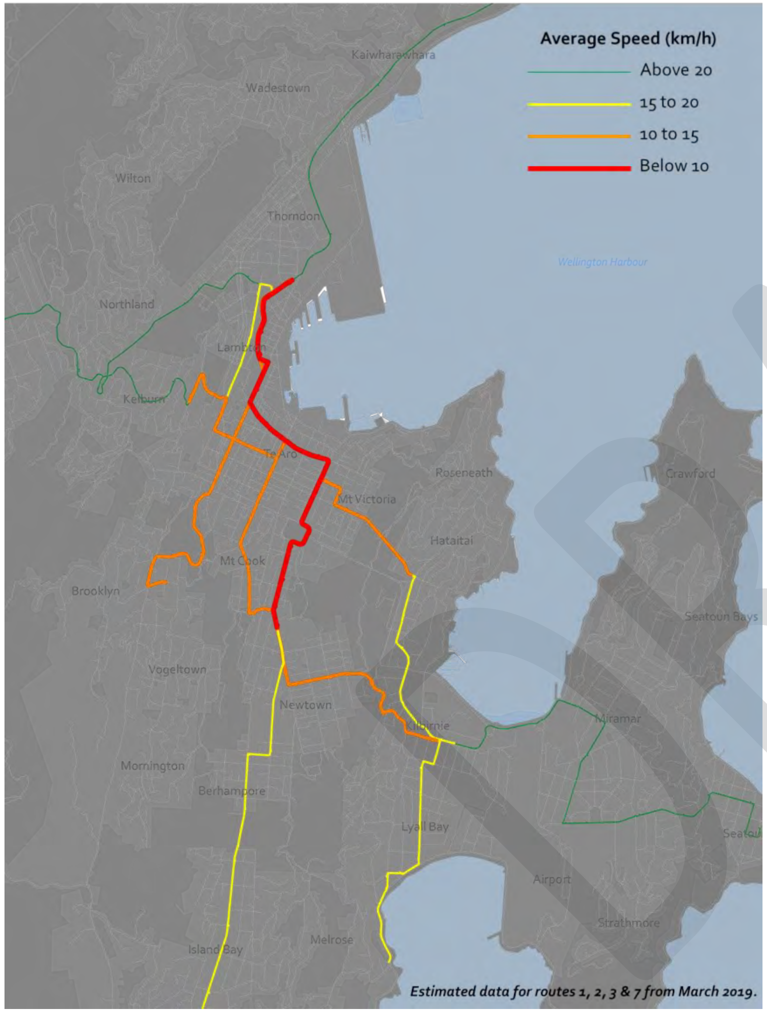
Figure 22: Outbound PM-peak average bus speed and travel time variability maps

Average Bus Speed - PM



Travel Time Variability - PM

Appendix 2 – Cost benefit analysis technical appendix

This technical note outlines how we can estimate the benefits of bus priority interventions to transport users, and sets out caveats and limitations to this analysis. It defines procedures for identifying the benefits of individual interventions at an indicative and detailed level and uses these to obtain an indicative programme-wide estimate of benefits.

It covers the following topics:

1. Overall process for long-list / short-list assessment and indicative BCR calculation
2. Definition of interventions that are under consideration for inclusion in the programme
3. Description of data sources used in assessment
4. Overview of evaluation methodology
5. Description of key parameters and assumptions used to implement this methodology
6. Description of methods used to calculate the impact of specific interventions on bus users and other transport users at an indicative or detailed level
7. Description of benefits / disbenefits that are excluded from this indicative analysis.

1. Overall process for long-list / short-list assessment and indicative BCR calculation

This note details a draft approach for calculating an indicative BCR for the suggested package of works. This is intended to be suitable for application to the National Land Transport Fund.

The indicative BCR calculation is the final stage of option assessment / economic analysis conducted for this project. The long-list / short-list process is as follows:

- Step 1: assess all bus corridors in the region to identify priority corridors (those which have slow speeds, unreliable journey times, and high passenger volumes)
- Step 2: define the bus priority toolkit – interventions that could be applied to improve bus speed and reliability
- Step 3: long-list to short-list process – undertake three successive ‘sieves’ to identify which bus priority interventions may be desirable in which locations:
    - Step 3a – Appropriateness**:** Is the magnitude of the problem worth fixing?
    - Step 3b – Effectiveness**:** Will the tool be effective in addressing the issue?
    - Step 3c – Feasibility**:** Is it technically possible to implement?
- Step 4: cost estimation for short-listed interventions
- Step 5: indicative BCR of package consisting of short-listed interventions across all corridors.

2. Interventions that can improve bus performance

Table 15 outlines the bus priority interventions for which benefits are estimated in this note. These measures can be grouped into four broad categories: signal improvements, in-lane bus priority measures, corridor improvements, and bus stop improvements.

Table 15: Bus priority interventions

Category	Option	How do they work?	When are they useful?
Signal improvements	Increased green phase	By giving the bus direction of travel and an increased share of the cycle time, the average delay at an intersection is reduced and the share of buses being delayed is reduced.	When there are large traffic signal delays at intersections in the bus direction of travel.
	Queue jump	Approaching buses exit the general traffic lane and enter the queue jump lane, allowing buses to bypass queued vehicles.	Where there are long queues of vehicles at a signalised intersection, causing long queue service times. Where buses must change lanes or turn at the intersection and benefit from traffic being held.
	Bus phase	Approaching buses in a bus / queue jump lane receive a 'B' signal phase before general traffic gets a green.	Where transit vehicles must manoeuvre between lanes or make movements that general traffic does not eg into a bus depot. When a bus stop immediately precedes a signal and buses can get a head start through the intersection.
	Minor Intersection redesign	Will vary from site to site. May include a redesign of signal phases, a reduction in allowed turning movements, and / or traffic lane reconfiguration.	When buses are experiencing moderate delays and / or there are safety issues at an intersection.
	Major Intersection redesign	Will vary from site to site. Likely to include major reconfiguration of traffic lanes and movements.	When buses are experiencing significant delays and / or there are safety issues at an intersection.
In-lane bus priority measures	In-line bus stops	Kerb extensions align the bus stop with the parking lane, creating an in-line bus stop. This enables buses to stop at the kerb line without making large lateral shifts.	Where merging into traffic from pull-out bus stops creates re-entry delays. Where passenger volumes require a larger dedicated waiting area than is available on the footpath. Where there are conflicts with people on bikes. Where large numbers of passengers must step into the road because the bus cannot stop at the kerb.
	Peak-only bus lanes	Dedicated traffic lanes for buses reduce conflicts with general traffic at peak times only.	When high v/c ratios are causing mid-block congestion at peak times only. When there is a high need / demand for parking outside peak times.

Category	Option	How do they work?	When are they useful?
	24-hour bus lanes	Dedicated traffic lanes for buses reduce conflicts with general traffic at all times.	When high v/c ratios are causing mid-block congestion across the day. When there is a not a high need / demand for parking or corridor widening is feasible.
Corridor improvements	Peak-hour clearways	Parking is restricted at peak times to allow for wider lanes and shoulders, and facilitate manoeuvring in and out of bus stops.	When narrow (>3.2m) traffic lanes and / or high amounts of side friction from parked vehicles cause delays for buses. When there is a high need / demand for parking outside peak times.
	Widened traffic lane	Traffic lanes are widened, either through removing parking or through corridor widening.	When narrow traffic lanes (>3.2m) and / or high amounts of side friction from parked vehicles cause delays for buses. When there is a not a high need / demand for parking or corridor widening is feasible.
Bus stop improvements	Bus stop rationalisation	A reduction in the number of bus stops reduces acceleration / deceleration / dwell time losses, reducing bus travel times.	When bus stops are close together, causing overlapping walking catchments. This causes the bus to stop frequently without substantially increasing access to bus stops.
	Entry / exit tapers	For off-line bus stops, this assists buses manoeuvring into and out of bus stops, allowing the bus to kerb easily.	When road layout / parking prevent buses from manoeuvring into bus stops, causing delays and passengers to step into the road because the bus cannot kerb.
	Lengthening bus stop	An increased number of stopping bays allows multiple buses to use the bus stop at the same time, reducing bus-bus congestion at bus stops.	When high frequency of buses and / or long dwell times (eg at bus interchanges) cause bus-bus congestion at bus stops.

Two additional categories of interventions are not included in this assessment as they are out of scope for the project. These are:

- **Increasing bus frequency**: this will reduce the average amount of time that passengers spend waiting at bus stops. On crowded routes, it will also improve passenger comfort and reduce the risk of being passed by a full bus.
- **Other operational improvements:** these include bus dispatching to maintain consistent intervals between buses, all-door boarding, off-board ticketing, and improved scheduling to reduce waits at timing points. These interventions can reduce average waiting times, reduce dwell times at stops, and / or reduce variability in travel times for users.

3. Description of data sources

This analysis is based on the following sources of data, which are used to identify current demands and travel times on bus corridors:

- Snapper data on boardings and alightings, which is used to estimate passenger loadings on buses, and to create origin-destination matrices showing the number of people travelling between stops, broken down by time period
- real-time information (RTI) on bus journey times between stops, which is used to identify delays along the route and infer causes of delays
- information on the location and characteristics of bus stops and other bus infrastructure such as priority lanes
- signal timing data from SCATS
- surveyed traffic volumes at selected points along bus corridors (note: traffic counts take place periodically, so survey dates are not the same for all sites).

Unless otherwise noted, all data refers to May 2019, which is a reasonably 'typical' month in terms of bus usage and system performance.

This analysis is not based on strategic transport modelling (WTSM). This is because strategic transport models are not fine-grained enough to identify all performance issues and model the impact of specific interventions such as bus stop rationalisation.

4. Methods used to disaggregate causes of delay for buses

The analysis of problems along bus corridors (and hence opportunities to improve) is based on a comparison of:

- observed (average) bus speeds and dwell times from RTI and Snapper boarding / alighting data
- estimated optimal bus speeds based on formulas in the Transit Capacity and Quality of Service Manual (TCQOSM) and Highway Capacity Manual (HCM).

TCQOSM formulae are used to calculate the delay that is incurred from bus stop spacing, long dwell times at bus stops, re-entry delay, and delays at signalised intersections. An HCM formula is used to calculate the delay that is incurred from narrow traffic lanes and shoulders. The impact of mid-block traffic congestion, un-signalised intersections, and on-street parking is then estimated as a residual.

4.1. Estimating dwell times and running times between stops

We divide public transport travel times into two components:

- dwell time, which refers to the time spent entering bus stops, positioning at the kerb, boarding and alighting passengers, and exiting bus stops; and
- running time between bus stops, including time spent accelerating out of and decelerating into bus stops, time travelling at free-flow speeds or in congested traffic, and time spent queuing at traffic lights and waiting for signals to turn green.

RTI and Snapper data provide information on dwell times and running times, but they do not always agree due to differences in the data-generation processes:

- RTI data tracks buses along their routes and records their arrival at and departure from waypoints like bus stops. Bus location is recorded at 30-second intervals, and buses are recorded as being present at bus stops if they are within 50 metres.
- Snapper data records passenger transactions (boardings and alightings) by use of Snapper cards. Because fare payments are based on the number of fare zones travelled, all boardings and alightings are matched to a bus stop. Time spent dwelling in bus stops and travelling between bus stops can therefore be estimated based on the time between boardings and alightings at each stop, and between bus stops.

We use RTI data to measure the overall average time spent travelling from bus stop to bus stop and Snapper data (with some minor adjustments) to estimate time spent dwelling at bus stops.

We prefer Snapper estimates of dwell times because:

- RTI data over-estimates dwell times for bus stops that are close to intersections or where traffic queues delay buses near bus stops. For instance, a bus waiting at a light 40 metres after a bus stop would be counted as still dwelling at the bus stop.
- RTI estimates of dwell times tend to be bunched at 30-second intervals, reflecting the ping time for bus location. This appears to result in an over-estimate of average dwell times for most bus stops.

However, Snapper data can mis-estimate dwell times in some cases due to:

- people tagging off buses before they arrive at bus stops. We dealt with this by filtering out trips with implausibly large times between first and last boarding / alighting[6]
- cash and SuperGoldCard passengers contributing to dwell times. Boardings by these passengers were recorded in the data, but alightings were not. Because around 85 percent of passengers pay by Snapper, we expect the lack of alighting times for non-Snapper passengers to have a negligible impact on dwell time estimates
- time required for buses to enter bus stops, position at the kerb, and exit bus stops, which is additional to the time that it takes passengers to get on or off buses. We therefore added an additional eight seconds to Snapper estimates of dwell times to account for this, based on a comparison of RTI and Snapper dwell-time estimates and field observations at selected stops.[7]

The following table compares estimated dwell times for buses that stopped, derived from these two data sources for one of the seven corridors we are analysing. On average, Snapper-derived dwell times are two-thirds as long as RTI-derived dwell times. However, there are some locations where adjusted Snapper dwell times are longer than RTI dwell-time estimates, which we think reflects the fact that RTI data can code short dwell times to zero seconds.

[6] Defined as total dwell time over 5 minutes or dwell time per boarding / alighting of more than 30 seconds.
[7] The comparison between Snapper and RTI data controlled for bus stops that had known issues that would increase RTI dwell-time estimates, such as close proximity to signalised intersections, location at a bus hub, or location on the Golden Mile.

Table 16: Comparison of RTI and Snapper dwell-time estimates for buses that stopped on corridor 1, 8-9am inbound

Corridor segment	Stop no.	RTI average dwell-time estimate	Snapper average dwell time (unadjusted)	Snapper average dwell time plus 8-sec adjustment	Ratio
Riddiford at Newtown to Riddiford at Hall	7019	38.9	17.1	25.1	64.4%
Riddiford at Hall to Wellington Hospital	7018	60.3	28.5	36.5	60.6%
Wellington Hospital to Adelaide at Hospital Road	7017	49.1	9.0	17.0	34.6%
Adelaide at Hospital Road to Adelaide at 80	7016	8.1	5.1	13.1	161.9%
Adelaide at 80 to Adelaide at Basin	7015	5.4	2.9	10.9	202.2%
Adelaide at Basin to Cambridge at Barker	7014	59.9	27.7	35.7	59.7%
Cambridge at Barker to Cambridge at Vivian	7013	12.1	8.0	16.0	132.1%
Cambridge at Vivian to Courtenay	7012	36.7	14.5	22.5	61.3%
Unweighted average		*33.8*	*14.1*	*22.1*	*65.4%*

To estimate average running time between bus stops, we subtracted average dwell time estimated from Snapper data from average stop-to-stop time from RTI data. In other words, we used RTI data as the key source for estimating how long buses took to get between points, and Snapper data to disaggregate this into dwell time and running time. We also adjusted for the fact that not all buses stopped at all bus stops.

This process is summarised in the following table.

Table 17: Decomposition of dwell time and running time

Variable	Derivation / notes
Total travel time from stop i to stop j ($TT_{i,j}$)	Calculated as average of RTI stop-to-stop travel times, including dwell times, for all bus services running within all one-hour time periods in May 2019 (eg 8-9am weekdays)
Estimated average dwell time for buses that stopped at stop i (DT_i^{stop})	Estimated as average of Snapper dwell times for all bus services stopping at stop i within each time period plus an adjustment of 8 seconds to adjust for the time required for buses to enter stops, position at the kerb, and exit stops.
Share of buses that stopped at stop i (S_i)	Estimated based on RTI / Snapper data. Buses are recorded as having stopped if they pick up or drop off one or more passengers.
Estimated average dwell time for all buses at stop i (DT_i^{all})	Calculated by multiplying together dwell time for buses that stopped with the share of buses that stopped: $DT_i^{all} = DT_i^{stop} * S_i$. This assumes that dwell time was equal to zero for buses that did not stop.
Estimated average running time travelling between stop i and stop j ($RT_{i,j}$)	Calculated by subtracting estimated average dwell time for all buses from total RTI travel time between stops: $RT_{i,j} = TT_{i,j} - DT_i^{all}$.

4.2. Drivers of dwell time

To understand the impact of boardings and alightings on dwell times, relative to other factors, we undertook an econometric analysis of Snapper-derived dwell times for all bus movements at bus stops. We investigated the following questions:

- What is the average impact of an additional boarding / alighting on dwell time?
- Does this impact differ between passengers using different ticketing products?
- Are there any economies of scale for boarding / alighting large numbers of people?
- Do the route or bus stop characteristics affect dwell times?

Table 18 summarises the results of this analysis. We tested seven different permutations of econometric model specifications. We used models 1–4 to investigate how boarding / alighting volumes affect dwell time, and models 5–7 to investigate whether route and bus stop characteristics have a large impact on dwell times.

Our key findings are as follows:

- On average, an additional boarding adds 3.4 seconds to dwell time, while an additional alighting adds 2.9 seconds (model 1). However, boardings by different ticket types have significantly different effects. On average, an additional Snapper boarding adds 3.0 seconds to dwell time, while an additional cash boarding adds 8.2 seconds (model 2).
- It is slightly more efficient to board or alight large numbers of people. The negative coefficients on the quadratic terms in model 3 indicate that the effect of additional boardings / alightings on dwell times diminishes with increased volumes. The negative coefficients on indicator variables for bus stops with only one boarding or alighting also suggest that the second passenger getting on adds more to dwell times than the first passenger.
- Variations in the number of passengers boarding / alighting at bus stops explain almost half of the observed variation in dwell times. (As shown by the R^2 values between 0.472 and 0.498 for models 1–4.) However, the remaining variation in dwell times cannot be explained by passenger volumes and may reflect inefficiencies arising from infrastructure design or idiosyncrasies in bus operation arising from weather or driver behaviour.
- In models 5-7, we added indicator variables for specific routes (model 5), bus stops (model 6), and types of bus stops (model 7). This analysis found that some routes and bus stops have consistently shorter or longer dwell times. Unreported coefficients from model 6 indicate that some bus stops have dwell times that are consistently 6-12 seconds longer than average. Similarly, some routes tend to have longer dwell times than others. Model 7 suggests that bus stops at bus hubs and bus stops on the Golden Mile tend to have dwell times that are 1.7 seconds and 3.6 seconds longer than average respectively, even after accounting for higher passenger volumes in these places.
- However, the inclusion of route and bus stop effects only resulted in a marginal increase in the share of the variation in dwell times explained by the model. A comparison of R^2 values for models 2 and 6 suggests that bus stop effects only explain around 2 percent of the variation in dwell times between services.

Lastly, preliminary analysis that we have not reported suggests that double-decker buses tend to have longer dwell times relative to smaller buses.

We use these results as an input to our analysis of the impact of bus stop consolidation, as merging two bus stops will increase boardings / alightings at the consolidated bus stop and hence may increase dwell times at this bus stop.

Table 18: Econometric analysis of the drivers of dwell times

Outcome variable	**Snapper estimate of dwell time (seconds)**						
Explanatory variables	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
Number of boardings	3.436***		4.119***	3.331***			
	(0.008)		(0.013)	(0.009)			
(Number of boardings)^2			-0.035***				
			(0.001)				
One boarding indicator				-2.158***			
				(0.063)			
Number of Snapper boardings		3.037***			3.071***	3.030***	2.997***
		(0.009)			(0.009)	(0.010)	(0.009)
Number of cash boardings		8.200***			7.990***	7.714***	8.068***
		(0.057)			(0.057)	(0.057)	(0.057)
Number of free boardings		4.889***			4.802***	4.502***	4.742***
		(0.041)			(0.041)	(0.041)	(0.041)
Number of other boardings		6.390***			6.210***	6.040***	6.240***
		(0.140)			(0.139)	(0.137)	(0.139)
Number of alightings	2.902***	2.916***	4.203***	2.824***	2.965***	3.035***	2.913***
	(0.008)	(0.008)	(0.013)	(0.008)	(0.008)	(0.009)	(0.008)
(Number of alightings)^2			-0.048***				
			(0.0004)				
One alighting indicator				-1.878***			
				(0.061)			
Bus hub indicator							1.711***
							(0.077)
Golden Mile indicator							3.597***
							(0.083)
Route indicator variables?					Yes		
Stop indicator variables?						Yes	
Constant	0.377***	0.123***	-2.139***	1.730***	2.399***	-2.312***	-0.364***
	(0.034)	(0.034)	(0.039)	(0.047)	(0.090)	(0.361)	(0.036)
Observations	324,742	324,742	324,742	324,742	324,742	324,742	324,742
R^2	0.472	0.487	0.498	0.474	0.495	0.509	0.490
Adjusted R^2	0.472	0.487	0.498	0.474	0.495	0.509	0.490
Residual Std. Error	14.618 (df = 324739)	14.404 (df = 324736)	14.253 (df = 324737)	14.579 (df = 324737)	14.297 (df = 324615)	14.089 (df = 324553)	14.357 (df = 324734)
F Statistic	144,937.600*** (df = 2; 324739)	61,647.070*** (df = 5; 324736)	80,445.400*** (df = 4; 324737)	73,295.940*** (df = 4; 324737)	2,522.907*** (df = 126; 324615)	1,792.669*** (df = 188; 324553)	44,634.690*** (df = 7; 324734)
BIC score	2663698	2654176	2647287	2661979	2650738	2641962	2652049
Note:	*p<0.1; **p<0.05; ***p<0.01						

4.3. Decomposing causes of delay

To understand the causes of bus delays, we benchmarked average observed travel times between all bus stop pairs along each of the eight corridors against an estimate of 'optimal' bus performance. We then decomposed estimated delays into seven causes:

- **Short bus stop spacing**: when bus stops are close together, it will reduce the amount of time that buses spend travelling at full running speeds and increase the amount of time spent decelerating into bus stops, positioning at bus stops, and accelerating out of bus stops
- **Long dwell times at bus stops**: lengthy dwell times increase journey times for passengers already on the bus. We benchmarked observed dwell times against the amount of time that would be required for observed passenger volumes to board / alight under 'optimal' conditions, which are defined as level boarding on vehicles with sufficient space for passengers to circulate, with off-board ticketing to reduce time required per passenger.
- **Re-entry delay**: buses exiting off-line bus stops into heavy traffic may be delayed while waiting for a gap in traffic.
- **Traffic light delay**: a share of buses must stop at traffic lights or signalised pedestrian crossings while waiting for the green phase. In addition to average wait times, this adds deceleration and acceleration time.
- **Queue service delay at lights**: signalised intersections with heavy traffic volumes typically build up queues that take a while to clear. If bus lanes are not available at these intersections then buses will be delayed.
- **Road layout**: narrow traffic lanes and narrow shoulders may make it difficult for buses to travel at the posted speed limits.
- **Mid-block traffic congestion and on-street parking**: buses may be delayed by general traffic congestion and cars moving in and out of on-street parking spaces.

This analysis was conducted for all segments of each corridor and for hourly time intervals during May 2019 weekdays.

Estimating 'optimal' bus performance

We used TCQOSM equations 6-27 through 6-33 to estimate unimpeded running time rates for each corridor segment. 'Running time rate' is defined as the amount of time required to travel one kilometre, eg minutes / kilometre. We modified these formulas to account for the fact that some buses do not stop at all bus stops.

Equation 1 describes the key elements of this calculation. We applied this calculation at the corridor segment level, ie for the distance between each successive pair of bus stops along the corridor.

Equation 1: Estimating running time rates based on bus stop spacing, share of buses stopping, and speed limits

Acceleration time: $t_{acc} = v_{run}/a$

Deceleration time: $t_{dec} = v_{run}/d$

Distance travelled at less than running speed per stop: $L_{ad} = 0.5at_{acc}^2 + 0.5dt_{dec}^2 + L_{st}$

Distance travelled at full running speed per km: $L_{rs} = 1000 - N_s L_{ad} = 1 - \frac{L_{seg}}{L_{ad}}$

Time spent travelling at full running speed per km: $t_{rs} = L_{rs}/v_{run}$

Unimpeded running time rate for buses that stop: $t_u^{stop} = t_{rs} + N_s(t_{dt} + t_{re} + t_{acc} + t_{dec})$

Unimpeded running time rate for buses that do not stop: $t_u^{nostop} = 1/v_{run}$

Average unimpeded running time rate for all buses: $t_u^{all} = s^{stop} t_u^{stop} + (1 - s^{stop}) t_u^{nostop}$

Where: v_{run} = maximum bus running speed achievable on this corridor segment (converted to m/sec); a = average bus acceleration rate; d = average bus deceleration rate; L_{st} = stop length; L_{seg} = length of the corridor segment; N_s = average number of stops per kilometre (calculated as $1/L_{seg}$); t_{dt} = average dwell time for buses that stop; t_{re} = re-entry delay for buses that stop; and s^{stop} = share of buses that stop.

We extended this calculation slightly to account for the fact that buses that do not stop are still likely to slow down on the approach to bus stops. We assume that they slow down to a speed of around 20–25km/hr on approaches, which should be 15 to 20 metres away from the bus stop. This results in a slight acceleration / deceleration penalty for buses that do not stop.

Maximum bus speed on each segment v_{run} is set either to the speed limit (*speedlim*) or the maximum speed that the bus can attain given segment length and acceleration/deceleration rates. We calculate it using the following formula. Note that v_{run} may be faster under ideal stop spacing relative to current bus stop spacing.

Equation 2: Calculation of maximum bus speed attainable on each segment

$$v_{run} = \min\left(speedlim, \sqrt{\frac{2ad(L_{seg} - L_{st})}{a + d}}\right)$$

To estimate optimal running time rates, we assume that:

- theoretical optimum bus stop spacing (N_s) is equal to 2.38 bus stops per kilometre, and hence segment length (L_{seg}) is equal to 420 metres, or current bus stop spacing on each segment if this is greater
- average dwell times (t_{dt}) are set equal to the minimum amount of time required to board and alight observed passenger volumes based on ‘optimal’ boarding and alighting conditions – this calculation is explained below
- re-entry delay (t_{re}) is set equal to zero.

Exact outcomes from changing from current bus stop spacing to theoretically optimal bus stop spacing may depend upon whether there is a positive or negative correlation between stopping patterns at successive bus stops. For instance, if 10 percent of buses stop at stop A and a *different* 10 percent stop at stop B, then 20 percent of buses might have to stop at a consolidated bus stop that serves the former catchments of both stops. This would offset some of the gains from bus stop rationalisation.

TCQOSM does not provide any methods for accounting for this issue, as it assumes either that all buses stop at all bus stops or that buses run a defined ‘skip-stop’ pattern. We therefore used Monte Carlo simulation to understand how different stopping patterns might affect outcomes from bus stop consolidation in a simplified two-stop case. This analysis suggests that the calculations outlined in TCQOSM could over-estimate running speed improvements from bus stop consolidation in cases where bus stops are currently close together and where there is a strong negative correlation between stopping patterns at successive bus stops.

However, observations of bus operations suggest that on high-frequency routes with peak travel mostly in one direction, negatively correlated stopping patterns are often caused by the fact that one bus may pass another while it is picking up passengers and proceed to pick up passengers at a nearby bus stop, and vice versa. In such a case, only one of those buses would stop to pick up passengers at a consolidated bus stop.

In short, some caveats apply to the calculations outlined in TCQOSM, but we have found that (a) there is no tractable alternative that could be implemented without detailed microsimulation modelling and (b) there are reasons to believe that the bias arising from TCQOSM calculations is likely to be small in practice.

Estimating the impact of short bus stop spacing

We used TCQOSM equations 6-27 through 6-33, summarised as Equation 1 above, to re-calculate unimpeded running time rates based on current bus stop spacing. To do so, we set N_s equal to the inverse of current distance between bus stops.

For instance, for a corridor segment with a distance of 250 metres between bus stops, $N_s = \frac{1000}{250} = 4$.

Short bus stop spacing has two impacts on running-time rates:

- it decreases the distance travelled at full running speed (L_{rs}) and hence decreases the average speed that buses travel at
- it increases the amount of time that buses must spend decelerating into, positioning at, dwelling in, and accelerating out of bus stops per kilometre.

Estimating the impact of long dwell times at bus stops

We used TCQOSM equations 6-27 through 6-33, summarised as Equation 1 above, to re-calculate unimpeded running-time rates based on current bus stop spacing and current observed dwell times. To do so, we set t_{dt} equal to the Snapper estimated average dwell time for buses that stopped at the bus stop in question, as defined in Table 17, rather than the theoretically optimum dwell time.

Theoretically optimal dwell times are calculated based on observed boardings and alightings at bus stops and TCQOSM parameters for average dwell time per passenger movement under optimal conditions. We define optimal conditions as street-level boarding with adequate circulation space on vehicles and off-board ticketing to speed up entry and exit. TCQOSM Exhibits 8-12 and 8-13 suggest that average boarding / alighting time under these conditions may be as low as 1.75 seconds per passenger. We have added an additional 5 seconds per bus stop for buses to position at the stop and open and close doors (per TCQOSM Exhibit 3-30). The following equation shows how 'optimal' dwell times were calculated.

Equation 3: Calculation of theoretically optimal dwell time

$$t_{dt}^{optimal} = min\left(t_{dt}^{observed}, 5 + 1.75 * Boardings + 1.75 * Alightings\right)$$

Long dwell times affect running-time rates by increasing the amount of time that buses spend at bus stops as opposed to moving between bus stops.

Long dwell times in some locations and at some time periods reflect high passenger boarding and alighting volumes, and current vehicle and ticketing standards. Econometric analysis reported in Table 18 indicates that passenger volumes explain a significant share, although not all, of variation in dwell times between services. Infrastructure improvements are unlikely to have a large impact on dwell times arising from passenger boarding / alighting, although operational improvements like off-board ticketing, all-door boarding, or vehicles with more circulation space will have an impact.

Estimating re-entry delay

Buses exiting off-line bus stops into heavy traffic may be delayed while waiting for a gap in traffic. We therefore calculated re-entry delay values based on the type of bus infrastructure in place and hourly traffic volumes in adjacent vehicle lanes. We then set average re-entry delay (t_{re}) in Equation 1 to this estimated value. If traffic volumes exceeded 1000 vehicles per hour, we capped re-entry delay at 12 seconds.

We set re-entry delay to zero if:

- there is an in-line bus stop, as opposed to an indented or off-line bus stop. Vehicles must queue behind buses stopping at in-line bus stops, and hence buses do not face re-entry delay when exiting from in-line bus stops
- a bus lane is operating in the selected time period. Hourly bus volumes are typically low enough so that there is negligible average re-entry delay when entering bus lanes.

For off-line bus stops without bus lanes, TCQOSM Exhibit 6-59 provides estimates of re-entry delay based on hourly traffic volumes in the adjacent vehicle lane. Table 19 summarises these estimates.

To estimate traffic volumes on each corridor segment, we used surveyed hourly traffic counts at the closest traffic counting site along the corridor. Where segments fell between two traffic counting sites, we averaged volumes at those sites.

Table 19: Average bus re-entry delay parameters

Adjacent lane traffic volume (veh/hr)	Average re-entry delay (s)
0	0
100	1
200	2
300	2.5
400	3
500	4
600	5
700	6
800	8
900	10
1000	12

Source: Adapted from TCQOSM Exhibit 6-59

Estimating traffic light delay

Traffic lights require vehicles arriving during the red phase to stop and wait for a green phase. As a result, signals reduce running time rates for a share of buses.

TCQOSM page 6–8 suggests that average waiting time at signals can be calculated as a function of the total signal cycle length (*CL*) and the green time ratio (*g/CL*). If we assume that buses arrive at a uniform rate, then the following equations show how to calculate the share of buses affected by signal delay, the average signal delay for buses stopped at red lights, and the average signal delay for all buses.[8]

We have also adjusted this calculation to reflect the fact that buses that stop at lights must spend additional time decelerating and accelerating, relative to free-flow speeds.[9]

Equation 4: Calculating average traffic light delay

Share of buses that must stop at red lights: $s^{red} = 1 - g/CL$

Average signal delay for buses stopped at red lights: $t_{sig}^{red} = 0.5 * CL * (1 - g/CL)$

Additional acceleration / deceleration time for buses stopped at red: $t_{accdec}^{red} = 0.5 * (t_{acc} + t_{dec})$

Average signal delay for all buses: $t_{sig} = s^{red} * (t_{sig}^{red} + t_{accdec}^{red})$

We used SCATS signal timing data for the AM and PM periods to estimate CL and g/CL for each signalised intersection on selected bus corridors, taking into account locations where buses avoid signal delay due to un-signalised slip lanes.

After calculating average traffic light delay, we adjust running time to account for the impedance from traffic lights. To do so, we add average delay from traffic lights to the unimpeded running time rate calculated in the previous step. This is shown in the following equation. N_{sig} refers to the average number of signals per kilometre, ie number of signals per segment divided by segment length.[10]

Equation 5: Average running time rate including signal delay

$$t_{sig}^{all} = t_u^{all} + N_{sig} t_{sig}$$

Estimating queue service delay at lights

Buses may incur further delay at signalised intersections if heavy traffic volumes result in long queues that take some time to clear. Queue service delays are additional to delays waiting for the red phase to end, as they delay buses during the green phase.

TCQOSM suggests that queue service delays are a function of the rate at which vehicles arrive at the intersection (*v*, converted to vehicles per second in the lane with buses), the rate at which vehicles clear the intersection during the green phase (saturation flow rate, s_f, in vehicles per second), and the length of the red phase ($r = CL * (1 - g/CL)$). We use equations 6-9 through 6-11 to calculate total queue service times and average queue service times for signalised intersections, assuming again that vehicles arrive at the intersection at a uniform rate.[11]

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[8] The assumption of uniform arrival is reasonable in most circumstances. However, it may not be accurate in cases where signals are managed to provide a 'green wave' for vehicles travelling through multiple intersections or where buses have priority at intersections.
[9] The added time for acceleration / deceleration relative to travelling at free-flow speeds is simply equal to half of the total time spent accelerating / decelerating.
[10] This formula is a slight simplification, as average signal delays may differ for different intersections along a single corridor segment.
[11] The assumption of uniform arrival is reasonable in most circumstances. However, it may not be accurate in cases where signals are managed to provide a 'green wave' for vehicles travelling through multiple intersections.

These calculations are summarised in Equation 6.[12]

Equation 6: Calculating average queue service delay

Queue size at end of red time (number of vehicles): $Q_r = v * r$

Total queue service time (seconds): $t_{queue}^{total} = \frac{Q_r}{s_f - v}$

Average queue service time for vehicles in queue (seconds): $t_{queue} = 0.5 * t_{queue}^{total}$

We estimated saturation flow rates through intersections based on TCQOSM exhibit 6–60, which states that $s_f = 1500\ veh/hr\ = 0.417\ veh/sec$ for central areas in cities with population under 250,000.

We use SCATS signal timing data to estimate red time for each intersection, during AM and PM periods.

To calculate the rates at which vehicles arrive at the intersection, we:

- estimated total vehicle flows in the direction of bus travel based on traffic count data at the nearest one or two counting points
- used Google Maps to identify the number of approach lanes to each intersection in the direction of bus travel, the lane that buses operate in, and whether bus lanes extend to the intersection
- allocated traffic volumes across approach lanes based on the best available data on turning counts and traffic volume breakdown across lanes, which includes either SCATS signal data, Sidra modelling of intersection functioning, turning count surveys collected in 2016, or traffic flow data on different intersection approaches where other data was not available
- where bus lanes extend to the intersection, it was assumed that buses and left-turning vehicles were the only vehicles operating in bus lanes during the times at which bus lanes operate.

For instance, if a given corridor segment had hourly traffic volumes of 800 veh/hr, two lanes on the approach to the intersection, and 40 percent of vehicles queuing in the left-most lane where buses run, then $v = 800\ veh/hr * 40\% = 320\ veh/hr = 0.089\ veh/sec$.

We checked estimated queue service times against the length of the green phase to ensure that we were not predicting that queue length would blow out without limit during peak times. In cases where the calculated queue service time exceeded the green time, the queue-service time was assumed to equal the green time.

We then adjust running time to account for average queue service delay at intersections. To do so, we add queue service delay to the running time rates we previously calculated. This is shown in the following equation. N_{sig} refers to the average number of signals per kilometre, ie number of signals per segment divided by segment length.[13]

Equation 7: Average running time rate including signal delay and queue service delay

$t_{sig}^{all} = t_u^{all} + N_{sig}(t_{sig} + t_{queue})$

[12] We have corrected several errors and redundancies in the TCQOSM formulas.
[13] This formula is a slight simplification, as average queue service delays may differ for different intersections along a single corridor segment.

Estimating delay from road layout

Buses may not be able to operate at the speed limit due to constrained corridor layout, such as narrow traffic lanes, lack of shoulders, and tight corners.

We manually measured lane and shoulder widths for each corridor segment using Wellington City Council's 2017 aerial imagery. Lane and shoulder width was measured at two points on each segment and averaged across those locations.

We then calculated speed reductions due to narrow lane widths and narrow shoulders using parameters from Exhibit 20-5 of the Highway Capacity Manual (2000), which are summarised below.[14] For instance, a 3.2 metre-wide lane with a 1.5 metre-wide shoulder would be assigned a 3.8 kilometre / hour reduction relative to speed limits.

Table 20: Free-flow speed reductions due to narrow lanes and shoulders

Lane width (m)	Reduction in free-flow speed by shoulder width			
	≥ 0.0 <0.6	≥ 0.6 <1.2	≥ 1.2 <1.8	≥ 1.8
2.7 <3.0	10.3	7.7	5.6	3.5
≥3.0 <3.3	8.5	5.9	3.8	1.7
≥3.3 <3.6	7.5	4.9	2.8	0.7
≥3.6	6.8	4.2	2.1	0.0

After estimating a speed reduction factor for each corridor segment (*speed reduction*), we re-calculated free-flow speeds using the following formula, and then re-calculated running time rates using Equation 1 and subsequent variations like Equation 7 that also account for signals.

Equation 8: Calculation of maximum bus speed attainable on each segment, accounting for road layout

$$v_{run} = \min\left(speedlim - speedreduction, \sqrt{\frac{2ad\left(L_{seg} - L_{st}\right)}{a + d}} \right)$$

Estimating delay from mid-block traffic congestion and on-street parking

Finally, we compared running time rates derived from real-time information with running-time rates calculated in the above steps to estimate the impact of mid-block traffic congestion and vehicles entering / exiting on-street parking. In effect, the impact of congestion and parking access is calculated as a 'residual' after delays arising from other sources are accounted for.

For instance, if the actual running time rate observed with RTI data was eight minutes per kilometre, and the estimated running time rate accounting for current bus stop spacing, current dwell times, re-entry delays, traffic light delays, queue service delays, and constrained road layout was 6.5 minutes per kilometre, then it implies that general traffic congestion increases running time rates by 1.5 minutes per kilometre.

Because mid-block traffic congestion impacts are calculated as a residual, we further benchmarked estimated mid-block delay during peak times against estimated mid-block delay during the 10–11pm evening period. This provided a further check to ensure that this does not mis-measure impacts of slope or constrained road layout.

[14] These reduction factors are intended to be used for general traffic, and it is possible that they under-estimate speed reductions for larger/longer vehicles than buses.

5. Identifying problems

We used the results from the bus delay analysis to identify where sources of delay are causing problems for buses on the corridors. We identified problems at every bus stop, segment (between bus stops), and signalised intersection, in both the inbound and outbound directions.

We then defined three packages for assessment on each corridor, each addressing a different severity of problems and considering interventions with varying levels of impact.

5.1. Parameters used to define problems

The following provides a breakdown of the parameters we used to define where a source of delay was considered to be causing a problem on the corridor.

At bus stops

Long dwell time at stops
Long dwell times were never identified as an issue for the bus priority programme to address, as they primarily arise from operational and ticketing considerations that are out of scope for the programme.

Re-entry delay
Buses can experience delay when trying to merge into congested traffic from off-line bus stops. To identify the bus stops where buses experience delays while trying to merge back into traffic, we looked at the estimated re-entry delay (calculated as described in Section 4.3).

Missing tapers
Off-line bus stops include entry and exit tapers to assist buses in manoeuvring into and out of bus stops. Where bus stops are missing tapers, buses may experience delays while manoeuvring into and out of the stop. To determine where buses experience delays due to insufficient tapers, we audited every bus stop to identify where off-line bus stops do not have entry and / or exit tapers.

Short bus box
Bus boxes need to be a minimum length of 15 metres to accommodate a stopped bus within the bus box. Where bus boxes are too short, buses may experience delays manoeuvring into and out of the bus stop. To identify where buses may experience delays due to short bus boxes, we audited every bus stop to determine the bus box length. We have not assessed where there is bus-bus delay and the bus box should be lengthened to accommodate more than one stopped bus. Rather, we have determined that all bus stops should be of adequate length and further analysis is not required at this stage of the process.

At signalised intersections

Traffic light delay
A share of buses experience delays at traffic lights or signalised pedestrian crossings. To identify which signalised intersections and signalised pedestrian crossings cause greater than ideal delays for buses, we looked at the control delay.[15] The control delay was calculated by adding together the estimated traffic light delay and estimated queue service delay (both

[15] Control delay is defined as the total time lost during negotiation of an intersection, including all deceleration and acceleration delays and stopping (idling) times.

calculated as described in Section 4.3). This was then assessed against the SIDRA level of service definitions for control delay, as outlined in Table 21.

Table 21: SIDRA method for level of service definitions based on delay only[16]

Level of service	Control delay per vehicle (s)	
	Lower limit	Upper limit
A	0	10
B	10	20
C	20	35
D	35	55
E	55	80
F	80	--

Queue service delay at lights

When there are heavy traffic volumes at signalised intersections, buses are delayed due to queues on the approach to the intersection. To identify where and when queue lengths at signalised intersections and signalised pedestrian crossings cause delays for buses, we looked at the estimated queue service delay (calculated as described in Section 4.3).

In the mid-block corridor

Short bus stop spacing

When bus stops are located close together, the buses experience delays due to a reduction in the amount of time they can spend travelling at full running speed and an increase in the amount of time they spend decelerating and accelerating into and out of bus stops. To determine the bus stops that are located closer than ideal, causing delay to buses, we undertook a GIS analysis of bus stop spacing along corridors and overlaps between walking catchments for different bus stops. Where there was a substantial amount of overlap between five-minute walking catchments, we identified short bus stop spacing as a problem.

Road layout

Buses may operate at reduced speeds due to constrained corridor layout, such as narrow traffic lanes and lack of shoulders. To identify where and when buses experience delay due to road layout, we looked at the estimated reduction in free-flow speed (calculated as described in Section 4.3). We set a materiality threshold of at least 12 seconds of layout delay per kilometre.

Mid-block congestion and on-street car parking

During times when traffic volumes are high, buses may experience delay due to heavy congestion and due to cars moving in and out of on-street parking spaces. To identify where and when buses experience delay due to vehicle volumes, we used the estimated residual delay (calculated as described in Section 4.3).

To further isolate the delay caused by traffic congestion and on-street parking manoeuvres, we identified the minimum residual delay value across a day (often occurring in the early morning or late evening). We assumed that this value is representative of the delay experienced due to factors unrelated to traffic volumes, such as hills, tight corners, and roundabout layout. This value was subtracted from the residual delay to determine the mid-block congestion and on-street car parking delay. We used this value to identify where and when buses experience

[16] See Table 5.14.1 of the *SIDRA Intersection 8 User Guide, August 2019*.

delay due to vehicle volumes. We then set a materiality threshold of at least 30 seconds of delay per kilometre to avoid capturing corridor segments with minimal congestion delay and to further limit the potential for mis-measurement of traffic congestion impacts.

5.2. Defining the packages for assessment

We defined three levels of packages to provide infrastructure and bus priority interventions on the corridors. Assessing three options allowed us to understand the value for money relative to the level of intervention and help to select the preferred interventions on each corridor.

Each package addresses problems of varying severity and considers interventions of varying impact. The three options for upgrading the bus corridors are defined as follows:

- **Option 1: fix everything**
  This option would:
    - address all problems identified on the corridor
    - implement any of the possible interventions that:
        - are effective at addressing all of the problems that have been identified on the corridor
        - are feasible to implement, allowing for construction of retaining walls and some private property acquisition
- **Option 2: fix the worst problems**
  This option would:
    - address only the most severe problems identified on the corridor
    - implement interventions that:
        - are effective at addressing the most severe problems that have been identified on the corridor
        - are feasible to implement, allowing for construction of retaining walls and some private property acquisition
- **Option 3: minimal interventions**
  This option would:
    - address only the most severe problems identified on the corridor
    - implement interventions that:
        - are effective at addressing the most severe problems that have been identified on each corridor
        - are feasible to implement within the available corridor space
        - involve only minimal reconfiguration of corridor space, and no construction of retaining walls or private property acquisition.

To compile each of the package options, we first defined the parameters that would determine the severity of problems on the corridor. We defined parameters for option 1 that would identify all significant sources of delays as a problem. For options 2 and 3, we set higher thresholds for the parameters, resulting in only the most severe sources of delay being identified as problems. The defined parameters are provided in Table 22.

When then determined a list of interventions to be considered across each of the package options. For options 1 and 2, we considered all interventions included in the bus priority toolkit (outlined in Section 2). For option 3, we did not consider any interventions that would require major physical works in the corridor. The interventions considered for each option are outlined in Table 23.

Table 22: Severity of problems considered in each package option

Location	Source of delay	Option 1: fix everything	Option 2: fix the worst problems	Option 3: minimal interventions
At bus stops	Re-entry delay	There is re-entry delay	The re-entry delay is greater than 0.05 min/stop (worst 50% of re-entry delay)	The re-entry delay is greater than 0.05 min/stop (worst 50% of re-entry delay)
	Missing tapers	The bus stop is missing an entry taper, an exit taper, or both	The bus stop is missing an entry taper, an exit taper, or both	The bus stop is missing an entry taper, an exit taper, or both
	Short bus box	The bus box is shorter than 15m	The bus box is shorter than 15m	The bus box is shorter than 15m
At signalised intersections	Traffic light delay	The control delay is greater than 20s (LOS C or worse)	The control delay is greater than 35s (LOS D or worse)	The control delay is greater than 35s (LOS D or worse)
	Queue service delay at lights	The queue service delay is greater than 5s (worst 50% of queue delay)	The queue service delay is greater than 10s (worst 25% of queue delay)	The queue service delay is greater than 10s (worst 25% of queue delay)
In the mid-block corridor	Short bus stop spacing	Bus stops are spaced closer than approximately 400m, excluding stops that serve unique walking catchments	Bus stops are spaced closer than approximately 300m, excluding stops that serve unique walking catchments	Bus stops that are closely spaced, provided that removal of these stops would not reduce walking catchments
	Road layout	Road layout causes a reduction of free-flow speed greater than 0.2 min/km	Road layout causes a reduction of free-flow speed greater than 0.4 min/km	Road layout causes a reduction of free-flow speed greater than 0.4 min/km
	Mid-block congestion and on-street parking	Mid-block congestion delay greater than 0.5 min/km	Mid-block congestion delay greater than 1.0 min/km	Mid-block congestion delay greater than 1.0 min/km

Table 23: Interventions considered in each package option

Category	Intervention	Option 1: fix everything	Option 2: fix the worst problems	Option 3: minimal interventions
In-lane bus priority	In-line bus stop	✓	✓	✓
	Transit lane	✓	✓	×
Bus stops	Bus stop rationalisation	✓	✓	✓
	Entry/exit tapers	✓	✓	✓
	Lengthen bus stop	✓	✓	✓
Signalised intersection improvements	Queue jump	✓	✓	×
	Bus phase	✓	✓	×
	Increased green phase	✓	✓	✓
	Intersection design requiring minimal physical works	✓	✓	×
	Intersection design requiring major physical works	✓	✓	×
Other corridor works	Widen traffic lane	✓	✓	×

6. Opportunities screening

We completed a two-stage screening process to identify options that would improve bus operations on each of the eight corridors. On every corridor, we screened all of the considered interventions at each location – every bus stop, segment, and signalised intersection in both the inbound and outbound directions – to determine whether:

- the intervention would be effective in addressing the documented problems
- it would be feasible to implement the intervention.

If an intervention passed both screening criteria, it was considered an opportunity with the package of works. The two screening processes are described below.

6.1. Effectiveness

The first stage of the opportunities screening was to consider the effectiveness of the intervention. If the intervention was considered appropriate to address the documented problems at that location, it passed the screening. The resulting list of interventions that were considered effective was then carried through to the next stage of screening.

For each of the sources of delay, we defined a list of which interventions would be effective in addressing the delay. Table 24 outlines the sources of delay and the corresponding interventions that could address the problem.

Table 24: Effectiveness screening

Cause of delay	Interventions to consider
Closely spaced bus stops	• Rationalise bus stops
Dwell time delay	• Consider other interventions outside the scope of this project: ○ increase bus frequency ○ operational improvements
Re-entry delay	• In-line bus stops
Traffic signal delay	• Bus phase • Increased green phase • Minor intersection re-design • Major intersection re-design
Queue service delay	• Queue jump • Bus phase • Increased green phase • Minor intersection re-design • Major intersection re-design
Road layout delay	• Widen traffic lanes
Mid-block congestion and on-street parking delay	• Transit lanes, including: ○ full-time bus lanes ○ part-time bus lanes ○ peak-hour clearways
Missing entry and/or exit tapers	• Provide entry and exit tapers
Short bus box	• Lengthen the bus box

6.2. Feasibility

Once interventions were identified, their space requirements were checked against the road layouts along the corridor to determine if the interventions could be physically accommodated within the available space. If corridor widening would be required to deliver the intervention, it was assumed that this would be undertaken if it could be achieved by acquiring four or less properties and through retaining wall construction. If corridor widening required the acquisition of more than four properties or required earthworks above and beyond retaining wall construction, the intervention was removed from the packages.

7. Evaluation methodology

The key steps in the analysis are outlined below.

Step 1: Estimate causes of existing bus delays

In the first step, we use the data described above, plus methods outlined in the Transit Capacity and Quality of Service Manual, Third Edition (TCQOSM), to estimate the degree to which buses are being delayed relative to 'optimal' performance and decompose this into separate causes. Broadly speaking, these causes relate to:

- the impact of bus stop spacing, bus stop design, and excess dwell times
- the impact of pedestrian and traffic signals at intersections
- the impact of general traffic congestion, on-street parking, and road layout.

The outputs from this analysis are:

- an estimate of total bus travel time (in minutes) along each segment of the bus corridor
- an estimate of the amount of delay added by each of the above causes (in minutes).

This analysis is undertaken for each segment of key bus corridors on an hourly basis. Because the AM peak hour (8–9am) experiences the most significant delays, economic analysis is based on this hour.

Step 2: Estimate changes in delay resulting from interventions

After estimating bus delays arising from each cause, we estimate the degree to which specific interventions (grouped into the three 'in scope' categories described above) will reduce these delays.

These estimates are based on:

- TCQOSM procedures, where available and relevant
- procedures from the Transport Agency's Economic Evaluation Manual, where available and relevant
- other published evaluation and bus planning literature, where necessary to supplement the above procedures.

This analysis is undertaken at a corridor segment level, or a bus stop level, depending upon what is most appropriate. For instance, changes to walking times to bus stops are best analysed at the bus stop level, while changes to bus speeds along the corridor are best analysed at the segment level.

Methods used to calculate the impact of specific interventions are defined in Section 9.

Step 3: Estimate other impacts of interventions

In some cases, interventions may generate benefits or disbenefits for other transport users. In general, we have not attempted to quantify these in detail, due to the fact that:

- costs to avoid or mitigate impacts on other road users have been included in the programme, eg to widen narrow corridors to enable a bus lane to be provided without compromising space for other vehicles or footpath users or to re-design complex intersections to provide bus priority measures
- interventions are expected to have both costs and benefits for other road users, and these effects are likely to roughly balance out, eg when re-timing intersections to prioritise movement in the bus direction of travel.

We have captured potential traffic delay disbenefits through sensitivity testing of lower values for decongestion benefits resulting from mode shift. Impacts on pedestrians and cyclists are also noted as potentially important, although unquantified at this stage.

Step 4: Calculate aggregate reductions in bus journey times between stop pairs

To calculate reductions in bus journey times, we sum up estimated bus journey times (from step 1) and reductions in delays (step 2) between all bus stops along each corridor. This enables us to calculate the total reduction in average journey times for each pair of bus stops.

Total journey times from origin bus stop i to destination bus stop j, along a given route k, are calculated as follows.

Equation 9: Calculating total journey times

$$JT_{i,j,k} = W_i + \frac{H_{i,k}}{2} + \sum_{i \le n < j} TT_{n,n+1,k} \sum_{i \le n < j} DT_n + W_j$$

Where i is the origin stop; j is the destination stop; k is the route; $JT_{i,j,k}$ is total journey time (in minutes); W_i and W_j are average time to walk to/from the origin and destination stops; $H_{i,k}$ is the average headway for services on this route, divided by two to obtain average wait time for a typical user;[17] $TT_{n,n+1}$ is the average travel time between stop n and the following stop; and DT_n is average dwell time at stop n. Each route k has a distinct ordering of stops, reflecting the path that the route follows between its first and last stops.

Reductions in average journey times are calculated in an analogous fashion.

Equation 10: Calculating changes in journey times

$$\Delta JT_{i,j,k} = \Delta W_i + \sum_{i \le n < j} \Delta TT_{n,n+1,k} \sum_{i \le n < j} \Delta DT_n + \Delta W_j$$

This calculation is undertaken for the selected peak-time period only. The output is a pair of matrices $\boldsymbol{JT}$ and $\Delta\boldsymbol{JT}$ that gives the estimated journey time and change in journey times between all pairs of bus stops. (Note: only half of the matrix will be filled in, as inbound and outbound stops are coded separately. In addition, as stated here, changes in journey time are negative if speeds increase and positive if they reduce.)

[17] Average wait times may be less than half of average headways if people use real-time information or bus schedules to time their arrivals at bus stops. There is some empirical evidence on this issue, eg Akatoaobi and Tawfik (2018). However, people may also perceive wait times to be longer than they actually are, meaning that perceived wait times may be closer to half of the average headway even if people time their arrivals: Mishalani, McCord, Wirtz (2006).

Step 5: Estimate user volumes between bus stop pairs

Snapper data is used to calculate the number of people travelling between all bus stop pairs by each individual bus route in Wellington City, with an adjustment for cash fares and SuperGoldCard (SGC) users.

While our analysis includes all routes and trips in the Wellington City bus network, not all trips will be affected by improvements to the priority corridors. We estimate that almost 70 percent of total AM peak trips on the Wellington City network traverse the priority corridors at some point. In many cases, boarding / alighting bus stops are outside the corridor, eg along the Golden Mile or at the outer end of routes.

We group trips by route as well as origin and destination bus stops as different bus routes can follow different routes between origin and destination stops.[18] This results in an origin-destination matrix that is also segmented by route.

Snapper cards provide information on the bus stops where people tagged on and tagged off, but cash fares and SGC only provide information on the location where people got on the bus. However, if we assume that cash fares and SGC users follow a similar general pattern of trip lengths as Snapper users, then we can infer total journeys as follows.

Equation 11: Factoring up Snapper data to total journeys

$$D_{i,j,k} = D_{i,j,k}^{Sna} * \frac{B_i^{Sna} + B_i^{Cash} + B_i^{SGC}}{B_i^{Sna}} * C$$

Where Di,j is the estimated total demand on route k between origin i and destination j; $D_{i,j}^{Sna}$ is the Snapper demand; and B_i^{Sna}, B_i^{Cash}, and B_i^{SGC} are boardings at stop i by Snapper, cash, and SGC, respectively. C is a conversion factor equal to 1/23 that converts monthly total weekday boardings to average weekday boardings.[19]

The output is a matrix of estimated total demand $\boldsymbol{D}$ during the time period being analysed. (Once again, only half of the matrix will be filled in, as inbound and outbound bus stops are coded separately.)

Step 6: Estimate changes in demands resulting from changes in journey times

The above data is used to estimate potential changes in bus demand using an elasticity function that relates changes in demand to changes in journey times. If it is easier or more convenient to use the bus to get between two locations, more people are likely to choose to do so. Changes in bus usage may reflect mode shift (ie people substituting bus trips for car or walking trips) or induced demand (ie people choosing to make new trips that they would not have otherwise done).

We implement the elasticity function for origin-destination pairs as follows.

Equation 12: Estimating changes in bus demand using an elasticity function

$$\Delta D_{i,j,k} = D_{i,j,k} * \left[\left(\frac{JT_{i,j,k} + \Delta JT_{i,j,k}}{JT_{i,j,k}} \right)^E - 1 \right]$$

[18] An example is the 1 and 32X buses, which follow different routes between Berhampore and the John / Adelaide / Riddiford intersection.
[19] There were 23 weekdays and no public holidays in May 2019.

Where $\Delta D_{i,j,k}$ is the estimated change in demand; E is the elasticity of public transport demand with respect to total journey time; and other variables are defined above. E is sourced from EEM Appendix A1 (see below).

After estimating changes in demand, we estimate mode shift from driving to public transport by making assumptions about the share of added bus trips that would be diverted from different modes. Not all added bus trips will reflect mode shift; some may represent induced trips. The total number of avoided car trips ΔCar and avoided vehicle kilometres travelled ΔVKT can be calculated as follows:

Equation 13: Estimating avoided car trips due to mode shift

$$\Delta Car = R * \sum_{i,j,k} \Delta D_{i,j,k}$$

Equation 14: Estimating change in vehicle kilometres travelled due to mode shift

$$\Delta VKT = R * \sum_{i,j,k} \Delta D_{i,j,k} * Dist_{i,j,k}$$

Where R is the diversion rate (ie the share of added bus trips that otherwise would have been by car) and $Dist_{i,j,k}$ is the road network distance between stops i and j, which is calculated based on the total length of bus route k between these stops. R is sourced from EEM Appendix A14 (see below).

The output from this step is a matrix of estimated changes in demand $\Delta \boldsymbol{D}$, as well as an estimate of the quantity of (peak) car travel that could be removed as a result of the intervention.

Step 7: Estimate public transport user benefits and other benefits/disbenefits during analysis period

To conclude, we use the above data to estimate bus user benefits and other transport benefits and disbenefits. These estimates are then used to produce a single estimate of total benefits during the peak period being analysed.

We calculate bus user benefits as follows:

Equation 15: Calculating bus user benefits

$$Bus\ user\ benefits = VOT * \sum_{i,j} \left[\Delta JT_{i,j} * D_{i,j} + 0.5 * \Delta JT_{i,j} * \Delta D_{i,j}\right]$$

The formula in brackets calculates benefits for both existing users (the first term) and new users (the second term). Benefits are summed up across all origin-destination pairs and converted from time into money using a value of travel time savings (VOT) parameter sourced from the EEM.

We use EEM simplified procedures to calculate decongestion benefits as follows:

Equation 16: Estimating decongestion benefits

$$Decongestion\ benefits = \Delta VKT * RTRB$$

Where RTRB is a parameter reflecting the marginal impact of a one-kilometre reduction in peak car travel, sourced from EEM Table SP9.1. This is a simplified procedure that has been used in indicative assessments in the past.

We also calculate the health benefits associated with additional walking to PT services as follows:

Equation 17: Estimating health benefits of added walking to PT services

$$Health\ benefits = \Delta Car * HB$$

Where HB is a parameter reflecting the average health benefits associated with walking to and from bus stops, based on values in EEM Appendix A20.

Other impacts could also be quantified and added to this benefit estimate as required. There are some additional benefits that we do not propose to quantify at this stage but which could also be included as an extension of this analysis (see below).

Step 8: Annualise benefits / disbenefits

The calculations above produce an estimate of benefits for a single, representative one-hour peak period. It is necessary to convert daily peak-hour benefits to annual total benefits, taking into account:

- the expected ratio of peak-hour to all-day impacts, based on relative volumes of passenger-delay on these corridors at different times of the day
- the expected number of working days per annum – 245 is a typical value, although it is conservative as it excludes impacts on weekends / public holidays.

We calculate specific annualisation factors for the affected corridors, based on the estimated magnitude of bus passenger delay at different time periods.

The following table summarises the annualisation factors we have used to convert AM peak hour to annual benefits. We use an annualisation factor of 1,340 to convert AM peak-hour bus user benefits and decongestion benefits to annual benefits. This value is based on the relative magnitude of delay experienced by bus users at different times of the day. We use a different annualisation factor of 1,649 to convert AM peak-hour health benefits from added bus use to annual benefits. This value is based only on the relative volume of users at different times of the day.

Table 25: Annualisation factors for transport user benefits and bus user volumes

Type	Peak hour	Peak hour total	Daily total	Ratio of daily to peak hour	Working days per year	Ratio of annual to peak hour
Bus user benefits	8am–9am	1,070 pax-hrs delay	5,857 pax-hrs delay	5.47	245	1,340
Bus volumes	8am–9am	3,973 pax	26,744 pax	6.73	245	1,649

Step 9: Project forward benefits and calculate present value of whole-of-life benefits

After estimating annual benefits for the current year, we project forward benefits to future years and discount projected future benefits back to a present value estimate of whole-of-life benefits. EEM guidance suggests using a discount rate of 6 percent and an evaluation period of 40 years, and sensitivity testing alternative discount rates and evaluation periods.

Benefits will tend to rise in future years if:

- bus usage increases over time due to increased population in catchment areas and / or modal shift to public transport

- general traffic congestion increases and slows down buses.

We have therefore included a demand growth factor (g^{demand}) and a benefit unit growth factor ($g^{benefit}$). These factors are multiplicative and are applied in straight-line fashion as shown in the following formula, where t indicates future evaluation years (ie as 2019 is the base year, 2020 would be t=1). We then multiply the total benefit growth factor against benefit estimates for the base year.[20]

Equation 18: Benefit growth calculation for year t

$$Total\ benefit\ growth = \left(1 + g^{demand} * t\right) * \left(1 + g^{benefit} * t\right)$$

To estimate growth factors, we have used ForecastID's medium population projections for Wellington City (covering the period to 2047) and WTSM projections for public transport demands and traffic congestion in the study area.

ForecastID population projections indicate that Wellington City's total population is expected to increase by 20 percent from 2019 to 2047. Because projected growth appears to follow a 'straight line' trend, we use linear extrapolation to project out over the full 40-year evaluation period. The city's population is expected to be 29 percent larger at the end of this period. If public transport mode share stays constant, then the demand growth factor will be equal to annual population growth.

However, public transport demand is expected to rise faster than population, at least for city centre-bound journeys. WTSM projections indicate that overall AM peak public transport journeys in Wellington City are expected to rise by 38 percent between 2013 and 2036 under the base scenario, ie with no additional investment in rapid transit. By comparison, ForecastID projections indicate a 21 percent increase in Wellington City's population over the same period.

In short, WTSM data suggests that public transport demand growth will be roughly 83 percent higher than population growth over the forecast period. We therefore multiply ForecastID population growth by 1.83 to account for rising PT demand. This results in a gradual increase in public transport mode share over the 40-year evaluation period.[21] A high scenario for faster growth in PT mode share is also included.[22]

Predicting future increases in delays on the bus system is more challenging, as WTSM is not sufficiently fine-grained to assess traffic conditions or public transport operations in detail. Moreover, as this analysis has shown, the causes of bus delay are complex. With that caveat, WTSM outputs are used to predict average growth in car travel times on the bus priority corridors and hence to infer growth in delay experienced by buses.

Between 2013 and 2036, AM peak travel times on these corridors are expected to rise by 10 percent. This equates to an annual straight-line increase of around 0.44 percent. Due to the fact that there are few existing bus priority measures on these corridors, buses will be exposed to this growth in delay under the base case scenario.

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[20] We have also calculated health benefits of added walking to access public transport trips and scaled these benefits up based only on expected demand growth.
[21] Household Travel Survey data indicates that public transport served 5.8 percent of all trips in the Wellington urban area in 2015-2017. This rate of growth would result in mode share rising to 6.8 percent by the late 2050s. As a point of comparison, HTS data indicates that a similarly-sized increase occurred in Auckland during the decade to 2015-2017.
[22] The high scenario has PT mode share for all trips rising to 8 percent by the end of the evaluation period.

However, per-user benefits may in fact rise faster than general traffic congestion. This reflects the fact that delays due to being caught in traffic represent *eradicable* delay that can be addressed by the measures identified in the programme. Because eradicable delays are equal to roughly one-third of total bus travel time on these corridors, a 0.44 percent increase in total bus travel time would translate into a more than 1 percent increase in delay. We therefore sensitivity test a higher value for the benefit unit growth factor. Overall growth factors and sensitivity tests are summarised in the following table.

8. Key parameters and assumptions

The following table summarises the key assumptions and parameters we use to value transport benefits, as well as key sensitivity tests.

Table 26: Key parameters and assumptions

Parameter	Value	Source(s)
VOT: Value of travel time savings	Central: $12.16/hr High: $17.33/hr	Central: EEM Table A4.1(b) VOT by trip purpose combined with HTS estimates of trip purposes for bus trips in Wellington urban area; EEM Table A12.3 Benefit update factors. See workings below. High: Multiply VOT by comfort factor to reflect impact of crowding; ATAP guidance suggests that VOT on a crowded service is 1.2-1.65 times as high as an uncrowded service.[23]
E: Elasticity of bus demand with respect to total journey time	Central: -1.3 Low: -0.8 High: -2.0	EEM Table A14.2 short-run direct elasticity estimates for changes in total generalised cost of public transport use. Note: Generalised cost elasticity used instead of in-vehicle time elasticity as some options will also affect walk times to bus stops and hence total journey times
R: Share of new bus trips that shift from driving	Central: 37.5% Low: 20% High: 70%	EEM Table A14.6 prior modes of new bus passengers indicates an average of around 50% of new bus trips were former car trips, of which around 75% percent were car drivers. We multiply these ratios together to obtain the reduction in number of car driver trips. Sensitivity tests are derived from ATAP guidance for variation between different types of projects.[24]
RTRB: Road traffic reduction benefit	Central: $1.21/veh-km avoided Low: $0.60/veh-km	EEM Table SP9.1 road traffic reduction benefit values for major urban corridors; EEM Table A12.3 Benefit update factors. This figure combines congestion, crash, vehicle operating costs, and emission cost savings. The proposed low assumption factors this down by 50%, bringing it more in line with estimates of the average congestion cost per vehicle kilometre in large Australian / NZ cities.
HB: Health benefit of added walking to bus trips	Central: $1.89/trip switching from car	EEM Table A20.3 new pedestrian facility benefits; EEM Table A12.3 Benefit update factors. This figure reflects the health benefits of added walking activity, with any decongestion benefits excluded. An average walk distance of 600 metres to and from bus stops is assumed, consistent with catchment analysis and journey time modelling assumptions.

[23] See Table 17 in https://www.atap.gov.au/mode-specific-guidance/public-transport/files/M1_Public_transport.pdf
[24] See pg 10-11 in https://www.atap.gov.au/mode-specific-guidance/public-transport/files/M1_Public_transport.pdf

Parameter	Value	Source(s)
Discount rate	Central: 6% Low: 4% High: 8%	EEM Section 2.5
Evaluation period	Central: 40 years Low: 30 years	EEM Section 2.6
Base date for costs and benefits	July 2019	EEM Section 2.6 Note that May 2019 public transport data is used for evaluation, eg to quantify existing delays and measure patronage. May was chosen as it is a moderately typical month in terms of demands and system performance.
Demand growth factor	Central: Forecast ID population growth projection * 1.83 Low: Forecast ID population growth projection High: Forecast ID population growth projection * 2.71	Central scenario implies 52% increase in demand over period; low implies 29% increase; high implies 77% increase
Benefit unit growth factor	Central: 0.44% growth in benefits per user per annum Low: Zero growth High: 0.88% growth	Central scenario implies 17% growth in benefits per user over period; low implies 0% growth; high implies 34% growth

8.1. Workings for value of travel time savings

The following table shows workings for the central assumption for the average value of travel time savings parameter used in analysis.

We note that the EEM provides indicative trip purpose shares for car passengers on urban arterials (work purpose: 15 percent; commute: 15 percent; other: 70 percent). We could obtain a higher average VOT figure of $14.37 per hour using the EEM trip purpose shares. There is an argument for doing so to improve comparability with other assessments that are more likely to default to trip purpose shares drawn from the EEM.

Table 27: Value of travel time savings calculations

Journey purpose	HTS share of PT trip legs	Value of travel time savings (2002 NZD/hr)	Benefit update factor	Value of travel time savings (2018 NZD/hr)
Commuting to/from work or study	47%	$7.80	1.5	$11.70
Other non-work travel purposes	48%	$6.90	1.5	$10.35
Work travel purpose	5%	$23.85	1.5	$35.78
Total				**$12.26**

Notes: Journey purpose for bus trip legs was measured based on 2014-2016 Household Travel Survey data for the Wellington urban area. Trips taken to return home were assumed to follow the same distribution as trips taken to reach non-home destinations. A total of 912 bus trip legs were recorded. VOT parameters were sourced from EEM Table A4.1(b) while benefit update factors were sourced from EEM Table A12.3.

As a sensitivity test, we propose increasing the VOT parameter to reflect the cost that passengers incur when travelling on crowded PT vehicles. Australian public transport appraisal guidance suggests that VOT for passengers in crowded seats is 1.2 times as high as VOT for uncrowded passengers, while VOT for standing passengers is 1.65 times as high. If we assume that a crowded bus has a roughly equal mix of standing and sitting passengers, then the average passenger on a crowded service experiences a VOT that is 1.425 times as high as the average passenger on an uncrowded service.

We therefore multiply our central VOT assumption by 1.425 to obtain a high VOT assumption. This could be interpreted as a reflection of the benefits of bus priority improvements in locations where public transport vehicles are crowded at peak times or in a scenario in which increasing travel demands results in consistent peak crowding across all main bus corridors.

9. Methods used to calculate impacts of specific interventions

This section describes the methods used to calculate the impact of specific interventions that are being considered as part of the programme. These assessments are indicative level assessments and could be revisited using, for instance, detailed intersection modelling at the design and detailed assessment stage.

9.1. Signal improvements

Traffic signals can cause significant delays for buses and for other users. Delays from traffic signals can be particularly large when there is a high density of traffic signals along a route and a large number of opposing movements through intersections.

Increased green phase

Increasing the length of the green signal cycle phase for the bus direction of travel can be an appropriate intervention when buses are experiencing large delays at an intersection and the share of people travelling in the bus direction of travel is large. This can be a universal green phase extension that is triggered, or a dynamic green phase extension only when a bus is detected, minimising disbenefits for other users.

It is assumed that buses benefit from a 10-second green time extension. Travel time savings per bus are estimated by re-estimating traffic signal delay using the formulas described in Section 4.3. There is a further benefit from reductions in queue service delay (due to smaller queues building up during the red phase) that is also assessed. Net traffic disbenefits can be assumed to be minimal as the green phase extension will benefit some vehicles while delaying others. If the green phase extension is targeted to bus movements, it will only be activated when a bus is present upstream of the traffic signal and will hence only impact a share of traffic signal cycles.

Queue jump

Providing a bus queue jump can be an appropriate intervention when there are long queues of vehicles at a signalised intersection, causing long queue service times. They can also be useful where buses must change lanes or turn at the intersection and benefit from traffic being held.

When there is a bus stop immediately before an intersection, the benefit of a queue jump is assumed to be 100 percent of the queue service time. Where there is no preceding bus stop, the benefit of a queue jump is assumed to be 50 percent of the queue service time. These assumptions are used because if there is a preceding bus stop, most buses will receive the full benefit from the presence of the queue jump, because otherwise they would end up at the end of the queue after departing the bus stop. If there is not a bus stop, it is assumed that the average location of the bus would be in the middle of the queue, so would face only 50 percent of the queue service time.

The queue service time is calculated using Equation 6-9, Equation 6-10, and Equation 6-11 in the TCQOSM (2013, pg. 6–74). For the purpose of calculations, the saturation flow rate has been assumed to be 1500 vehicles per hour, the default value in urban environments with higher pedestrian and traffic volumes and constrained roadway layouts (TCQOSM, 2013).

Disbenefits will vary depending upon whether queue jumps reallocate general traffic lanes or parking spaces.

Bus phase

A bus signal phase can be an appropriate intervention where buses must manoeuvre between lanes or make movements that general traffic does not, such as into a bus depot. They can also be useful when a bus stop immediately precedes a signal and the phase allows buses to get a head start through the intersection.

The benefit of a bus phase is similar to the benefits of a green phase extension and hence we model these two options using the same approach.

Minor or major intersection redesign

A minor intersection re-design can be an appropriate intervention when buses are experiencing large delays and / or there are safety issues at an intersection. Specific interventions will vary from site to site but could include a re-design of signal phases, a reduction in allowed turning movements, and / or traffic lane reconfiguration.

A major intersection re-design can be an appropriate intervention when buses are experiencing delays and / or there are safety issues at an intersection. Specific interventions will vary from site to site but are likely to include major changes to traffic lane configuration and traffic movements.

For indicative assessment, we assume that intersection re-designs provide a combination of increased green time and queue jumps for buses. The distinction between minor and major re-designs is primarily due to the complexity of the intersection and the degree of existing traffic delay – more complex intersections require a larger (and more costly) re-design to deliver similar benefits.

9.2. In-lane bus priority measures

Buses can face congestion from general traffic at traffic signals, mid-block, and when manoeuvring in and out of bus stops. In-lane bus priority measures can reduce or eliminate these sources of delay for buses.

In-line bus stops

In-line bus stops can be an appropriate intervention when buses are facing congestion when merging into traffic from off-line bus stops, causing re-entry delays. They can also be an appropriate intervention when an improved level of service for waiting passengers is desired; in-line bus stops can create room for larger waiting areas than is available on the footpath and prevent people who are boarding the bus from stepping into the road because the bus cannot pull in to the kerb. They can also reduce conflicts between buses and people on bikes when combined with a bike lane.

The benefit to people in buses is assumed to be equivalent to the reduction in re-entry delay. Re-entry delay is estimated using average re-entry delay estimates for sites away from traffic signals from Exhibit 6-59 of the TCQOSM (2013, pg. 6–73), outlined in Table 4. This will provide a slight underestimate of the benefit of in-line bus stops as it does not account for the benefit of reduced manoeuvring time.

Table 28: Average re-entry delay (bus stops not near traffic signals)

Adjacent lane traffic volumes (veh/h)	Average re-entry delay (s)
1	0
100	1
200	2
300	2
400	3
500	4
600	5
700	6
800	8
900	10
1000	12

Disbenefits to people in private vehicles are assumed to be equivalent to the sum of the average bus dwell time and the expected bus deceleration and acceleration time, taking into account the fact that only a share of buses may stop at each bus stop. These disbenefits will only apply to a share of private vehicle users. Supplementary analysis of targeted bus stops suggests that traffic delay disbenefits do not outweigh benefits to bus users, provided that in-line bus stops are well-targeted.

Peak-only or 24/7 bus lanes

Peak-only bus lanes can be an appropriate intervention when high volume to capacity ratios in general traffic lanes are causing mid-block congestion for buses at peak times only and there is high demand for parking outside peak times.

Full-time (24/7) bus lanes can be an appropriate intervention when high volume to capacity ratios in general traffic lanes are causing mid-block congestion for buses across the day and there is not high demand for parking outside peak times, or corridor widening is feasible.

To estimate the benefits of peak-only bus lanes at mid-block locations, it will be assumed that delay from mid-block traffic congestion and parking operations reduces to the level estimated for the off-peak (10–11pm) period. These benefits apply only to the hours when the bus lane is in operation.

Mid-block bus lanes may be designed to reach intersections and hence provide queue service delay reduction benefits. However, we have assessed these benefits separately.

Disbenefits will vary depending upon whether bus lanes reallocate general traffic lanes or parking spaces. If the former, we will assume that traffic is reallocated to the remaining lane(s) and consider whether this is likely to lead to any reduction in operating speeds.

9.3. Corridor improvements

Buses can operate at reduced speeds due to constrained corridor layout, such as narrow traffic lanes, lack of shoulders, and tight corners. Corridor improvements can reduce or eliminate these sources of delay.

Widened traffic lanes can be an appropriate intervention when narrow traffic lanes, narrow shoulders, and / or high amounts of side friction from parked vehicles is causing delays for buses and there is a high demand for parking outside peak times.

The impacts of wider vehicle lanes and shoulders on free-flow vehicle speeds are estimated using Exhibit 20-5 of the Highway Capacity Manual (2000), as outlined in Table 5. Widening traffic lanes or providing shoulders is expected to reduce delay due to inefficient road layout. In the case of peak-hour clearways, these benefits will accrue during peak hours only, whereas in the case of widened traffic lanes, these benefits will accrue at all hours.

Table 29: Estimated impact of traffic lane width and shoulder width on free-flow speeds for general traffic

Lane width (m)	Reduction in free-flow speed by shoulder width			
	≥ 0.0 <0.6	≥ 0.6 <1.2	≥ 1.2 <1.8	≥ 1.8
2.7 <3.0	10.3	7.7	5.6	3.5
≥3.0 <3.3	8.5	5.9	3.8	1.7
≥3.3 <3.6	7.5	4.9	2.8	0.7
≥3.6	6.8	4.2	2.1	0.0

Note that:

- Benefits may in fact be higher for buses, due to the fact that they are wider, longer, and slower to accelerate than cars.
- Corridor improvements will also benefit private vehicle users as well as bus passengers.

9.4. Bus stop improvements

Increased time spent stopping at bus stops can substantially increase travel times for buses. Ensuring that bus stops are optimally spaced and designed can improve travel times.

Bus stop rationalisation

Bus stop rationalisation can be an appropriate intervention when bus stops are very close together, causing overlapping walking catchments. This causes the bus to stop frequently, increasing travel times without substantially increasing access to bus stops.

To assess the impact of removing a bus stop, we:

- identify the number of people who board / alight at that bus stop

- estimate the added time that passengers would have to walk to the nearest remaining bus stop[25]
- identify the number of passengers on the bus and who do not board / alight at the bus stop
- estimate the change in delay that bus passengers face, taking into account reduced dwell time (net of any increased dwell time at other bus stops), reduced entry / re-entry delay, and reduced time spent accelerating / decelerating at bus stops[26]
- calculate total increases and decreases in travel times and identify net benefits / disbenefits.

Entry / exit tapers

Entry / exit tapers can be an appropriate intervention when road layout or adjacent parking is preventing buses from manoeuvring into a bus stop, causing delays and causing passengers to step into the road because the bus cannot kerb.

We do not calculate the benefits of these improvements as they are likely to be positive but small and highly location-specific.

Lengthening bus stops

Lengthening bus stops can be an appropriate intervention when high frequency of buses or long dwell times (eg at bus interchanges) causes bus-bus congestion at bus stops.

We do not calculate the benefits of these improvements as they are likely to be positive but small and highly location-specific.

10. Benefits / disbenefits that are excluded from analysis

The proposed approach to analysis is suitable for an indicative or single-stage business case. As currently outlined, it does not attempt to quantify some categories of benefits / disbenefits that may be considered in a more detailed assessment.

This means that the results of this assessment should be seen as a *conservative* estimate of project benefits. Quantifying additional impacts is likely to raise the BCR, rather than lower it.

The following impacts are either not included or are included using simplified procedures:

- Comfort and quality of experience for bus passengers: this assessment focuses on travel time benefits for bus passengers and does not consider impacts related to:
  - quality improvements at bus stops or facilities, eg installation of real-time boards or improved lighting
  - changes to bus crowding that affect passenger discomfort (except insofar as a higher VOT is sensitivity tested)
  - perceived comfort / inconvenience in different parts of the journey, eg when waiting at bus stops rather than travelling on the bus.

[25] After consideration of catchment size, potential origins of people walking to bus stops, and distances to other nearby bus stops, we estimated that the average user would experience increased walking distances equal to approximately two-thirds of the distance to the nearest bus stop up or down the line. This assumes that a share of people will face the 'worst case' scenario of walking to their original stop and then walking the full distance to the next stop, but that some people will be able to take shorter routes to their new stop.
[26] A deceleration rate of 1.2 m/s and an acceleration rate of 0.85 m/s have been assumed (TCQOSM, 2013).

- Improved travel time reliability for bus passengers: this assessment focuses on changes in *average* travel times, rather than reductions in the *variability* of travel times. In reality, the proposed interventions are also likely to improve reliability, with corresponding benefits to users. This issue is discussed below.
- Impacts on people who are walking: some changes, such as footpath widening associated with in-line bus stops or removal of footpath clutter due to bus stop rationalisation may benefit pedestrians. Other changes, such as altering signal timing, may increase delays experienced by pedestrians.
- Impacts on people who are cycling: if corridor improvements include cycling facility improvements it will improve safety and comfort and encourage more people to cycle. Analysing these changes would require additional analysis and data.
- Some impacts on car users: many impacts on car users are estimated using simplified procedures or targeted analysis, such as changes in queue service delay at intersections where bus priority measures are introduced and general decongestion impacts from mode shift (using EEM SP9). However, some impacts such as system-wide impacts of signal timing changes may only be partly quantified using the methods described above. A full assessment would require more detailed traffic data and / or traffic modelling, which is out of scope at this stage.
- Other environmental and health impacts: reduced vehicle emissions due to mode shift are captured in the parameter for road traffic reduction benefits. Changes to bus operations may also lead to increases or decreases in vehicle emissions, which we have not assessed at this stage.
- Wider economic benefits: improved accessibility can generate wider economic benefits, such as increased agglomeration economies and labour supply benefits. To assess these, it would be necessary to model average transport costs across all modes, eg integrating the above analysis with outputs from a strategic transport model.

This analysis also excludes a detailed consideration of renewal costs and residual value at the end of the evaluation period for new or changed transport facilities. This is appropriate for indicative analysis, as assessing renewal costs and residual value requires more detailed cost estimation than is expected to be available at this stage.

10.1. Travel time variability on bus corridors

There are two dimensions to travel time variability:

- variations in average travel times between different time periods – for instance, average travel times are typically slower during the AM peak hour relative to the off-peak period
- day-to-day or trip-to-trip variation in travel times within time periods – for instance, bus travel times may deviate significantly from the average due to bad weather, unpredictable traffic congestion, crash incidents, or random variations in demand and driver performance.

Analysis of bus priority options is based on average travel times within time periods. Variability in travel times between different time periods is captured in the analysis through the use of annualisation factors that incorporate differences in delay experienced by bus passengers during peak and off-peak periods.

However, day-to-day or trip-to-trip variation in travel times is not captured in the analysis. This is in spite of the fact that users cite unreliable journey times as one of their key problems with Wellington bus services. To understand the extent and magnitude of unreliability, we analysed

Snapper data to estimate variation in travel times along corridor sections within each one-hour period. We used the standard deviation of travel time as a measure of travel time reliability – a higher standard deviation means that travel times vary more from trip to trip or day to day, and vice versa.[27]

We then compared travel time variability within periods to average delay during those periods. We found that unreliable travel times are highly correlated with delay. Corridor sections with a large amount of delay are also likely to have a higher standard deviation of travel times. In addition, time periods with more delay are also likely to be more unreliable.

The following table shows the relationship during average delays and standard deviation of travel times during the AM and PM peak hours. On average, the standard deviation of travel times is equal to 38 percent of delay.

Because there is a strong relationship between delay and unreliability, we would expect that measures to reduce bus delay will also reduce travel time variability. This will provide additional benefits for bus users. We would expect these benefits to be equal to roughly 38 percent of the value of reduced delay, following the observed relationship. This is included as a sensitivity test in cost benefit analysis.

[27] Standard deviation reflects both 'upside' and 'downside' variability relative to average travel times. However, additional analysis suggests that people are more likely to encounter unexpectedly bad travel times rather than unexpectedly good travel times, and hence the standard deviation may under-estimate the negative effects of variability.

Table 30: Relationship between travel time delay and travel time variability

Corridor section	Average minutes delay per kilometre	Standard deviation of travel time per kilometre	Standard deviation / delay
Inbound, 8–9am			
1	3.99	1.06	27%
2A	4.95	2.88	58%
2B	1.38	0.54	39%
2C	2.09	0.82	39%
3A	1.05	0.55	52%
3B	1.88	0.45	24%
3C	3.08	0.66	21%
3D	2.52	0.80	32%
4	4.12	0.88	21%
5	2.20	0.70	32%
6	3.88	1.08	28%
7	3.35	0.78	23%
8A	6.49	2.60	40%
8B	1.73	1.13	65%
8C	1.13	0.63	56%
Outbound, 5–6pm			
1	4.26	0.68	16%
2A	1.73	0.49	28%
2B	2.70	0.70	26%
2C	1.86	0.36	19%
3A	2.21	0.36	16%
3B	2.64	0.28	10%
3C	0.83	0.55	66%
3D	0.99	0.89	90%
4	4.59	1.17	25%
5	1.76	0.68	39%
6	2.65	0.69	26%
7	4.07	0.80	20%
8A	2.46	2.04	83%
8B	0.97	0.74	76%
8C	2.52	0.91	36%

11. Cost estimates

11.1. Capital cost estimation approach

Capital costs were estimated on a per corridor basis using two main inputs: estimated overhead costs per corridor which are not intervention-specific and estimated costs per intervention unit.

Corridor-level overhead costs were estimated for five activities: communications and engagement, traffic resolutions, draft engineering design, detailed engineering design, and contract management. Estimated overhead costs are outlined in Table 32.

Costs per intervention unit were estimated based on actual incurred costs for previous projects delivered by Wellington City Council over the past five years. For each intervention, a low and a high estimate was produced for both construction costs and days of construction. This approach was chosen in the absence of detailed design at the IBC stage, as there is a degree of uncertainty surrounding the actual costs and delivery time required for each type of intervention. Traffic management costs were estimated by multiplying the estimated number of days of construction by the daily traffic management cost, assumed to be $1800 per day. Construction costs and traffic management costs were then combined to produce an overall estimated cost per intervention unit. Estimated costs per intervention are outlined in Table 34.

To calculate the need for road widening and other enabling works, it was necessary to make an indicative assumption of the space required to make provisions for transit lanes given that streets must generally also accommodate general traffic lanes and footpaths for each direction of travel. These are outlined in Table 31. If the current corridor width was not sufficient to accommodate transit lanes, general traffic lanes, and footpaths, it was assumed corridor widening was required.

Table 31: Assumed widths required for corridor elements (m)

	Town centre	Arterial >10,000 AADT	Arterial <10,000 AADT
Transit lane	3.2	3.2	3.2
General traffic lane	3.2	3.2	3.0
Footpath	3.0	2.0	2.0

For the purposes of cost benefit analysis, the mid-point of the low and high cost was used for analysis. This is considered appropriate at this stage, as detailed designs for interventions would be required to produce a more informed estimate of the distribution between the low and high cost estimate levels.

Table 32: Corridor-level cost estimates

Cost item	Units	Cost ($)		
		Low	Mid-point	High
Communications and engagement	Annual per corridor	1,000,000	1,500,000	2,000,000
Traffic resolutions	Kilometre treated	15,000	17,500	20,000
Draft engineering design	Kilometre treated	100,000	150,000	200,000
Detailed engineering design	Kilometre treated	100,000	150,000	200,000
Contract management	Kilometre treated	50,000	75,000	100,000

Programme costs for next stage business case development and project overheads are covered by the allowances above for communications and engagement, traffic resolutions, and engineering design.

Contingency allowances were accounted for in the analysis by identifying a low, medium, and high cost range. Low and high costs were used in sensitivity testing.

A summary of the scenario option costs is set out in Table 33.

Table 33: Programme cost summary

Option	Option 1 fix everything	Option 2 fix worst	Option 3 minimal works
Costs (present value, $m)			
Construction costs	$185.44m	$91.63m	$24.22m
Land purchase costs	$12.38m	$6.88m	NA
Operation costs	-$4.84m	$0.68m	$1.23m
Renewal costs	NA	NA	NA
Total	**$192.97m**	**$99.19m**	**$25.44m**

Table 34: Estimated costs per intervention

Type	Intervention	Unit	Costs per unit ($)		Days of construction		Traffic management costs ($)		Total cost ($)		
			Low	High	Low	High	Low	High	Low	Mid-point	High
Signal improvements	Green phase extension	Intersection	5,000	8,000	0	0	-	-	5,000	6,500	8,000
	Queue jump	Metre	200	300	42	42	75,600	75,600	75,800	75,850	75,900
	Bus phase	Intersection	10,000	50,000	3	14	5,400	25,200	15,400	45,300	75,200
	Minor intersection re-design	Intersection	50,000	500,000	14	60	25,200	108,000	75,200	341,600	608,000
	Major intersection re-design	Intersection	1,000,00 0	3,000,000	60	180	108,000	324,000	1,108,000	2,216,000	3,324,000
Lane priority	In-line bus stops	Bus stop	15,000	120,000	5	21	9,000	37,800	24,000	90,900	157,800
	Peak-only bus lanes	Kilometre	65,000	300,000	3	60	5,400	108,000	70,400	239,200	408,000
	24-hour bus lanes	Kilometre	65,000	300,000	3	60	5,400	108,000	70,400	239,200	408,000
Corridor	Peak-hour clearways	Kilometre	5,000	10,000	2	5	3,600	9,000	8,600	13,800	19,000
	Widen traffic lane	Kilometre	750,000	1,500,000	60	120	108,000	216,000	858,000	1,287,000	1,716,000
Bus stops	Bus stop rationalisation	Bus stop	4,000	6,000	2	4	3,600	7,200	7,600	10,400	13,200
	Bus stop relocation	Bus stop	30,000	60,000	5	14	9,000	25,200	39,000	62,100	85,200
	Entry/exit tapers	Bus stop	500	1,000	1	2	1,800	3,600	2,300	3,450	4,600
	Lengthening bus stop	Bus stop	500	1,000	1	2	1,800	3,600	2,300	3,450	4,600
Enabling works	Retaining wall	Square metre	3,000	6,100	0.2	0.3	360	540	3,360	5,000	6,640
	Pole relocation	Pole	20,000	30,000	1	2	1,800	3,600	21,800	27,700	33,600
	Tree removal	Large tree	20,000	30,000	2	3	3,600	5,400	23,600	29,500	35,400

11.2. Operating cost estimation approach

The bus priority programme can be expected to influence operating costs through two main pathways.

First, faster journeys reduce operating costs directly by reducing the time it takes to operate a given service. If journey times are substantially improved, it may also be possible to achieve the desired headways using fewer vehicles, resulting in further operating cost savings above and beyond what would be expected based on reduced journey times alone.

Second, faster journeys can be expected to result in an increase in patronage. If increased peak loads result in a need for additional bus services, this will increase day-to-day operating costs and may also incur costs associated with purchasing additional vehicles.

Increased patronage will also result in increased revenue for the transport operator, which will not impact the social cost benefit analysis but will reduce the net cost to government.

We have undertaken a high-level, simplified calculation of potential changes in operating costs. This focuses on bus travel on the priority corridors and does not consider issues such as how buses travel on the rest of the network, how bus trips are scheduled, and where and how buses lay over between journeys. It has been assumed that vehicles operate on a loop on a single corridor only, ie there are no interactions between corridors or other sections of the bus network. As a result, we caution that this is unlikely to be an accurate estimate of operating cost impacts, although it does highlight that added costs and avoided costs may at least partly offset each other.

Change in patronage

Change in patronage is calculated using estimated changes in journey times and the elasticity of demand published in EEM, as outlined in Section 0. Changes in patronage on each individual route are estimated and the results are used to scale up peak loads along the bus corridors.

Change in number of vehicles required to serve passengers

The change in the number of vehicles required to serve passengers is calculated on an hourly basis using three inputs: projected change in journey times along the bus priority corridors by hour of day, projected change in peak passenger loads along the bus priority corridors by hour of day, and assumed capacity per bus.

This calculation proceeds in four stages:

- First, data on corridor length and estimated average travel times under each option are used to estimate the number of one-direction runs that a single bus can make in an hour. An allowance for layover and recovery time (five minutes per one-directional run) is made. For instance, if it takes 22 minutes to travel the length of the corridor (27 minutes with layover and recovery time), a single bus can make two runs per hour. However, if it takes 14 minutes to travel the length of the corridor (19 minutes including layover/recovery), a single bus can make three runs per hour.
- Second, the number of vehicles required to serve peak passenger loads is estimated by dividing peak passengers under each option by vehicle capacity and then dividing by runs per bus per hour under that option. Vehicle capacity is defined as ideally 90 percent of full capacity for a large bus with capacity for 75 passengers, but no more than 95 percent of full capacity.

- Third, the number of vehicles required to provide basic service headway is estimated by dividing on-directional travel time on the corridor plus layover / recovery time by target service headway of 10 minutes.
- Fourth, the number of vehicles required to provide service in each hour is estimated as the maximum of either vehicles required to serve peak passenger loads or vehicles required to provide minimum headways.

This method generally results in changes to vehicle requirements to serve peak demand but few changes in other time periods.

Change in service-hours and service-kilometres

To calculate service-hours required during each hour of the day, vehicle requirements are multiplied by runs per bus and then by time spent travelling and laying over / recovering per bus.

To calculate service-kilometres required during each hour of the day, vehicle requirements are multiplied by runs per bus and then by corridor length. No allowance is made for distance spent travelling to the start of other runs, as this is assumed to not change as a result of improvements on these corridors.

Changes in service outputs under each option reflect changes in vehicle requirements, changes in number of vehicles required to meet demand, and reductions in travel times. Service-kilometres increase due to an increase in required bus runs, while impacts on service-hours could either be positive or negative.

Change in operating costs

Impacts of the bus priority programme on operating costs are then estimated using the projected change in peak vehicle requirements and service outputs and the parameters outlined in Table 35.

Three types of operating cost impacts are estimated:

- **Change in bus fleet size**
    - If increases in patronage result in a need for additional vehicles during the AM week-day peak, it is assumed that this leads to the purchase of additional buses, thus increasing annual operating costs associated with acquiring and servicing the vehicles. Conversely, if faster travel times allow buses to turn around faster and provide additional services, it will reduce peak vehicle requirements and reduce costs.
- **Change in service-hours**
    - Changes in journey times and bus fleet size result in changes to the number of service-hours required. Added costs or cost savings are estimated based on the average cost per service-hour.
- **Change in service-kilometres**
    - Changes in bus service requirements result in changes to the number of service-hours required. Added costs or cost savings are estimated based on the average cost per service-kilometre.

Table 35: Operating cost calculation assumptions

Parameter	Value	Assumptions and source(s)
Hourly cost of bus operations	$33.40	It is assumed that benefits only accrue by the hour, ie there are no benefits for fractions of buses or fractions of hours. Source: GWRC
Cost per km of bus operations	$2.12	Large size vehicle assumed. Source: GWRC
Annual cost per additional bus required	$55,600	Large size vehicle assumed. It is assumed that an additional vehicle is required for additional AM peak services only. Source: GWRC
Actual revenue per passenger	$1.85	This figure represents the average fare box recovery rate in Wellington City and reflects the number of zones travelled and mix of fare types. Actual revenue per passenger is likely to vary by corridor and bus route. Source: GWRC
Ideal maximum vehicle loadings	68 passengers	90% of the full capacity of a large 75-person bus. A tolerance of 95% of full capacity is applied if passenger loads are only marginally above this level.
Corridor headways	10 minutes	All-day service headways of one bus per 10 minutes.
Layover and recovery time per one-directional run	5 minutes	Note that corridors are shorter than the full length of some bus routes, meaning that this only captures a portion of the full layover time.

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Appendix 3 – Newtown to city (corridor 1): corridor analysis summary

1. Corridor overview

1.1. Context

The Newtown to city corridor (corridor 1) is a 2.4-kilometre-long transport corridor that connects Newtown, Mt Cook, and Mt Victoria to the central city. There are eight public bus services and five school bus services operating on the corridor. On weekdays, there are more than 10,000 daily bus passenger trips along the corridor.

When travelling by bus, the journey from one end of the corridor to the other takes 11–12 minutes on average. There are two peak travel periods in the inbound direction: a morning peak hour at 8am–9am and an afternoon peak hour at 4pm–5pm, which is the slowest hour in the inbound direction. The average journey time to travel the length of the corridor is 14 minutes during the morning peak and 15 minutes during the afternoon peak. The outbound peak hour occurs at 5pm–6pm, when the average journey time is 15 minutes.

Table 36: Summary of key facts on the corridor

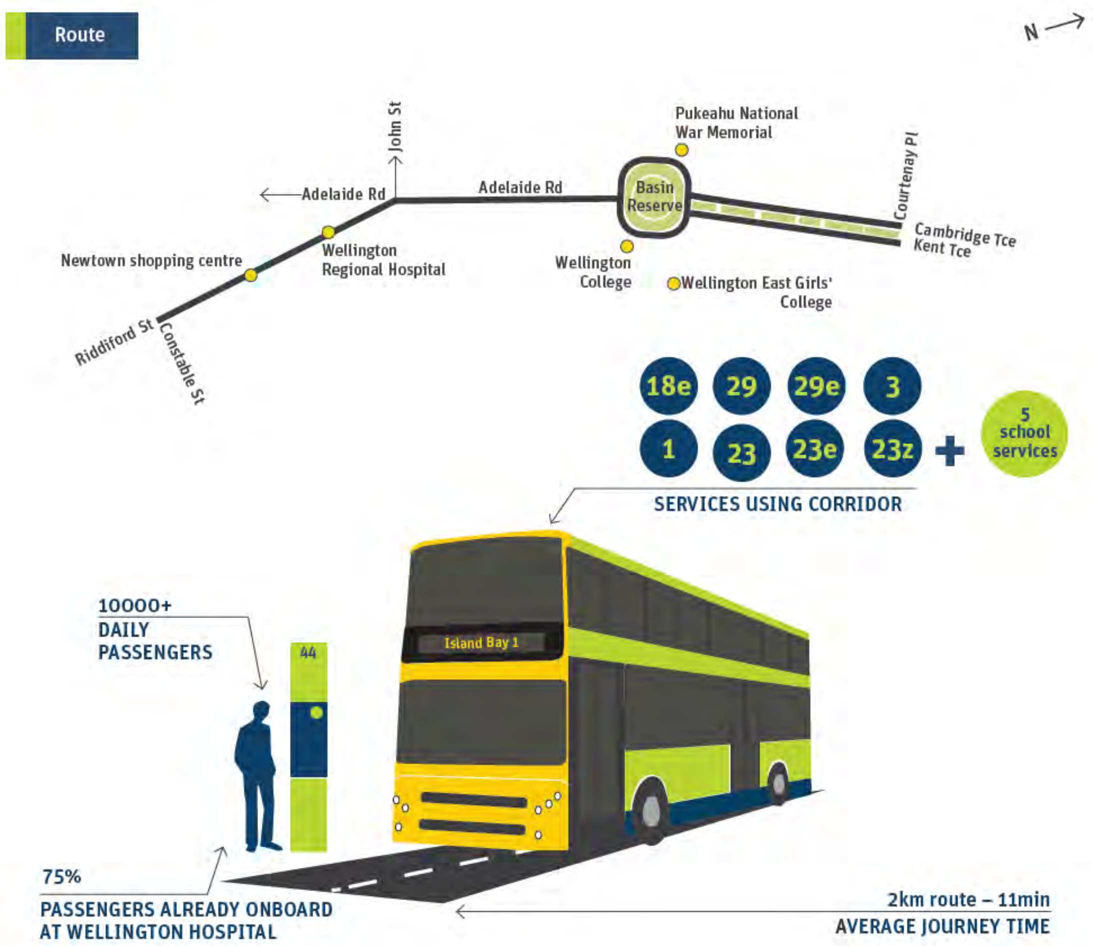
	Inbound	Outbound
Maximum daily passengers[28]	5,500	5,300
Corridor length (km)	2.4	2.4
Number of bus stops	8	7
Average bus stop spacing (m)	296	337
Average speed (km/h)	13.1	12.2
Average travel time (min)	11	12
Minimum travel time (min)	7	9
Maximum travel time (min)	15	15
Slowest weekday hour	4pm–5pm	5pm–6pm

Extensive Let's Get Wellington Moving investment is signalled for this corridor. This could include mass transit along Adelaide Road and Riddiford Street and changes to the Basin Reserve and Kent and Cambridge terraces. This is likely to involve significant changes to multiple streets and intersections.

Currently, there are no provisions for cycling on this corridor. However, cycleway investment is planned for the future.

[28] 'Maximum daily passengers' refers to the maximum number of passengers passing through a point on the corridor. On corridor 1, this occurs on Riddiford Street, south of Wellington Regional Hospital, which serves more bus routes than other sections of the corridor.

Figure 23: Corridor context summary



Area

There are several significant destinations located along the Newtown to city corridor, including Courtenay Place, the Basin Reserve, Wellington College, Newtown town centre, and Wellington Regional Hospital.

The land use along the corridor is principally classified as central area or centre zones, with one institutional precinct, which is Wellington Regional Hospital. The corridor also passes through a heritage area in the Newtown town centre.

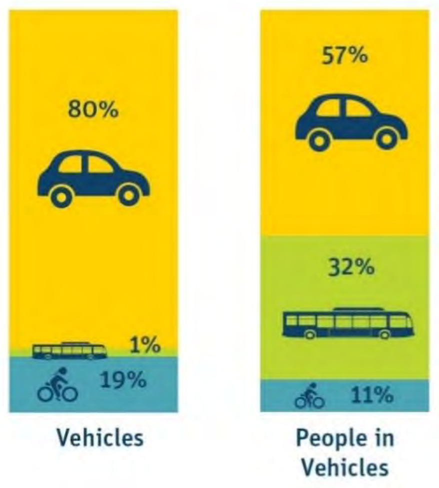
Roads

The Newtown to city corridor is made up of arterial, principal, and collector roads with a section of State Highway 1 (SH1), as shown in Figure 24. There are 10 signalised intersections, three signalised pedestrian crossings, and no roundabouts along the corridor.

Figure 24: Road hierarchy map[29,30]

During the morning peak hour (8am–9am), the majority of vehicles on the corridor are private vehicles (80 percent), followed by bikes (19 percent). Buses make up only 1 percent of the vehicles on the corridor. However, they transport roughly one-third of the people on the corridor (32 percent). This is indicative of the 'heavy lifting' that buses are doing to move people on this corridor. Figure 25 presents a full breakdown of the modal split on the corridor.

Figure 25: Modal split on the corridor (inbound peak period 8-9am)



1.2. Bus operations

There are eight public bus services and five school services operating on this corridor. There are eight bus stops in the inbound direction and seven in the outbound direction. These stops are located in fare zones 1 or 2. Three bus stops on this corridor are part of the Wellington

[29] Road hierarchy data sourced from WCC District Plan Map 33: Hierarchy of Roads.
[30] In the WCC District Plan, the road classifications are defined as follows:
- Motorway: high standard limited access roads designed to carry long distance through traffic at speed
- Arterial Road: high standard limited access roads designed to carry long distance through traffic
- Principal Road: roads that provide access to motorways and to arterial roads having a dominant through-traffic function and carrying the major public transport routes
- Collector Road: roads that distribute traffic between and within local areas and form the link between principal and secondary roads

Hospital bus hub: *Wellington Hospital – Stop A*, *Wellington Hospital – Stop B*, and *Wellington Hospital – Stop C*.

There are existing bus priority measures in place on the corridor. On Adelaide Road, Cambridge Terrace, and Kent Terrace, bus lanes operate Monday to Friday, 7am–9am in the inbound direction and 4pm–6pm in the outbound direction.

Bus stop locations

Inbound

The average bus stop spacing along the corridor in the inbound direction is 296 metres. The closest spacing is 180 metres, between two stops in Newtown town centre.

Figure 26: Bus stop locations and spacing – Inbound

Outbound

The average bus stop spacing along the corridor in the outbound direction is 337 metres. The closest spacing is 203 metres, between *Adelaide Road at Hospital Road* and *Wellington Hospital – Stop A*.

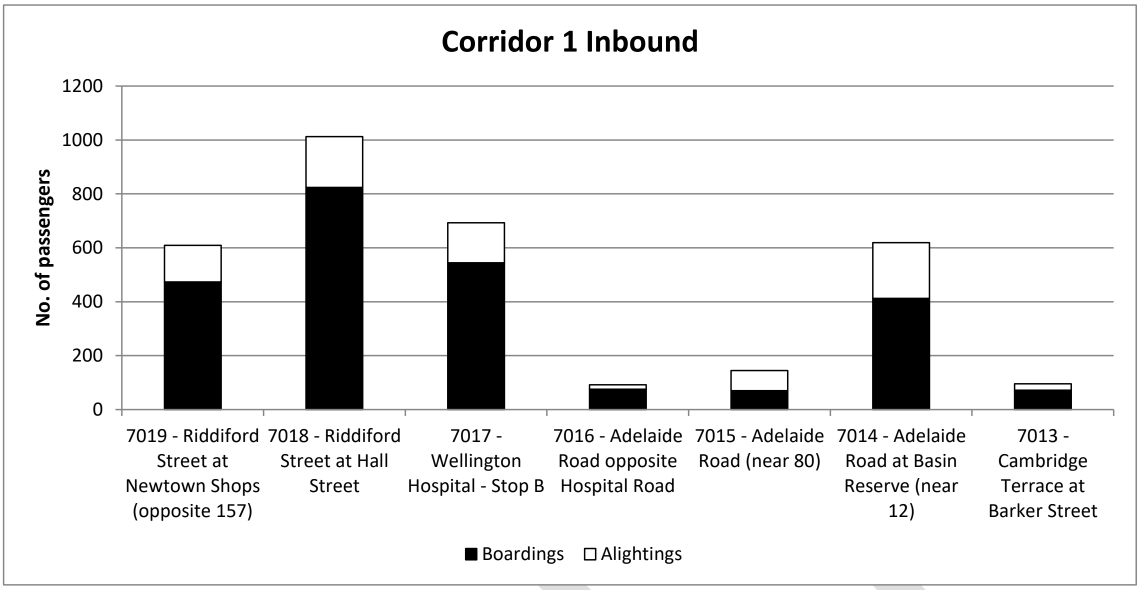
Figure 27: Bus stop locations and spacing – Outbound

Boardings and alightings

Inbound

The busiest bus stop along the corridor in the inbound direction is *Riddiford Street at Hall Street*, with more than 1000 daily boardings and alightings. The least busy bus stop, with less than 100 daily boardings and alightings, is *Adelaide Road opposite Hospital Road*. Figure 28 shows the daily number of people boarding and alighting at each bus stop along the corridor in the inbound direction. This includes all bus routes that service each bus stop.

Figure 28: Daily boardings and alightings – Inbound

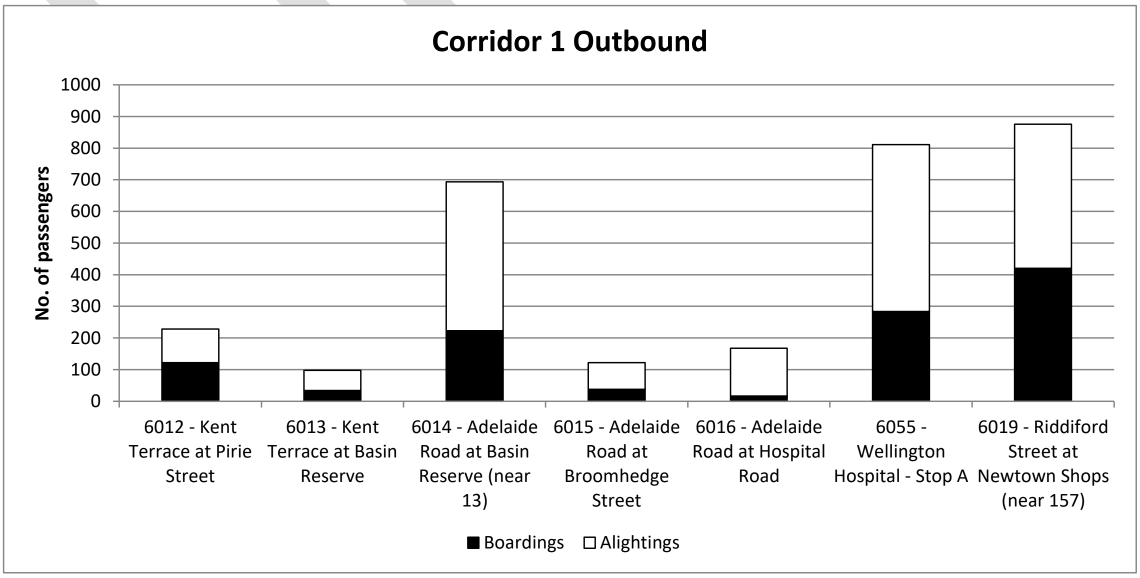


Outbound

There are two bus stops in the outbound direction outside Wellington Regional Hospital: *Wellington Hospital – Stop A* and *Wellington Hospital – Stop C*. When considering these two stops as one, *Wellington Hospital* is the busiest bus stop on the corridor in the outbound direction, with almost 1000 combined boardings and alightings. The least busy outbound bus stop is *Kent Terrace at Basin Reserve*. However, this bus stop is likely to be busier during events at the Basin Reserve, such as cricket tests.

Figure 29 shows the number of people boarding and alighting at each bus stop along the corridor in the outbound direction. This includes all bus routes that service each bus stop. The figures presented in the chart include data from only the busier of the two *Wellington Hospital* stops, *Wellington Hospital – Stop A*.

Figure 29: Daily boardings and alightings – Outbound

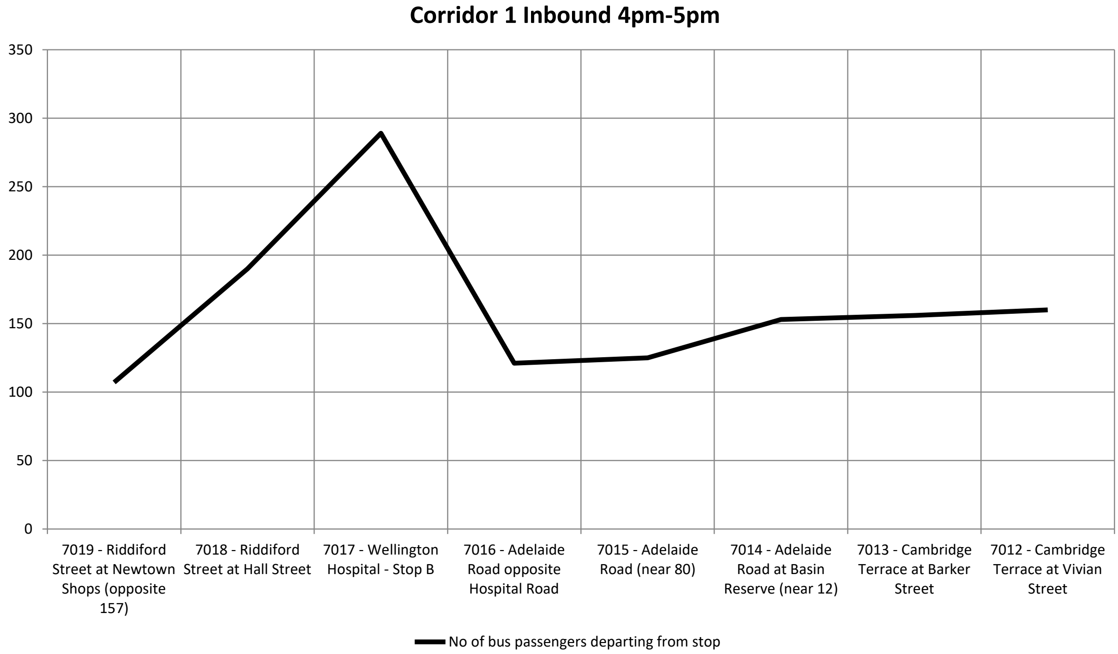


Cumulative passenger load

Inbound

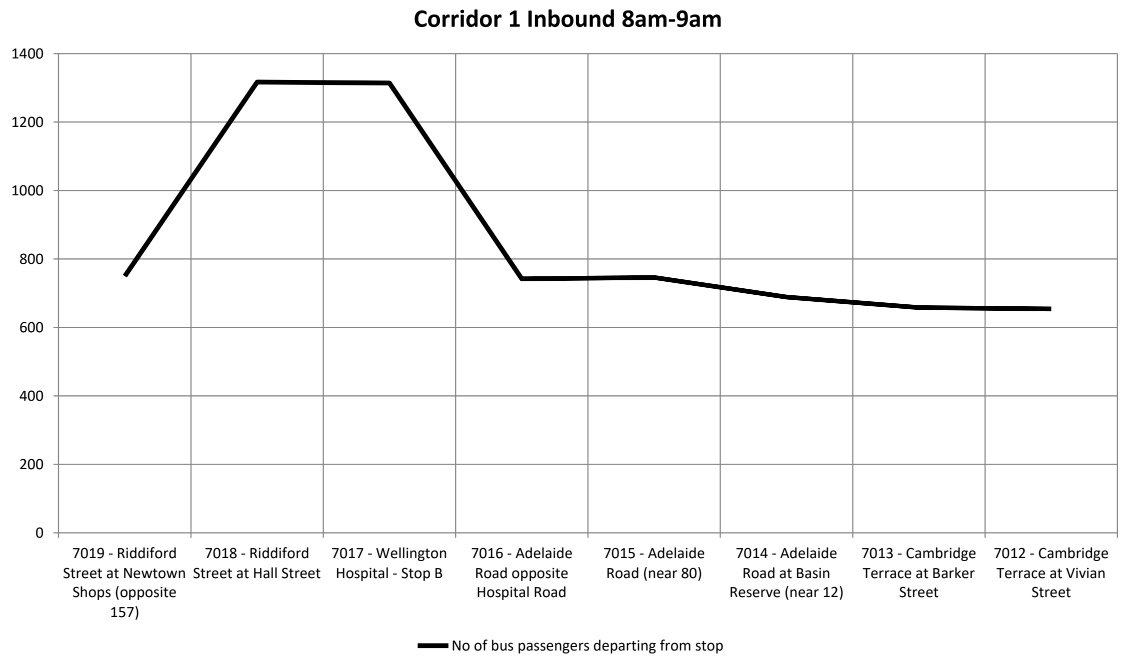
During the slowest hour on the corridor in the inbound direction (4pm–5pm), the highest passenger numbers occur at *Wellington Hospital – Stop B*, which serves more bus routes than other parts of the corridor. Figure 30 shows the average number of passengers on the bus departing from each bus stop during this hour.

Figure 30: Cumulative bus passenger load – Inbound slowest hour (4pm–5pm)



While the slowest hour along the corridor in the inbound direction is 4pm–5pm, the busiest hour for carrying passengers inbound is 8am–9am. The chart in Figure 31 shows that the highest numbers of passengers are carried on Riddiford Street, which serves more bus routes than other sections of the corridor.

Figure 31: Cumulative bus passenger load – Inbound morning peak hour (8am–9am)

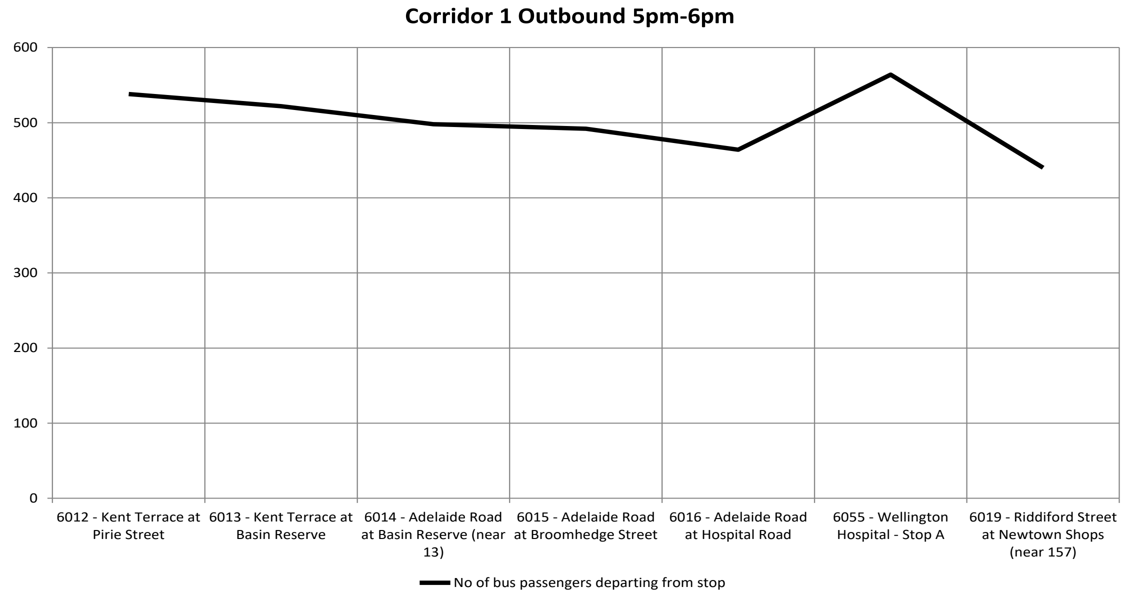


Outbound

During the outbound peak hour on the corridor, there are steadily decreasing numbers of bus passengers along the corridor until *Wellington Hospital – Stop A*. There is an increase in the number of bus passengers at the hospital bus stop, which serves multiple bus services. Figure 32 shows the average number of passengers on the bus departing from each bus stop during this hour.

Note that there are two bus stops in the outbound direction outside Wellington Regional Hospital: *Wellington Hospital – Stop A* and *Wellington Hospital – Stop C*. The figures presented in the chart are from the busier of these two stops, *Wellington Hospital – Stop A*.

Figure 32: Cumulative bus passenger load – Outbound afternooon peak hour (5pm–6pm)



2. Issues

2.1. Travel time

The average travel times along corridor 1 in the inbound direction are similar to travel times in the outbound direction. The slowest travel times are approximately four minutes slower than average for both directions. Table 37 provides a summary of the average travel times on the corridor and the travel times during the slowest and fastest hours in each direction.

Table 37: Summary of travel times on the corridor

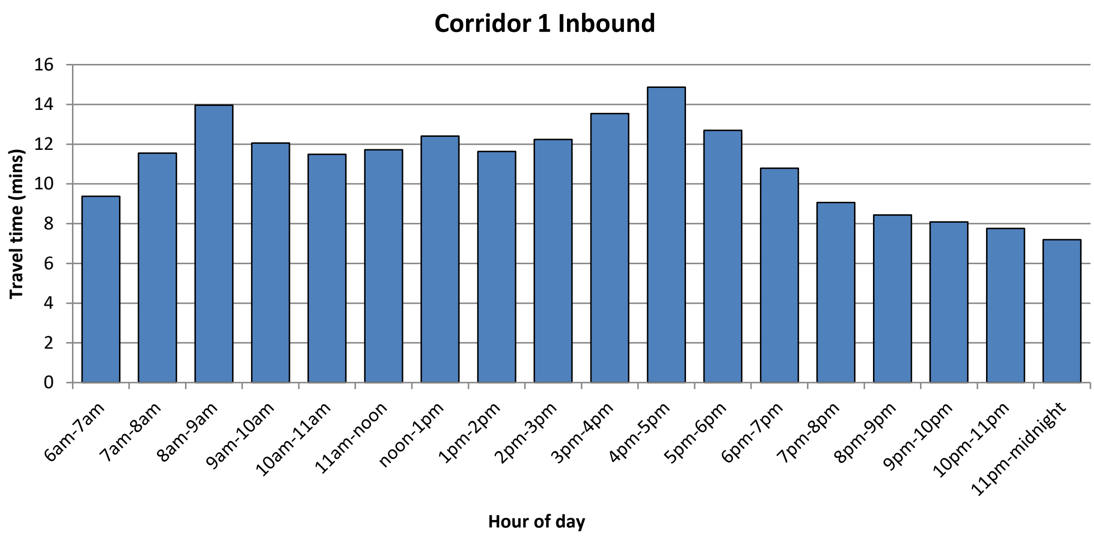
	Inbound	Outbound
Corridor length (km)	2.4	2.4
Average travel time (min)	11	11.8
Slowest hour	4pm–5pm	5pm–6pm
Travel time at slowest hour (min)	14.9	15.1
Fastest hour	11pm–midnight	10pm–11pm
Travel time at fastest hour (min)	7.2	8.9

Travel time by hour

Inbound

On corridor 1 in the inbound direction, the slowest hour for buses is 4pm–5pm, when it takes an average of 14.9 minutes to travel between the Newtown shops and Courtenay Place. The morning peak hour travel time is 14 minutes and occurs at 8am–9am, when there are the highest numbers of passengers on the buses. These travel times are approximately twice as long as travel times during the fastest hour of the day (11pm–midnight). Figure 33 shows the average time it takes for a bus to travel the length of the corridor in the inbound direction for every hour between 6am and midnight.

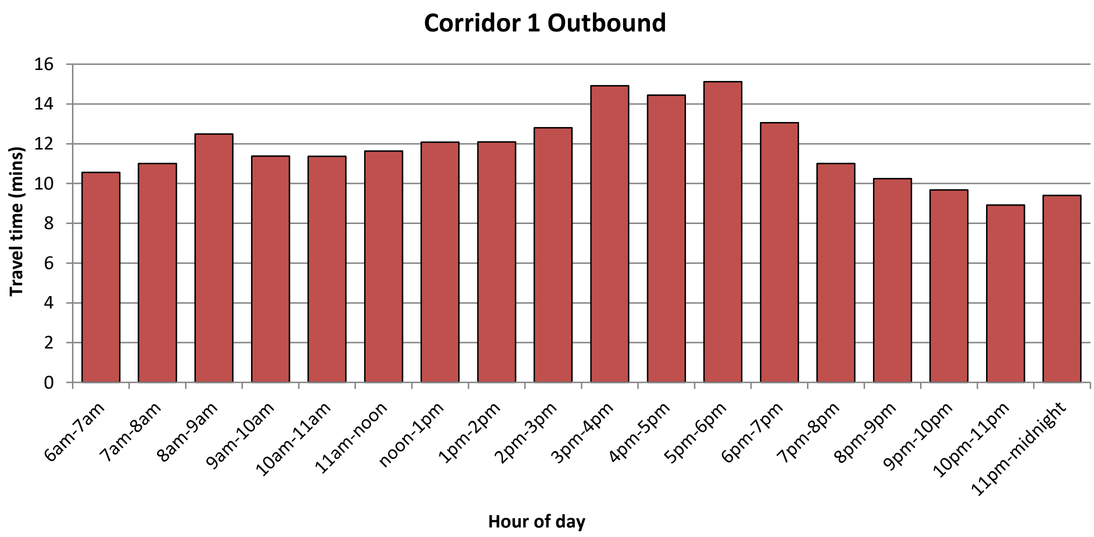
Figure 33: Travel times by hour of day – Inbound



Outbound

On corridor 1 in the outbound direction, the slowest hour for buses is 5pm–6pm, when it takes an average of 15.1 minutes to travel between Courtenay Place and the Newtown shops. This is despite bus lanes being in operation along parts of the corridor at this time. Figure 34 shows the average time it takes for a bus to travel the length of the corridor in the outbound direction for every hour between 6am and midnight.

Figure 34: Travel times by hour of day – Outbound

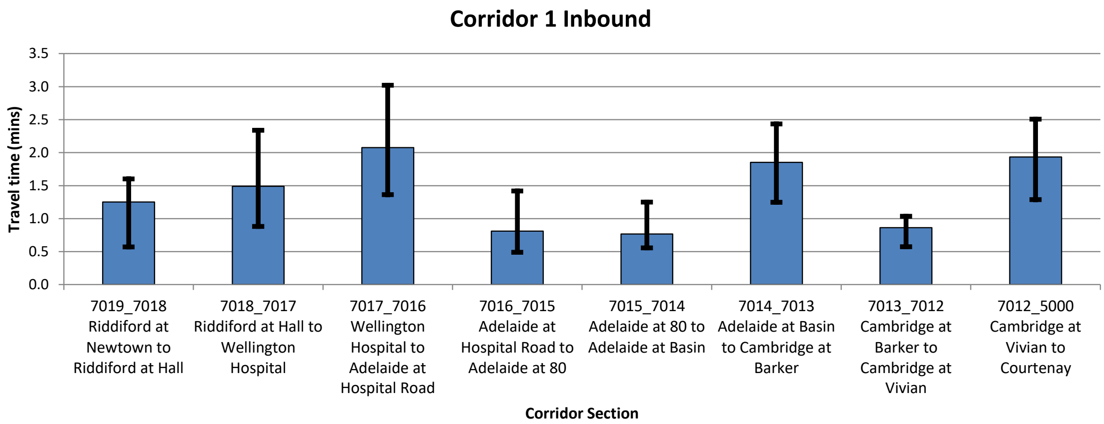


Travel time variability

Inbound

Figure 35 shows the average time it takes for a bus to travel along each segment of the corridor in the inbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

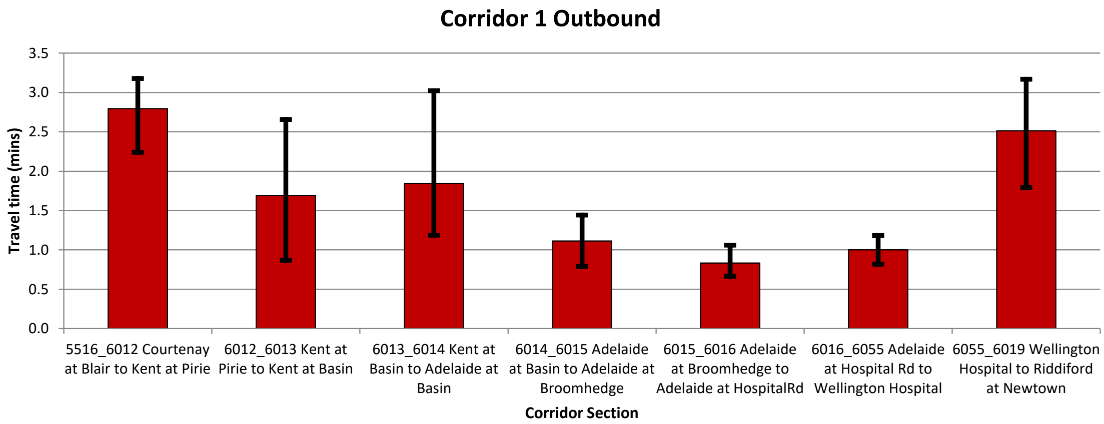
Figure 35: Variation in travel times – Inbound



Outbound

Figure 36 shows the average time it takes for a bus to travel along each segment of the corridor in the outbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

Figure 36: Variation in travel times – Outbound



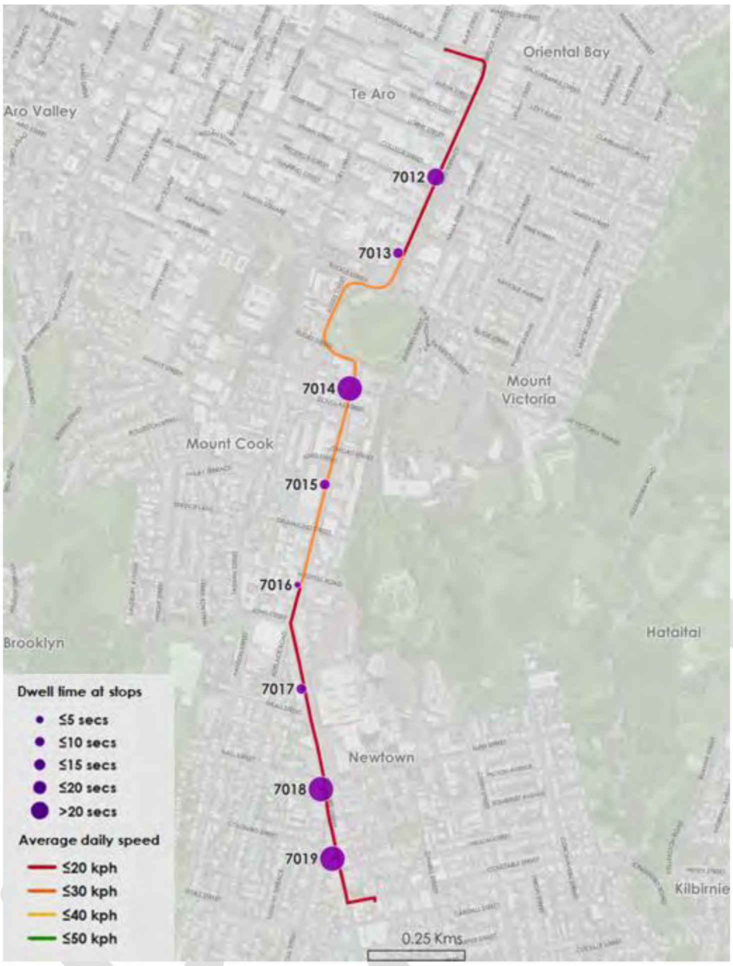
Bus operating speeds and dwell time delay

The maps below show the average speeds at which buses operate along the corridor and the average time buses dwell at bus stops during the peak hours.

Inbound

During the morning peak hour in the inbound direction (8am–9am), bus operating speeds on the corridor are slowest along Riddiford Street and Cambridge Terrace.

Figure 37: Operating speeds and dwell times – Inbound morning peak hour (8am–9am)



Outbound

During the slowest hour in the outbound direction (5pm–6pm), bus operating speeds on the corridor are slowest along parts of Kent Terrace, around the Basin Reserve, and on Riddiford Street.

Figure 38: Operating speeds and dwell times – Outbound afternoon peak hour (5pm–6pm)

2.2. Bus stop audit

There are eight inbound bus stops between Newtown town centre and Courtenay Place. There are seven outbound bus stops between Courtenay Place and Newtown town centre (eight in total, if both of the outbound bus stops at Wellington Regional Hospital are counted).

Of these bus stops, six are off-line stops, two are not of sufficient length to accommodate a bus, and three do not have sufficient entry and / or exit tapers for buses to easily manoeuvre into and out of the stop. Such issues can lead to increased dwell times, as passengers have to make awkward movements to get on and off of the bus. This is particularly difficult for mobility-impaired pedestrians, as well as for the young, elderly, and people with prams or carrying other heavy or bulky items.

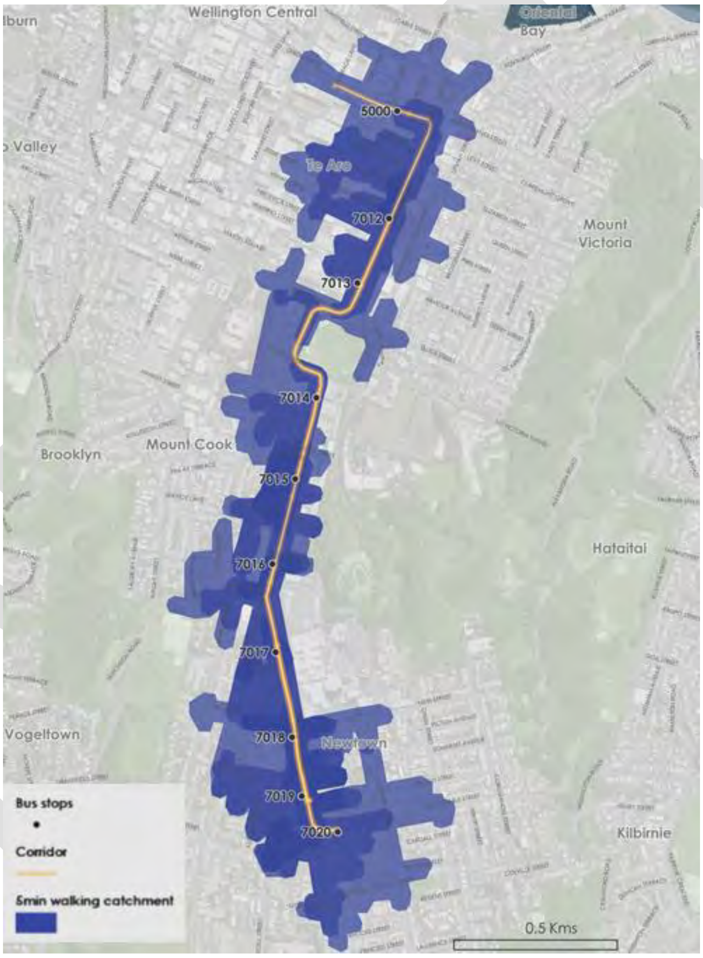
Table 38: Bus stop details[31]

	Number of bus stops	
	Inbound	Outbound
Total number of bus stops	8	7
Number of off-line bus stops	4	2
Number of bus boxes with insufficient length (<15m)	1	1
Number of bus stops missing tapers	2	1

Bus stop walking catchments

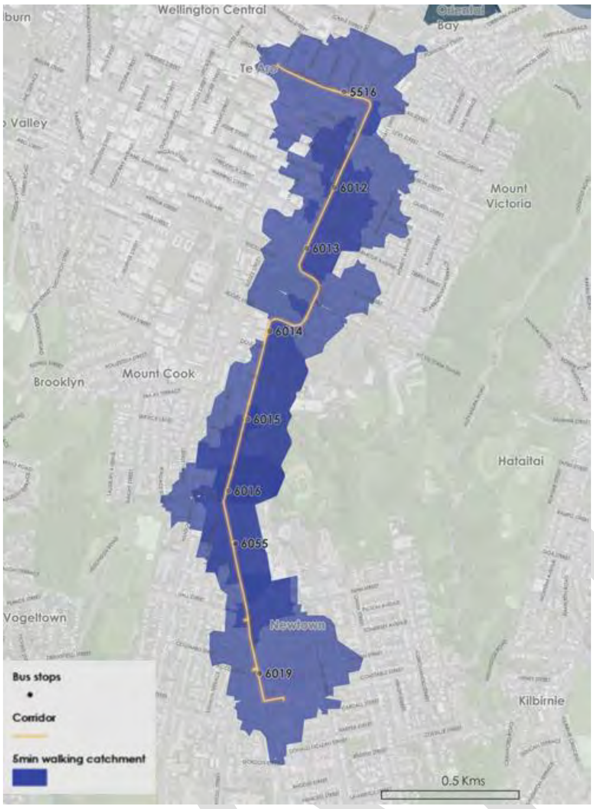
The following maps show the areas that are within a five-minute walk of the bus stops on the corridor. The darker blue areas represent where the catchments of multiple bus stops overlap.

Figure 39: Bus stop catchment – Inbound



[31] Note that the WCC Transport and Infrastructure team is currently working through a list of bus stop improvements, which includes marking out standard bus lengths and entry/exit tapers.

Figure 40: Bus stop catchment – Outbound



2.3. Sources of delay

Percentage delay

The delay that buses experience during the peak hours and slowest hours of travel have been analysed to estimate a breakdown in the sources of delay. Delay is defined as the extra running time of buses, beyond an estimated unimpeded running time. For a full breakdown of how unimpeded running time and delay is estimated, refer to Appendix 2.

To understand the sources of bus delays on the corridor, estimated delays have been decomposed into seven causes:

- long dwell times
- close bus stop spacing
- congestion at bus stops
- congestion at traffic lights
- narrow traffic lanes
- traffic signal delays
- other, which includes delay due to mid-block traffic congestion, un-signalised intersections, hills and corners, roundabouts, and side friction from parking.

Note that in the commentary in the following sections, 'traffic lights' refers to the combination of 'traffic signal delays' and 'congestion at traffic lights'.

Inbound

During the slowest hour in the inbound direction (4pm–5pm), the delay along corridor 1 results in an average bus travel time that is more than three times as long as the estimated unimpeded running time.

Table 39: Theoretical versus actual travel time – Inbound slowest hour (4pm–5pm)

Estimated unimpeded travel time	4.6 minutes
Delay	10.2 minutes
Total travel time	14.9 minutes

During this hour, traffic lights add a combined 4.3 minutes to the running time of buses in the inbound direction. Another 4.3 minutes of delay is attributable to 'other' reasons. Given the traffic volumes at this time, this is most likely to be delay due to mid-block congestion. However, other drivers completing parking manoeuvres or turning into side streets and driveways may also be a contributing factor. A full breakdown of the sources of delay experienced by buses travelling in the inbound direction during the slowest hour (4pm–5pm) is provided in Figure 41 and Table 40.

Figure 41: Sources of delay – Inbound slowest hour (4pm–5pm)

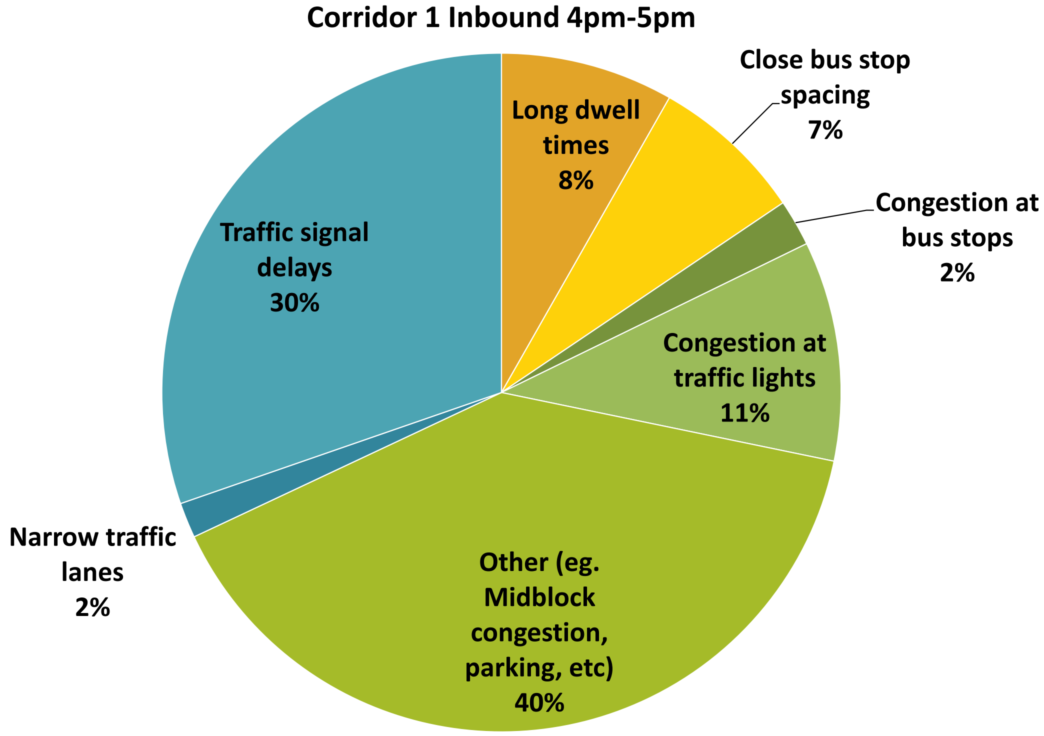


Table 40: Estimated minutes of delay by source – Inbound slowest hour (4pm–5pm)

	Minutes added (delay)	Percentage of delay
Long dwell times	0.9	8%
Close bus stop spacing	0.8	7%
Congestion at bus stops	0.2	2%
Congestion at traffic lights	1.1	11%
Narrow traffic lanes	0.2	2%
Traffic signal delays	3.2	30%
Other	4.3	40%

During the morning peak hour (8am–9am), when the bus lanes are in operation, there is only 3.2 minutes of delay attributable to 'other' sources, more than a minute less than during the slowest hour (4pm–5pm). This decrease in delay is likely due to the Adelaide Road and Cambridge Terrace bus lanes being in operation during the morning peak. A full breakdown of the sources of delay experienced by buses travelling in the inbound direction during the peak hour (8am–9am) is provided in Figure 42 and Table 42.

Table 41: Theoretical versus actual travel time – Inbound morning peak hour (8am–9am)

Estimated unimpeded travel time	4.7 minutes
Delay	9.3 minutes
Total travel time	14 minutes

Figure 42: Sources of delay – Inbound morning peak hour (8am–9am)

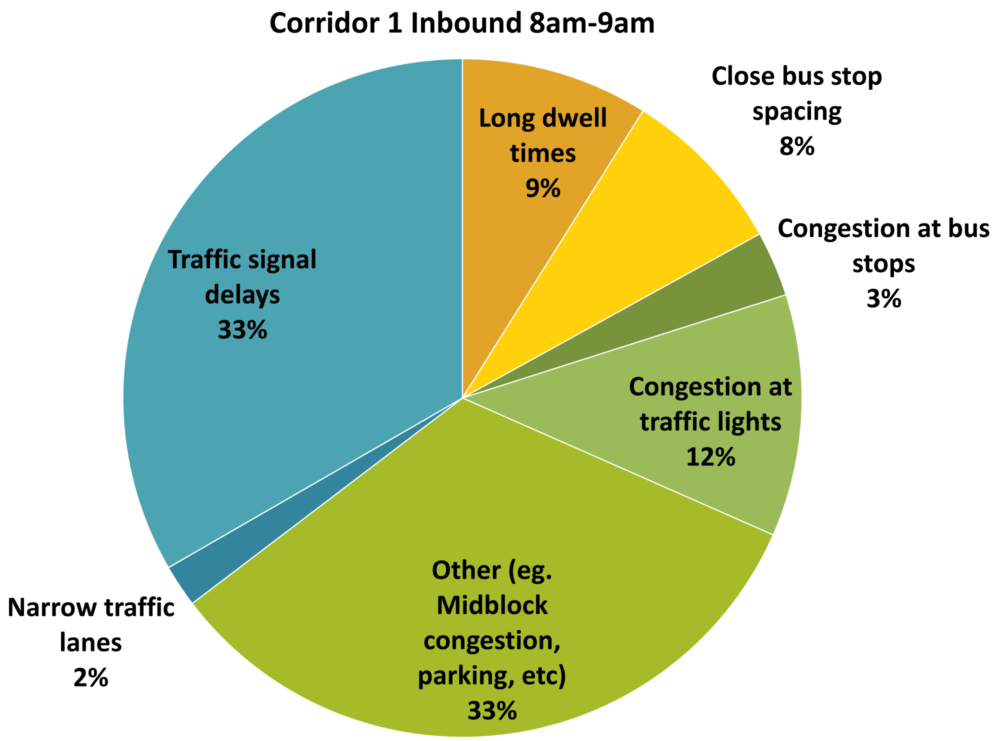


Table 42: Estimated minutes of delay by source – Inbound morning peak hour (8am–9am)

	Minutes added (delay)	Percentage of delay
Long dwell times	0.8	9%
Close bus stop spacing	0.9	8%
Congestion at bus stops	0.3	3%
Congestion at traffic lights	1.1	12%
Narrow traffic lanes	0.2	2%
Traffic signal delays	3.2	33%
Other	3.2	33%

Outbound

During the peak hour in the outbound direction (5pm–6pm), the delay along corridor 1 results in a bus travel time that is more than three times as long as the estimated unimpeded running time.

Table 43: Theoretical versus actual travel time – Outbound afternoon peak hour (5pm–6pm)

Estimated unimpeded travel time	4.8 minutes
Delay	10.3 minutes
Total travel time	15.1 minutes

During this hour, traffic lights add a total of 4.7 minutes of delay to the running time of buses in the outbound direction. Another 3.5 minutes of delay is attributable to 'other' reasons. Given the traffic volumes at this time, this is most likely to be traffic congestion, even though bus lanes are in operation on parts of the corridor at this time. Other drivers completing parking manoeuvres or turning into side streets and driveways may also be a contributing factor. A full breakdown of the sources of delay experienced by buses travelling in the outbound direction during the slowest hour (5pm–6pm) is provided in Figure 43 and Table 44.

Figure 43: Sources of delay – Outbound afternoon peak hour (5pm–6pm)

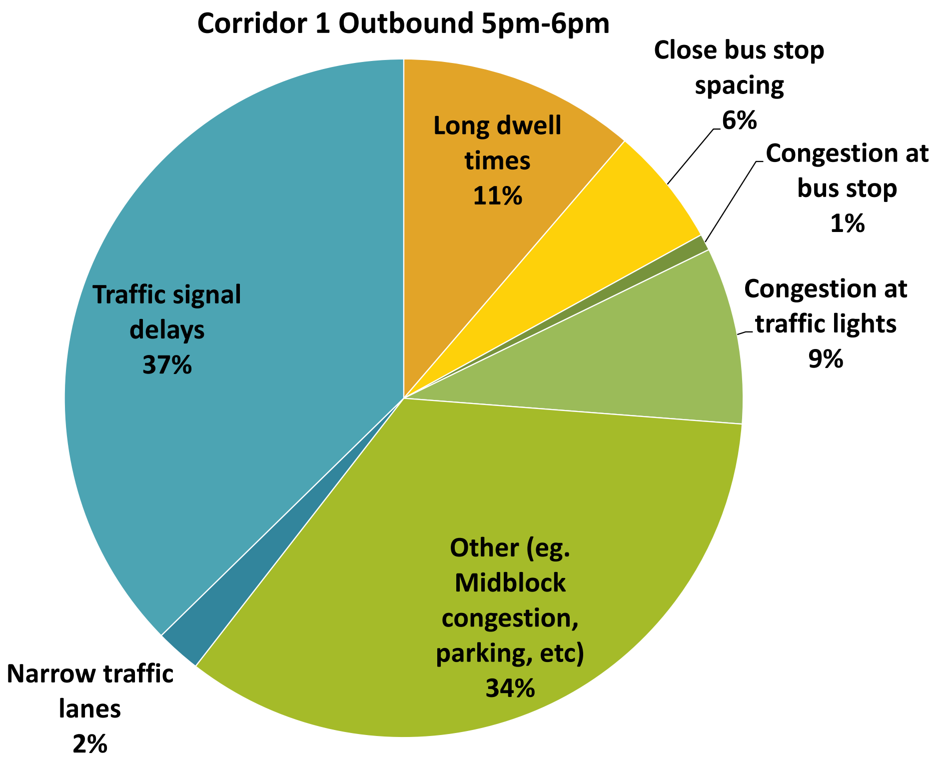


Table 44: Estimated minutes of delay by source – Outbound afternoon peak hour (5pm–6pm)

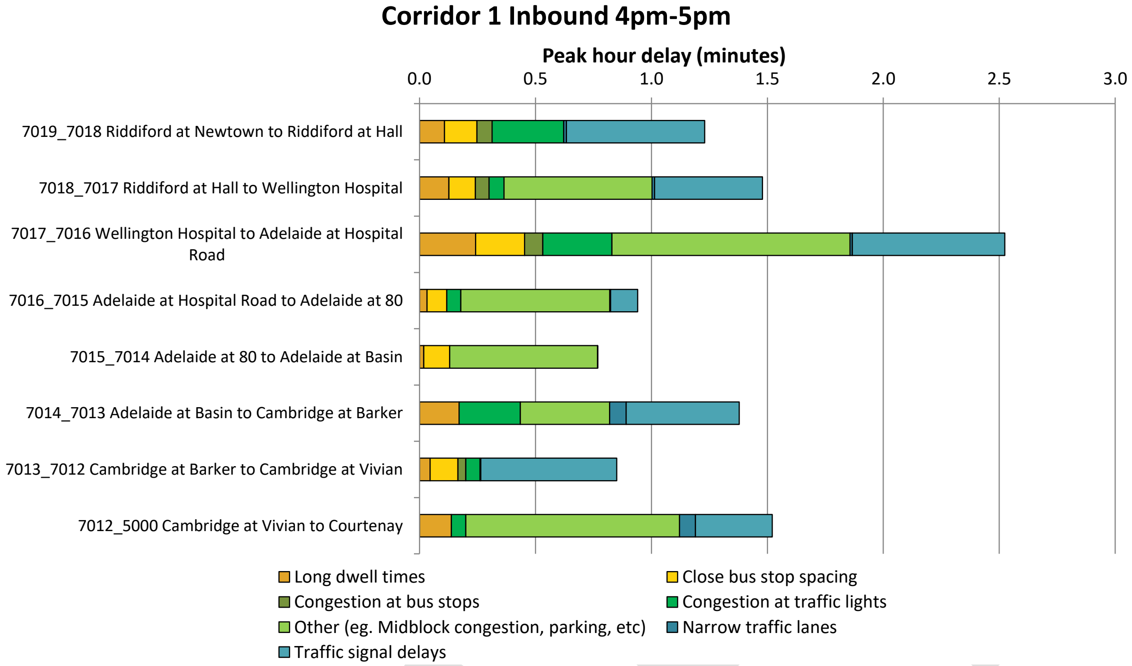
	Minutes added (delay)	Percentage of delay
Long dwell times	1.2	11%
Close bus stop spacing	0.6	6%
Congestion at bus stops	0.1	1%
Congestion at traffic lights	0.9	9%
Narrow traffic lanes	0.2	2%
Traffic signal delays	3.8	37%
Other	3.5	34%

Delay breakdown by segment

Inbound

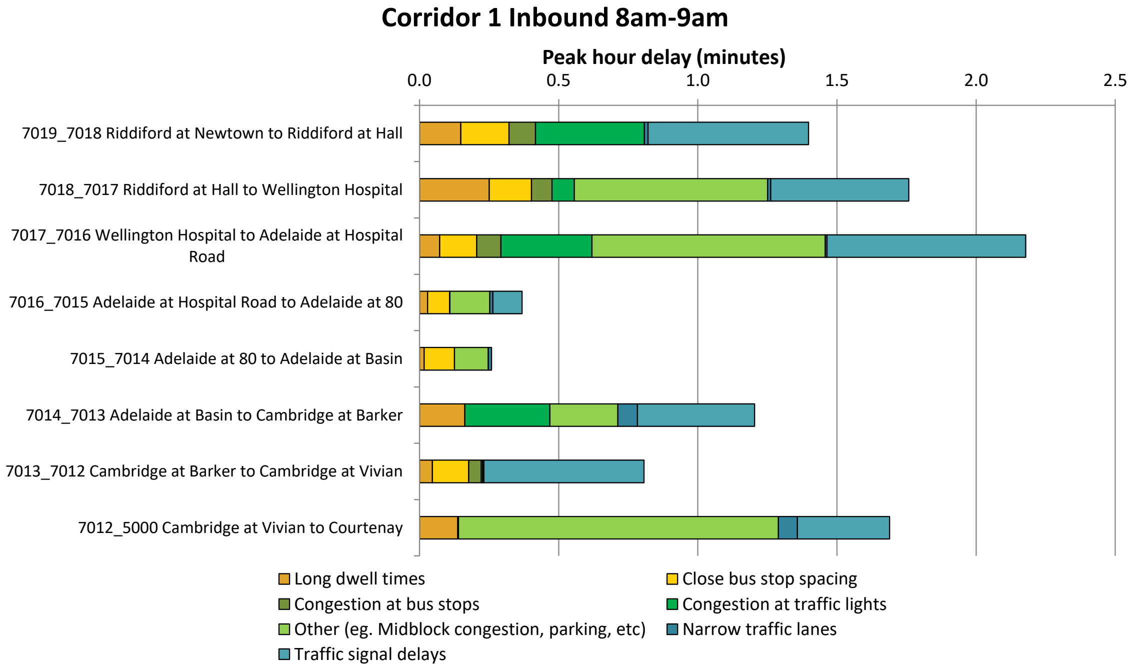
During the slowest hour for buses travelling in the inbound direction on the corridor (4pm–5pm), the segment experiencing the most delay is on Riddiford Street, between the hospital and Adelaide Road, where buses experience more than two-and--a-half minutes of delay (over a 220 metre-long segment). Figure 44 provides a breakdown of the sources of delay on corridor 1 by segment for buses travelling in the inbound direction during this hour.

Figure 44: Sources of delay by segment – Inbound slowest hour (4pm–5pm)



The most significant variation in delay between the morning peak hour (8am–9am) and the slowest hour (4pm–5pm) in the inbound direction occurs on Adelaide Road, between Riddiford Street and the Basin Reserve. This can likely be attributed to the inbound bus lanes on Adelaide Road being in operation during the morning peak hour, resulting in more delay in the afternoon. Figure 45 provides a breakdown of the sources of delay on corridor 1 by segment for buses travelling in the inbound direction during the morning peak hour (8am–9am).

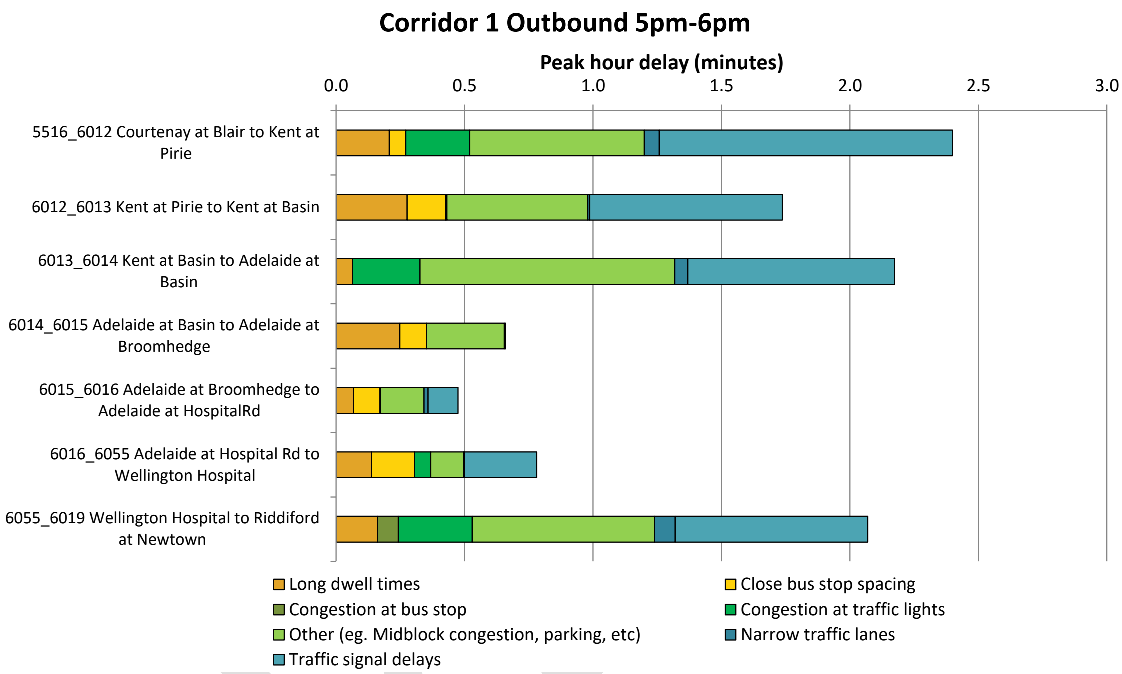
Figure 45: Sources of delay by segment – Inbound morning peak hour (8am–9am)



Outbound

During the peak hour for buses travelling in the outbound direction on the corridor (5pm–6pm), the segments experiencing the most delay are Kent Terrace and Riddiford Street between the hospital and Newtown town centre. Figure 46 provides a breakdown of the sources of delay on corridor 1 by segment for buses travelling in the outbound direction during this hour.

Figure 46: Sources of delay by segment – Outbound afternoon peak hour (5pm–6pm)



2.4. Issues summary

Figure 47 and Figure 48 provide a summary of the key issues across corridor 1 in both the inbound and outbound directions. These issues have been identified as key sources of delay for buses travelling along the corridor.

Figure 47: Key issues – Inbound morning peak hour (8am–9am)

Figure 48: Key issues – Outbound afternoon peak hour (5pm–6pm)

3. Opportunities

For corridor 1, a list of opportunities to improve bus operations has been identified. These opportunities include the implementation of bus priority interventions that would be effective in addressing the documented sources of delay along the corridor and would improve bus travel times.

There are multiple levels of interventions that could be implemented across the corridor that would have varying impacts on bus journey times. For this reason, three packages of opportunities for the corridor have been selected. The package options are defined as follows:

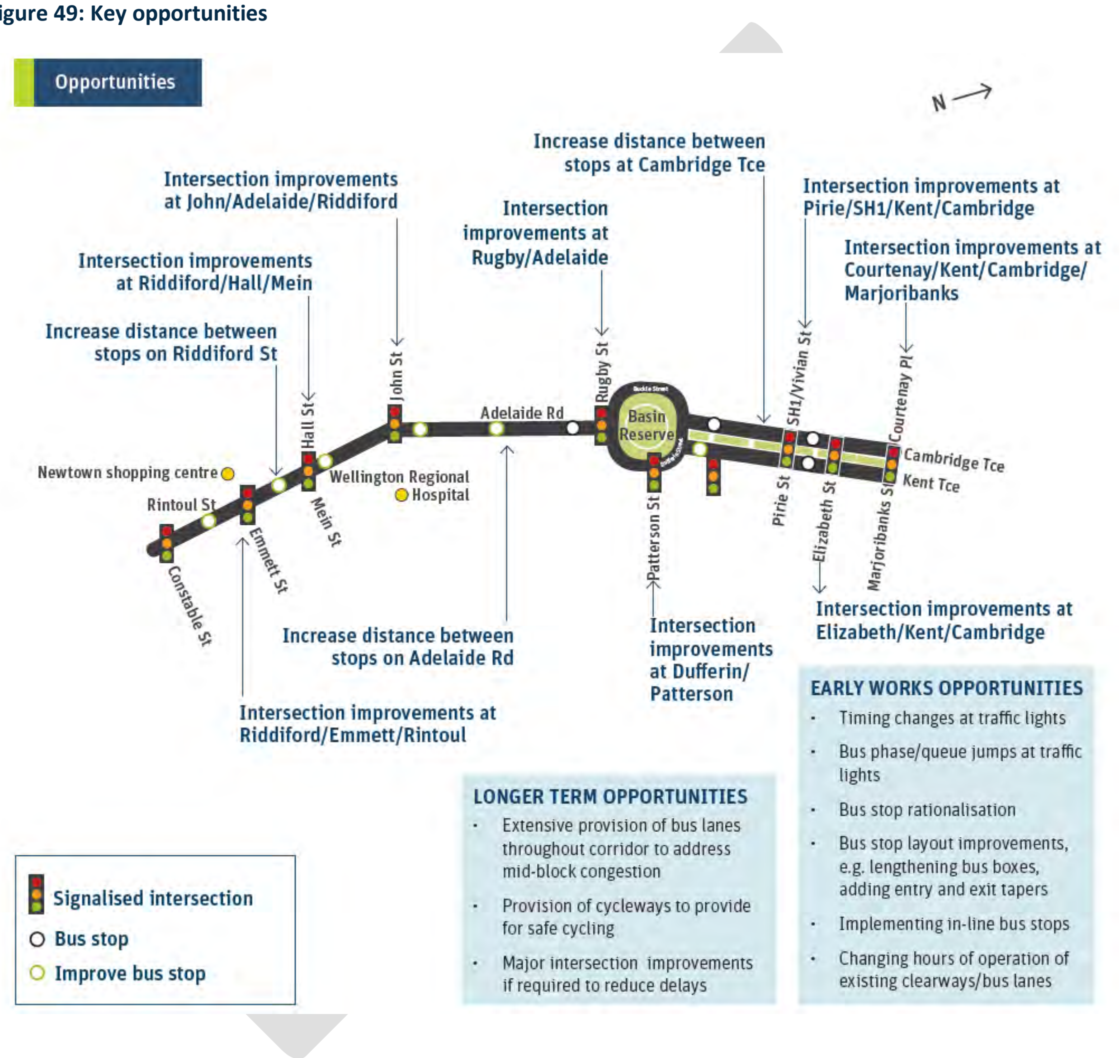
- **Option 1: fix everything**
  This option would address all problems identified on the corridor and implement any of the possible interventions that are effective at addressing the problems that have been identified on the corridor.
- **Option 2: fix the worst problems**
  This option would address only the most severe problems identified on the corridor and only implement interventions that do not involve major reconfiguration of corridor space.

- **Option 3: minimal interventions**
  This option would address only the most severe problems identified on the corridor and implement interventions that involve only minimal reconfiguration of corridor space.

A context map of the location of the key opportunities is provided in Figure 49.

For a full list of the bus priority interventions considered, the package identification process, ad a detailed description of the criteria that was used to identify opportunities on the corridor, refer to Appendix 2.

Figure 49: Key opportunities



Appendix 4 – Karori to city (corridor 2): corridor analysis summary

1. Corridor overview

1.1. Context

The Karori to city corridor (corridor 2) is a 6.3-kilometre-long transport corridor that connects the western suburbs of Wellington, including Karori, Northland, and Thorndon, to the central city. There are five public bus services and 11 school bus services operating on the corridor. On weekdays, there are more than 5500 daily bus passenger trips along the corridor. In the inbound direction, the majority of passengers are on board by Marsden village.

When travelling by bus, the journey from one end of the corridor to the other takes 17 minutes on average. The inbound peak hour occurs in the morning at 8am–9am, when the average journey time is 30 minutes. The outbound peak hour occurs in the afternoon at 5pm–6pm, when the average journey time is 24 minutes.

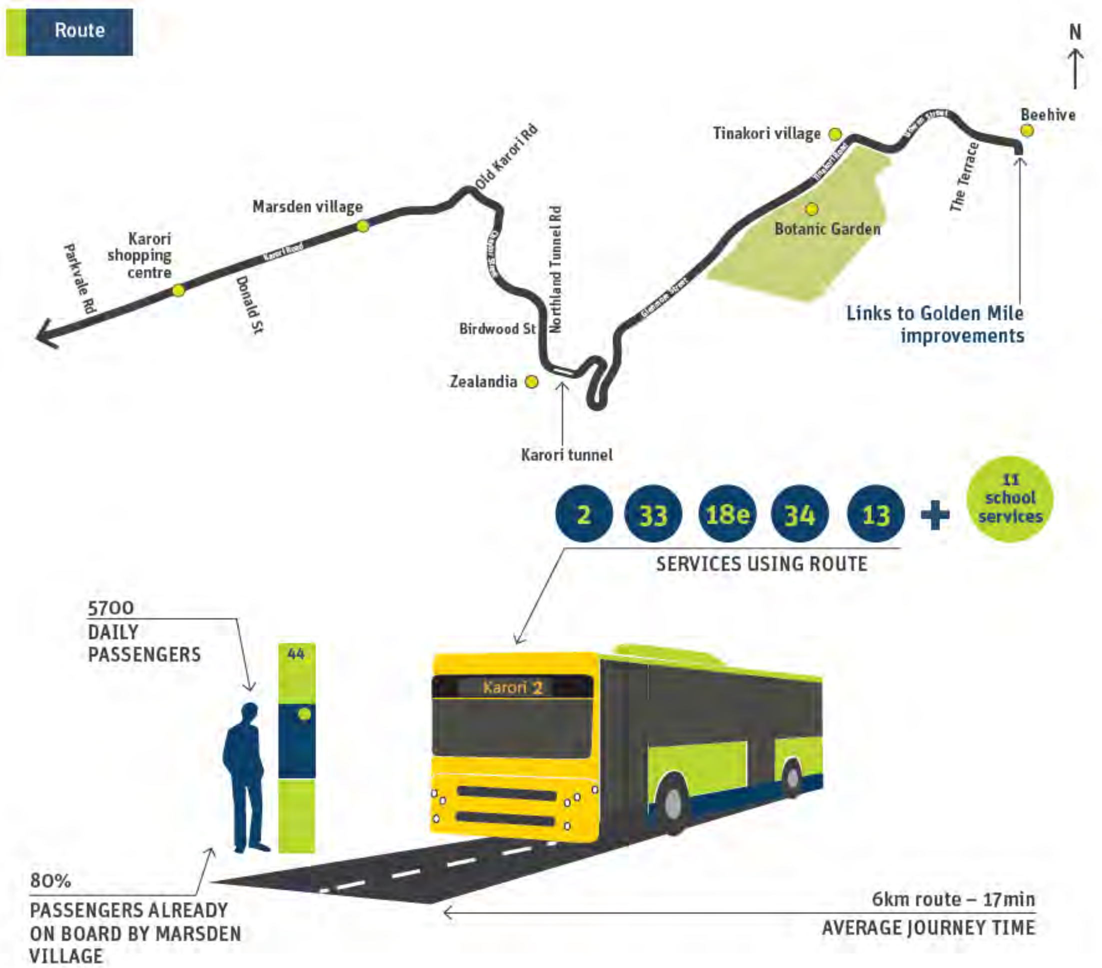
Table 45: Summary of key facts on the corridor

	Inbound	Outbound
Maximum daily passengers[32]	4,100	4,600
Corridor length (km)	6.3	6.2
Number of bus stops	21	20
Average bus stop spacing (m)	302	310
Average speed (km/h)	22.6	21.5
Average travel time (min)	17	17
Minimum travel time (min)	12	14
Maximum travel time (min)	30	24
Slowest weekday hour	8am–9am	5pm–6pm

The Karori Town Centre Public Space Improvement is due to be completed in 2020. This work will take place outside of the road corridor. Currently, there are no provisions for cycling on this corridor. However, cycleway investment is planned for the future.

[32] 'Maximum daily passengers' refers to the maximum number of passengers passing through a point on the corridor. On corridor 2, this occurs through Karori Tunnel, which serves more bus routes than other sections of the corridor.

Figure 50: Corridor context summary



Area

There are several significant destinations located along the Karori to city corridor, including Parliament Buildings, the Botanic Garden, and Zealandia. Multiple neighbourhood centres are also located on this corridor, including Karori town centre, Marsden village, and Tinakori village.

The land use along the corridor is principally classified as outer residential, with some centres, conservation, and open space zones, as well as a number of educational precincts in Karori.

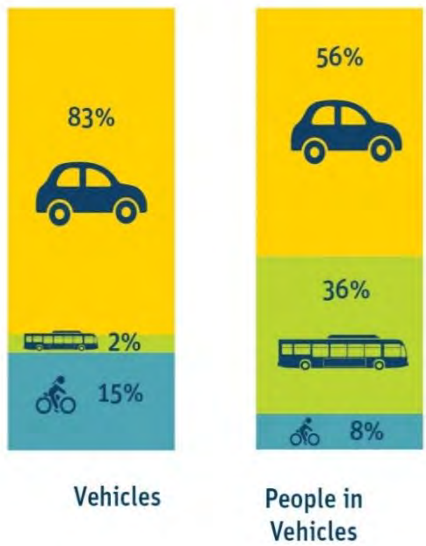
Roads

The Karori to city corridor is made up entirely of principal roads, as shown in Figure 51. There are seven signalised intersections, one signalised pedestrian crossing, and one roundabout along the corridor. The Karori Tunnel is also located on the corridor.

Figure 51: Road hierarchy map[33,34]

During the morning peak hour (8am–9am), the majority of vehicles on the corridor are private vehicles (83 percent), followed by bikes (15 percent). Buses make up only 2 percent of the vehicles on the corridor. However, they transport more than one-third of the people on the corridor (36 percent). This is indicative of the 'heavy lifting' that buses are doing to move people on this corridor. Figure 52 presents a full breakdown of the modal split on the corridor.

Figure 52: Modal split – Inbound morning peak period (8am–9am)



1.2. Bus operations

There are five public bus services and 11 school services operating on this corridor. There are 21 bus stops in the inbound direction and 20 in the outbound direction. Most bus stops are located in fare zones 2 or 3. *Karori Tunnel – Stop* A and *Karori Tunnel – Stop B* are part of the Karori Tunnel bus hub.

[33] Road hierarchy data sourced from WCC District Plan Map 33: Hierarchy of Roads
[34] In the WCC District Plan, the road classifications are defined as follows:
- Principal Road: roads that provide access to motorways and to arterial roads having a dominant through-traffic function and carrying the major public transport routes

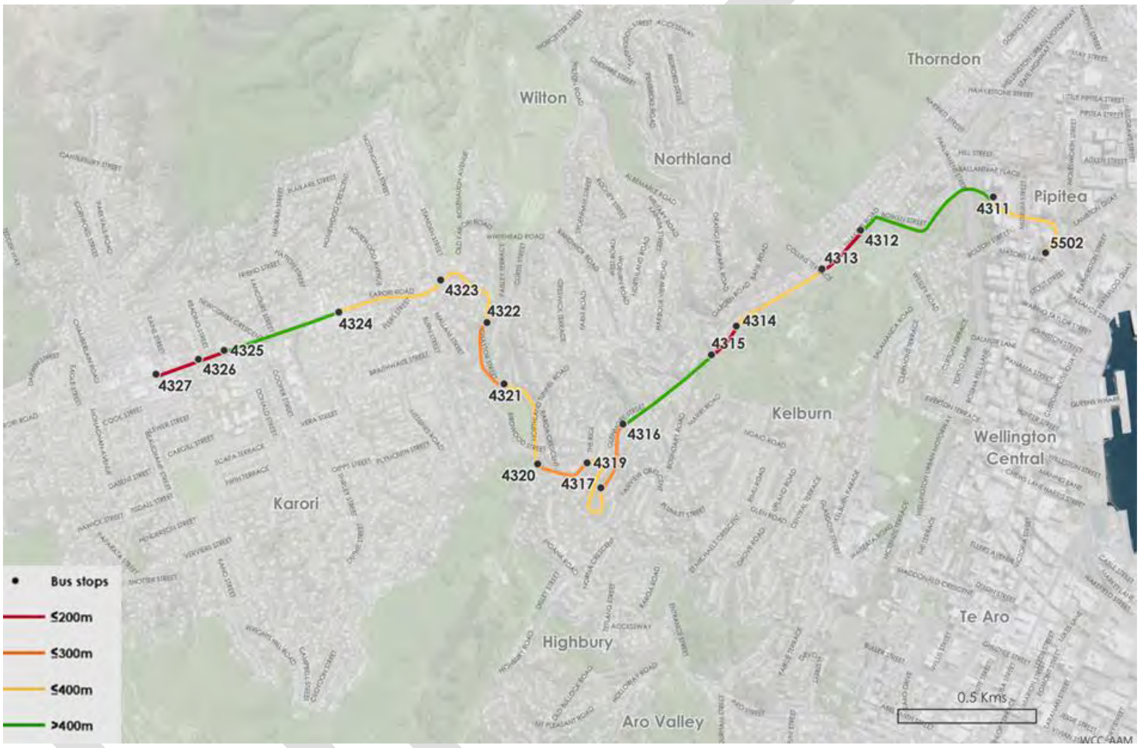
There are existing bus priority measures in place on the corridor. On Chaytor Street, bus lanes operate Monday to Friday, 7am–9am in the inbound direction. On Glenmore Street, bus lanes operate Monday to Friday, 4pm–6pm in the outbound direction.

Bus stop spacing

Inbound

The average bus stop spacing along the corridor in the inbound direction is 302 metres. The closest spacing is 98 metres, between two stops on Karori Road between Karori town centre and Marsden village.

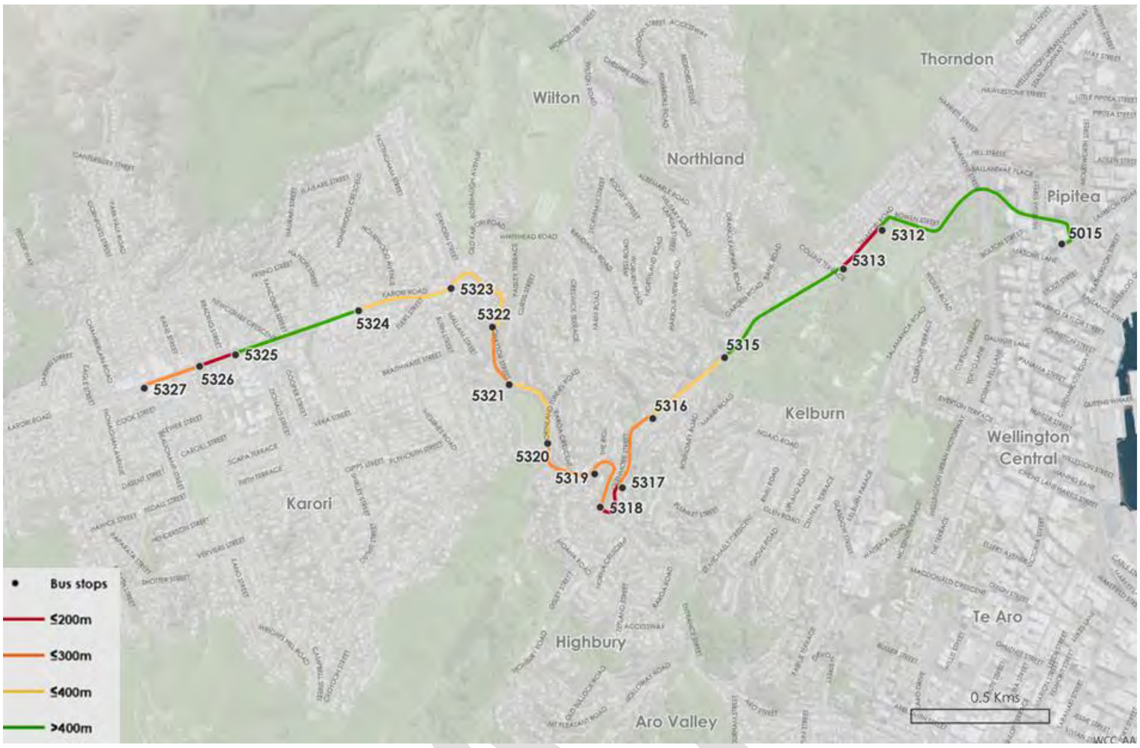
Figure 53: Bus stop locations and spacing – Inbound



Outbound

The average bus stop spacing along the corridor in the outbound direction is 310 metres. The closest spacing is 137 metres, between two stops on Karori Road between Marsden village and Karori town centre.

Figure 54: Bus stop locations and spacing – Outbound

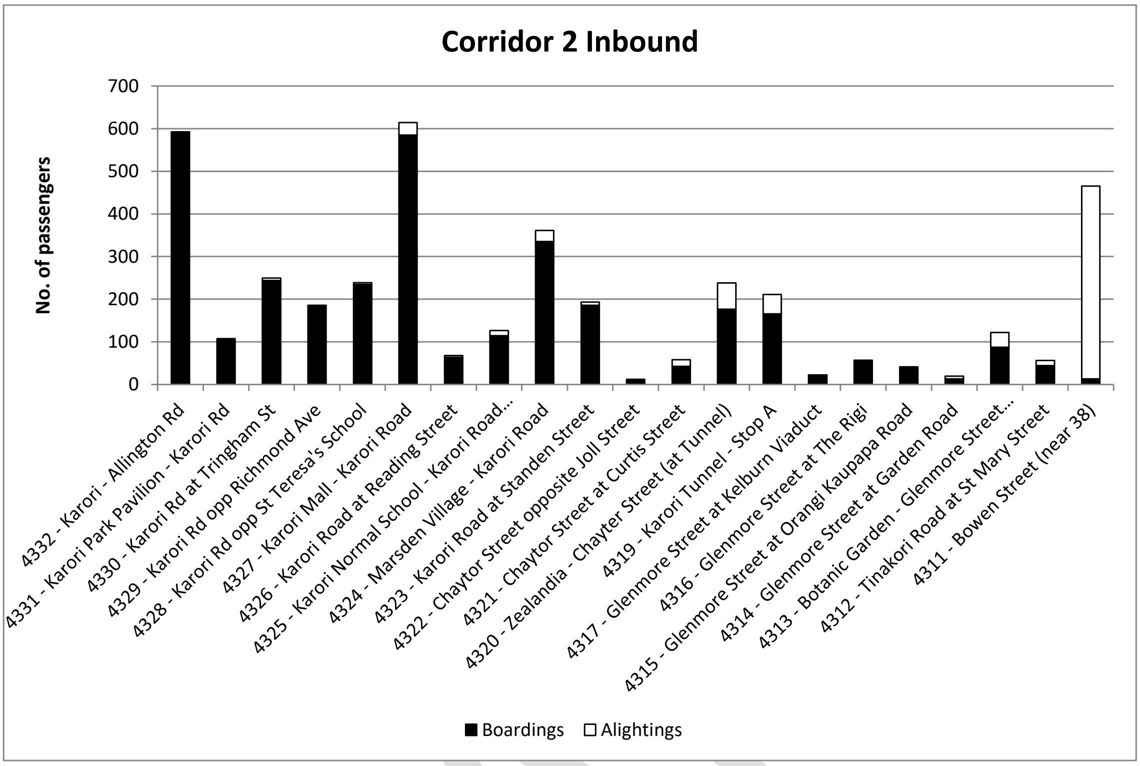


Boardings and alightings

Inbound

The busiest bus stop along the corridor in the inbound direction is *Karori Mall – Karori Road*, with just over 600 daily boardings and alightings. This is followed closely by *Karori Road – Allington*, with just under 600 daily boardings. There are eight bus stops with less than 100 daily boardings and alightings, and four stops with less than 50. Figure 55 shows the daily number of people boarding and alighting at each bus stop along the corridor in the inbound direction. This includes all bus routes that service each bus stop.

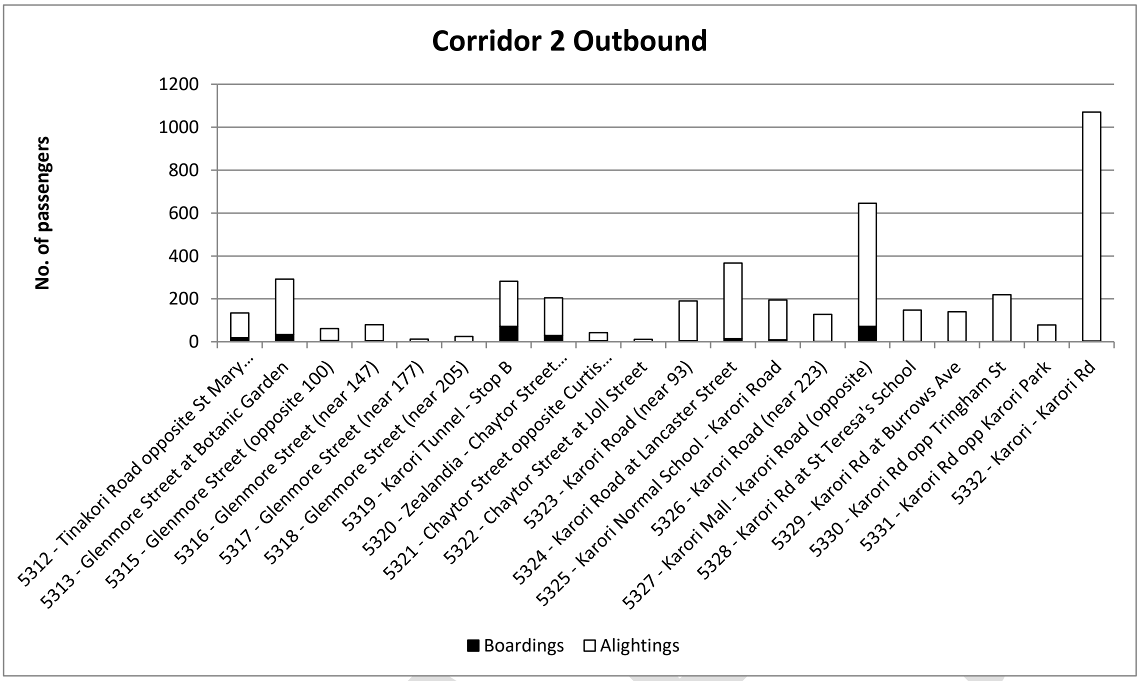
Figure 55: Daily boardings and alightings – Inbound



Outbound

The busiest stop along the corridor in the outbound direction is the last stop, *Karori – Karori Road*, with more than 1000 daily alightings. There are seven bus stops with less than 100 boardings and alightings throughout the day, and four with less than 50. Across all of the outbound bus stops, there are very few boardings. Figure 56 shows the daily number of people boarding and alighting at each bus stop along the corridor in the outbound direction. This includes all bus routes that service each bus stop.

Figure 56: Daily boardings and alightings – Outbound

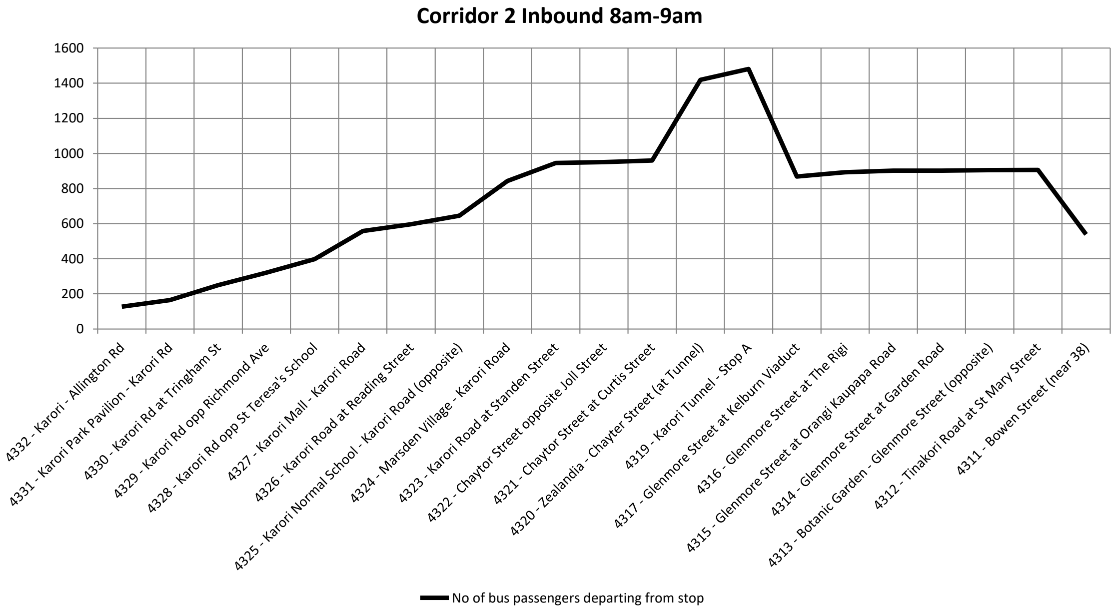


Cumulative passenger numbers

Inbound

During the inbound peak hour on the corridor (8am–9am), the highest bus passenger numbers occur at Karori Tunnel, which serves more bus routes than other parts of the corridor. Excluding this section where additional bus routes join the corridor, the majority of passengers are already on the bus by the time the service leaves Karori during the morning peak. Figure 57 shows the average number of bus passengers on the bus departing from each bus stop during this hour.

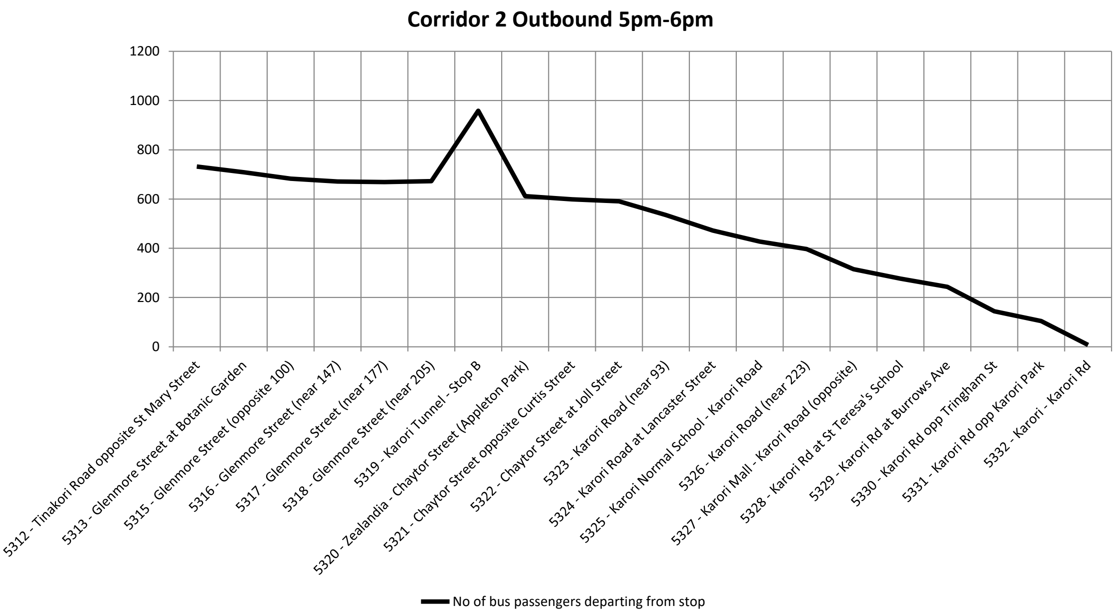
Figure 57: Cumulative bus passenger load – Inbound morning peak hour (8am–9am)



Outbound

During the outbound peak hour on the corridor (5pm–6pm), the highest bus passenger numbers occur at Karori Tunnel, similar to the inbound direction during the morning peak hour. Passenger numbers decrease steadily along the corridor as it travels outbound. Figure 58 shows the average number of bus passengers on the bus departing from each bus stop during this hour.

Figure 58: Cumulative bus passenger load – Outbound afternooon peak hour (5pm–6pm)



2. Issues

2.1. Travel time

The average travel times along corridor 2 in the inbound direction are similar to travel times in the outbound direction. Travel times in the outbound direction have less variability, with a 10-minute difference between the fastest and slowest travel times compared to a 17-minute difference between the inbound travel times.

Table 46: Summary of travel times on the corridor

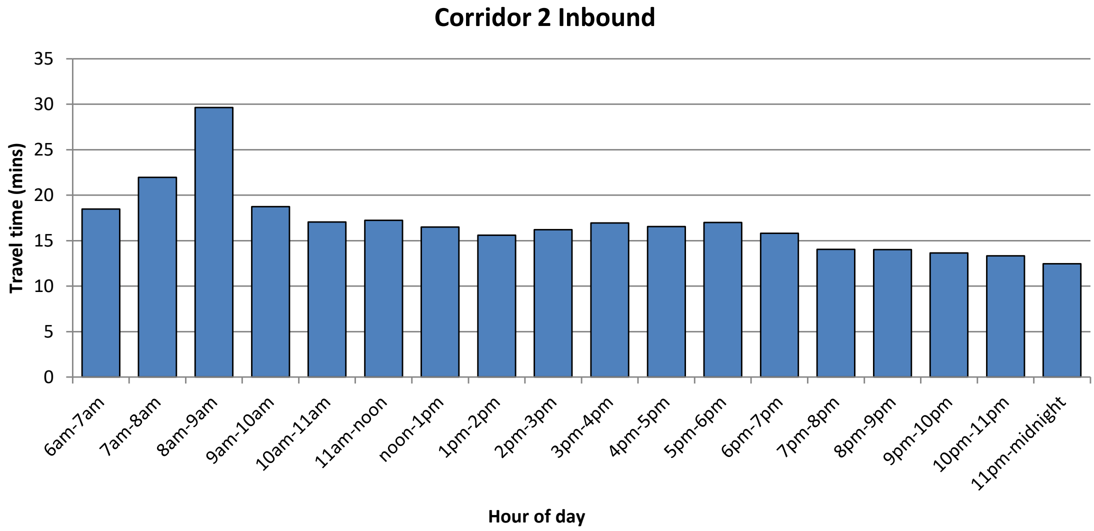
	Inbound	Outbound
Corridor length (km)	6.3	6.2
Average travel time (min)	17	17.3
Slowest hour	8am–9am	5pm–6pm
Travel time at slowest hour (min)	29.6	23.8
Fastest hour	11pm–midnight	7am–8am
Travel time at fastest hour (min)	12.5	14

Travel time by hour

Inbound

On corridor 2 in the inbound direction, the slowest hour for buses is 8am–9am, when it takes an average of 29.6 minutes to travel between the west end of Karori Road and Lambton Quay. This is almost eight minutes longer than the next slowest hour, at 7am–8am, and is despite bus lanes being in operation along parts of the corridor at this time. This travel time is more than twice as long as travel times during the fastest hour of the day (11pm–midnight). Figure 59 below shows the average time it takes for a bus to travel the length of the corridor in the inbound direction for every hour between 6am and midnight.

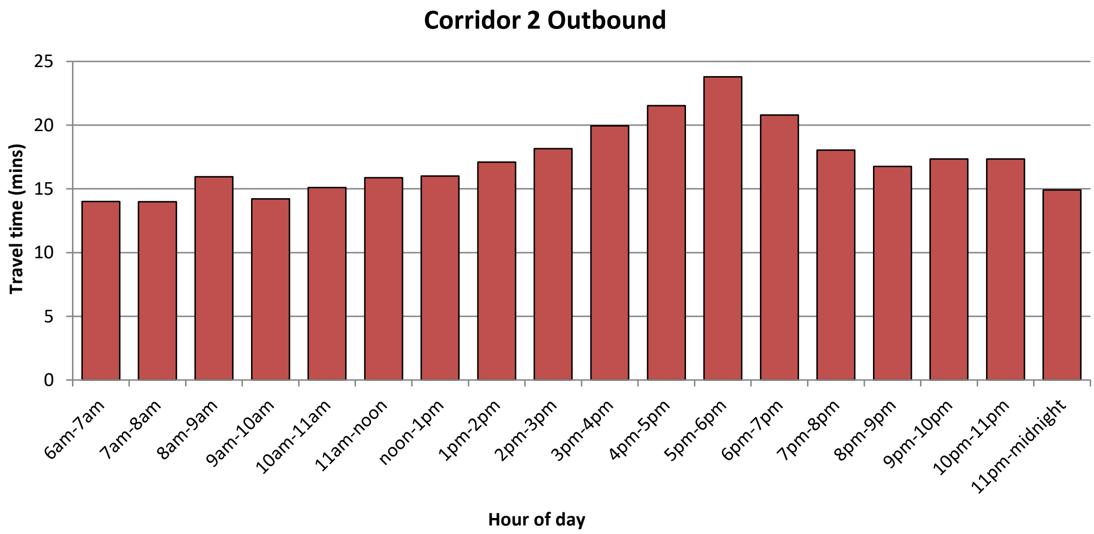
Figure 59: Travel times by hour of the day – Inbound



Outbound

On corridor 2 in the outbound direction, the slowest hour for buses is 5pm–6pm, when it takes an average of 23.8 minutes to travel between Lambton Quay and the west end of Karori Road. This is despite bus lanes being in operation along parts of the corridor at this time. The afternoon peak period for travel times of outbound buses is more spread out than the morning peak period for inbound buses. Figure 34 shows the average time it takes for a bus to travel the length of the corridor in the outbound direction for every hour between 6am and midnight.

Figure 60: Travel times by hour of the day – Outbound

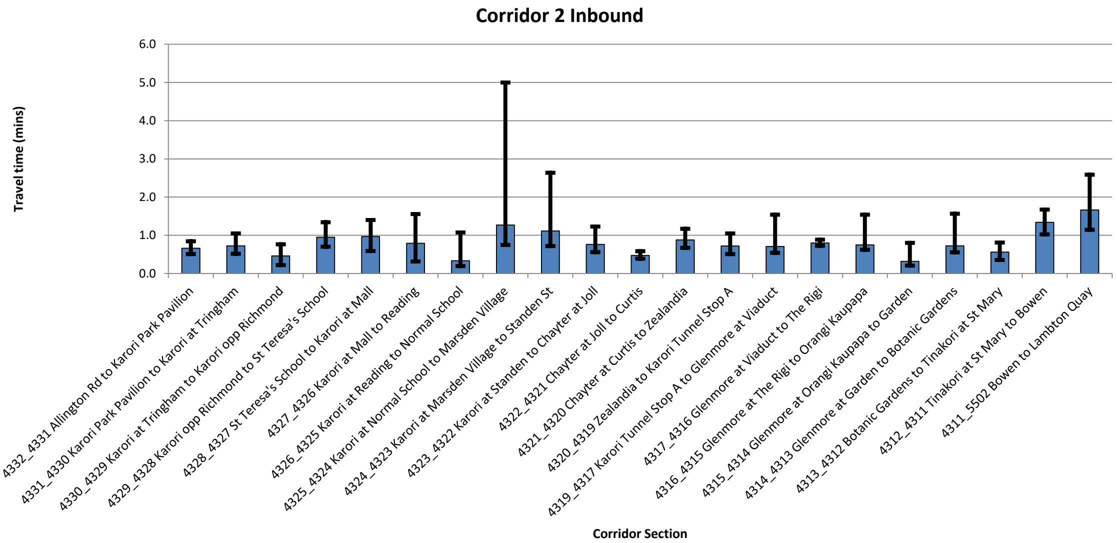


Travel time variability

Inbound

Figure 61 shows the average time it takes for a bus to travel along each segment of the corridor in the inbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

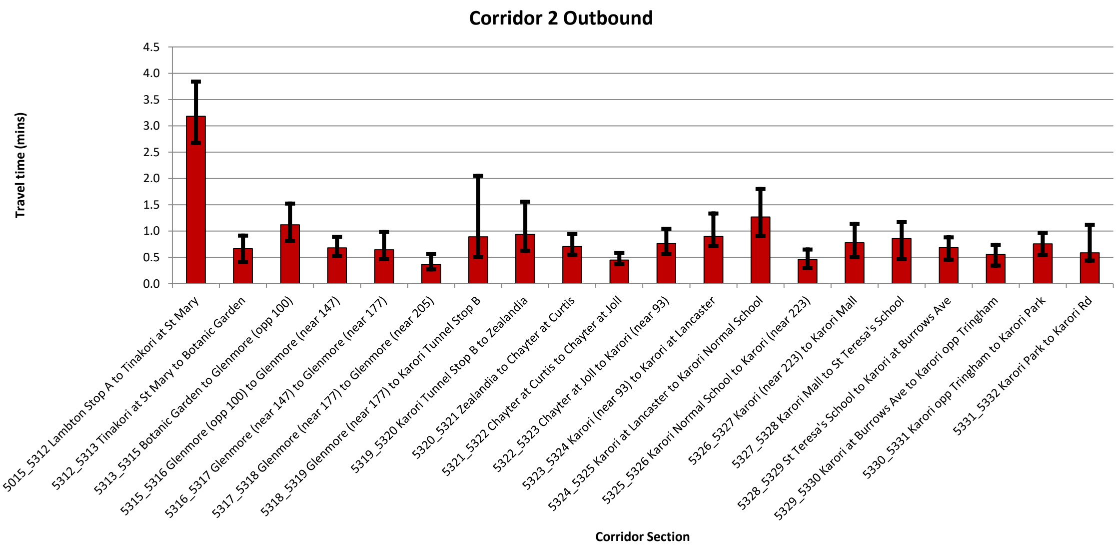
Figure 61: Variation in travel times – Inbound



Outbound

Figure 62 shows the average time it takes for a bus to travel along each segment of the corridor in the outbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

Figure 62: Variation in travel times – Outbound



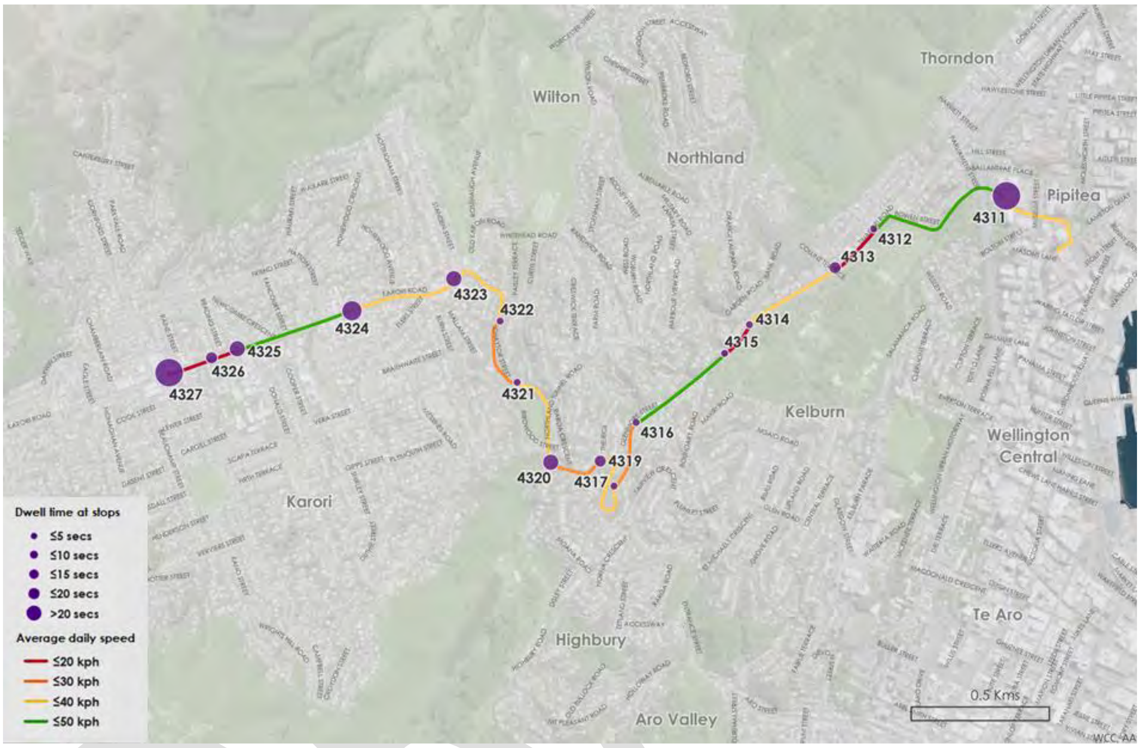
Bus operating speeds and dwell time delay

The maps below show the average speeds at which buses operate along the corridor and the average time buses dwell at bus stops during the peak hours.

Inbound

During the morning peak hour in the inbound direction (8am–9am), bus operating speeds on the corridor are slowest through Karori town centre and on sections of Glenmore Street.

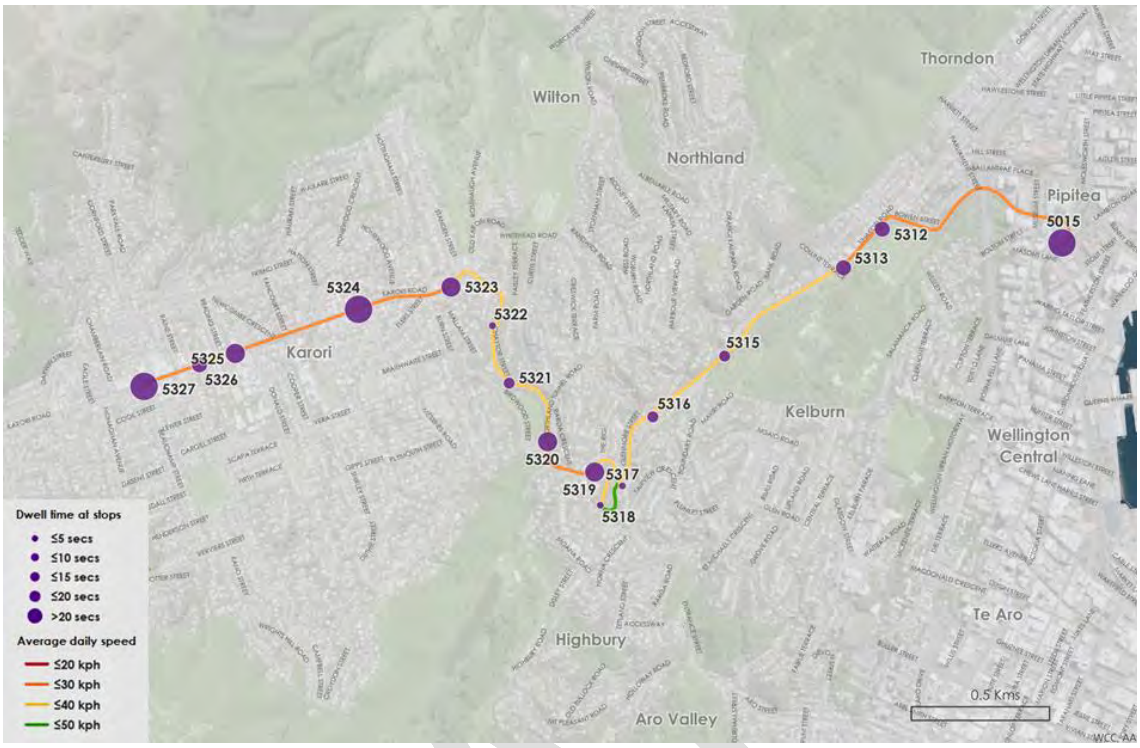
Figure 63: Operating speeds and dwell times – Inbound morning peak hour (8am–9am)



Outbound

During the slowest hour in the outbound direction (5pm–6pm), bus operating speeds on the corridor are slowest along Bowen Street and Tinakori Road and on Karori Road.

Figure 64: Operating speeds and dwell times – Outbound afternoon peak hour (5pm–6pm)



2.2. Bus stop audit

There are 21 inbound bus stops between the west end of Karori Road and Lambton Quay. There are 20 outbound bus stops between Lambton Quay and the west end of Karori Road.

Of these bus stops, 38 are off-line stops, nine are not of sufficient length to accommodate a bus, and 29 do not have sufficient entry and / or exit tapers for buses to easily manoeuvre into and out of the stop. Such issues can lead to increased dwell times as passengers have to make awkward movements to get on and off the bus. This is particularly so for mobility-impaired pedestrians, as well as for the young, elderly, and people with prams or carrying other heavy or bulky items.

Table 47: Bus stop details[35]

	Number of bus stops	
	Inbound	Outbound
Total number of bus stops	21	20
Number of off-line bus stops	19	19
Number of bus boxes with insufficient length (<15m)	5	4
Number of bus stops missing tapers	13	16

Bus stop walking catchments

The following maps show the areas that are within a five-minute walk of the bus stops on the corridor. The darker blue areas represent where the catchments of multiple bus stops overlap.

[35] Note that the WCC Transport and Infrastructure team is currently working through a list of bus stop improvements, which includes marking out standard bus lengths and entry/exit tapers.

Figure 65: Bus stop catchment – Inbound

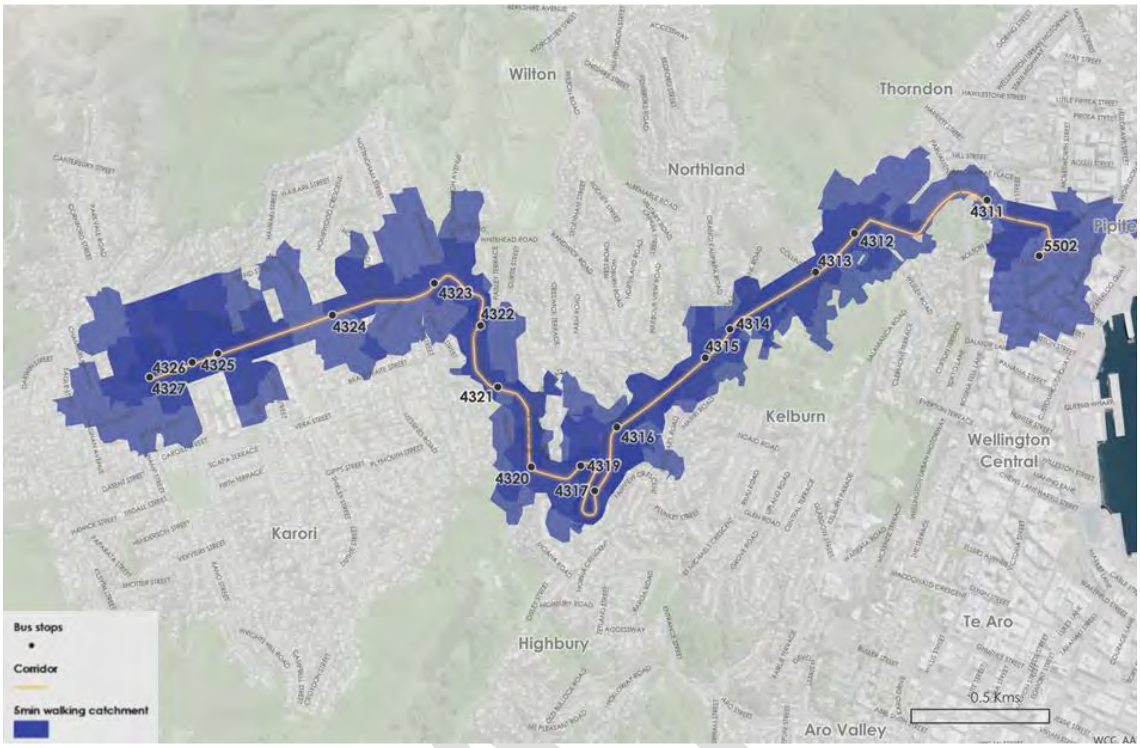
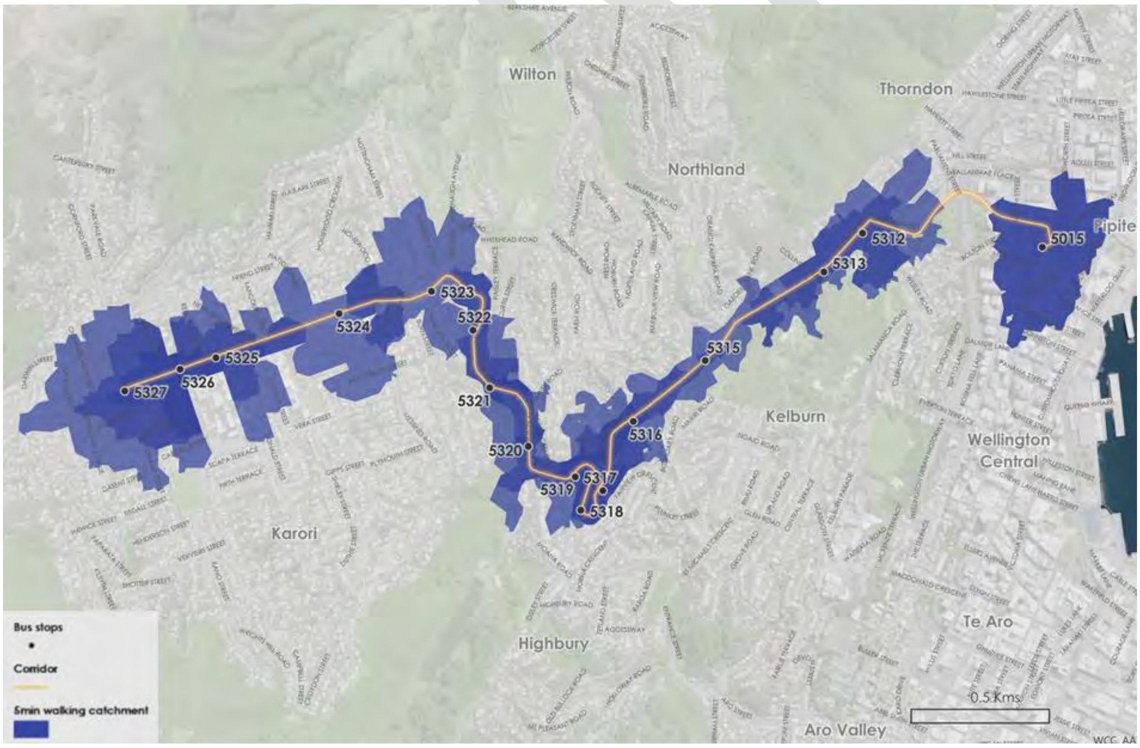


Figure 66: Bus stop catchment – Outbound



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2.3. Sources of delay

Percentage delay

The delay that buses experience during the peak hours and slowest hours of travel have been analysed to estimate a breakdown in the sources of delay. Delay is defined as the extra running time of buses, beyond an estimated unimpeded running time. For a full breakdown of how unimpeded running time and delay is estimated, refer to Appendix 2.

To understand the sources of bus delays on the corridor, estimated delays have been decomposed into seven causes:

- long dwell times
- close bus stop spacing
- congestion at bus stops
- congestion at traffic lights
- narrow traffic lanes
- traffic signal delays
- other, which includes delay due to mid-block traffic congestion, un-signalised intersections, hills and corners, roundabouts, and side friction from parking.

Note that in the commentary in the following sections, 'traffic lights' refers to the combination of 'traffic signal delays' and 'congestion at traffic lights'.

Inbound

During the slowest hour in the inbound direction (8am–9am), the delay along corridor 2 results in an average bus travel time that is approximately two-and-a-half times as long as the estimated unimpeded running time.

Table 48: Theoretical versus actual travel time – Inbound morning peak hour (8am–9am)

Estimated unimpeded travel time	12.1 minutes
Delay	17.6 minutes
Total travel time	29.6 minutes

During the hour, almost two-thirds of the delay – 11 minutes – is attributable to 'other' reasons. Given the traffic volumes at this time, this is most likely due to mid-block congestion. However, other drivers completing parking manoeuvres or turning into side streets and driveways may also be a contributing factor. The other sources of delay fairly evenly make up the rest of the delay during this hour. A full breakdown of the sources of delay experienced by buses travelling in the inbound direction during the slowest hour (8am–9am) is provided in Figure 67 and Table 49.

Figure 67: Sources of delay – Inbound morning peak hour (8am–9am)

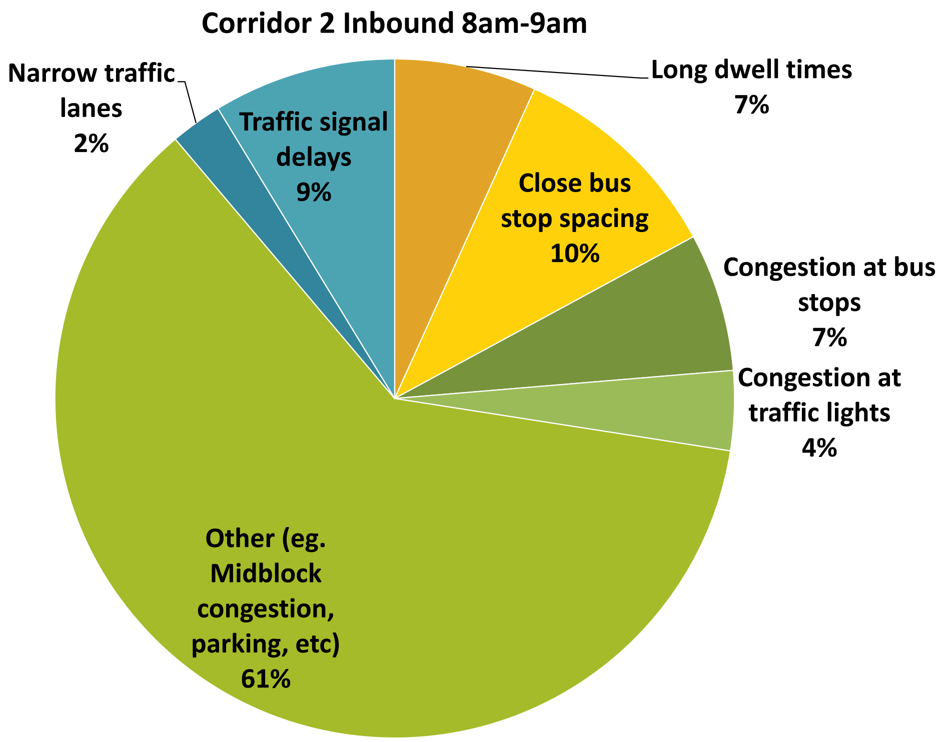


Table 49: Estimated minutes of delay by source – Inbound morning peak hour (8am–9am)

	Minutes added (delay)	Percentage of delay
Long dwell times	1.2	7%
Close bus stop spacing	1.9	10%
Congestion at bus stops	1.2	7%
Congestion at traffic lights	0.7	4%
Narrow traffic lanes	0.4	2%
Traffic signal delays	1.6	9%
Other	11.0	61%

Outbound

During the slowest hour in the outbound direction (5pm–6pm), the delay along corridor 2 results in a bus travel time that is more than twice as long as the estimated unimpeded running time.

Table 50: Theoretical versus actual travel time – Outbound afternoon peak hour (5pm–6pm)

Estimated unimpeded travel time	11.7 minutes
Delay	12.1 minutes
Total travel time	23.8 minutes

During this hour, the sources of delay affecting the bus running times are much more varied than during the morning inbound peak hour. The largest source of delay is the ‘other’ category, contributing to 3.3 minutes of delay. Given the traffic volumes at this time, this is most likely to be traffic congestion, even though bus lanes are in operation on parts of the corridor at this time. Other drivers completing parking manoeuvres or turning into side streets and driveways may also be a contributing factor.

Traffic lights add a total of 3.5 minutes of delay, and close bus stop spacing and long dwell times each add another two minutes of delay. A full breakdown of the sources of delay experienced by buses travelling in the outbound direction during the slowest hour (5pm–6pm) is provided in Figure 68 and Table 51.

Figure 68: Sources of delay – Outbound afternoon peak hour (5pm–6pm)

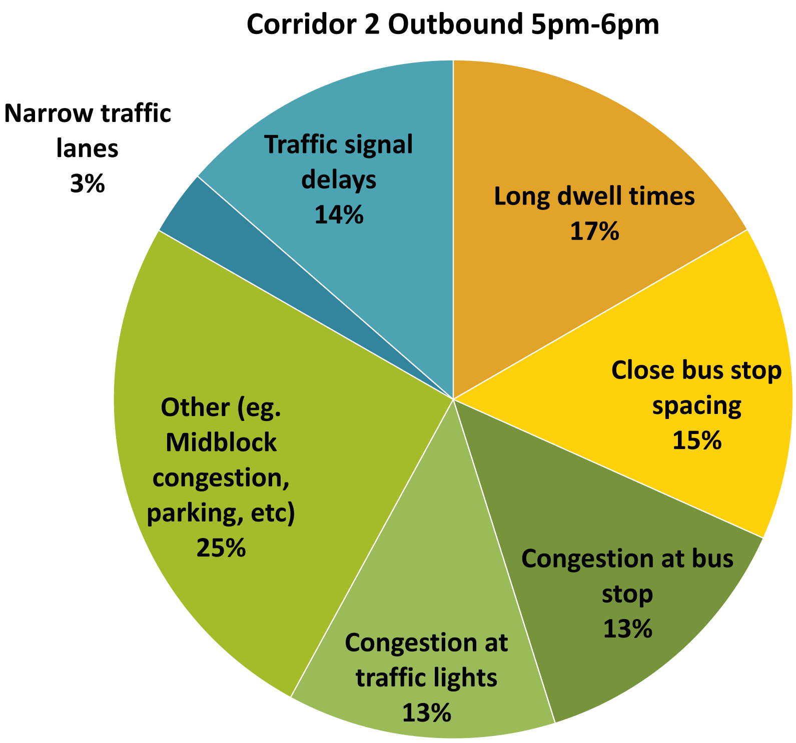


Table 51: Estimated minutes of delay by source – Outbound afternoon peak hour (5pm–6pm)

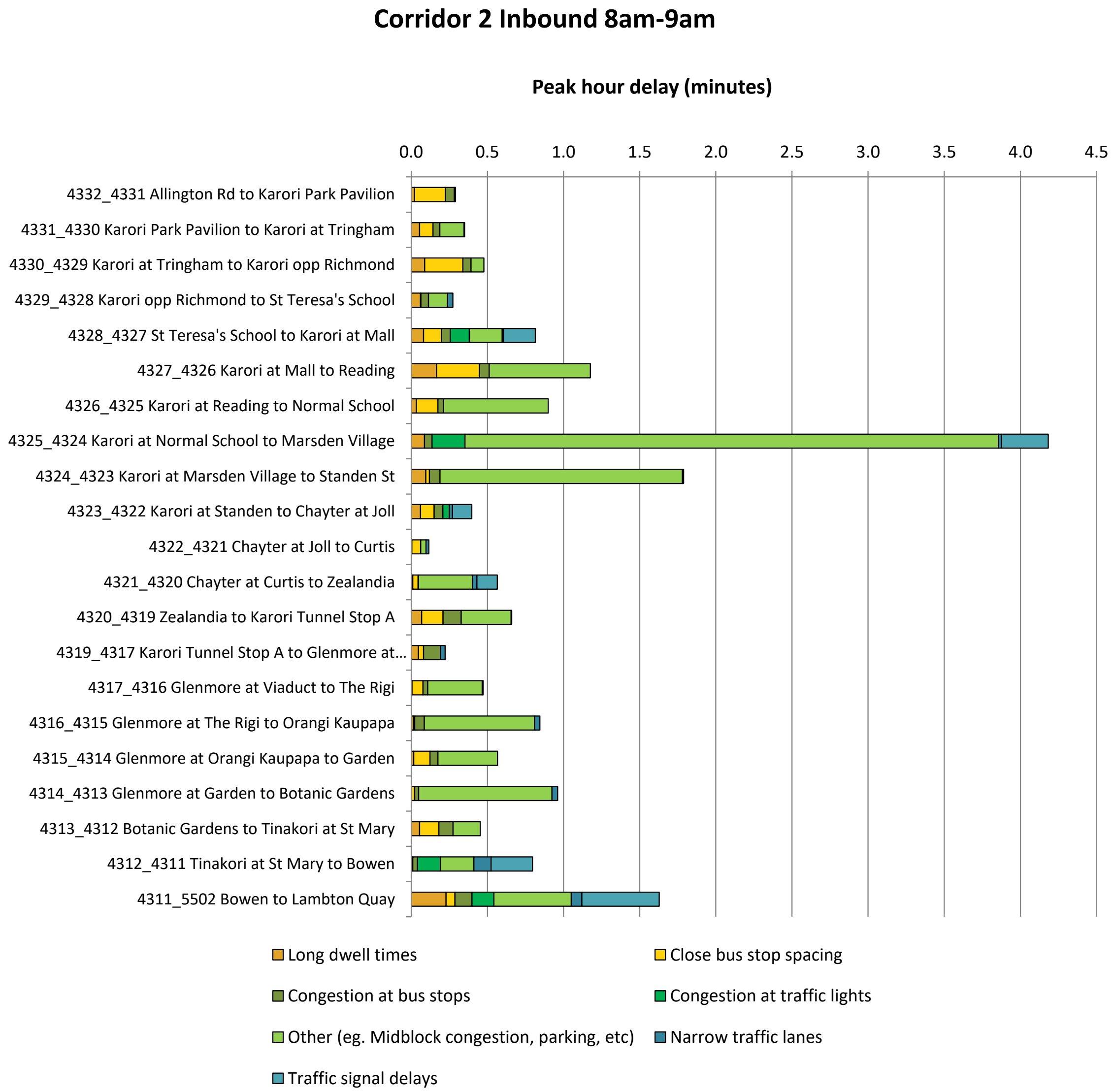
	Minutes added (delay)	Percentage of delay
Long dwell times	2.2	17%
Close bus stop spacing	2.0	15%
Congestion at bus stops	1.7	13%
Congestion at traffic lights	1.7	13%
Narrow traffic lanes	0.4	3%
Traffic signal delays	1.8	14%
Other	3.3	25%

Delay breakdown by segment

Inbound

During the peak hour for buses travelling in the inbound direction on the corridor (8am–9am), the segment experiencing the most delay is on Karori Road, between Karori Normal School and Standen Street, travelling through Marsden village. Here, buses experience almost six minutes of delay (over a 832 metre-long segment). There are also two other segments on the corridor where buses experience more than one minute of delay – on Karori Road between Karori Mall and Reading Street and on Bowen Street approaching Lambton Quay. Figure 69 provides a breakdown of the sources of delay on corridor 2 by segment for buses travelling in the inbound direction during this hour.

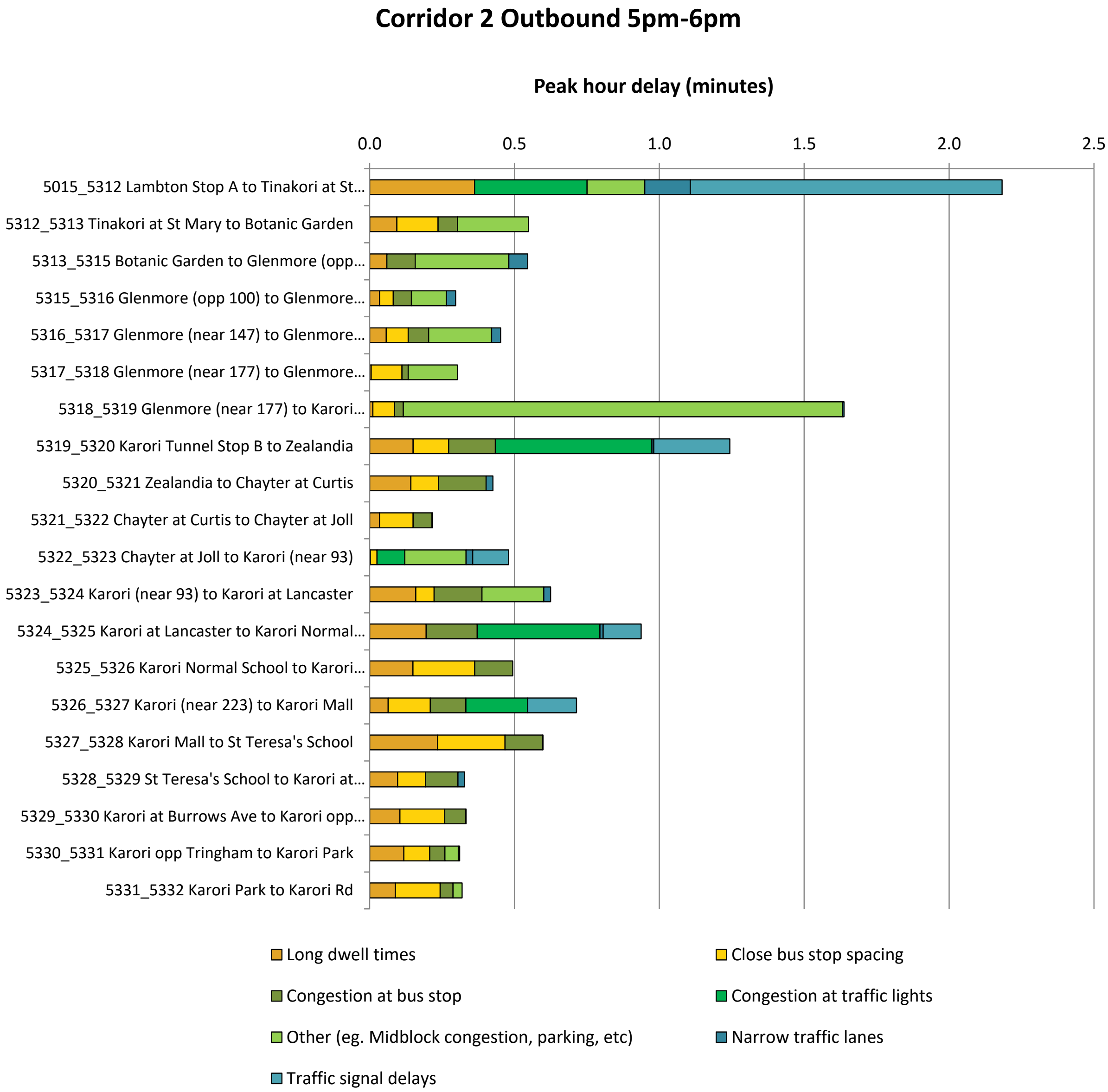
Figure 69: Sources of delay by segment – Inbound morning peak hour (8am–9am)



Outbound

During the peak hour for buses travelling in the outbound direction on the corridor (5pm–6pm), the segment experiencing the most delay is Bowen Street, where buses experience more than two minutes of delay across approximately 900 metres. The two uppermost sections of Glenmore Street also experience more than one minute of delay each. Figure 70 provides a breakdown of the sources of delay on corridor 2 by segment for buses travelling in the outbound direction during this hour.

Figure 70: Sources of delay by segment – Outbound afternoon peak hour (5pm–6pm)



2.4. Issues summary

Figure 71 and Figure 72 provide a summary of the key issues across corridor 2, in both the inbound and outbound directions. These issues have been identified as key sources of delay for buses travelling along the corridor.

Figure 71: Key issues – Inbound morning peak hour (8am–9am)

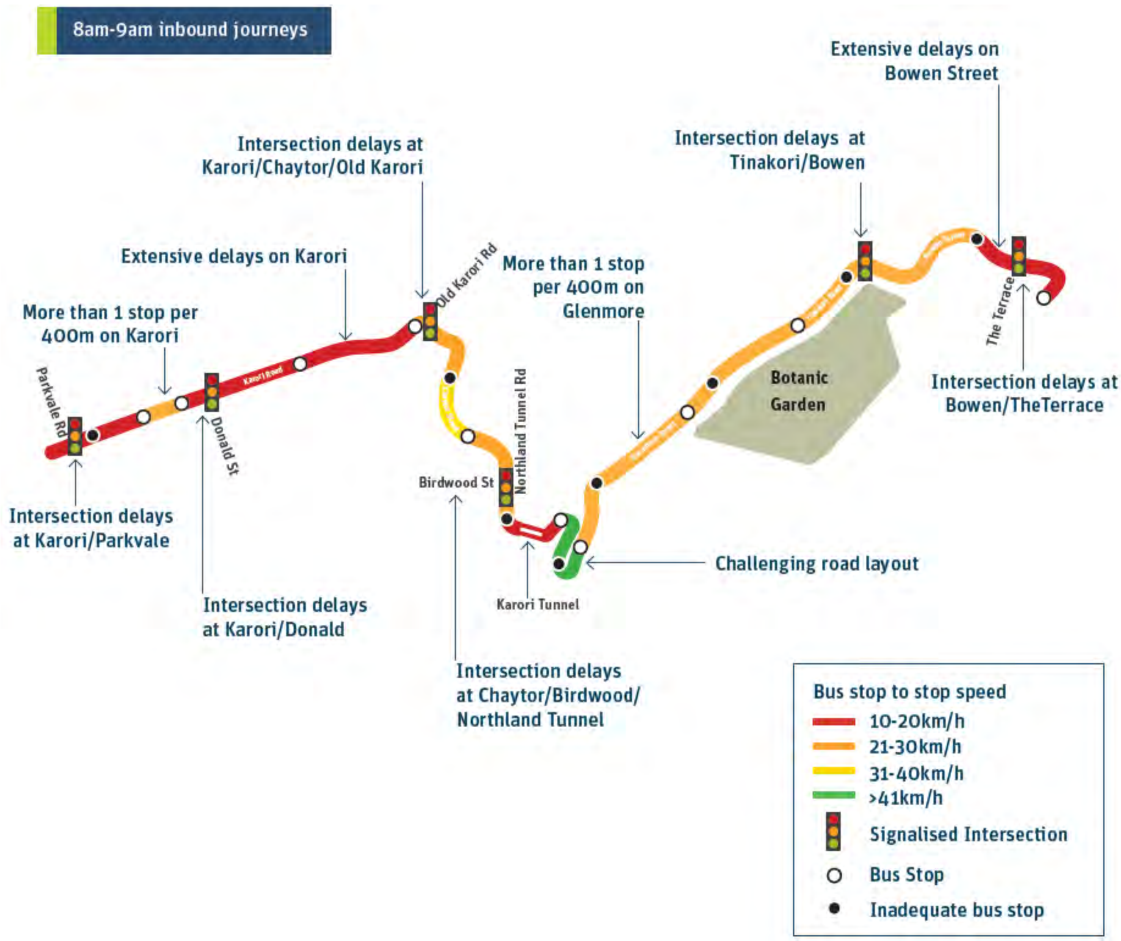
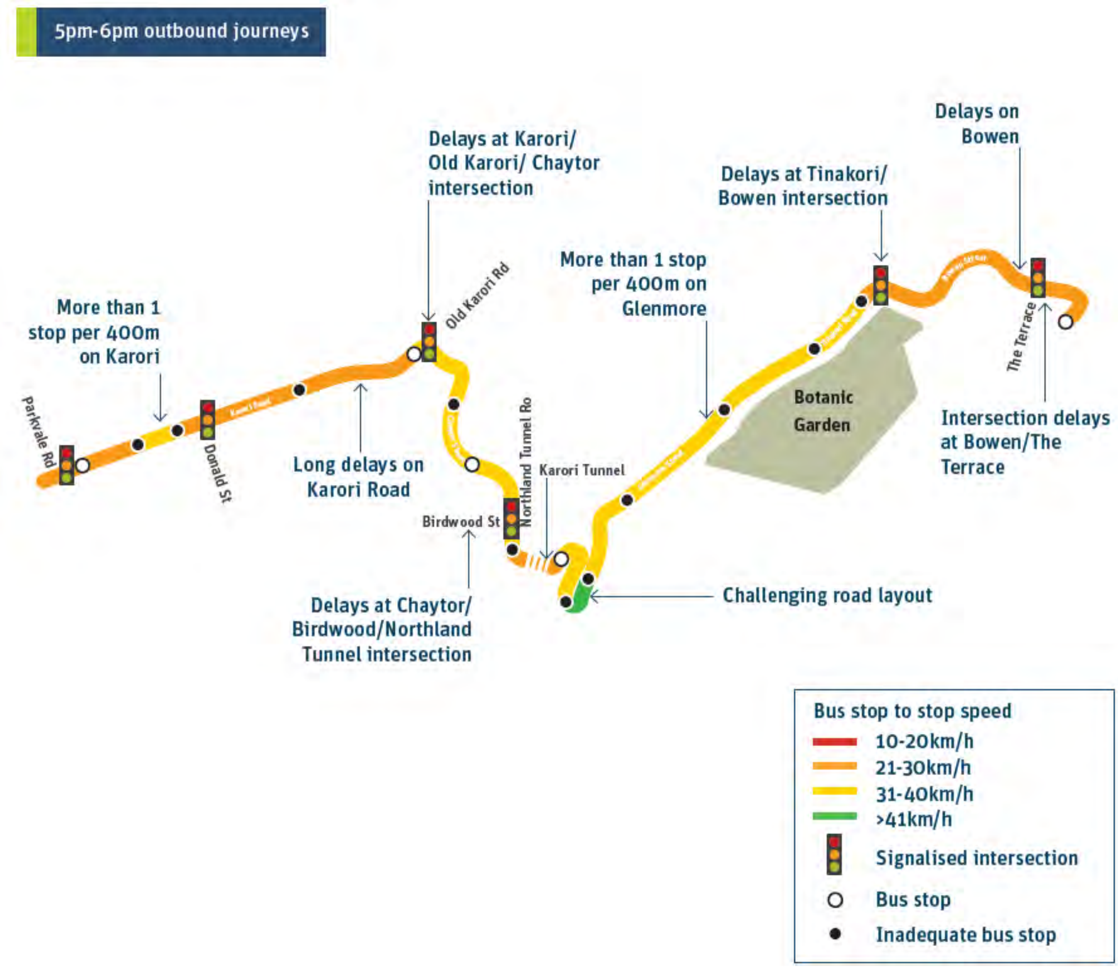


Figure 72: Key issues – Outbound afternoon peak hour (5pm–6pm)



3. Opportunities

For corridor 2, a list of opportunities to improve bus operations has been identified. These opportunities include the implementation of bus priority interventions that would be effective in addressing the documented sources of delay along the corridor and would improve bus travel times.

There are multiple levels of interventions that could be implemented across the corridor that would have varying impacts on bus journey times. For this reason, three packages of opportunities for the corridor have been selected. The package options are defined as follows:

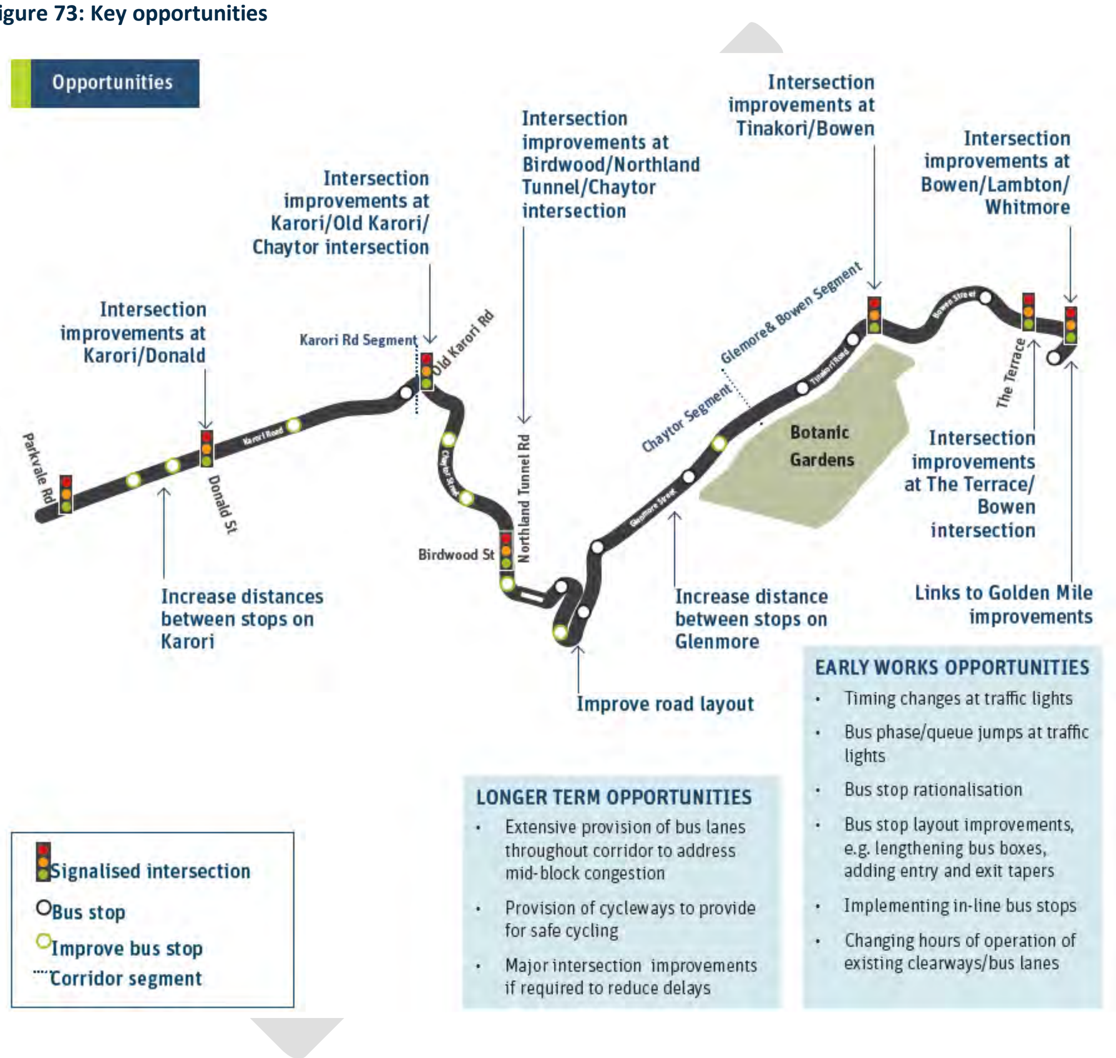
- **Option 1: fix everything**
  This option would address all problems identified on the corridor and implement any of the possible interventions that are effective at addressing the problems that have been identified on the corridor.
- **Option 2: fix the worst problems**
  This option would address only the most severe problems identified on the corridor and only implement interventions that do not involve major reconfiguration of corridor space.

- **Option 3: minimal interventions**
  This option would address only the most severe problems identified on the corridor and implement interventions that involve only minimal reconfiguration of corridor space.

A context map of the location of the key opportunities is provided in Figure 73.

For a full list of the bus priority interventions considered, the package identification process, ad a detailed description of the criteria that was used to identify opportunities on the corridor, refer to Appendix 2.

Figure 73: Key opportunities



Appendix 5 – Seatoun to city (corridor 3): corridor analysis summary

1. Corridor overview

1.1. Context

The Seatoun to city corridor (corridor 3) is an 8.9-kilometre-long transport corridor that connects the eastern suburbs of Mt Victoria, Hataitai, Kilbrinie, Miramar, and Seatoun to the central city. There are seven public bus services and 10 school bus services operating on the corridor. On weekdays, there are more than 7000 daily bus passenger trips along the corridor.

When travelling by bus, the journey from one end of the corridor to the other takes 27 minutes on average. The inbound peak hour occurs in the morning at 8am–9am, when the average journey time is approximately 35 minutes. In the outbound direction, there are two hours with the longest bus travel time: 3pm–4pm and 5pm–6pm. During these hours, the average journey time is 33 minutes.

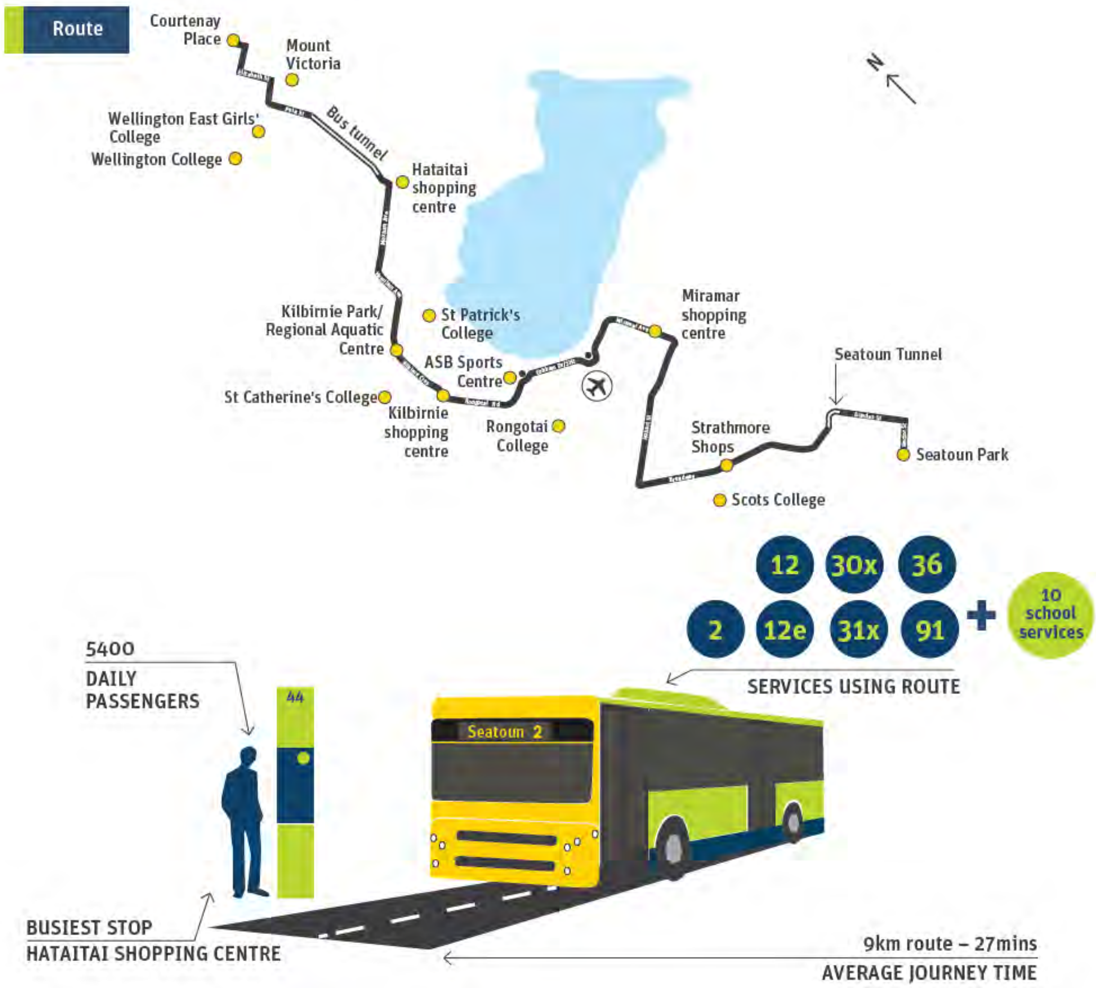
Table 52: Summary of key facts on the corridor

	Inbound	Outbound
Maximum daily passengers[36]	4,200	3,700
Corridor length (km)	9.0	8.9
Number of bus stops	30	30
Average bus stop spacing (m)	300	297
Average speed (km/h)	19	20
Average travel time (min)	27	27
Minimum travel time (min)	22	23
Maximum travel time (min)	35	33
Slowest weekday hour	8am–9am	3pm–4pm / 5pm–6pm

There are on-road cycleways on parts of this corridor, through Kilbirnie. A future off-road cycleway is soon to be completed on Cobham Drive.

[36] 'Maximum daily passengers' refers to the maximum number of passengers passing through a point on the corridor. On corridor 3, this occurs through Hataitai and the Hataitai bus tunnel.

Figure 74: Corridor context summary



Area

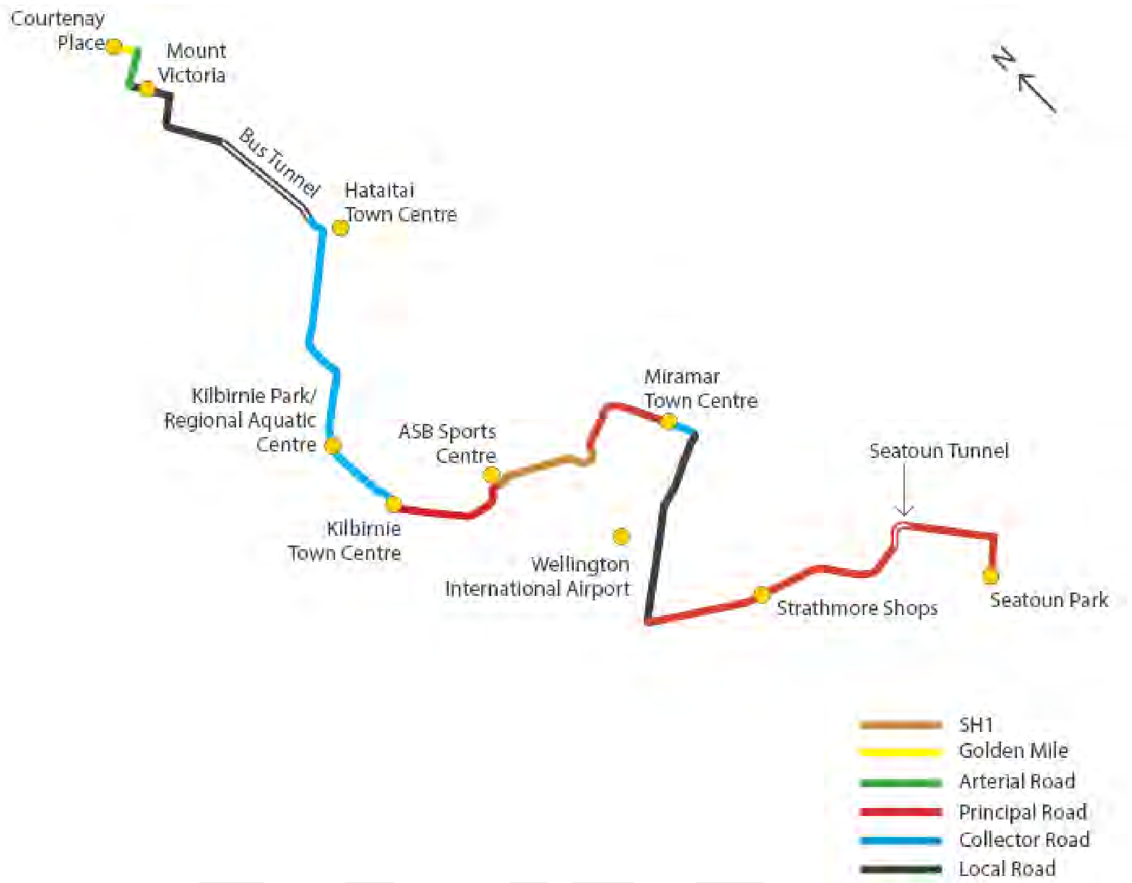
There are several significant destinations located along the Seatoun to city corridor, including Miramar town centre, Wellington International Airport, ASB Sports Centre, Kilbirnie town centre, Wellington Regional Aquatic Centre, Hataitai town centre, and Courtenay Place.

The land uses along the corridor are principally classified as outer residential, along with some central area, centre, business, open space, medium-density residential, and airport zones.

Roads

The Seatoun to city corridor is made up of arterial, principal, collector, and local roads with sections of SH1 and the Golden Mile, as shown in Figure 75. There are six signalised intersections, five roundabouts, and no signalised pedestrian crossings along the corridor. The Hataitai bus tunnel and Seatoun Tunnel are also located on the corridor.

Figure 75: Road hierarchy map[37,38]

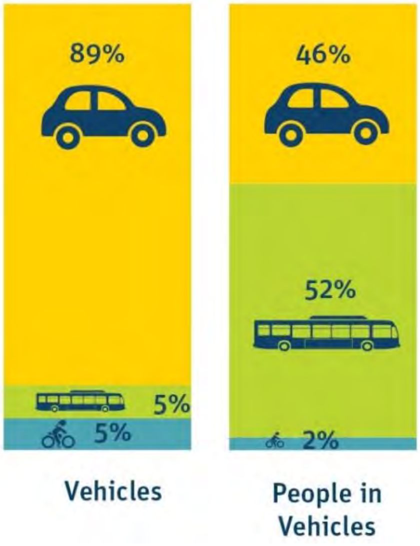


During the morning peak hour (8am–9am), the majority of vehicles on the corridor are private vehicles (89 percent). However, private vehicles transport just under half of the people on the corridor (46 percent). Buses make up only 5 percent of vehicles. However, they transport more than half of the people on the corridor (52 percent). This is indicative of the 'heavy lifting' that buses are doing to move people on this corridor. Figure 76 presents a full breakdown of the modal split on the corridor.

[37] Road hierarchy data sourced from WCC District Plan Map 33: Hierarchy of Roads
[38] In the WCC District Plan, the road classifications are defined as follows:

- Motorway: high standard limited access roads designed to carry long distance through traffic at speed
- Golden Mile: the main retail and commercial strip extending from Cenotaph (near Parliament Buildings) to the eastern end of Courtenay Place
- Arterial Road: high standard limited access roads designed to carry long distance through traffic
- Principal Road: roads that provide access to motorways and to arterial roads having a dominant through-traffic function and carrying the major public transport routes
- Collector Road: roads that distribute traffic between and within local areas and form the link between principal and secondary roads
- Local Road: roads that provide direct access to properties fronting the road and include both long and short cul-de-sacs

Figure 76: Modal split – Inbound morning peak period (8am–9am)



1.2. Bus operations

There are seven public bus services and 10 school services operating on this corridor. There are 30 stops in the inbound direction and 30 in the outbound direction. Bus stops between Seatoun and Kilbirnie are in fare zone 3; bus stops between Kilbirnie and Pirie Street are fare zone 2; and the Mt Victoria bus stops on Brougham and Elizabeth streets are in fare zone 1. There are two bus hubs on this corridor: Kilbirnie (*Kilbirnie – Stop A* and *Kilbirnie – Stop B*) and Miramar shops (*Miramar Shops – Stop A* and *Miramar Shops – Stop B*).

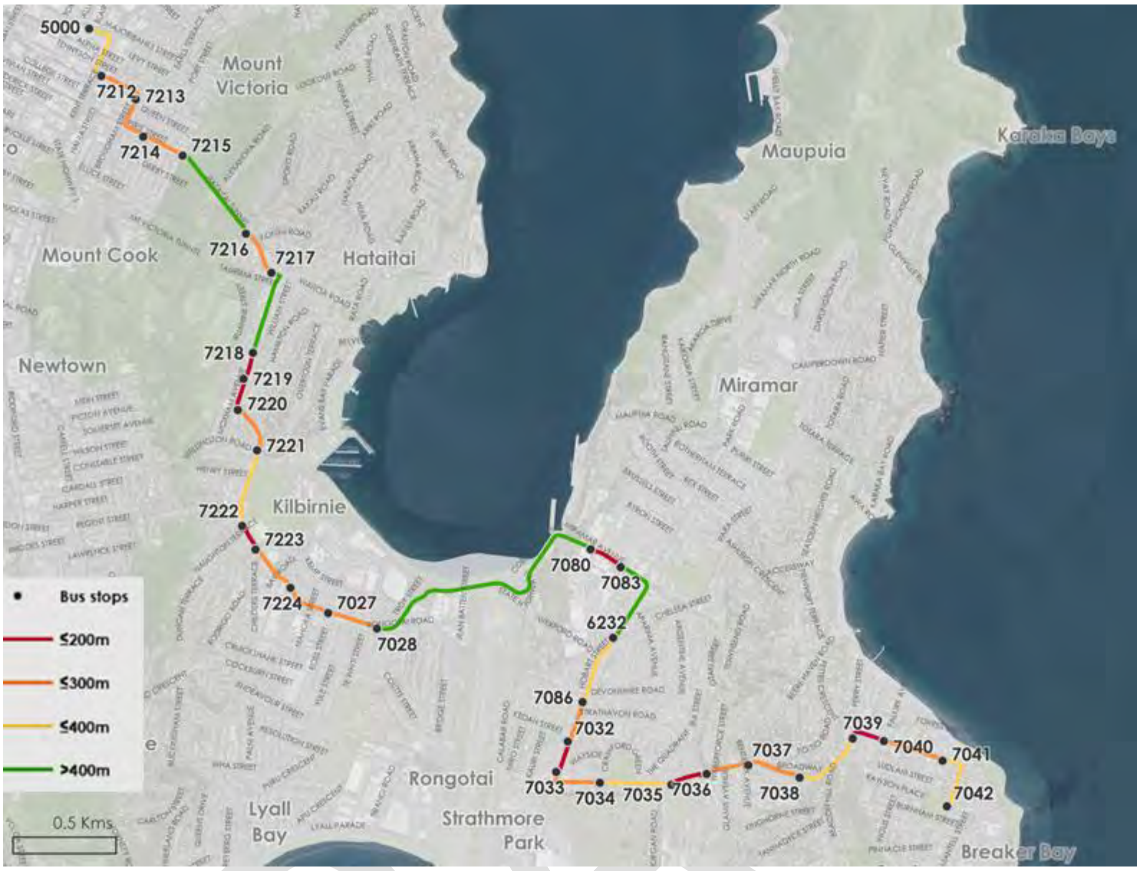
The Hataitai bus tunnel is located on the corridor and serves as a piece of bus priority infrastructure, providing a bus-only connection between Mt Victoria and Hataitai. There are no other bus priority measures in place on this corridor.

Bus stop spacing

Inbound

The average bus stop spacing along the corridor in the inbound direction is 300 metres. The closest spacing is 130 metres, between the bus stops at Wellington Regional Aquatic Centre and Ruth Gotlieb (Kilbirnie) Library on Kilbirnie Crescent.

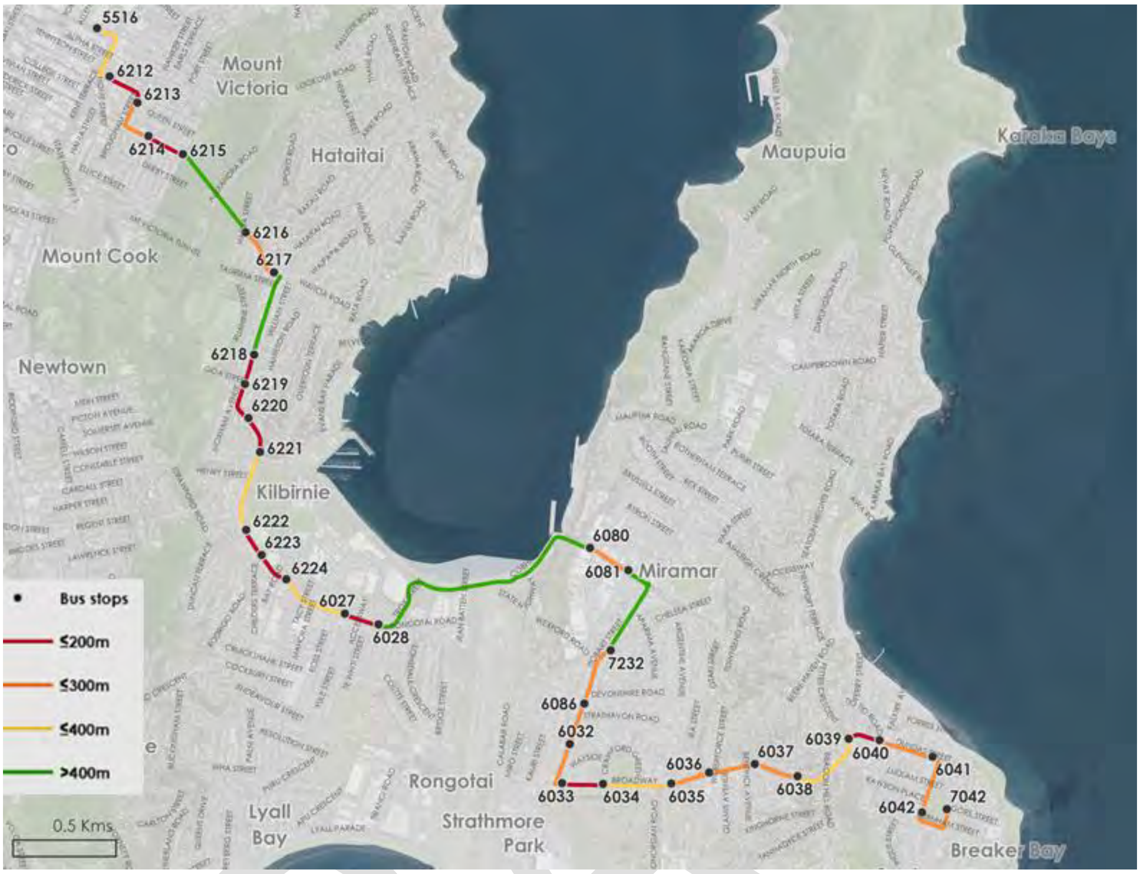
Figure 77: Bus stop locations and spacing – Inbound



Outbound

The average bus stop spacing along the corridor in the outbound direction is 297 metres. The closest spacing is 143 metres, between the bus stops at Wellington Regional Aquatic Centre and Ruth Gotlieb (Kilbirnie) Library on Kilbirnie Crescent.

Figure 78: Bus stop locations and spacing – Outbound



Boardings and alightings

Inbound

The busiest bus stop along the corridor in the inbound direction is *Kilbirnie – Stop B*, with more than 1100 daily boardings and alightings. This is likely due to a large number of passengers transferring between bus services at the Kilbirnie bus hub.[39] The bus stops located at the Miramar and Hataitai town centres (*Miramar Shops – Stop A* and *Hataitai– Stop A*) also have significant usage, with more than 800 and 500 daily boardings and alightings respectively.

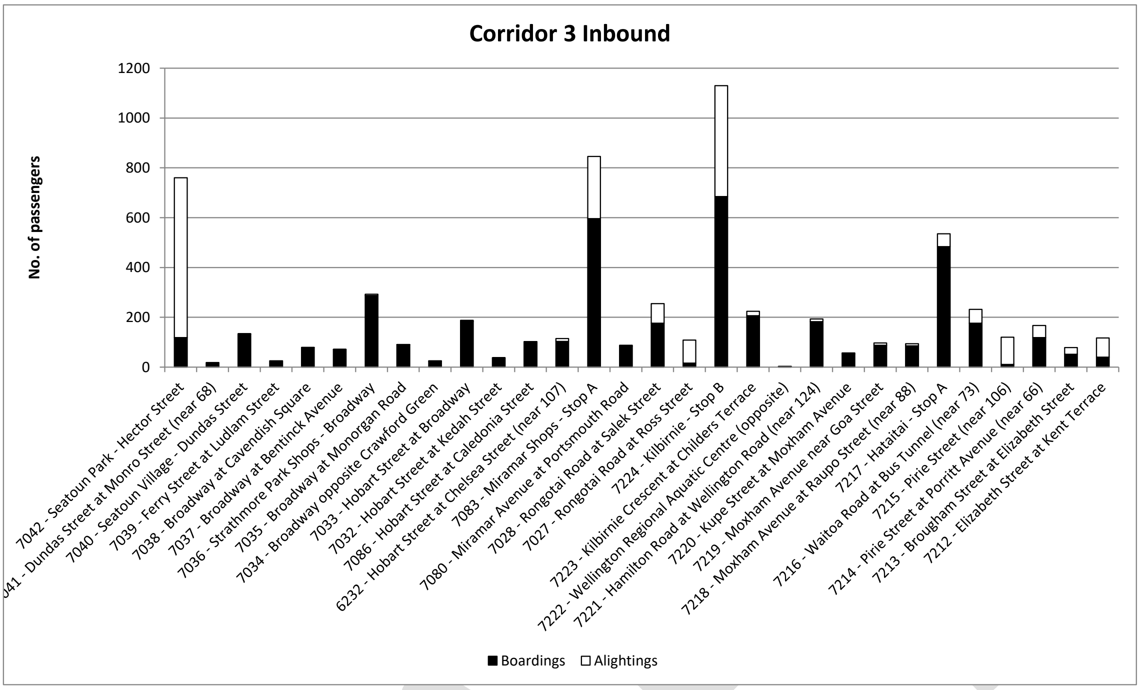
Seatoun Park – Hector Street serves as both the first inbound bus stop and the last outbound bus stop, hence the high number of passengers alighting here.

The bus stop at *Wellington Regional Aquatic Centre (opposite)* was not in service for much of the data collection period in May 2019. Excluding this bus stop, there are 12 bus stops with less than 100 daily boardings and alightings, and four bus stops with less than 50.

Figure 79 shows the daily numbers of people boarding and alighting at each bus stop along the corridor in the inbound direction. This includes all bus routes that service each bus stop.

[39] There are two inbound bus stops located at the Kilbirnie bus hub: Kilbirnie – Stop B and Kilbirnie – Stop C. Only Kilbirnie – Stop B data has been included in the corridor 3 analysis. The bus services that use Kilbirnie – Stop C travel along the Kilbirnie to Newtown corridor (corridor 6) and have been included in the corridor 6 analysis (refer Appendix 8).

Figure 79: Daily boardings and alightings – Inbound

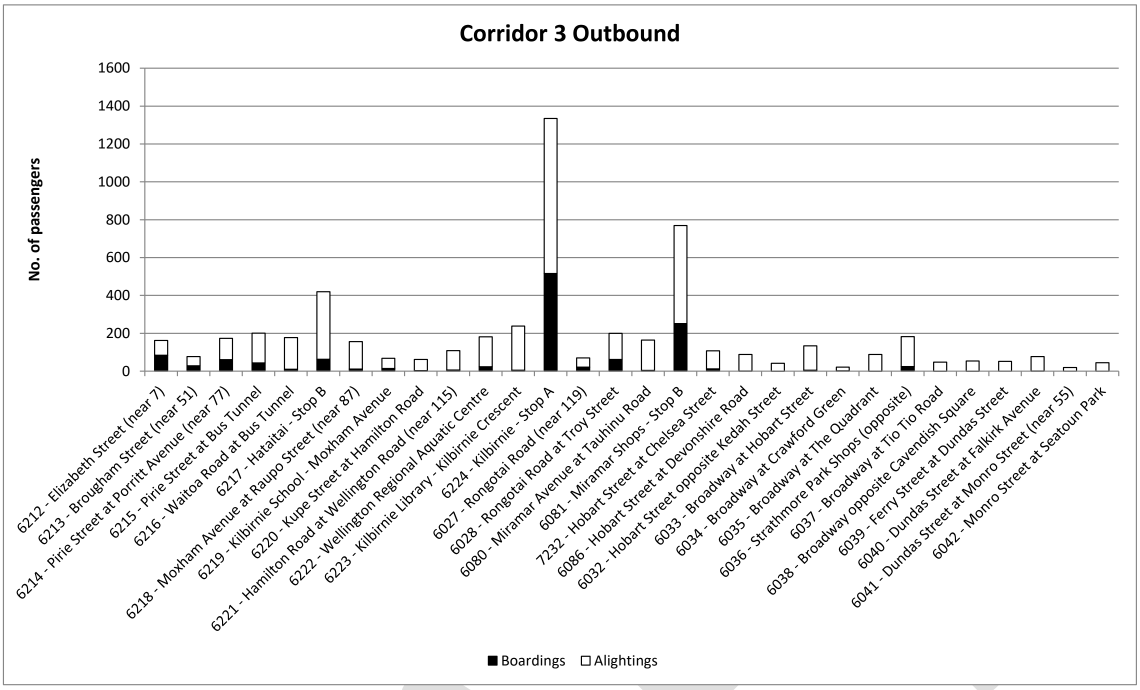


Outbound

The busiest bus stop along the corridor in the inbound direction is *Kilbirnie – Stop A*, with more than 1300 daily boardings and alightings. This is likely due to a large number of passengers transferring between bus services at the Kilbirnie bus hub. The bus stop located at Miramar town centre, *Miramar Shops – Stop B*, also has significant usage, with almost 800 daily boardings and alightings. There are 14 bus stops with less than 100 boardings and alightings throughout the day, and five with less than 50. Except for *Kilbirnie – Stop A*, there are very few boardings across the outbound bus stops.

Figure 80 shows the daily number of people boarding and alighting at each bus stop along the corridor in the outbound direction. This includes all bus routes that service each bus stop.

Figure 80: Daily boardings and alightings – Outbound



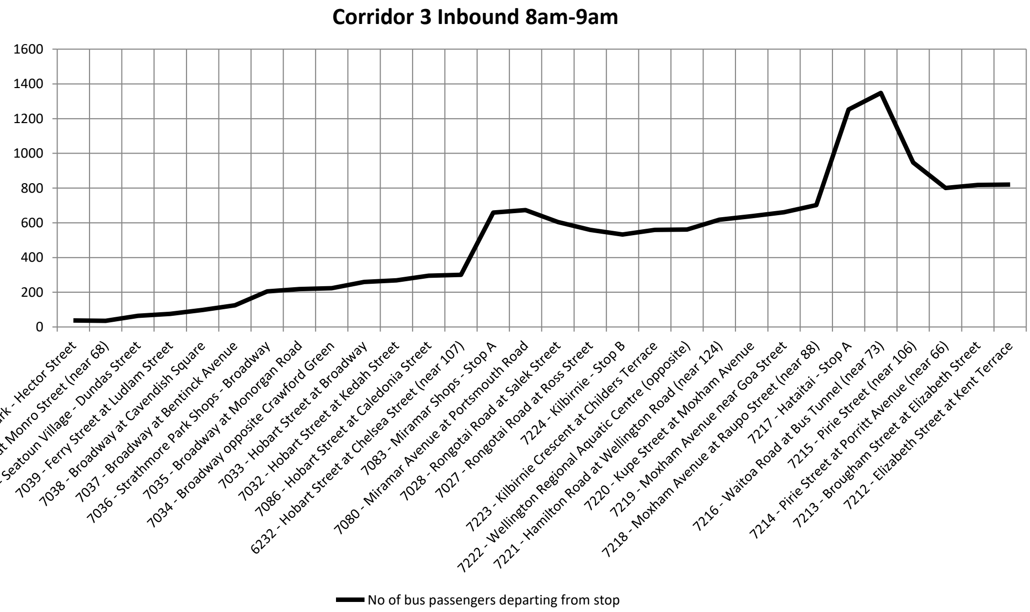
Cumulative passenger numbers

Inbound

During the inbound peak hour on the corridor (8am–9am), the highest bus passenger numbers occur starting at Hataitai town centre and through the Hataitai bus tunnel. There is a sharp drop-off in passenger numbers at *Pirie Street (near 106)*, the bus stop just inbound of the bus tunnel. This is likely due to the fact that the bus stop is a fare zone boundary and passengers get off the bus here to avoid a paying a higher fare. Additionally, a number of students get off here to attend nearby schools.

There is another peak in passenger numbers through Miramar, which serves more bus routes than other parts of the corridor. Figure 81 shows the average number of bus passengers on the bus departing from each bus stop during the morning peak hour.

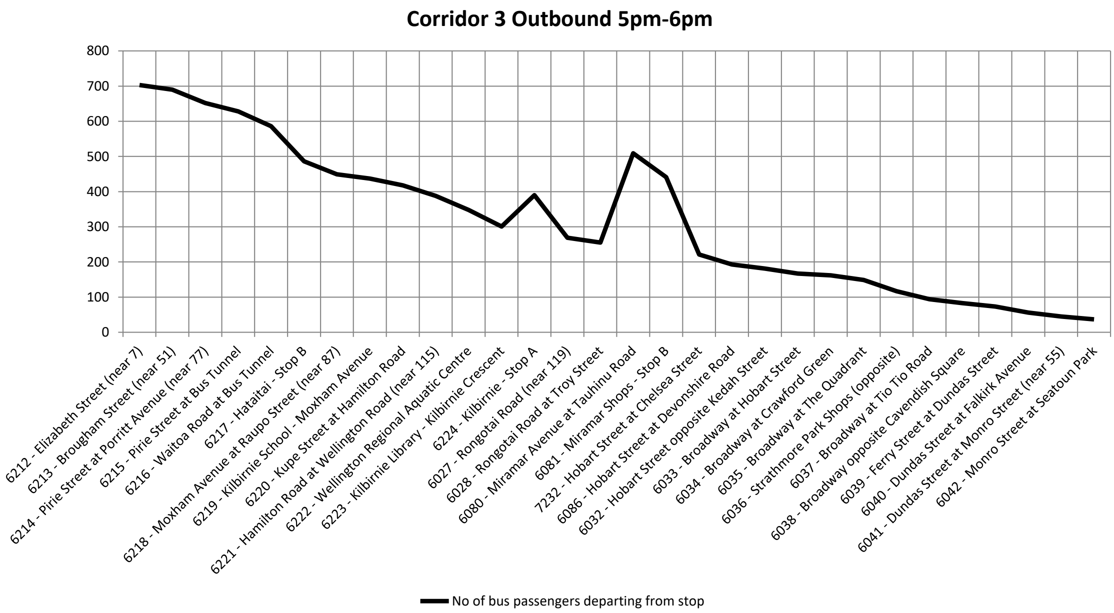
Figure 81: Cumulative bus passenger load – Inbound morning peak hour (8am–9am)



Outbound

During the outbound peak hour on the corridor (5pm–6pm), the number of bus passengers gradually declines as services travel east, with the exception of two peaks. One is at the Kilbirnie bus hub, where passengers from other services board, and the other occurs through Miramar, which serves more bus routes than other parts of the corridor. Figure 82 shows the average number of bus passengers on the bus departing from each stop during this hour.

Figure 82: Cumulative bus passenger load – Outbound afternooon peak hour (5pm–6pm)



2. Issues

2.1. Travel time

Average travel times along corridor 3 in the inbound direction are similar to travel times in the outbound direction. There is slightly more variability in the inbound direction than the outbound direction, with a 13-minute difference between the fastest and slowest travel times compared to a nine-minute difference between the outbound travel times.

Table 53: Summary of travel times on the corridor

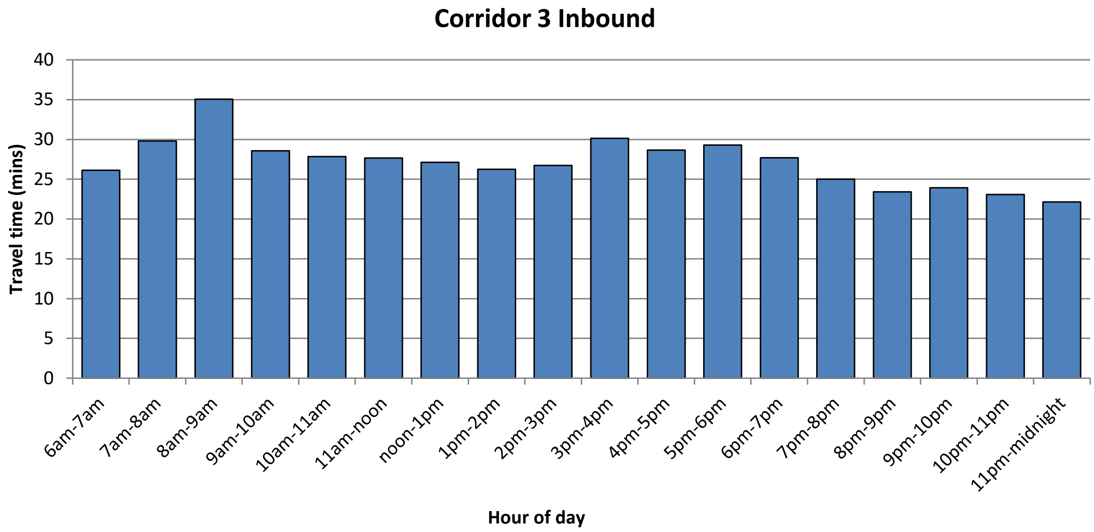
	Inbound	Outbound
Corridor length (km)	9.0	8.9
Average travel time (min)	27.1	27.2
Slowest hour	8am–9am	3pm–4pm/5pm–6pm
Travel time at slowest hour (min)	35.1	32.7
Fastest hour	11pm–midnight	11pm–midnight
Travel time at fastest hour (min)	22.1	23.4

Travel time by hour

Inbound

On corridor 3 in the inbound direction, the slowest hour for buses is 8am–9am, when it takes an average of 35.1 minutes to travel between Seatoun Park and Courtenay Place. This is eight minutes longer than the average travel time and more than 1.5 times longer than travel times during the fastest hour of the day (11pm–midnight). Figure 83 below shows the average time it takes for a bus to travel the length of the corridor in the inbound direction for every hour between 6am and midnight.

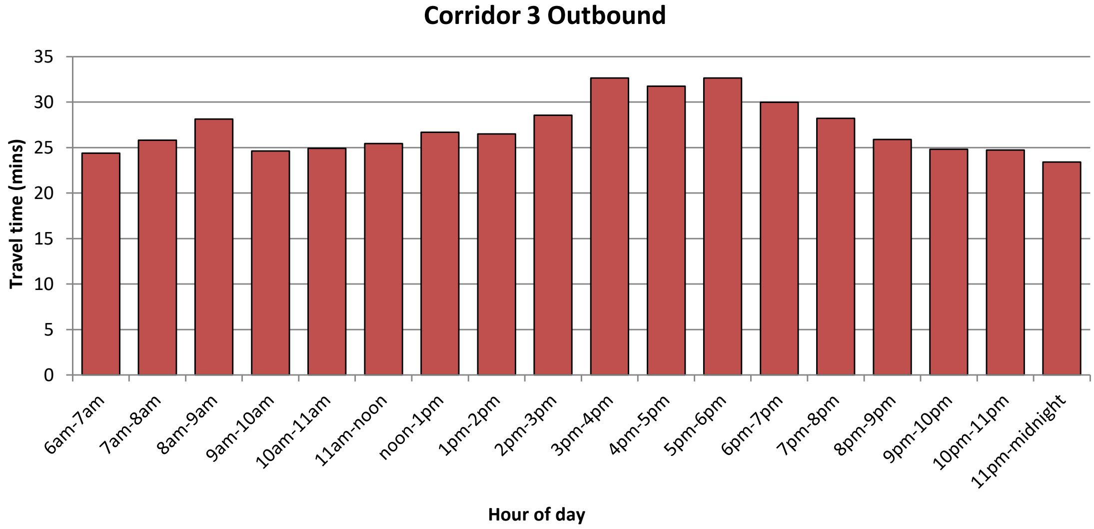
Figure 83: Travel times by hour of day – Inbound



Outbound

On corridor 3 in the outbound direction, the peak period is more spread out than in the inbound direction. The slowest travel times for buses occur at 3pm–4pm and 5pm–6pm, when it takes an average of 32.7 minutes to travel between Courtenay Place and Seatoun Park. This is more than five minutes longer than the average travel time. Students being picked up from school (by car and bus) is likely to be a key reason behind the 3pm–4pm hour taking as long as the typical 5pm–6pm commuting peak. Figure 84 shows the average time it takes for a bus to travel the length of the corridor in the outbound direction for every hour between 6am and midnight.

Figure 84: Travel times by hour of day – Outbound

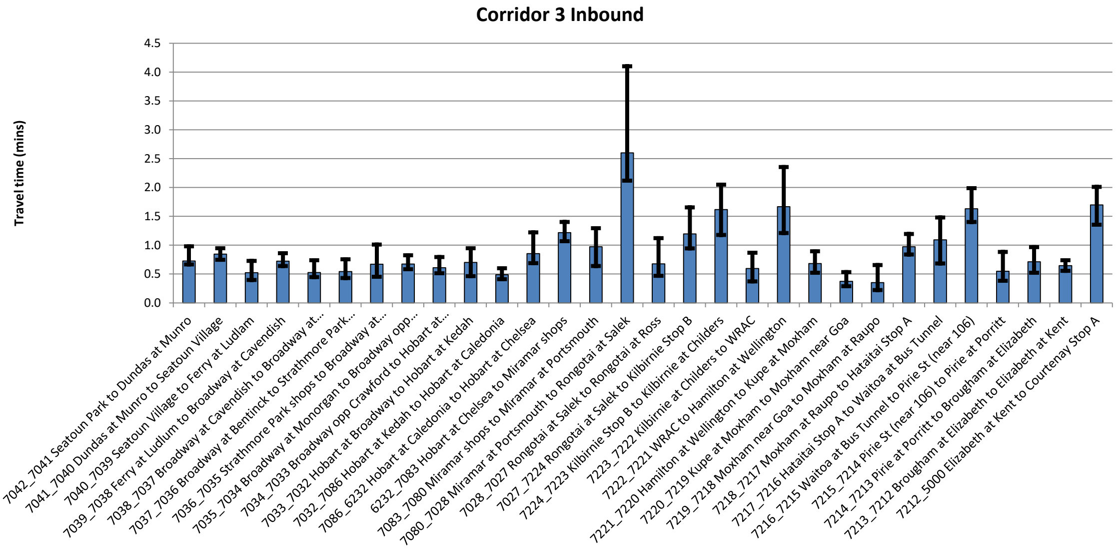


Travel time variability

Inbound

Figure 85 shows the average time it takes for a bus to travel along each segment of the corridor in the inbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

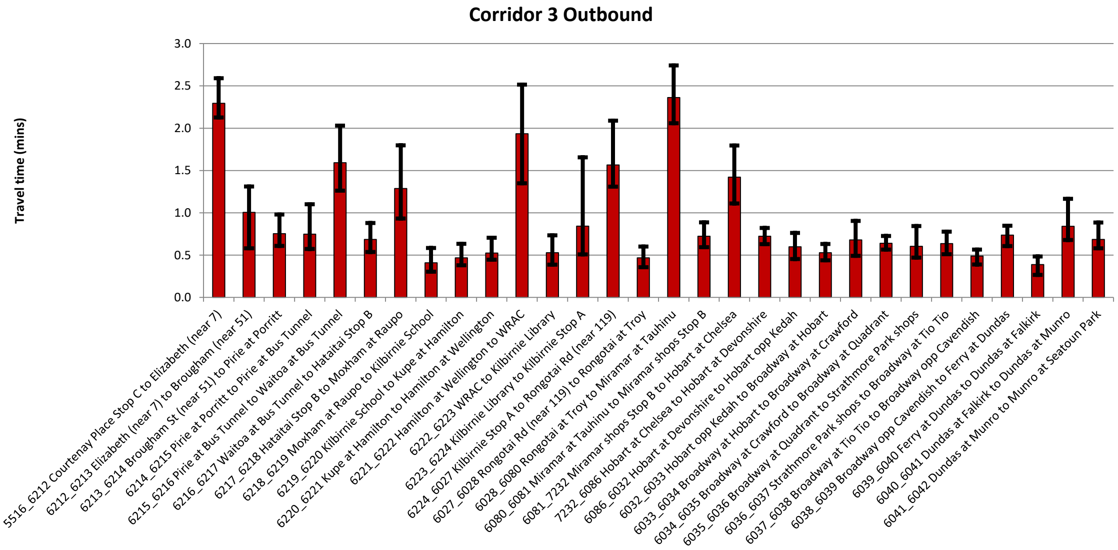
Figure 85: Variation in travel times – Inbound



Outbound

Figure 86 shows the average time it takes for a bus to travel along each segment of the corridor in the outbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

Figure 86: Variation in travel times – Outbound



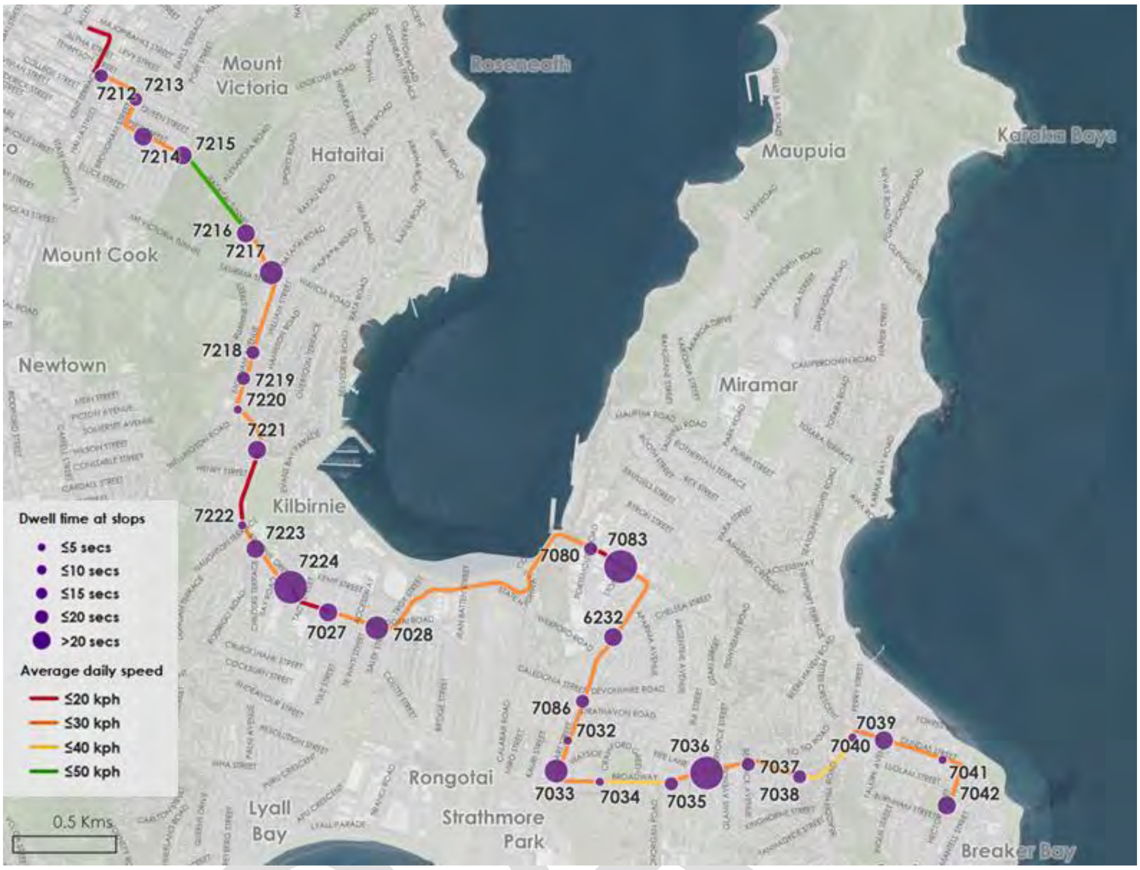
Bus operating speeds and dwell time delay

The maps below show the average speeds at which buses operate along the corridor and the average time buses dwell at bus stops during the peak hours.

Inbound

During the morning peak hour in the inbound direction (8am–9am), bus operating speeds on the corridor are slowest along parts of Kilbirnie Crescent, Rongotai Road and Miramar Avenue.

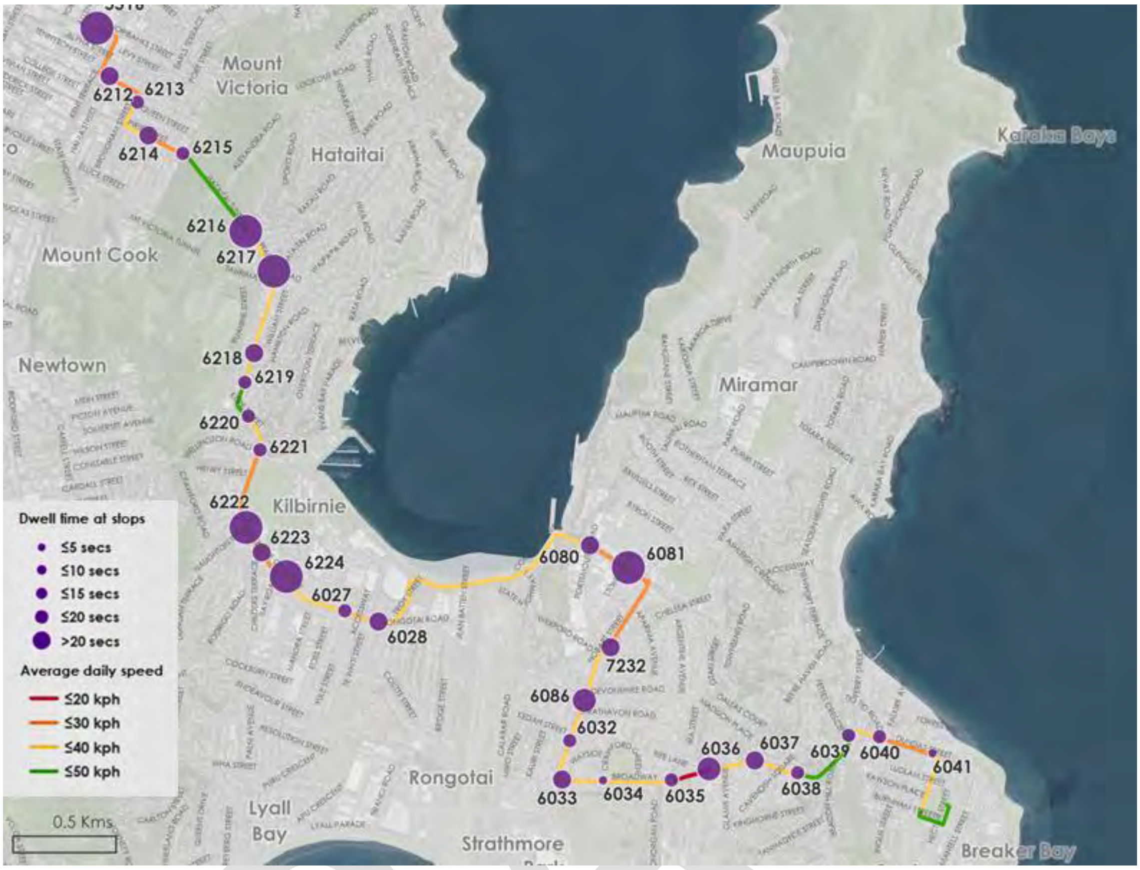
Figure 87: Operating speeds and dwell times – Inbound morning peak hour (8am–9am)



Outbound

During the slowest hour in the outbound direction (5pm–6pm), bus operating speeds on the corridor are slowest along Kilbirnie Crescent.

Figure 88: Operating speeds and dwell times – Outbound afternoon peak hour (5pm–6pm)



2.2. Bus stop audit

There are 30 inbound bus stops between Seatoun Park and Courtenay Place. There are 30 outbound bus stops between Courtenay Place and Seatoun Park.

Of these bus stops, 50 are off-line stops, 33 are not of sufficient length to accommodate a bus, and 35 do not have sufficient entry and / or exit tapers for buses to easily manoeuvre into and out of the stop. Such issues can lead to increased dwell times as passengers have to make awkward movements to get on and off the bus. This is particularly so for mobility-impaired pedestrians, as well as for the young, elderly, and people with prams or carrying other heavy or bulky items.

Table 54: Bus stop details[40]

	Number of bus stops	
	Inbound	**Outbound**
Total number of bus stops	30	30
Number of off-line bus stops	25	25
Number of bus boxes with insufficient length (<15m)	13	20
Number of bus stops missing tapers	15	20

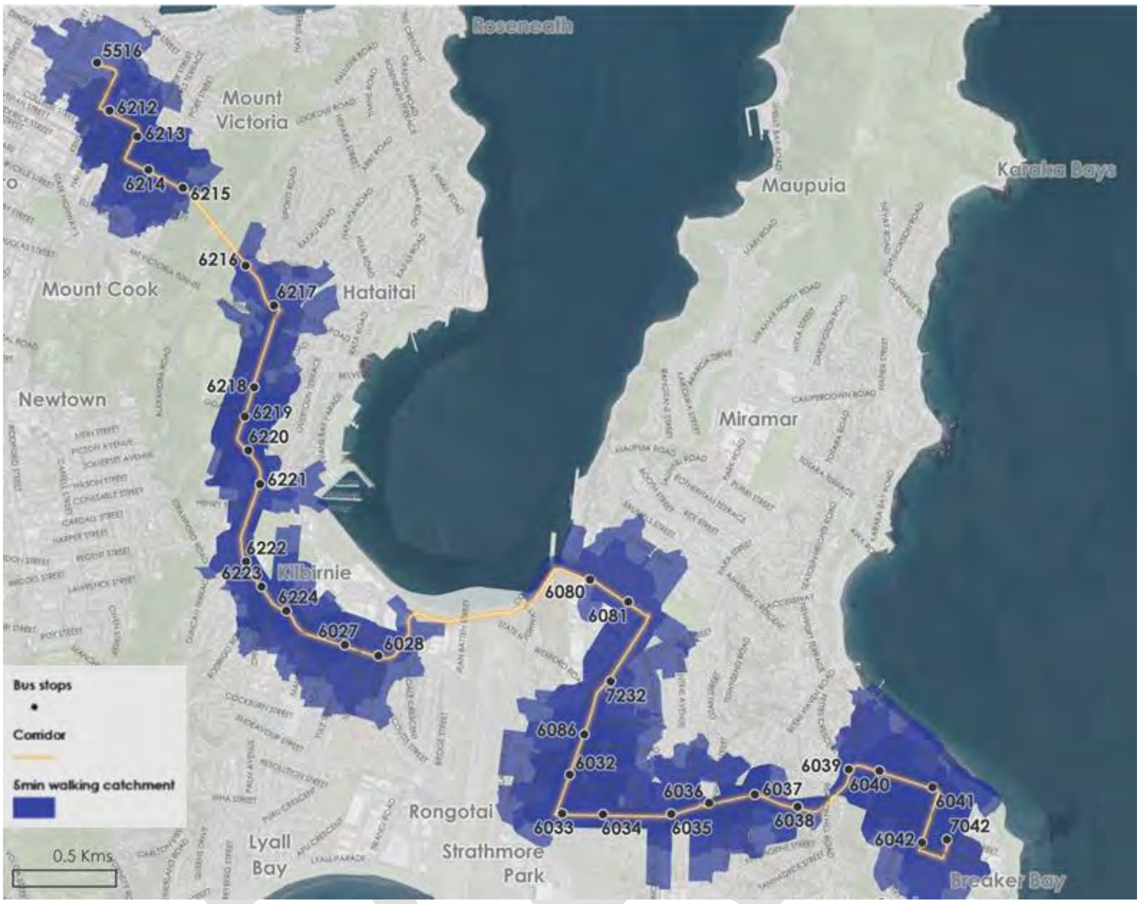
[40] Note that the WCC Transport and Infrastructure team is currently working through a list of bus stop improvements, which includes marking out standard bus lengths and entry/exit tapers.

Bus stop walking catchments

The following maps show the areas that are within a five-minute walk of the bus stops on the corridor. The darker blue areas represent where the catchments of multiple bus stops overlap.

Figure 89: Bus stop catchment – Inbound

Figure 90: Bus stop catchment – Outbound



2.3. Sources of delay

Percentage delay

The delay that buses experience during the peak hours and slowest hours of travel have been analysed to estimate a breakdown in the sources of delay. Delay is defined as the extra running time of buses, beyond an estimated unimpeded running time. For a full breakdown of how unimpeded running time and delay is estimated, refer to Appendix 2.

To understand the sources of bus delays on the corridor, estimated delays have been decomposed into seven causes:

- long dwell times
- close bus stop spacing
- congestion at bus stops
- congestion at traffic lights
- narrow traffic lanes
- traffic signal delays
- other, which includes delay due to midblock traffic congestion, un-signalised intersections, hills and corners, roundabouts, and side friction from parking.

Note that in the commentary in the following sections, 'traffic lights' refers to the combination of 'traffic signal delays' and 'congestion at traffic lights'.

Inbound

During the slowest hour in the inbound direction (8am–9am), the delay along corridor 3 results in an average bus travel time that is more than twice as long as the estimated unimpeded running time.

Table 55: Theoretical versus actual travel time – Inbound morning peak hour (8am–9am)

Estimated unimpeded travel time	16.4 minutes
Delay	18.7 minutes
Total travel time	35.1 minutes

During the hour, half of the delay – 9.4 minutes – is attributable to 'other' reasons. Given the traffic volumes at this time, this is most likely due to mid-block congestion. However, other drivers completing parking manoeuvres or turning into side streets and driveways may also be a contributing factor.

Close bus stop spacing is the second largest contributor to delay, adding more than three minutes to the total travel time as a result of buses frequently stopping. Traffic lights add an additional three minutes of delay. A full breakdown of the sources of delay experienced by buses travelling in the inbound direction during the slowest hour (8am–9am) is provided in Figure 91 and Table 56.

Figure 91: Sources of delay – Inbound morning peak hour (8am–9am)

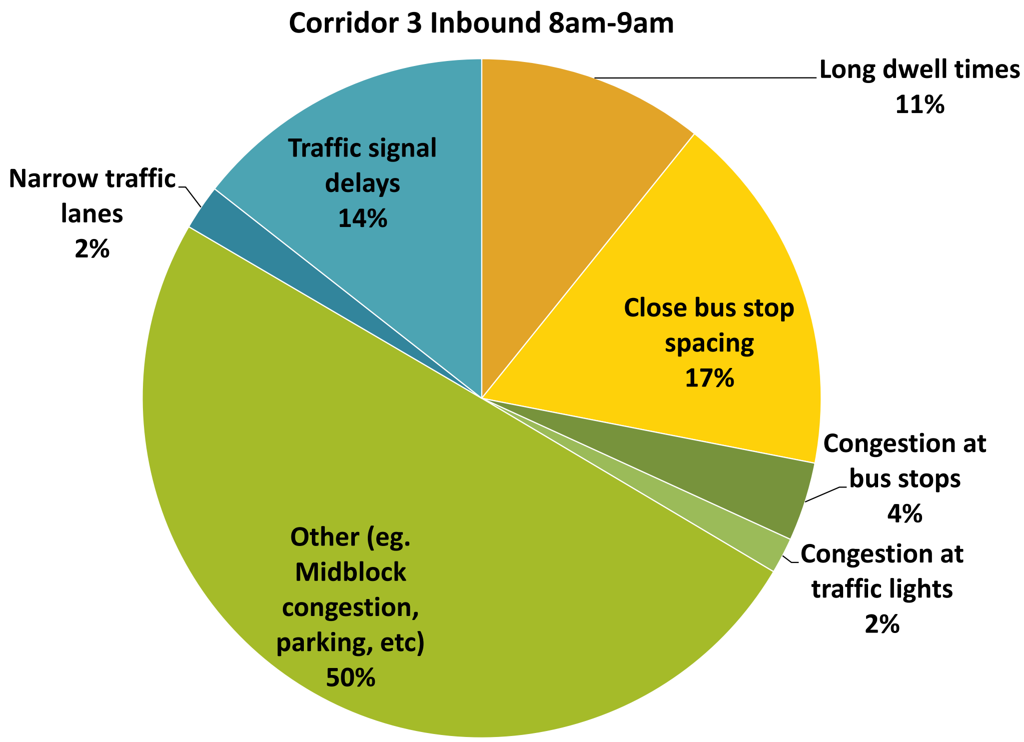


Table 56: Estimated minutes of delay by source – Inbound morning peak hour (8am–9am)

	Minutes added (delay)	Percentage of delay
Long dwell times	2.0	11%
Close bus stop spacing	3.2	17%
Congestion at bus stops	0.7	4%
Congestion at traffic lights	0.3	2%
Narrow traffic lanes	0.4	2%
Traffic signal delays	2.7	14%
Other	9.4	50%

Outbound

During the slowest hour in the outbound direction (5pm–6pm), the delay along corridor 3 results in a bus travel time that is almost twice as long as the estimated unimpeded running time.

Table 57: Theoretical versus actual travel time – Outbound afternoon peak hour (5pm–6pm)

Estimated unimpeded travel time	16.9 minutes
Delay	15.8 minutes
Total travel time	32.7 minutes

During this hour, the sources of delay affecting the bus running times are much more varied than during the morning inbound peak hour. The largest source of delay is the 'other' category, contributing to six minutes of delay. Given the traffic volumes at this time, this is most likely to be traffic congestion, even though bus lanes are in operation on parts of the corridor at this time. Other drivers completing parking manoeuvres or turning into side streets and driveways may also be a contributing factor.

Close bus stop spacing is the second largest contributor to delay, adding more than three minutes to the total travel time as a result of buses frequently stopping. Long dwell times and traffic lights each add almost another three minutes of delay. A full breakdown of the sources of delay experienced by buses travelling in the outbound direction during the slowest hour (5pm–6pm) is provided in Figure 92 and Table 58.

Figure 92: Sources of delay – Outbound afternoon peak hour (5pm–6pm)

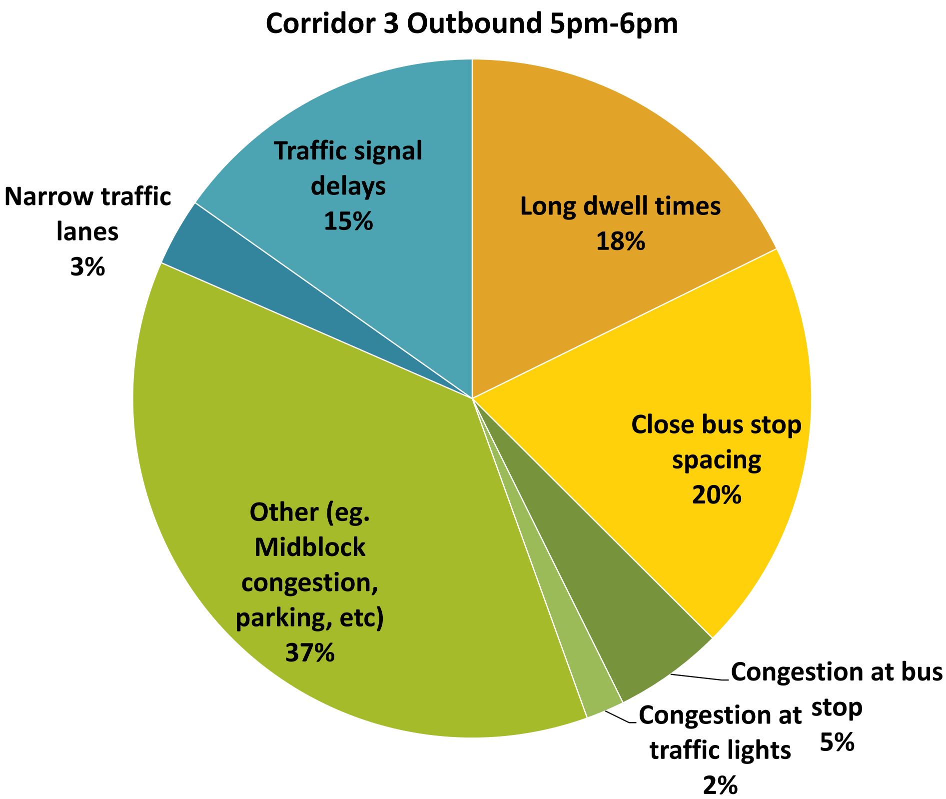


Table 58: Estimated minutes of delay by source – Outbound afternoon peak hour (5pm–6pm)

	Minutes added (delay)	Percentage of delay
Long dwell times	2.9	18%
Close bus stop spacing	3.2	20%
Congestion at bus stops	0.8	5%
Congestion at traffic lights	0.3	2%
Narrow traffic lanes	0.5	3%
Traffic signal delays	2.5	15%
Other	6.0	37%

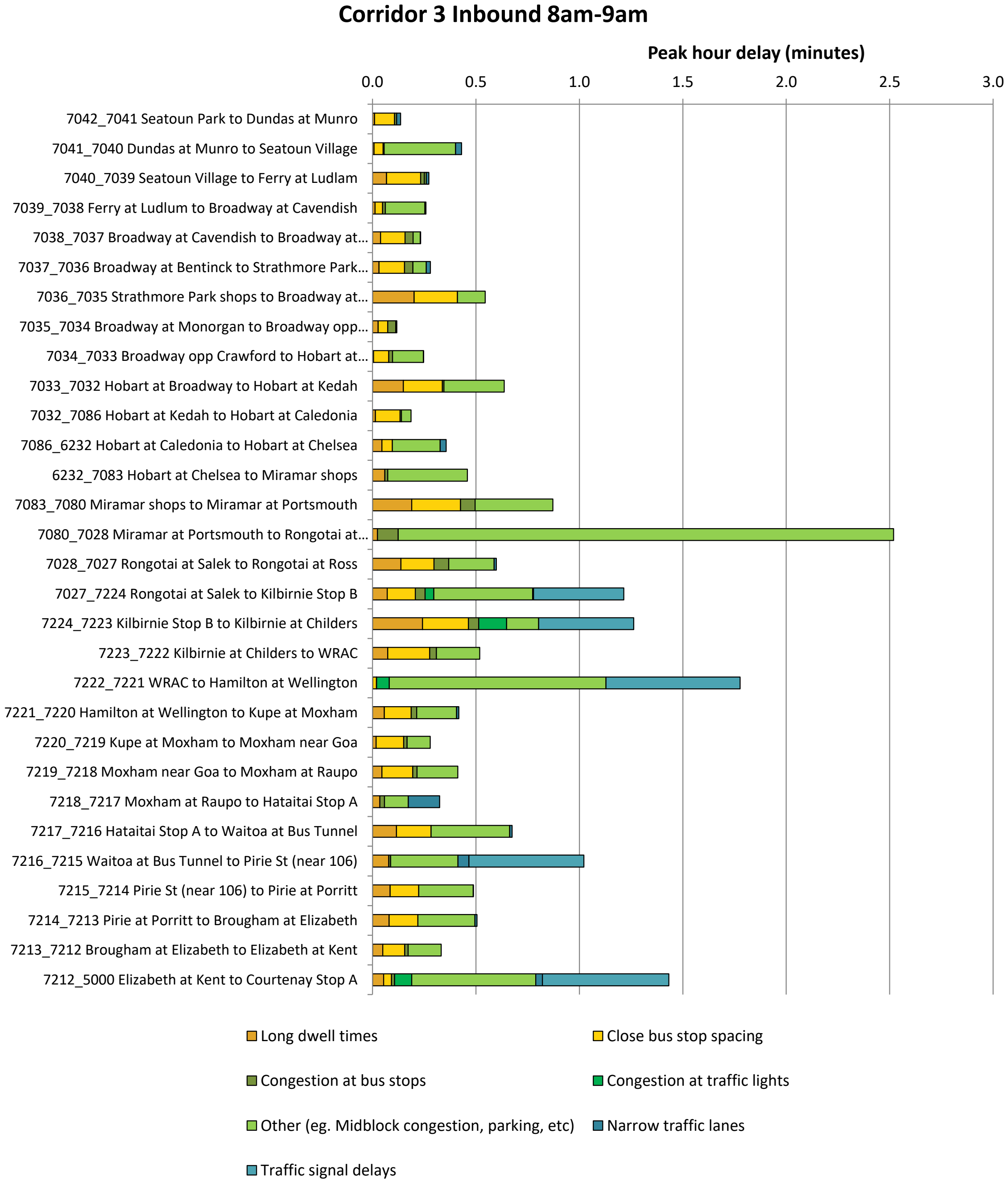
Delay breakdown by segment

Inbound

During the peak hour for buses travelling in the inbound direction on the corridor (8am–9am), the segment experiencing the most delay is on Cobham Drive, between Miramar and Kilbirnie. Here, buses experience almost six minutes of delay (over an 832 metre-long segment). This is the longest segment of the corridor (more than one kilometre long) and experiences more than 2.5 minutes of delay during the inbound peak hour.

Buses also experience more than one minute of delay on multiple segments through Kilbirnie, through the Hataitai bus tunnel, and on Cambridge Terrace. Figure 93 provides a breakdown of the sources of delay on corridor 3 by segment for buses travelling in the inbound direction during this hour.

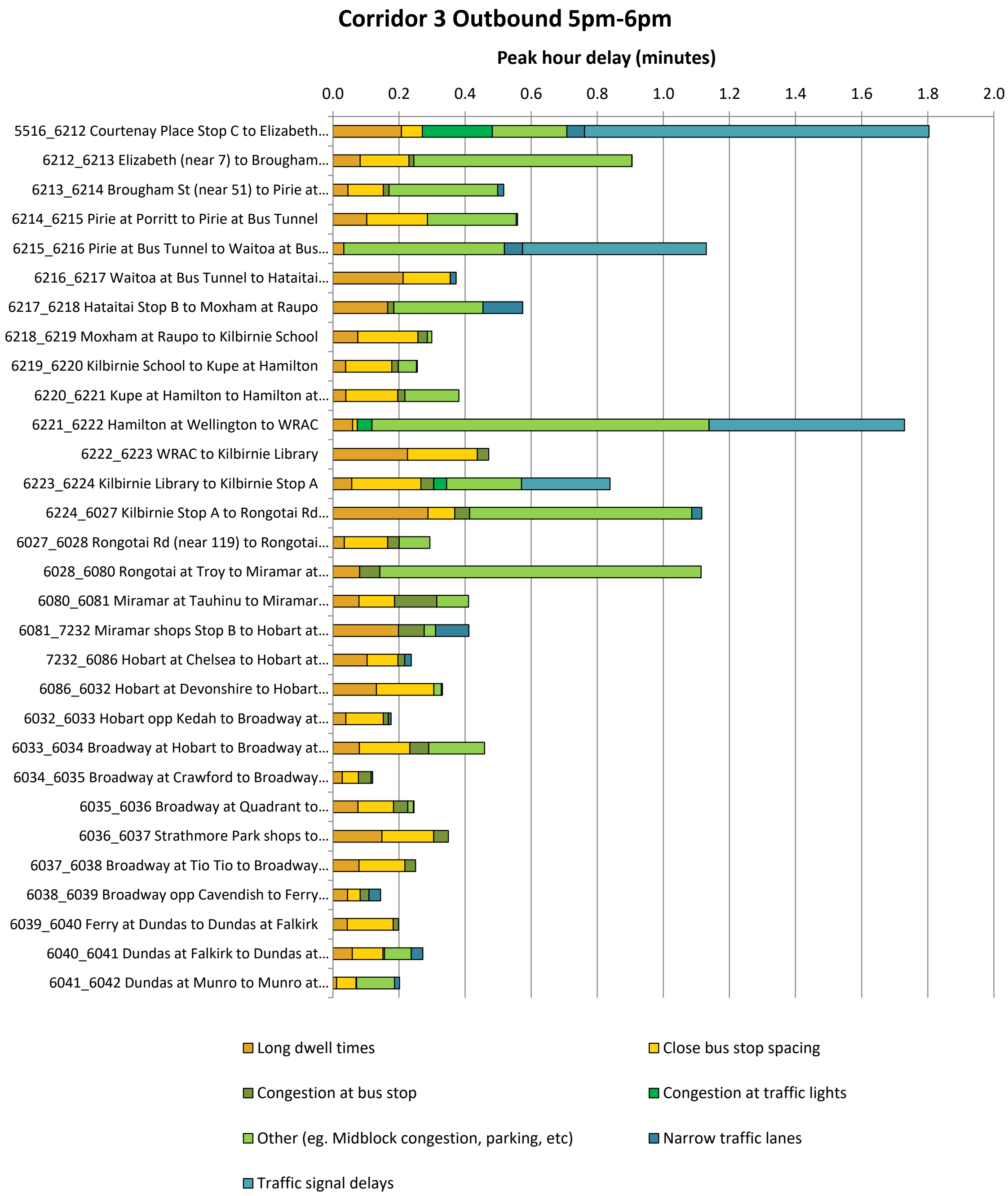
Figure 93: Sources of delay by segment – Inbound morning peak hour (8am–9am)



Outbound

During the peak hour for buses travelling in the outbound direction on the corridor (5pm–6pm), the segment experiencing the most delay is Kent Terrace, mostly due to two traffic signals. The segment from Hataitai to Wellington Regional Aquatic Centre in Kilbirnie also experiences significant delay. Figure 94 provides a breakdown of the sources of delay on corridor 3 by segment for buses travelling in the outbound direction during this hour.

Figure 94: Sources of delay by segment – Outbound afternoon peak hour (5pm–6pm)



2.4. Issues summary

Figure 95 and Figure 96 provide a summary of the key issues across corridor 3, in both the inbound and outbound directions. These issues have been identified as key sources of delay for buses travelling along the corridor.

Figure 95: Key issues – Inbound morning peak hour (8am–9am)

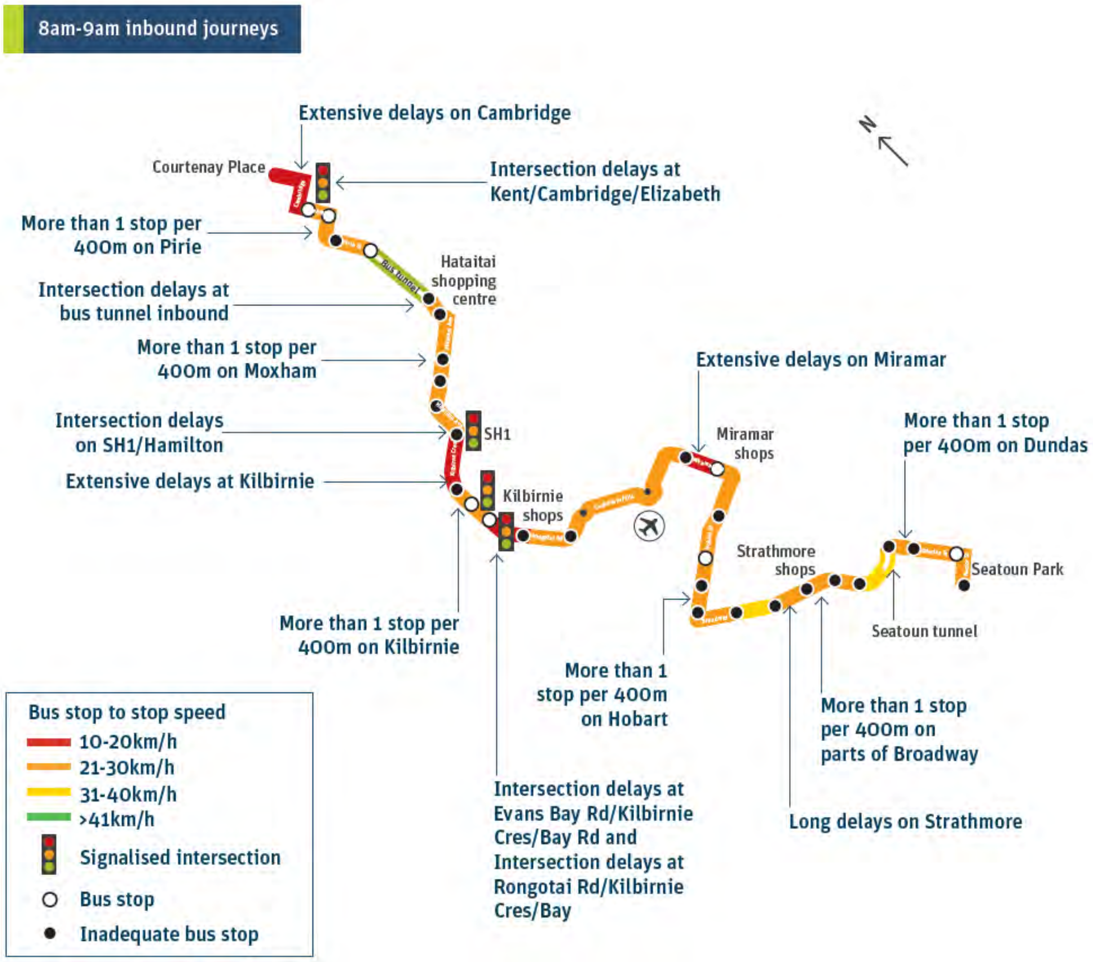
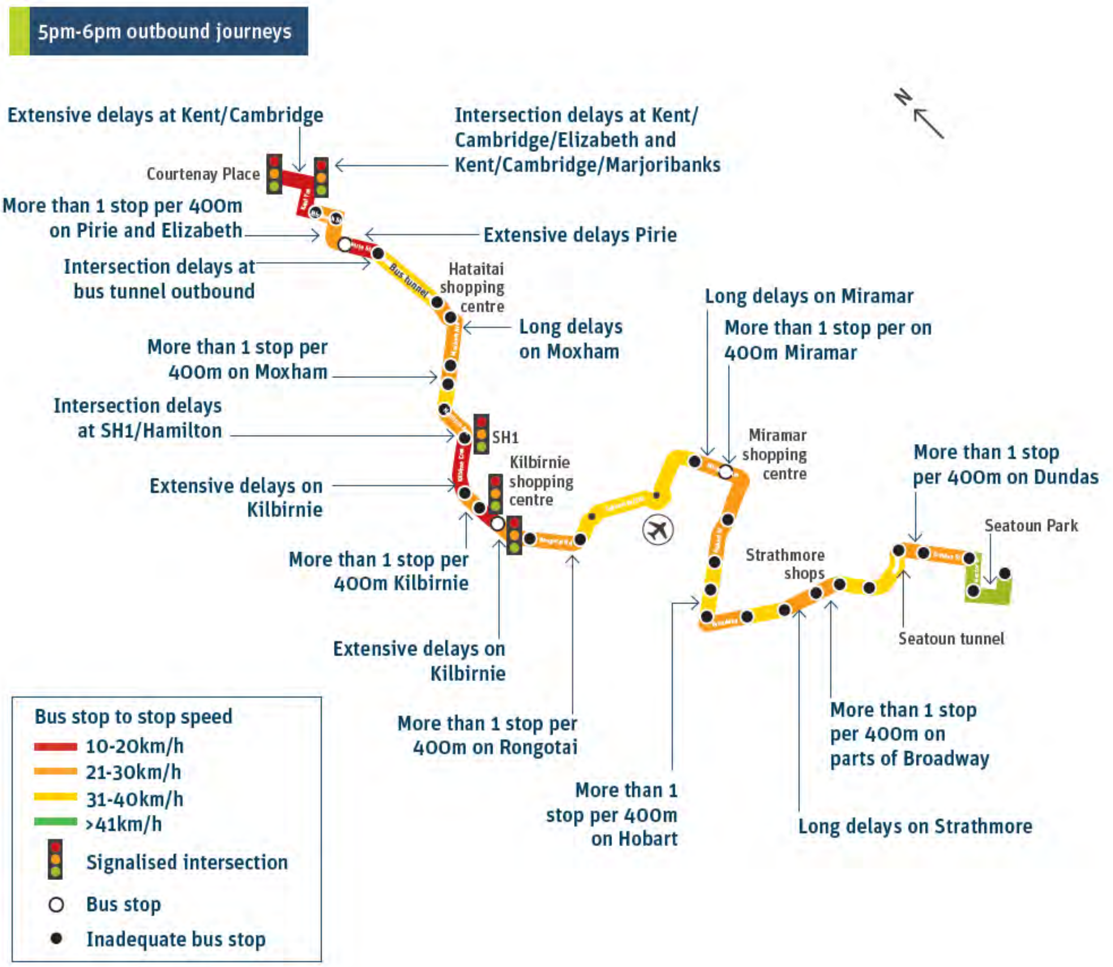


Figure 96: Key issues – Outbound afternoon peak hour (5pm–6pm)



3. Opportunities

For corridor 3, a list of opportunities to improve bus operations has been identified. These opportunities include the implementation of bus priority interventions that would be effective in addressing the documented sources of delay along the corridor and would improve bus travel times.

There are multiple levels of interventions that could be implemented across the corridor that would have varying impacts on bus journey times. For this reason, three packages of opportunities for the corridor have been selected. The package options are defined as follows:

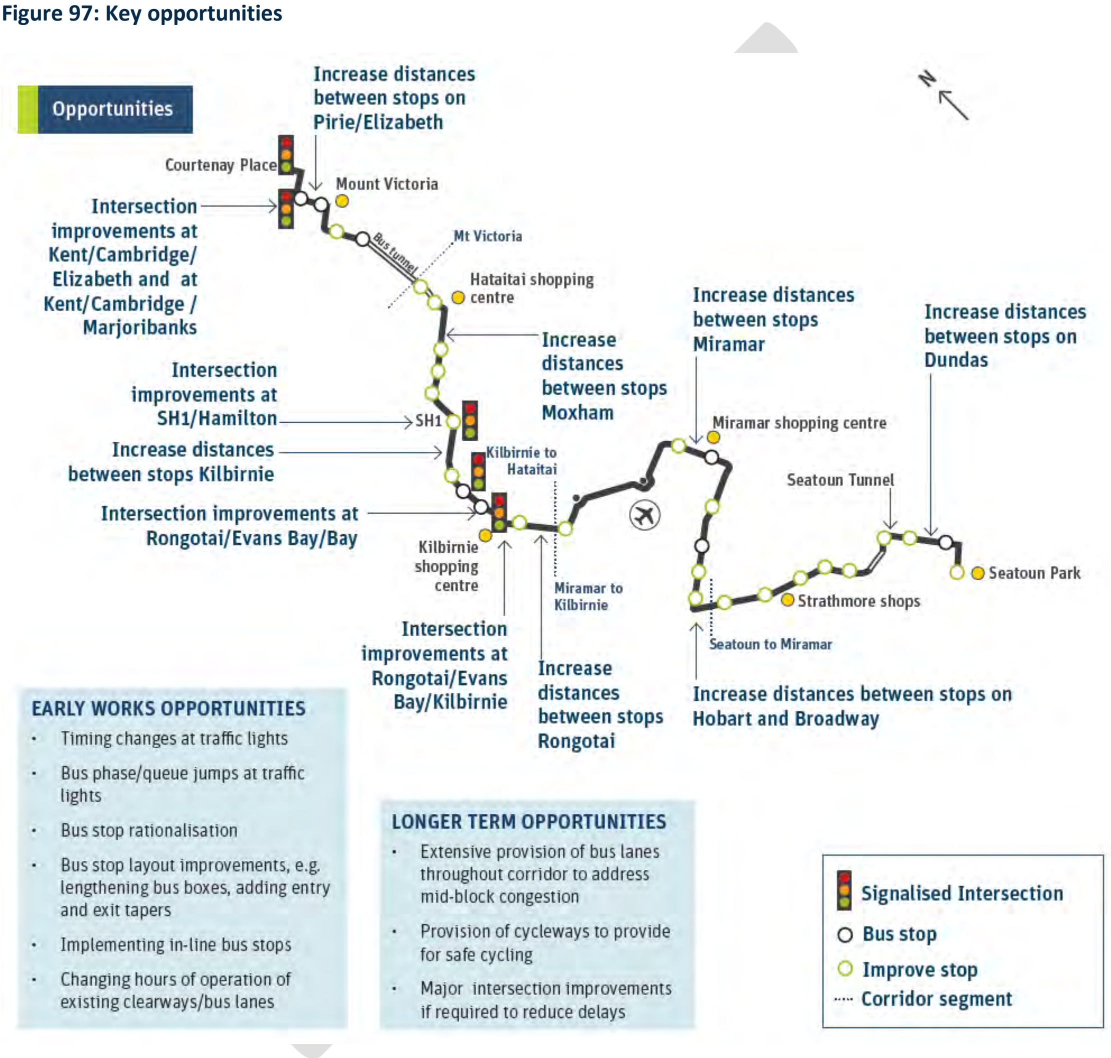
- **Option 1: fix everything**
  This option would address all problems identified on the corridor and implement any of the possible interventions that are effective at addressing the problems that have been identified on the corridor.
- **Option 2: fix the worst problems**
  This option would address only the most severe problems identified on the corridor and only implement interventions that do not involve major reconfiguration of corridor space.

- **Option 3: minimal interventions**
  This option would address only the most severe problems identified on the corridor and implement interventions that involve only minimal reconfiguration of corridor space.

A context map of the location of the key opportunities is provided in Figure 97.

For a full list of the bus priority interventions considered, the package identification process, ad a detailed description of the criteria that was used to identify opportunities on the corridor, refer to Appendix 2.

Figure 97: Key opportunities



Appendix 6 – Mt Cook to city (corridor 4): corridor analysis summary

1. Corridor overview

1.1. Context

The Mt Cook to city corridor (corridor 4) is a 2.1-kilometre-long transport corridor that connects the southern suburbs of Mt Cook and Newtown to the central city. There are three public bus services and three school services operating on the corridor. On weekdays, there are more than 6500 daily bus passenger trips along the corridor.

When travelling by bus, the journey from one end of the corridor to the other takes 12 minutes on average. There are two peak travel periods in the inbound direction: a morning peak hour at 8am–9am and an afternoon peak hour at 4pm–5pm, which is the slowest hour in the inbound direction. The average journey time to travel the length of the corridor is 15 minutes during the morning peak and 16 minutes during the afternoon peak. The outbound peak hour occurs at 5pm–6pm, when the average journey time is 16 minutes.

Table 59: Summary of key facts on the corridor

	Inbound	Outbound
Maximum daily passengers[41]	3,500	3,100
Corridor length (km)	2.1	2.1
Number of bus stops	8	7
Average bus stop spacing (m)	261	297
Average speed (km/h)	12.5	13.0
Average travel time (min)	12	12
Minimum travel time (min)	7	8
Maximum travel time (min)	16	16
Slowest weekday hour	4pm–5pm	5pm–6pm

Currently, there are no provisions for cyclists on this corridor. The Let's Get Wellington Moving programme signals investment in cycling and mass transit for the Taranaki Street section of this corridor.

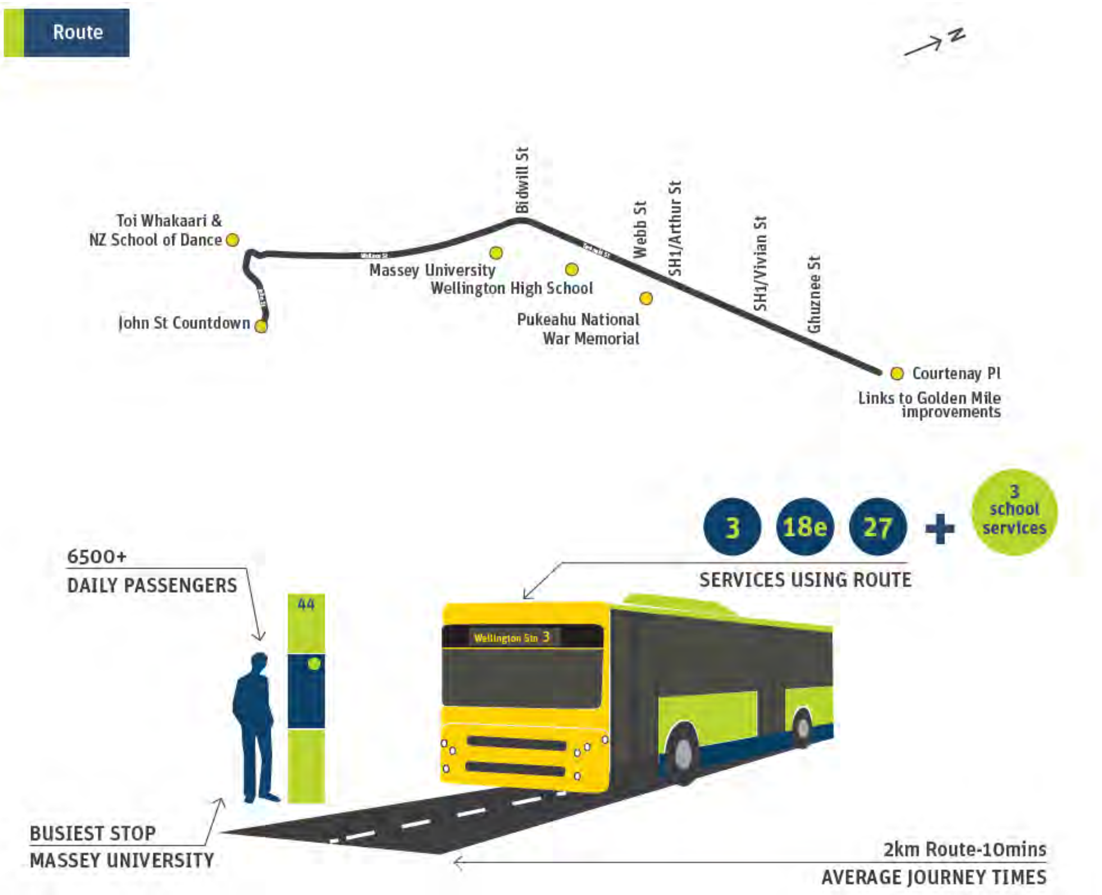
Area

There are several significant cultural and educational destinations along this route, including Toi Whakaari, New Zealand School of Dance, Massey University Wellington campus, Pukeahu National War Memorial Park, and Courtenay Place.

The land use along the corridor is principally classified as inner residential and central area zones. The corridor also passes through one institutional precinct, which is Massey University, and one area of open space, which is the Toi Whakaari / New Zealand School of Dance campus.

[41] 'Maximum daily passengers' refers to the maximum number of passengers passing through a point on the corridor. On corridor 4, this occurs on Taranaki Street, north of SH1.

Figure 98: Corridor context summary



Roads

The Mt Cook to city corridor is made up entirely of collector roads, as shown in Figure 99. There are seven signalised intersections, one signalised pedestrian crossing, and no roundabouts along the corridor.

Figure 99: Road hierarchy map[42,43]

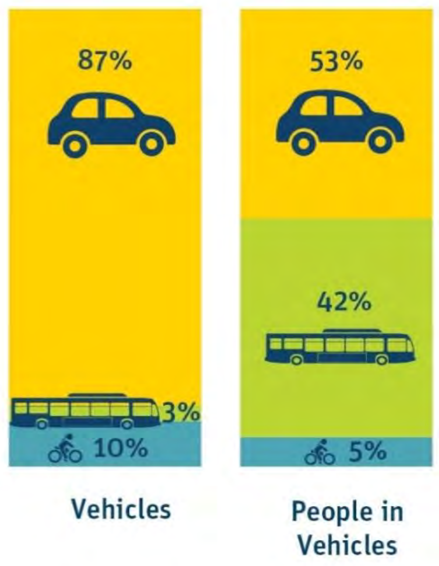
[42] Road hierarchy data sourced from WCC District Plan Map 33: Hierarchy of Roads

[43] In the WCC District Plan, the road classifications are defined as follows:

- Collector Road: roads that distribute traffic between and within local areas and form the link between principal and secondary roads

During the morning peak hour (8am–9am), the majority of vehicles on the corridor are private vehicles (87 percent), followed by bikes (10 percent). Buses make up only 3 percent of the vehicles on the corridor. However, they transport almost half of the people on the corridor (42 percent). This is indicative of the 'heavy lifting' that buses are doing to move people on this corridor. Figure 100 presents a full breakdown of the modal split on the corridor.

Figure 100: Modal split – Inbound morning peak period (8am–9am)



1.2. Bus operations

There are three public services and three school services operating on this corridor. There are nine stops in the inbound direction and eight in the outbound direction. These stops are located in fare zones 1 or 2.

There are no existing bus priority measures in place on the corridor.

Bus stop spacing

Inbound

The average bus stop spacing along the corridor in the inbound direction is 266 metres. The closest spacing is 196 metres, between John Street at Adelaide Road and the Hutchinson Road terminus.

Figure 101: Bus stop locations and spacing – Inbound

Outbound

The average bus stop spacing along the corridor in the outbound direction is 300 metres. The closest spacing is 114 metres, between the Hutchinson Road terminus and John Street at Adelaide Road.

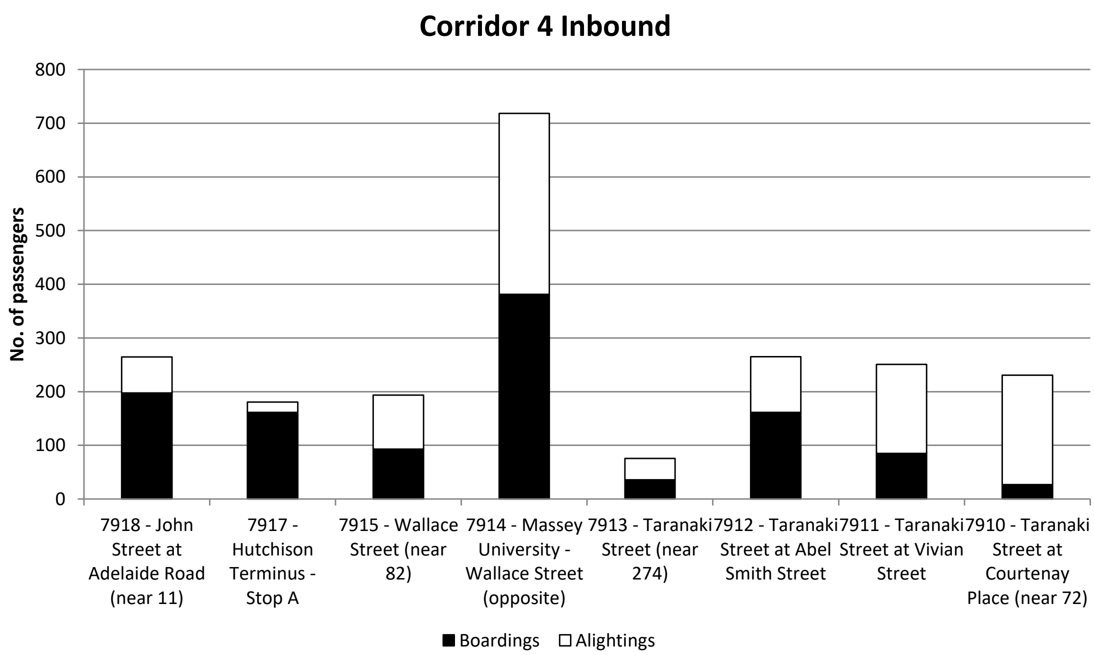
Figure 102: Bus stop locations and spacing – Outbound

Boardings and alightings

Inbound

The busiest bus stop along the corridor in the inbound direction is *Massey University – Wallace Street (opposite)*, with more than 700 daily boardings and alightings. There is one bus stop with less than 100 daily boardings and alightings, *Taranaki Street (near 274)*. Figure 103 shows the daily number of people boarding and alighting at each bus stop along the corridor in the inbound direction. This includes all bus routes that service each bus stop.

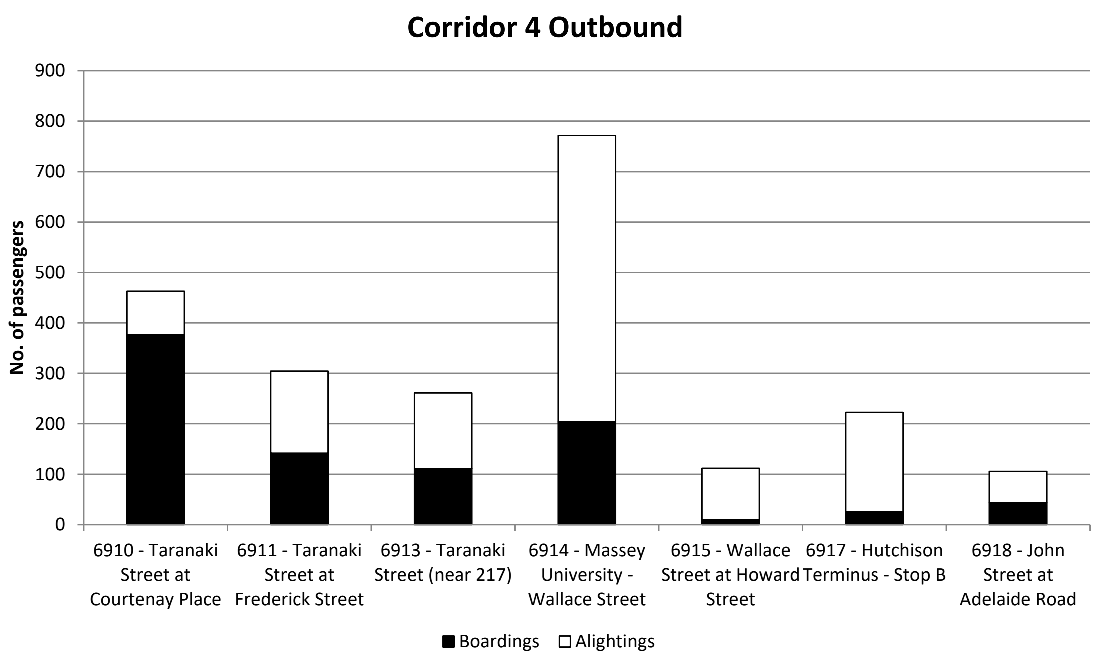
Figure 103: Daily boardings and alightings – Inbound



Outbound

The busiest stop along the corridor in the outbound direction is *Massey University – Wallace Street*, with more than 700 daily boardings and alightings. There are no bus stops with less than 100 boardings and alightings throughout the day. Figure 104 shows the daily number of people boarding and alighting at each bus stop along the corridor in the outbound direction. This includes all bus routes that service each bus stop.

Figure 104: Daily boardings and alightings – Outbound

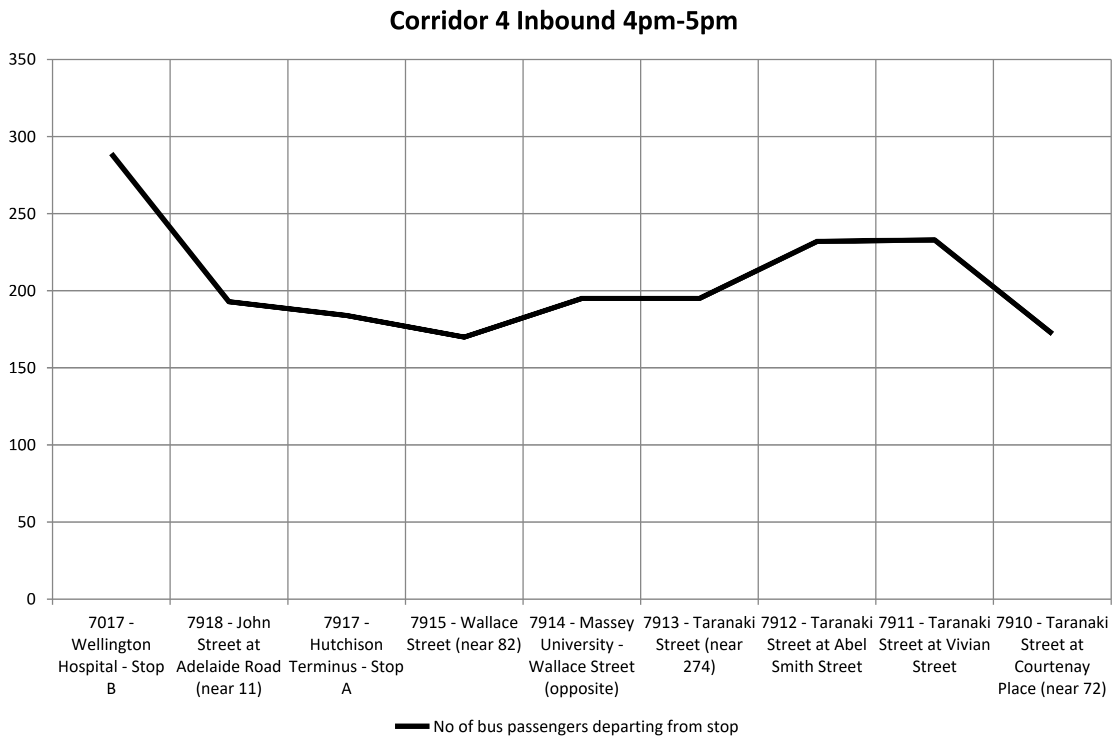


Cumulative passenger numbers

Inbound

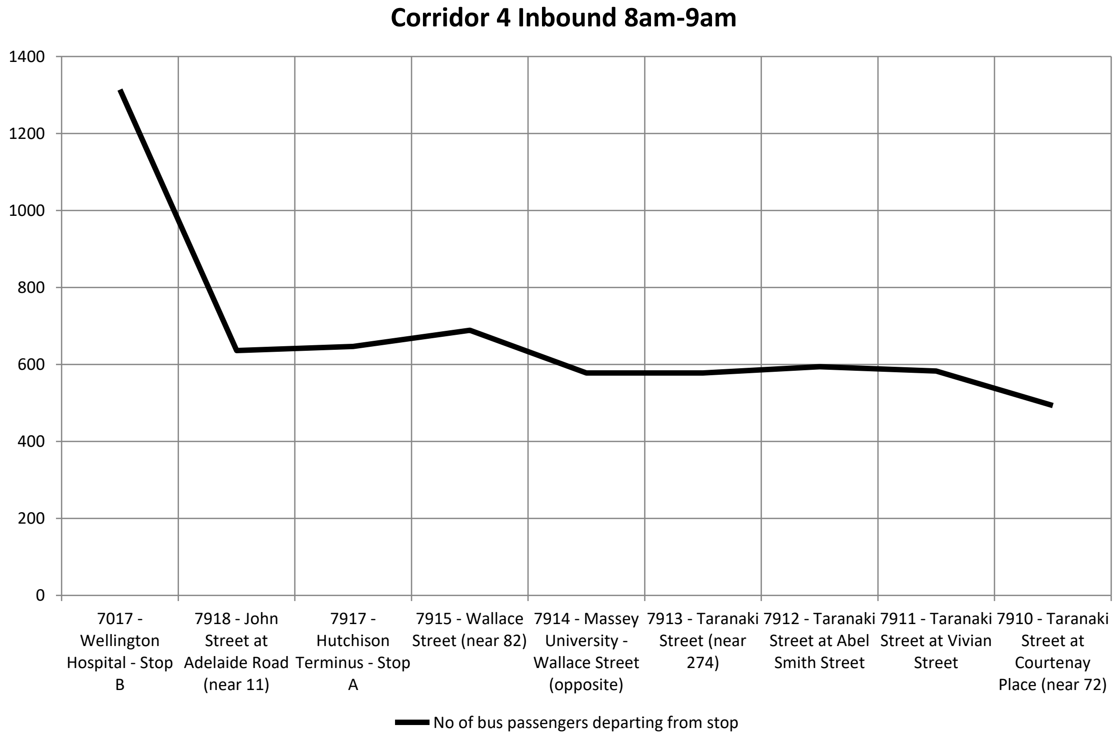
During the slowest hour on the corridor in the inbound direction (4pm–5pm), the highest passenger numbers occur at *Wellington Hospital – Stop B*, which serves more bus routes than other parts of the corridor. There is an increase in passenger numbers at Massey University, and again on Taranaki Street heading towards Courtenay Place. Figure 105 shows the average number of passengers on the bus departing from each bus stop during this hour.

Figure 105: Cumulative bus passenger load – Inbound slowest hour (4pm–5pm)



While the slowest hour along the corridor in the inbound direction is 4pm–5pm, the busiest hour for carrying passengers inbound is 8am–9am. The chart in Figure 106 shows that the highest passenger numbers occur at *Wellington Hospital – Stop B*, which serves more bus routes than other parts of the corridor. Beyond the hospital, the cumulative passenger load peaks along Wallace Street before dropping passengers off at Massey University.

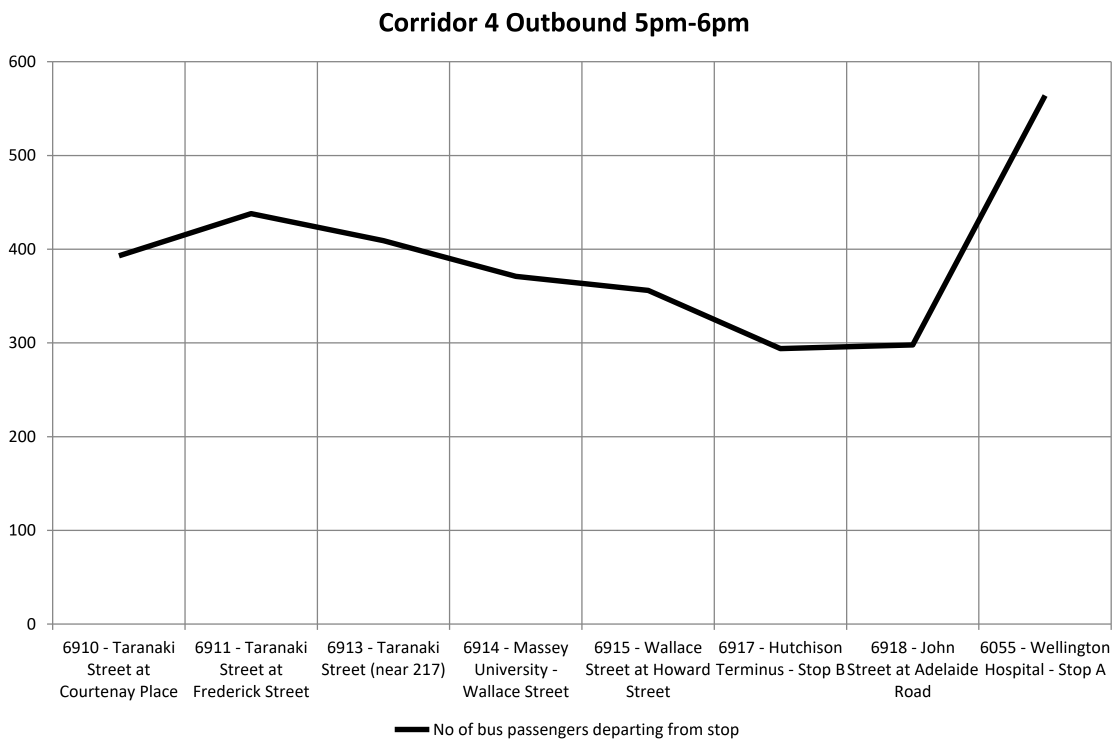
Figure 106: Cumulative bus passenger load – Inbound morning peak hour (8am–9am)



Outbound

During the outbound peak hour on the corridor, there are steadily decreasing numbers of bus passengers along the corridor until *Wellington Hospital – Stop A*. There is an increase in the number of bus passengers at the hospital bus stop, which serves multiple bus services. Figure 107 shows the average number of passengers on the bus departing from each bus stop during this hour.

Figure 107: Afternoon peak hour (5-6pm) cumulative passenger numbers – Outbound



2. Issues

2.1. Travel time

The average travel times along corridor 4 in the inbound direction are slightly faster than travel times in the outbound direction. However, there is more variability in the inbound travel times, with a nine-minute difference between the fastest and slowest times compared to less than eight minutes between the outbound travel times. Table 60 provides a summary of the average travel times on the corridor and the travel times during the slowest and fastest hours in each direction.

Table 60: Summary of travel times on the corridor

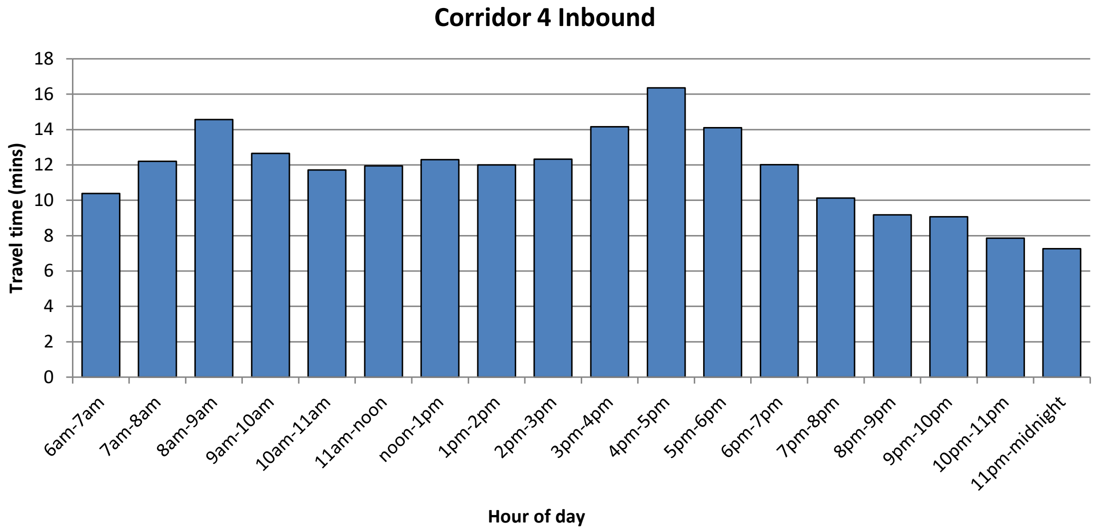
	Inbound	Outbound
Corridor length (km)	2.1	2.1
Average travel time (min)	11.7	12.2
Slowest hour	4pm–5pm	5pm–6pm
Travel time at slowest hour (min)	16.4	16.2
Fastest hour	11pm–midnight	11pm–midnight
Travel time at fastest hour (min)	7.3	8.5

Travel time by hour

Inbound

On corridor 4 in the inbound direction, the slowest hour for buses is 4pm–5pm, when it takes an average of 16.4 minutes to travel between Wellington Regional Hospital and Manners Street. This travel time is five minutes longer than the average travel time and two minutes longer than the morning peak hour (8am–9am) which is the second slowest hour and the busiest hour. The travel time during the slowest hour is more than twice as long as the travel time during the fastest hour of the day (11pm–midnight). Figure 108 shows the average time it takes for a bus to travel the length of the corridor in the inbound direction for every hour between 6am and midnight.

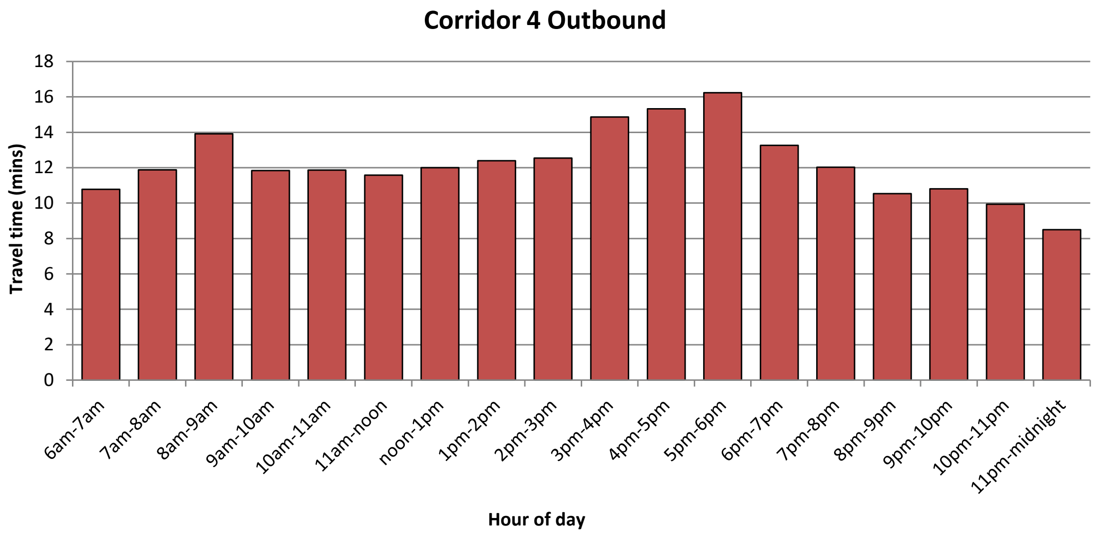
Figure 108: Travel times by hour of day – Inbound



Outbound

On corridor 4 in the outbound direction, the slowest hour for buses is 5pm–6pm, when it takes an average of 16.2 minutes to travel between Manners Street and Wellington Regional Hospital. The peak travel time is almost twice as long as the travel time during the slowest hour of the day (11pm–midnight). Figure 108 shows the average time it takes for a bus to travel the length of the corridor in the outbound direction for every hour between 6am and midnight.

Figure 109: Travel times by hour of day – Outbound

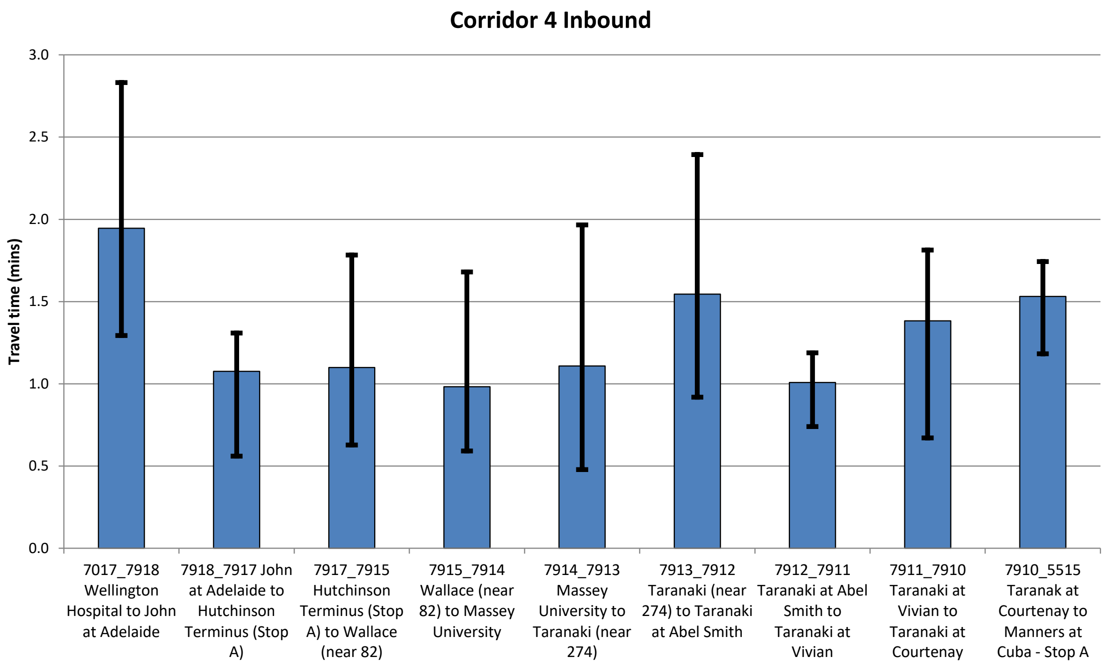


Travel time variability

Inbound

Figure 110 shows the average time it takes for a bus to travel along each segment of the corridor in the inbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

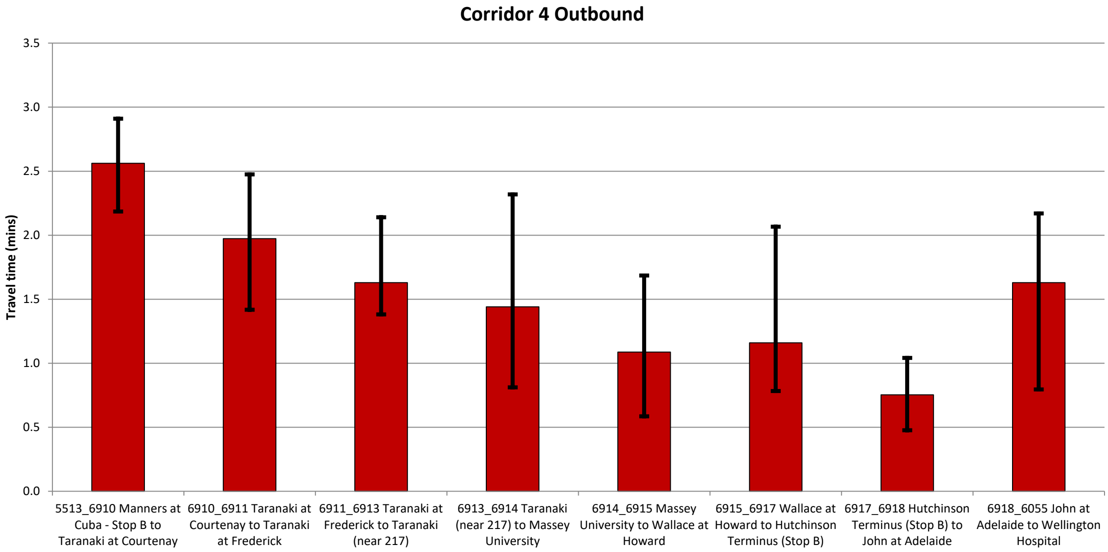
Figure 110: Variation in travel times – Inbound



Outbound

Figure 111 shows the average time it takes for a bus to travel along each segment of the corridor in the outbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

Figure 111: Variation in travel times – Outbound



Bus operating speeds and dwell time delay

The maps below show the average speeds at which buses operate along the corridor and the average time buses dwell at bus stops during the peak hours.

Inbound

During the morning peak hour in the inbound direction (8am–9am), bus operating speeds on the corridor are slowest along sections of Wallace Street and Taranaki Street.

Figure 112: Operating speeds and dwell times – Inbound morning peak hour (8am–9am)

Outbound

During the slowest hour in the outbound direction (5pm–6pm), bus operating speeds on the corridor are slowest along sections of Wallace Street and Taranaki Street.

Figure 113: Operating speeds and dwell times – Outbound afternoon peak hour (5pm–6pm)

2.2. Bus stop audit

There are eight inbound bus stops between John Street and the northern end of Taranaki Street. There are seven outbound bus stops between the northern end of Taranaki Street and John Street.

Of these bus stops, 12 are off-line stops, all of them are of sufficient length to accommodate a bus, and three do not have sufficient entry and / or exit tapers for buses to easily manoeuvre into and out of the stop. Such issues can lead to increased dwell times as passengers have to make awkward movements to get on and off the bus. This is particularly so for mobility-impaired pedestrians, as well as for the young, elderly, and people with prams or carrying other heavy or bulky items.

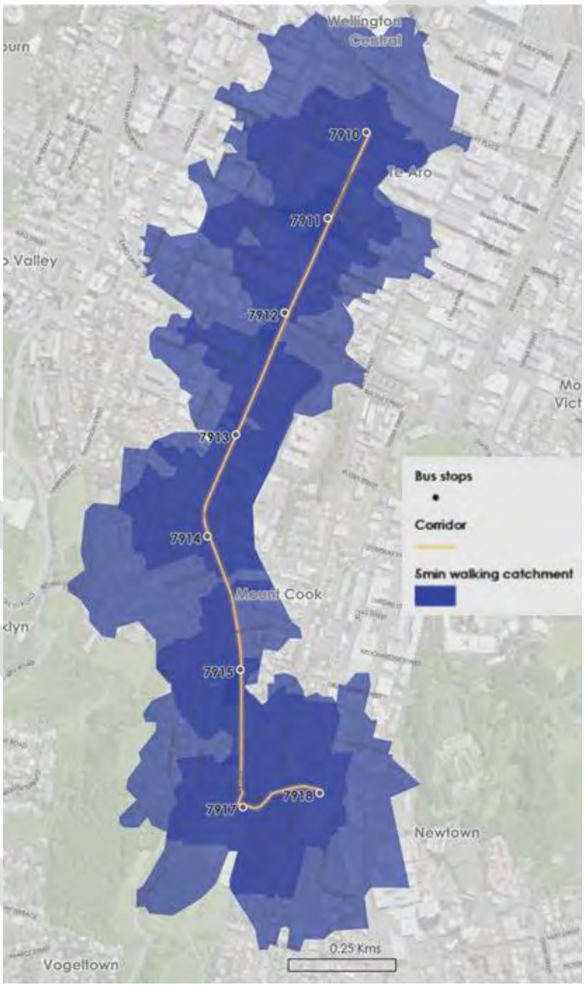
Table 61: Bus stop details[44]

	Number of bus stops	
	Inbound	Outbound
Total number of bus stops	8	7
Number of off-line bus stops	7	5
Number of bus boxes with insufficient length (<15m)	0	0
Number of bus stops missing tapers	3	0

Bus stop walking catchments

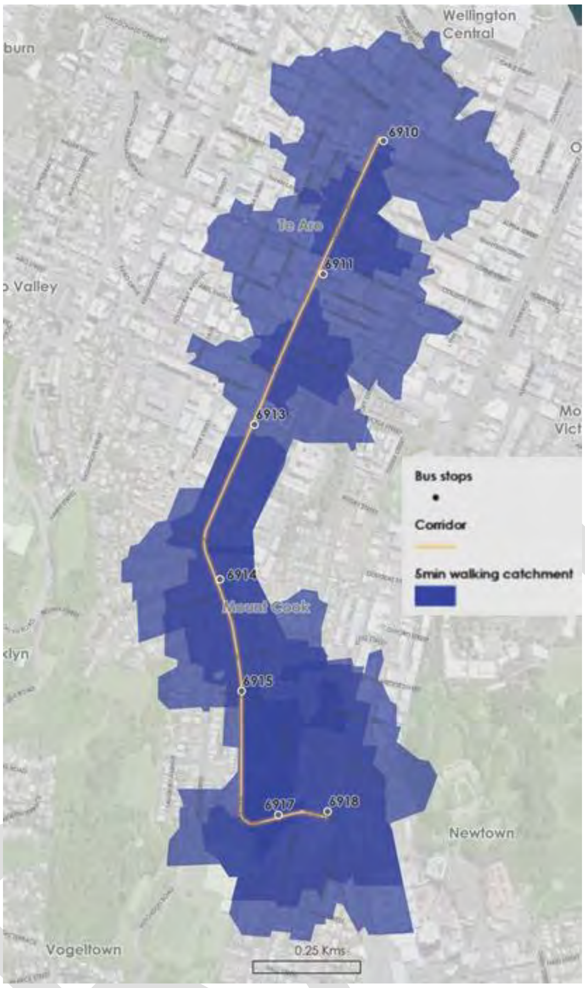
The following maps show the areas that are within a five-minute walk of the bus stops on the corridor. The darker blue areas represent where the catchments of multiple bus stops overlap.

Figure 114: Bus stop catchment – Inbound



[44] Note that the WCC Transport and Infrastructure team is currently working through a list of bus stop improvements, which includes marking out standard bus lengths and entry/exit tapers.

Figure 115: Bus stop catchment – Outbound



2.3. Sources of delay

Percentage delay

The delay that buses experience during the peak hours and slowest hours of travel have been analysed to estimate a breakdown in the sources of delay. Delay is defined as the extra running time of buses, beyond an estimated unimpeded running time. For a full breakdown of how unimpeded running time and delay is estimated, refer to Appendix 2.

To understand the sources of bus delays on the corridor, estimated delays have been decomposed into seven causes:

- long dwell times
- close bus stop spacing
- congestion at bus stops
- congestion at traffic lights
- narrow traffic lanes
- traffic signal delays
- other, which includes delay due to mid-block traffic congestion, un-signalised intersections, hills and corners, roundabouts, and side friction from parking.

Note that in the commentary in the following sections, 'traffic lights' refers to the combination of 'traffic signal delays' and 'congestion at traffic lights'.

Inbound

During the slowest hour in the inbound direction (4pm–5pm), the delay along corridor 4 results in an average bus travel time that is more than three times as long as the estimated unimpeded running time.

Table 62: Theoretical versus actual travel time – Inbound slowest hour (4pm–5pm)

Estimated unimpeded travel time	4.8 minutes
Delay	11.5 minutes
Total travel time	16.4 minutes

During this hour, most of the delay can be attributed to the 'other' category and traffic lights. There is 4.9 minutes of delay attributable to 'other' reasons. Given the traffic volumes at this time, this is most likely to be delay due to mid-block congestion. However, other drivers completing parking manoeuvres or turning into side streets and driveways may also be a contributing factor.

Traffic lights add another 4.4 minutes to the running time of buses in the inbound direction. A full breakdown of the sources of delay experienced by buses travelling in the inbound direction during the slowest hour (4pm–5pm) is provided in Figure 116 and Table 63.

Figure 116: Sources of delay – Inbound slowest hour (4pm–5pm)

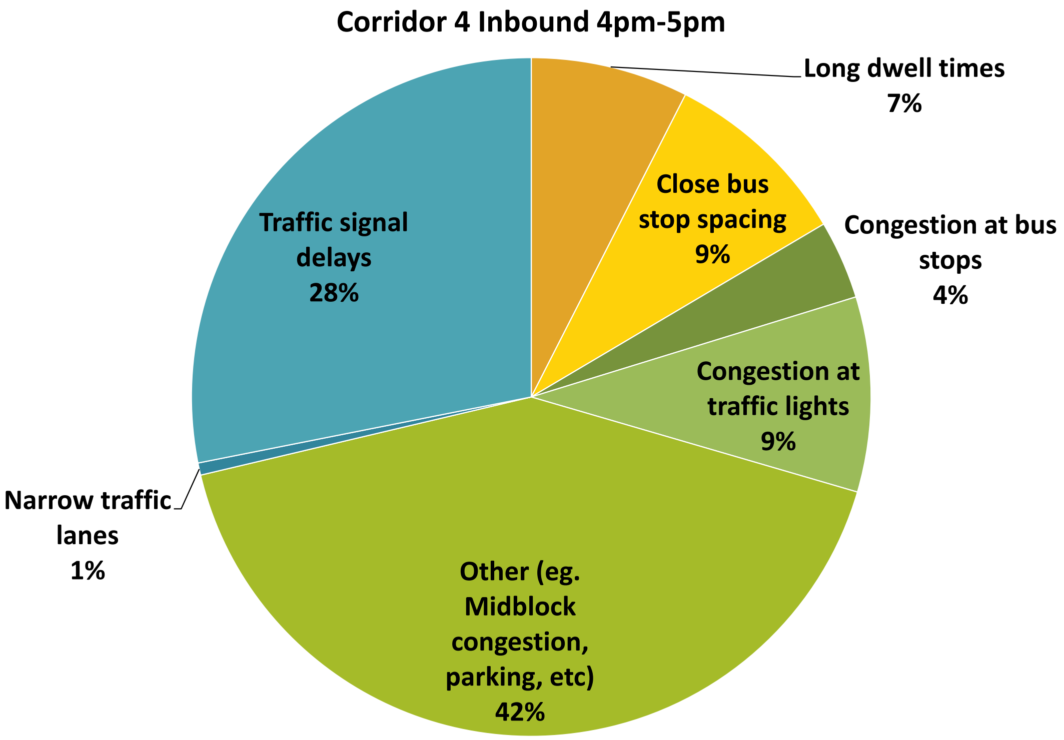


Table 63: Estimated minutes of delay by source – Inbound slowest hour (4pm–5pm)

	Minutes added (delay)	Percentage of delay
Long dwell times	0.9	7%
Close bus stop spacing	1.1	9%
Congestion at bus stops	0.4	4%
Congestion at traffic lights	1.1	9%
Narrow traffic lanes	0.1	1%
Traffic signal delays	3.3	28%
Other	4.9	42%

During the morning peak hour (8am–9am), when the passenger numbers are highest in the inbound direction, travel times are almost two minutes faster than during the slowest inbound hour (4pm–5pm). The majority of this difference in delay can be attributed to 'other' sources of delay, which add only 3.4 minutes to the travel time during the morning peak hour (compared to 4.9 minutes during the slowest hour, 4pm–5pm). A full breakdown of the sources of delay experienced by buses travelling in the inbound direction during the peak hour (8am–9am) is provided in Figure 117 and Table 65.

Table 64: Theoretical versus actual travel time – Inbound morning peak hour (8am–9am)

Estimated unimpeded travel time	4.9 minutes
Delay	9.7 minutes
Total travel time (8-9am)	14.6 minutes

Figure 117: Sources of delay – Inbound morning peak hour (8am–9am)

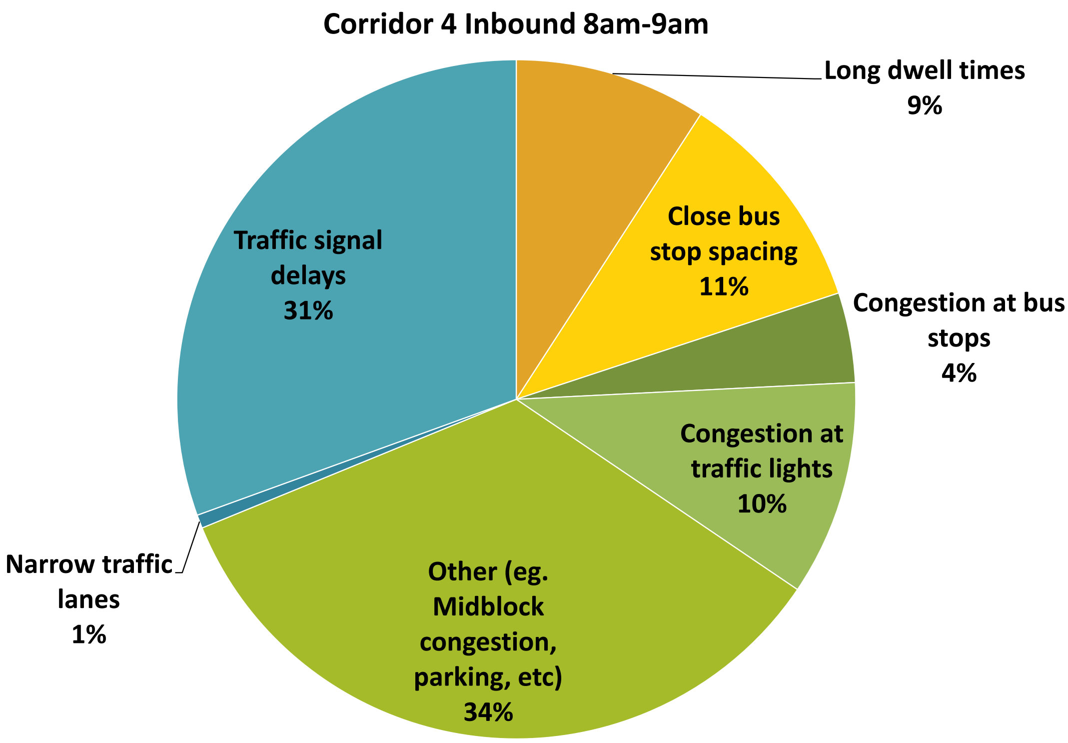


Table 65: Estimated minutes of delay by source – Inbound morning peak hour (8am–9am)

Inbound 8-9am	Minutes added (delay)	Percentage of delay
Long dwell times	0.9	9%
Close bus stop spacing	1.1	11%
Congestion at bus stops	0.4	4%
Congestion at traffic lights	1.0	10%
Narrow traffic lanes	0.1	1%
Traffic signal delays	3.0	31%
Other	3.4	34%

Outbound

During the peak hour in the outbound direction (5pm–6pm), the delay along corridor 4 results in a bus travel time that is more than three times as long as the estimated unimpeded running time.

Table 66: Theoretical versus actual travel time – afternoon peak hour (5-6pm) outbound

Estimated unimpeded travel time	5.3 minutes
Delay	11 minutes
Total travel time (5-6pm)	16.2 minutes

During this hour, the 'other' category adds a total of 4.7 minutes of delay to the running time of buses in the outbound direction. Given the traffic volumes at this time, this is most likely to be traffic congestion, even though bus lanes are in operation on parts of the corridor at this time. Other drivers completing parking manoeuvres or turning into side streets and driveways may also be a contributing factor. Another 3.3 minutes of delay is attributable to traffic lights and 1.6 minutes is caused by long dwell times. A full breakdown of the sources of delay experienced by buses travelling in the outbound direction during the slowest hour (5pm–6pm) is provided in Figure 118 and Table 67.

Figure 118: Sources of delay – Outbound afternoon peak hour (5pm–6pm)

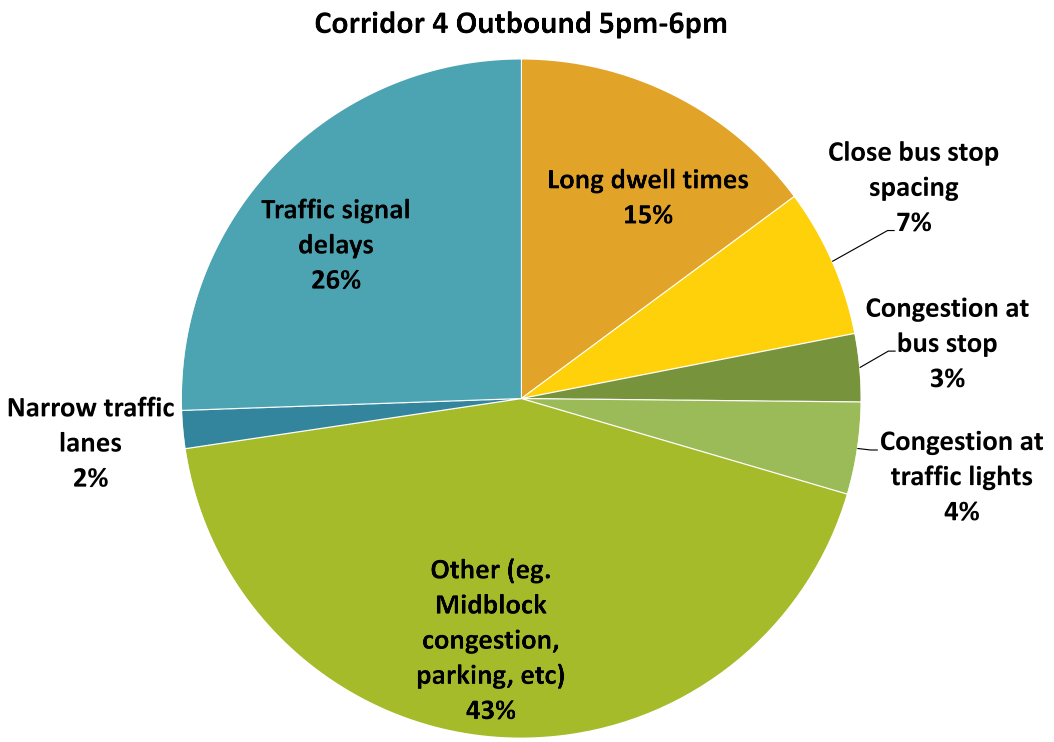


Table 67: Estimated minutes of delay by source – Outbound afternoon peak hour (5pm–6pm)

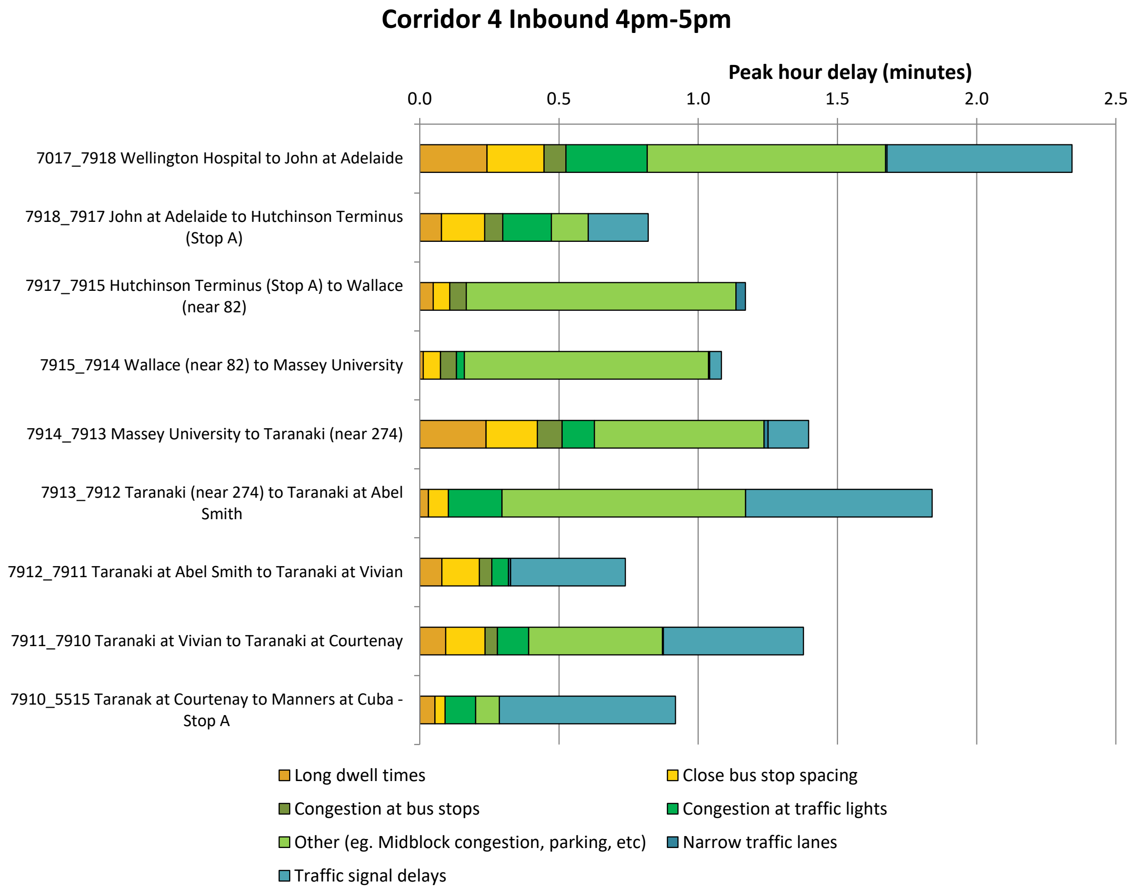
Outbound 5-6pm	Minutes added (delay)	Percentage of delay
Long dwell times	1.6	15%
Close bus stop spacing	0.8	7%
Congestion at bus stops	0.4	3%
Congestion at traffic lights	0.5	4%
Narrow traffic lanes	0.2	2%
Traffic signal delays	2.8	26%
Other	4.7	43%

Delay breakdown by segment

Inbound

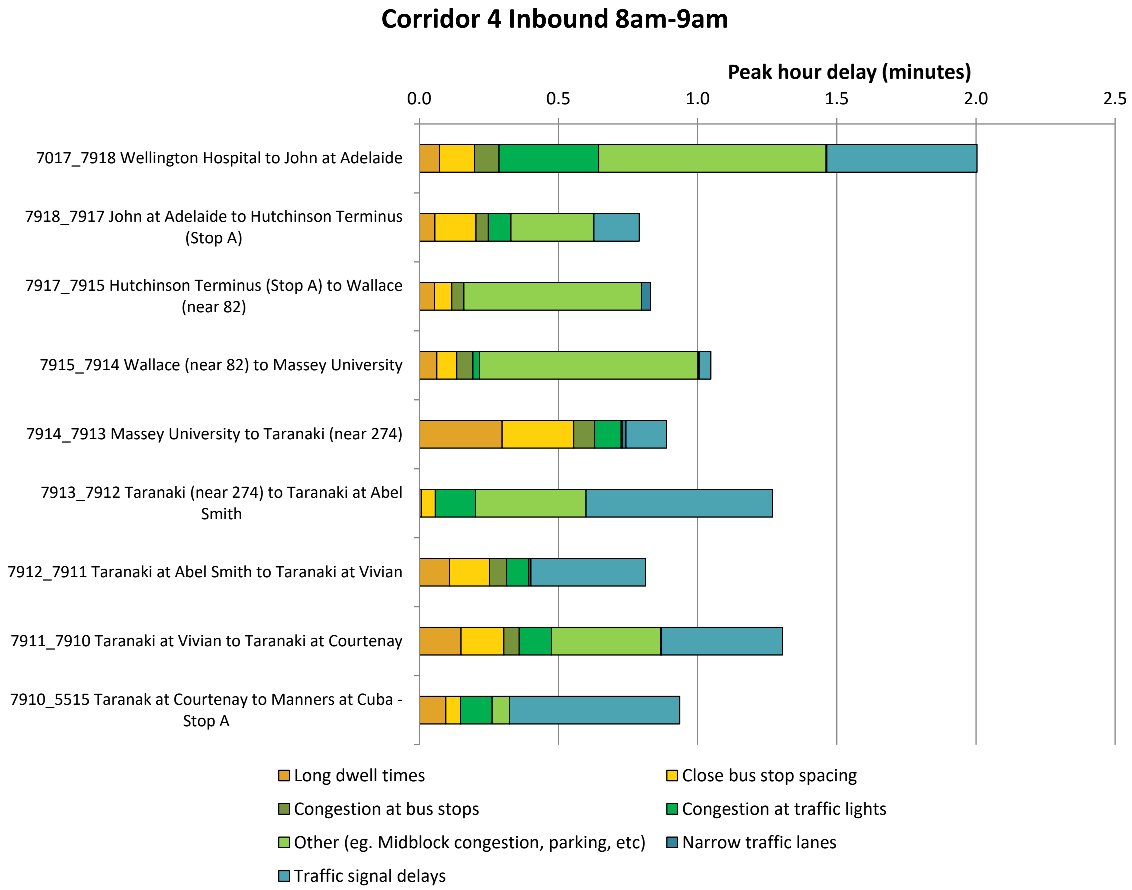
During the slowest hour for buses travelling in the inbound direction on the corridor (4pm–5pm), the segment experiencing the most delay is on Riddiford Street, between the hospital and Adelaide Road, where buses experience more than two minutes of delay (over a 220 metre-long segment). Most segments on the corridor (all but three) experience more than one minute of delay. Figure 119 provides a breakdown of the sources of delay on corridor 4 by segment for buses travelling in the inbound direction during this hour.

Figure 119: Sources of delay by segment – Inbound slowest hour (4pm–5pm)



The most significant variation in delay between the morning peak hour (8am–9am) and the slowest hour (4pm–5pm) in the inbound direction occurs due to 'other' reasons on Taranaki Street, between Hankey Street and Abel Smith Street. Most of the other segments have a similar travel time during both hours. Figure 120 provides a breakdown of the sources of delay on corridor 4 by segment for buses travelling in the inbound direction during the morning peak hour (8am–9am).

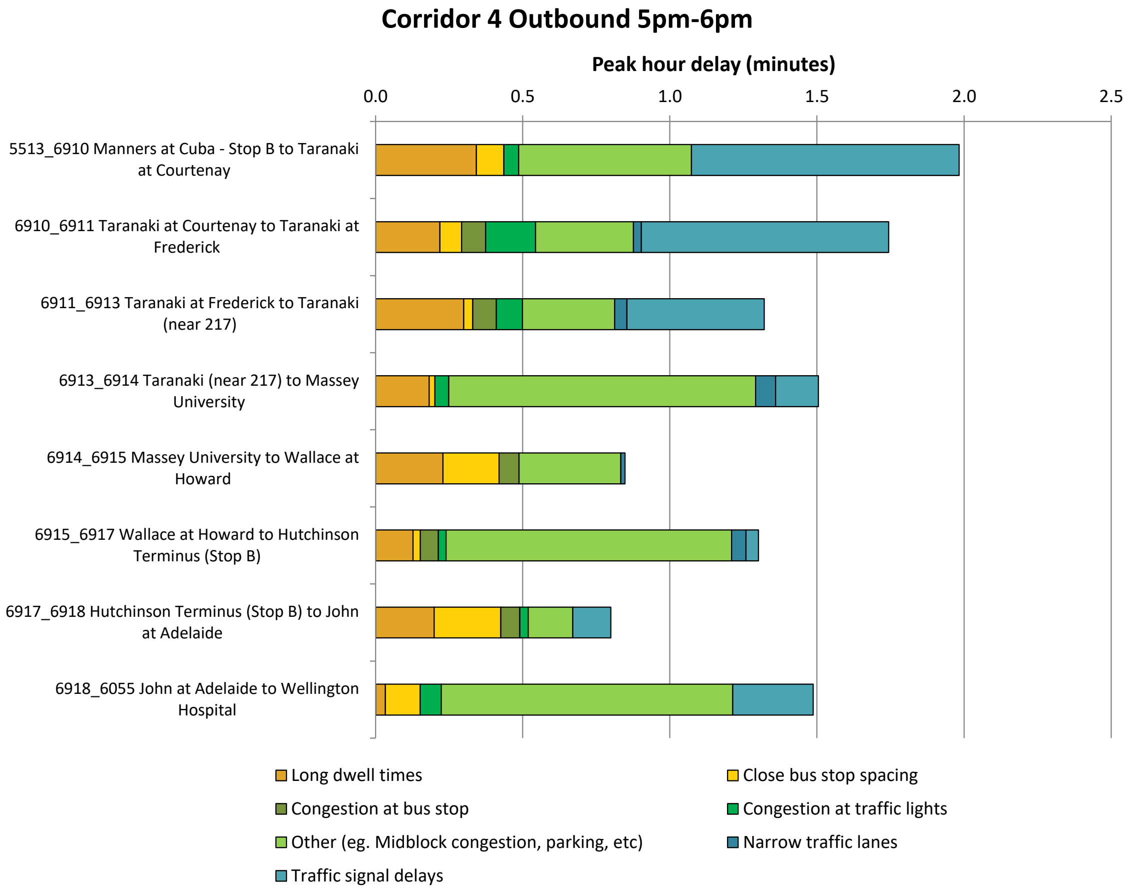
Figure 120: Sources of delay by segment – Inbound morning peak hour (8am–9am)



Outbound

During the peak hour for buses travelling in the outbound direction on the corridor (5pm–6pm), the segments experiencing the most delay are the segments on Tarankai Street, between Manners Street and Abel Smith Street. Figure 121 provides a breakdown of the sources of delay on corridor 4 by segment for buses travelling in the outbound direction during this hour.

Figure 121: Sources of delay by segment – Outbound afternoon peak hour (5pm–6pm)



2.4. Issues summary

Figure 122 and Figure 123 provide a summary of the key issues across corridor 4 in both the inbound and outbound directions. These issues have been identified as key sources of delay for buses travelling along the corridor.

Figure 122: Key issues – Inbound morning peak hour (8am–9am)

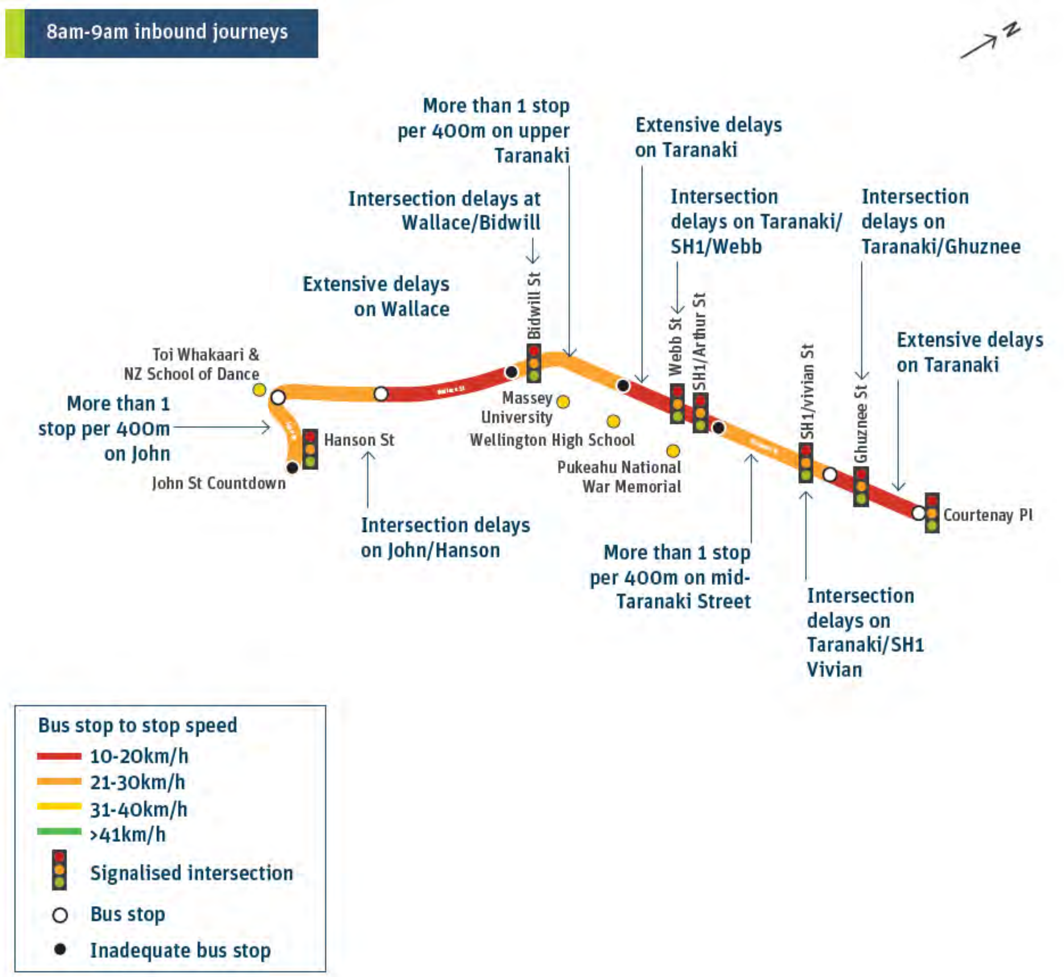
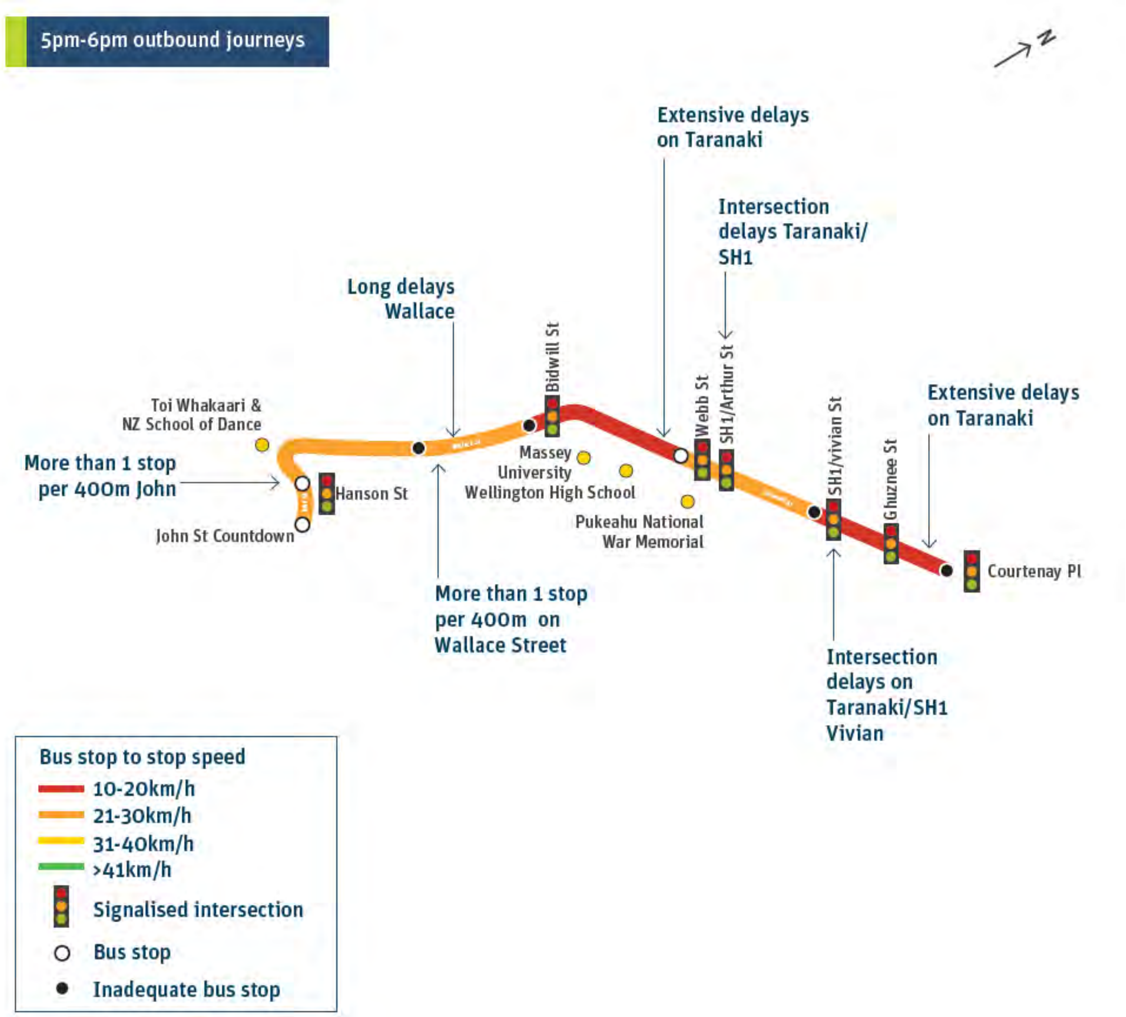


Figure 123: Key issues – Outbound afternoon peak hour (5pm–6pm)



3. Opportunities

For corridor 4, a list of opportunities to improve bus operations has been identified. These opportunities include the implementation of bus priority interventions that would be effective in addressing the documented sources of delay along the corridor and would improve bus travel times.

There are multiple levels of interventions that could be implemented across the corridor that would have varying impacts on bus journey times. For this reason, three packages of opportunities for the corridor have been selected. The package options are defined as follows:

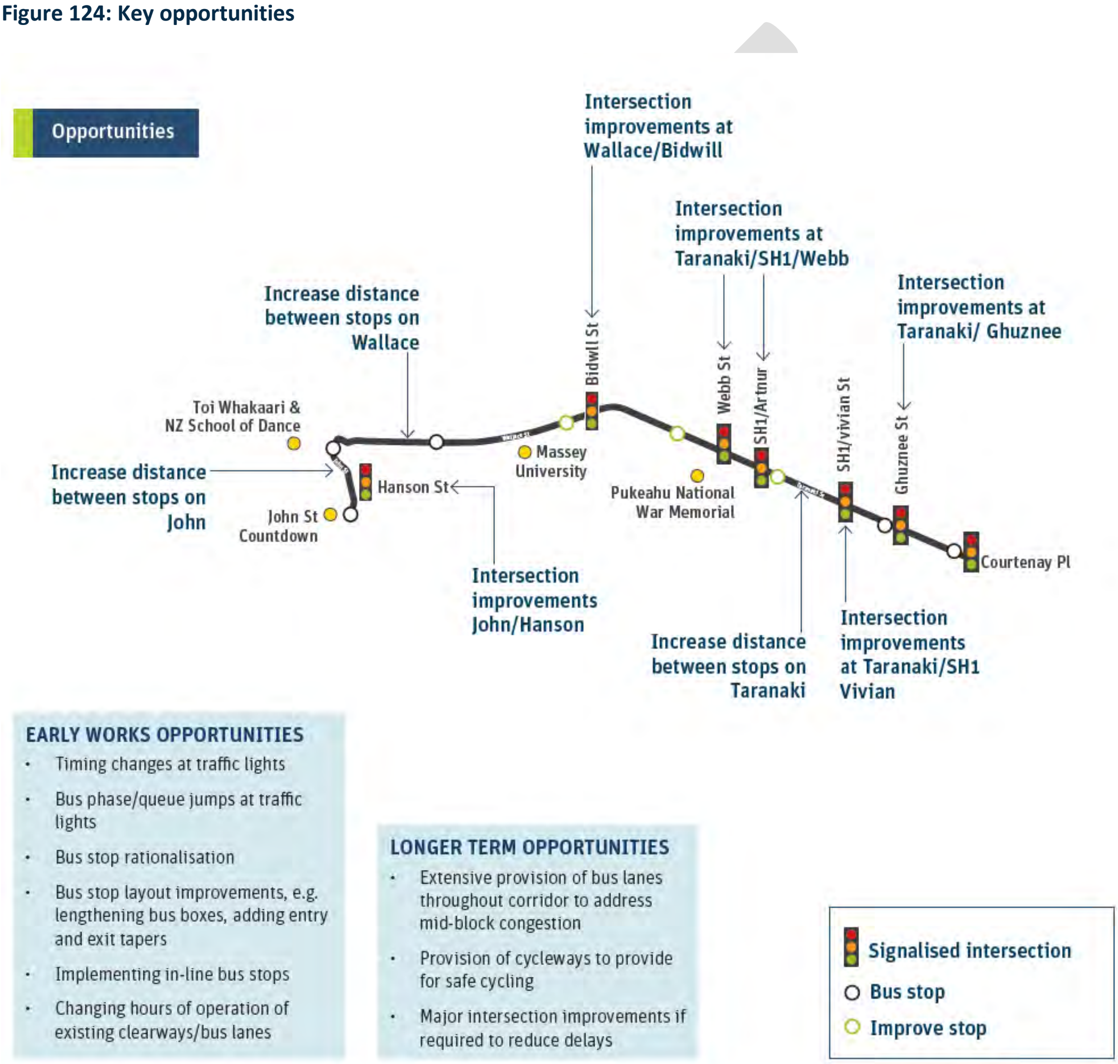
- **Option 1: fix everything**
  This option would address all problems identified on the corridor and implement any of the possible interventions that are effective at addressing the problems that have been identified on the corridor.
- **Option 2: fix the worst problems**
  This option would address only the most severe problems identified on the corridor and only implement interventions that do not involve major reconfiguration of corridor space.

- **Option 3: minimal interventions**
  This option would address only the most severe problems identified on the corridor and implement interventions that involve only minimal reconfiguration of corridor space.

A context map of the location of the key opportunities is provided in Figure 124.

For a full list of the bus priority interventions considered, the package identification process, ad a detailed description of the criteria that was used to identify opportunities on the corridor, refer to Appendix 2.

Figure 124: Key opportunities



Appendix 7 – Kelburn to city (corridor 5): corridor analysis summary

1. Corridor overview

1.1. Context

The Kelburn to city corridor (corridor 5) is a 2.3-kilometre-long transport corridor that connects the western suburb of Kelburn to the central city. There are eight public bus services and nine school services operating on this corridor. On weekdays, there are more than 6500 daily bus passenger trips along the corridor.

When travelling by bus, the journey from one end of the corridor to the other takes seven minutes on average. The inbound peak hour occurs in the morning at 8am–9am, when the average journey time is nine minutes. The outbound peak hour occurs in the afternoon at 5pm–6pm, when the average journey time is eight minutes.

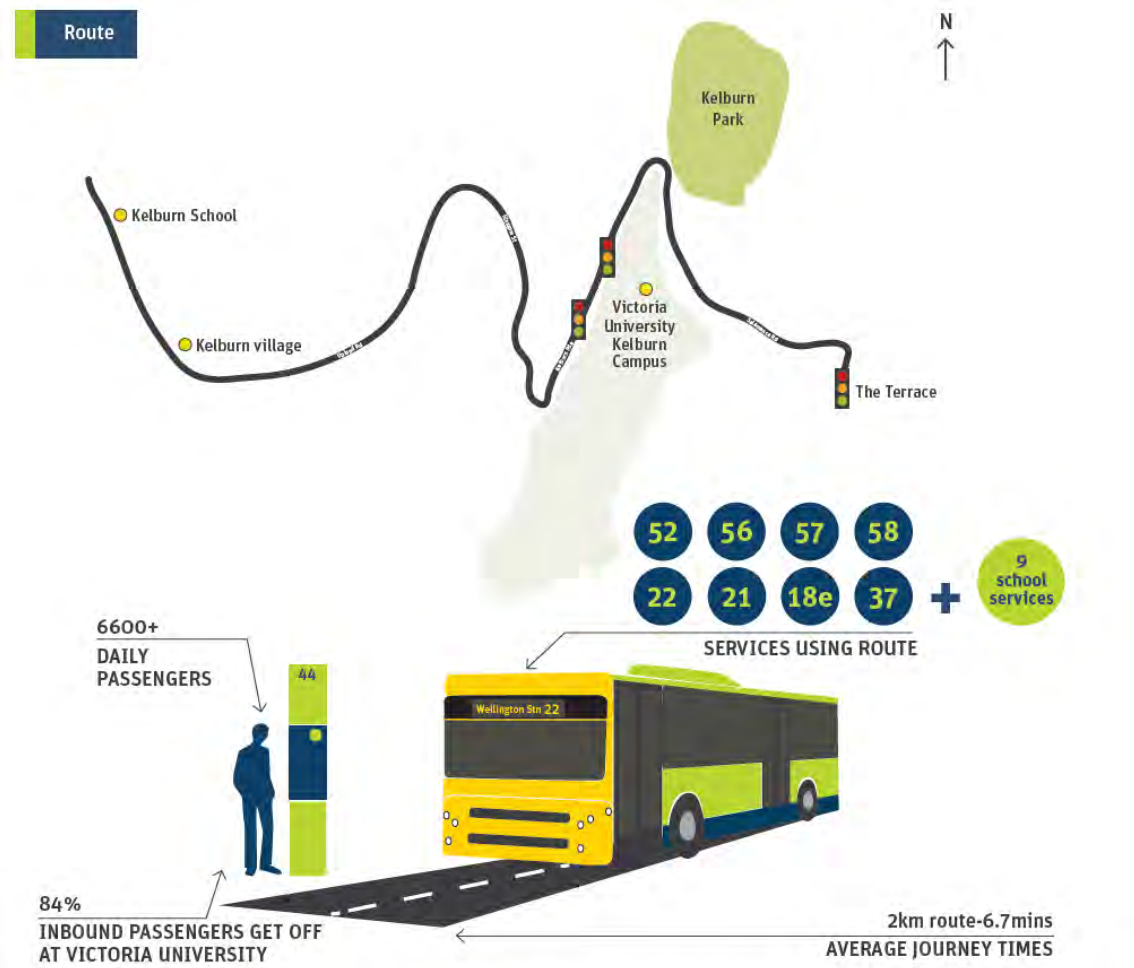
Table 68: Summary of key facts on the corridor

	Inbound	Outbound
Maximum daily passengers[45]	2,500	4,200
Corridor length (km)	2.3	2.2
Number of bus stops	5	5
Average bus stop spacing (m)	452	435
Average speed (km/h)	19.7	20.3
Average travel time (min)	7	7
Minimum travel time (min)	5	5
Maximum travel time (min)	9	8
Slowest weekday hour	8am–9am	5pm–6pm

Currently, there are no provisions for cycling on this corridor.

[45] 'Maximum daily passengers' refers to the maximum number of passengers passing through a point on the corridor. On corridor 5, this occurs on Salamanca Road.

Figure 125: Corridor context map



Area

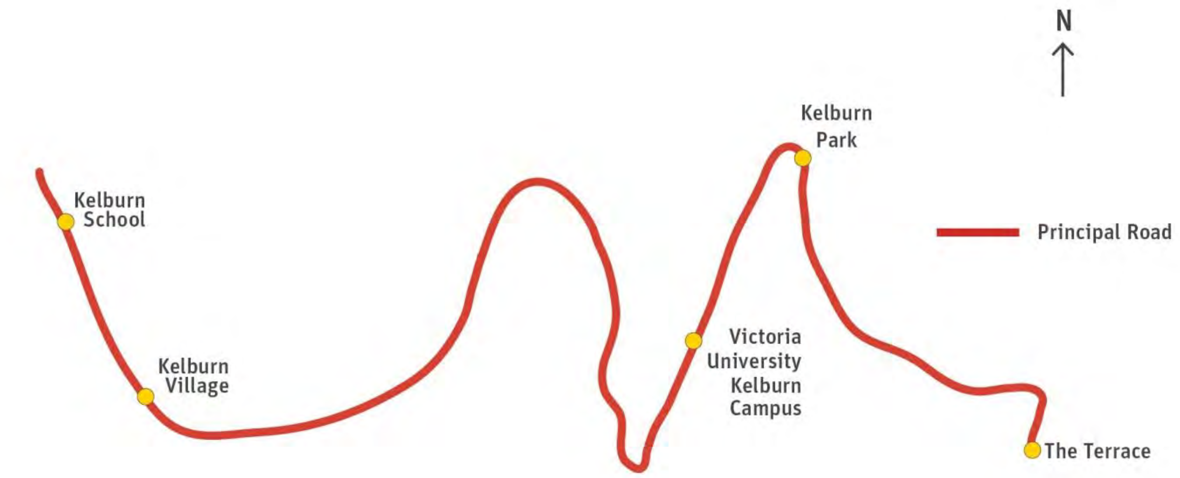
There are several significant destinations along the Kelburn to city corridor, including Victoria University of Wellington, Kelburn village, and Kelburn Park.

The land use along the corridor is principally outer residential and institutional precinct zones, with some open space and centre zones.

Roads

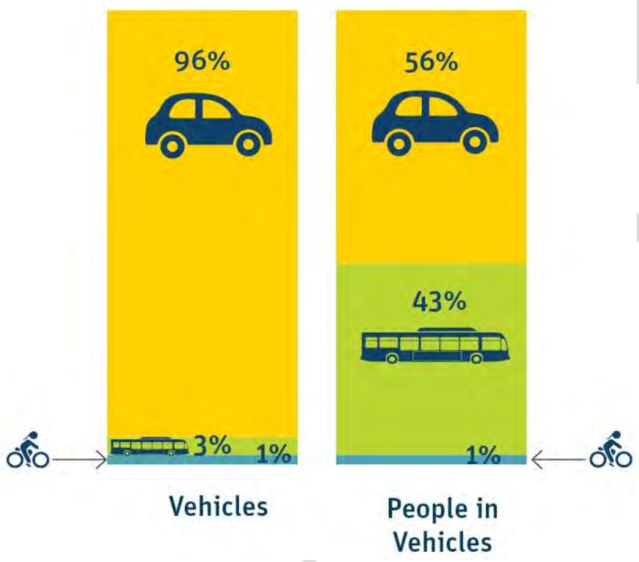
The Kelburn to city corridor is made up entirely of principal roads, as shown in Figure 126. There is one signalised intersection, two signalised pedestrian crossings, and three roundabouts along the corridor.

Figure 126: Road hierarchy map[46,47]



During the morning peak hour (8am–9am), the vast majority of vehicles on the corridor are private vehicles (96 percent). Buses make up only 3 percent of the vehicles on the corridor. However, they transport almost half of the people on the corridor (43 percent). This is indicative of the 'heavy lifting' that buses are doing to move people on this corridor. Figure 127 presents a full breakdown of the modal split on the corridor.

Figure 127: Modal split – Inbound morning peak period (8am–9am)



1.2. Bus operations

There are eight public bus services on this corridor and nine school services. There are five bus stops in each direction on the corridor; all of the stops are located in fare zones 1 or 2.

There are no existing bus priority measures in place on the corridor.

[46] Road hierarchy data sourced from WCC District Plan Map 33: Hierarchy of Roads
[47] In the WCC District Plan, the road classifications are defined as follows:

- Principal Road: roads that provide access to motorways and to arterial roads having a dominant through-traffic function and carrying the major public transport routes

Bus stop spacing

Inbound

The average bus stop spacing along the corridor in the inbound direction is 444 metres. The closest spacing is 253 metres between Kelburn Normal School and Kelburn village. This is the only spacing between bus stops that is less than 350 metres.

Figure 128: Bus stop locations and spacing – Inbound

Outbound

The average bus stop spacing along corridor 5 in the outbound direction is 435 metres. The closest spacing is 297 metres between Kelburn village and Kelburn Normal School. This is the only spacing between bus stops that is less than 300 metres.

Figure 129: Bus stop locations and spacing – Outbound

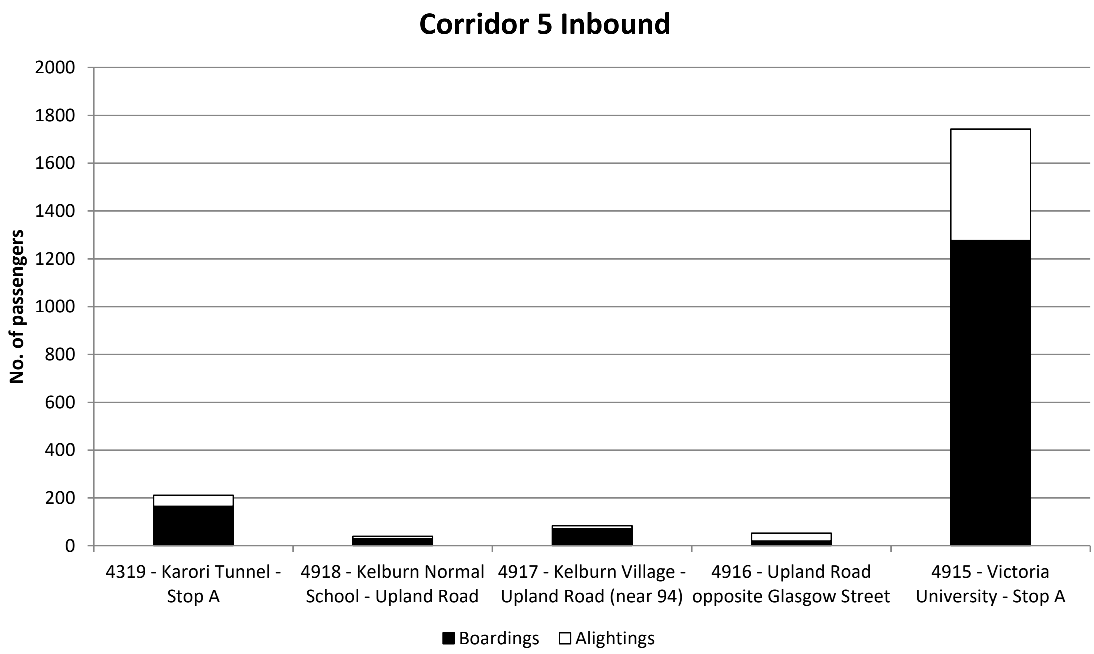
Boardings and alightings

Daily boardings and alightings are much higher in the outbound direction than in the inbound direction. This is likely due to a significant number of passengers coming from the city to Victoria University, choosing to take the bus uphill in the outbound direction but walking downhill in the inbound direction.

Inbound

The busiest bus stop along the corridor in the inbound direction is *Victoria University – Stop A*, with more than 1700 daily boardings and alightings. The other four bus stops each have fewer than 250 daily boardings and alightings. Figure 130 shows the daily number of people boarding and alighting at each bus stop along the corridor in the inbound direction. This includes all bus routes that service each bus stop.

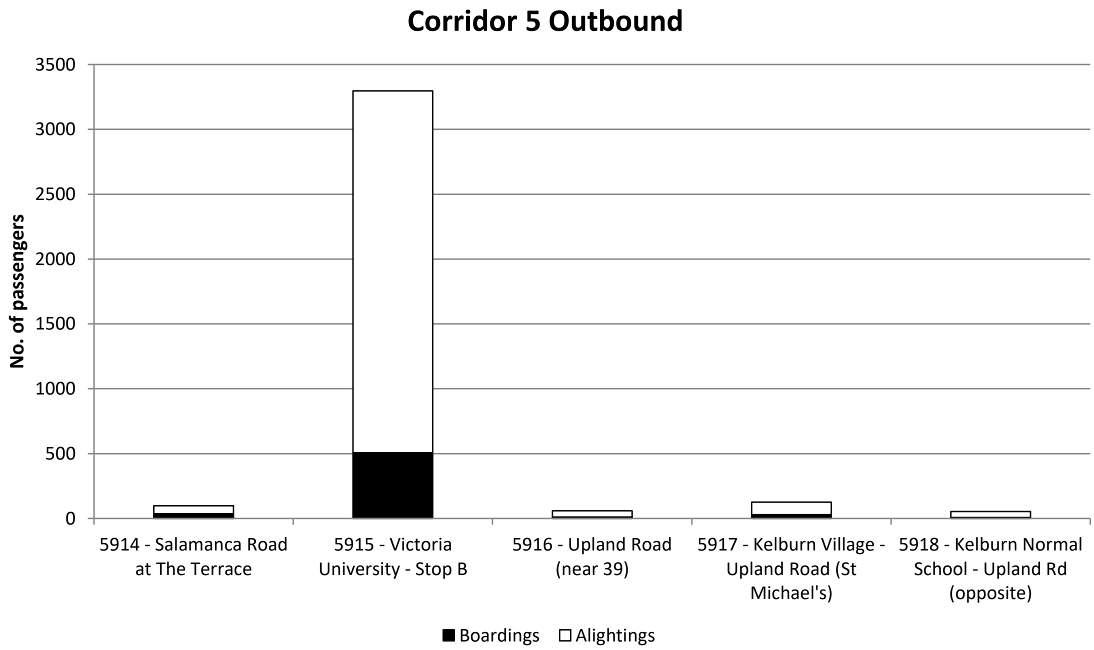
Figure 130: Daily boardings and alightings – Inbound



Outbound

The busiest stop along the corridor in the outbound direction is the last stop, *Victoria University – Stop B*, with almost 3300 daily boardings and alightings. This is the fifth busiest bus stop across the entire Wellington bus network and the second busiest bus stop for alightings. The other four bus stops on the corridor each have fewer than 150 daily boardings and alightings. Figure 131 shows the daily number of people boarding and alighting at each bus stop along the corridor in the outbound direction. This includes all bus routes that service each bus stop.

Figure 131: Daily boardings and alightings – Outbound

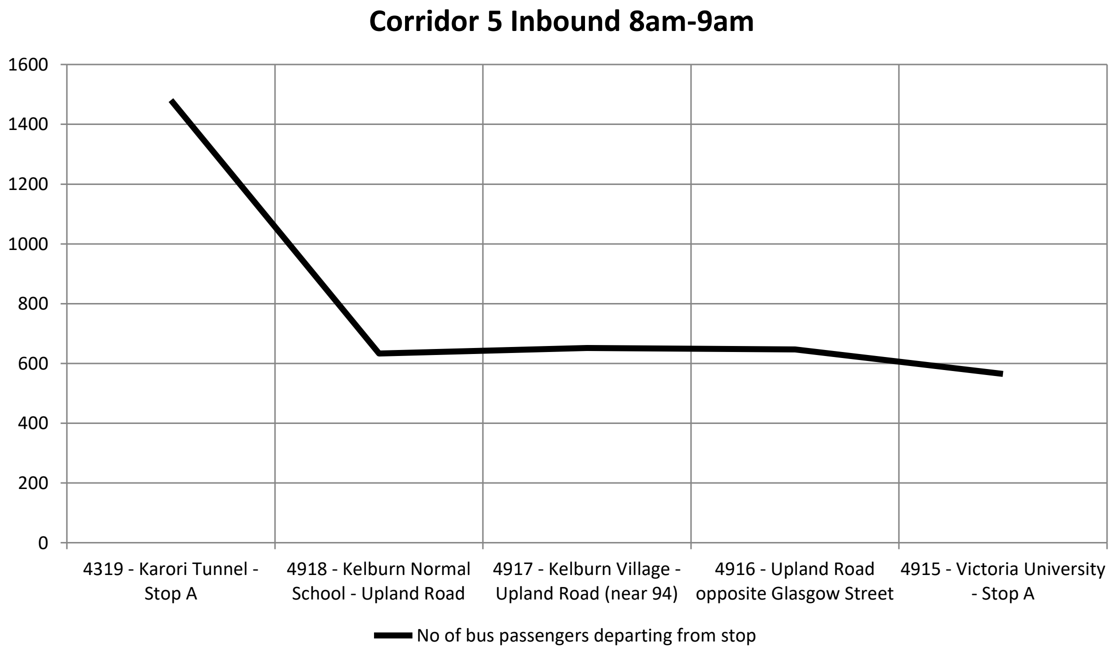


Cumulative passenger numbers

Inbound

During the inbound peak hour on the corridor (8am–9am), the highest bus passenger numbers occur at Karori Tunnel, which serves more bus routes than other parts of the corridor. Beyond the tunnel, the passenger numbers are fairly uniform until the bus stop at Victoria University. Figure 132 shows the average number of bus passengers on the bus departing from each bus stop during this hour.

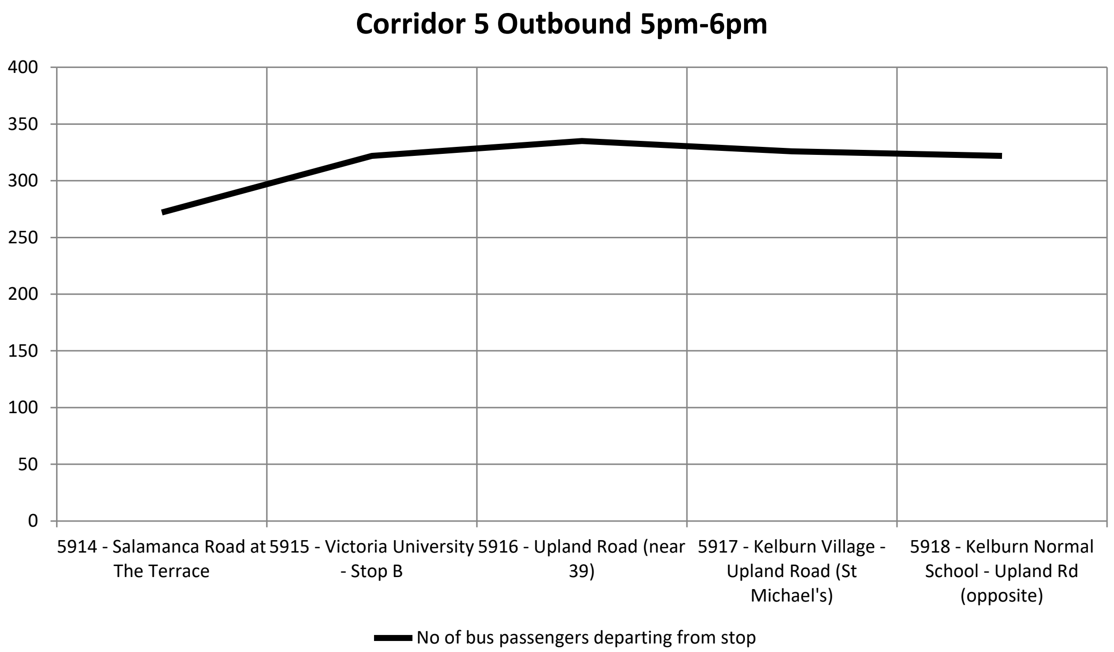
Figure 132: Cumulative bus passenger load – Inbound morning peak hour (8am–9am)



Outbound

During the outbound peak hour on the corridor (5pm–6pm), the bus passenger numbers are fairly uniform across the corridor. Figure 133 shows the average number of bus passengers on the bus departing from each bus stop during this hour.

Figure 133: Cumulative bus passenger load – Outbound afternooon peak hour (5pm–6pm)



2. Issues

2.1. Travel time

The average travel times along corridor 5 in the inbound direction are similar to travel times in the outbound direction. Travel times in both directions have similar levels of variability, with a 3.6-minute difference between the fastest and slowest travel times in the inbound direction and a 3.5-minute difference between the outbound travel times.

Table 69: Summary of travel times on the corridor

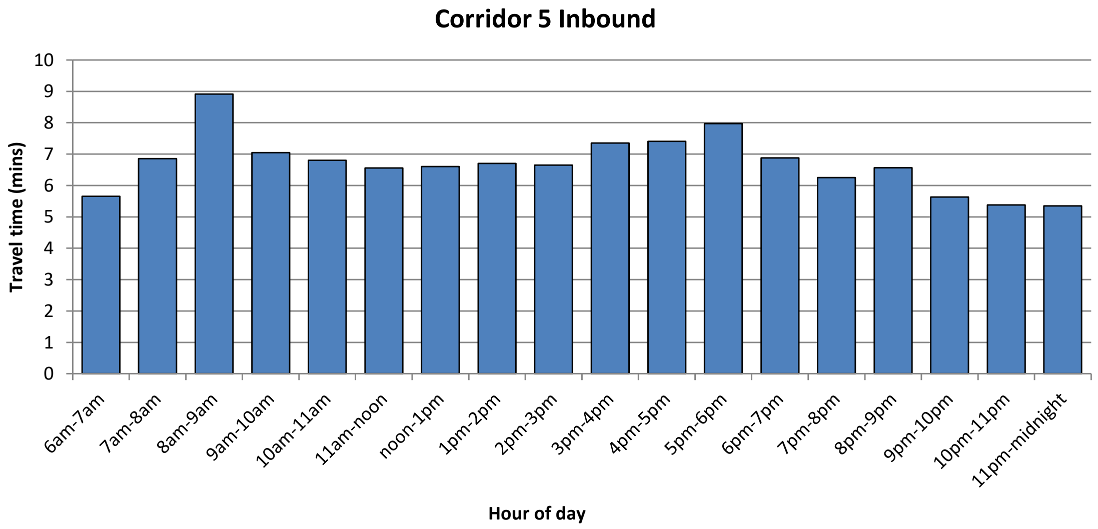
	Inbound	Outbound
Corridor length (km)	2.3	2.2
Average travel time (min)	6.7	6.5
Slowest hour	8am–9am	5pm–6pm
Travel time at slowest hour (min)	8.9	8.4
Fastest hour	11pm–midnight	6am–7am
Travel time at fastest hour (min)	5.3	4.9

Travel time by hour

Inbound

On corridor 5 in the inbound direction, the slowest hour for buses is 8am–9am, when it takes an average of 8.9 minutes to travel between Karori Tunnel and The Terrace. This is more than 1.5 times longer than the travel time during the fastest hour of the day (11pm–midnight). Figure 134 shows the average time it takes for a bus to travel the length of the corridor in the inbound direction for every hour between 6am and midnight.

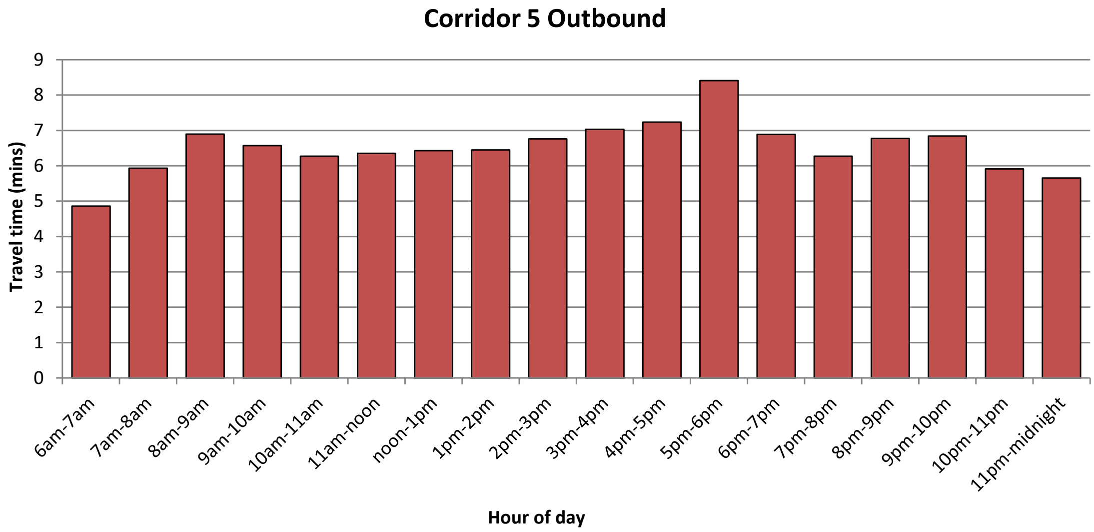
Figure 134: Travel times by hour of day – Inbound



Outbound

On corridor 5 in the outbound direction, the slowest hour for buses is 5pm–6pm, when it takes an average of 8.4 minutes to travel between The Terrace and Karori Tunnel. This is more than 1.5 times longer than the travel time during the fastest hour of the day (6am–7am). Figure 135 shows the average time it takes for a bus to travel the length of the corridor in the inbound direction for every hour between 6am and midnight.

Figure 135: Travel times by hour of day – Outbound

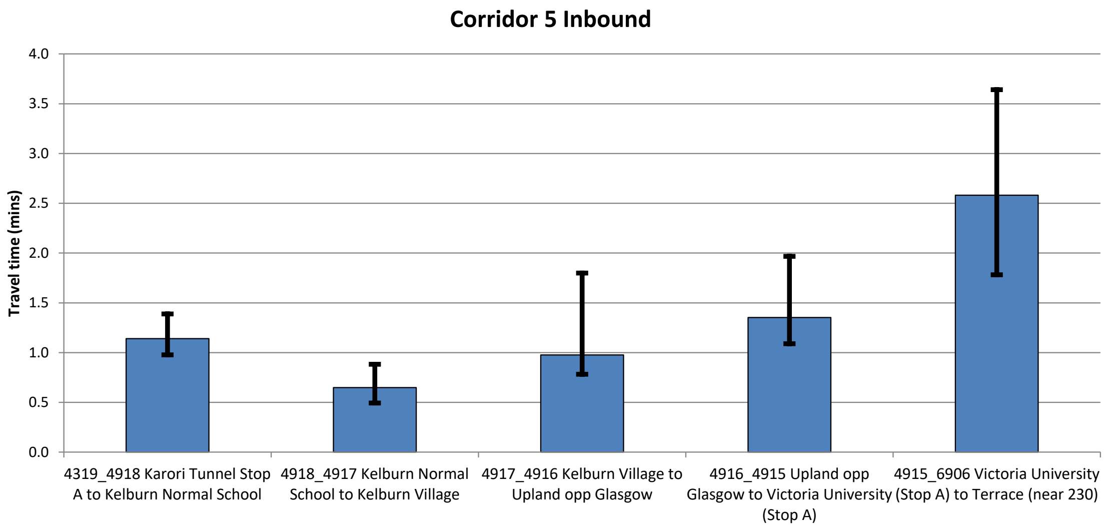


Travel time variability

Inbound

Figure 136 shows the average time it takes for a bus to travel along each segment of the corridor in the inbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

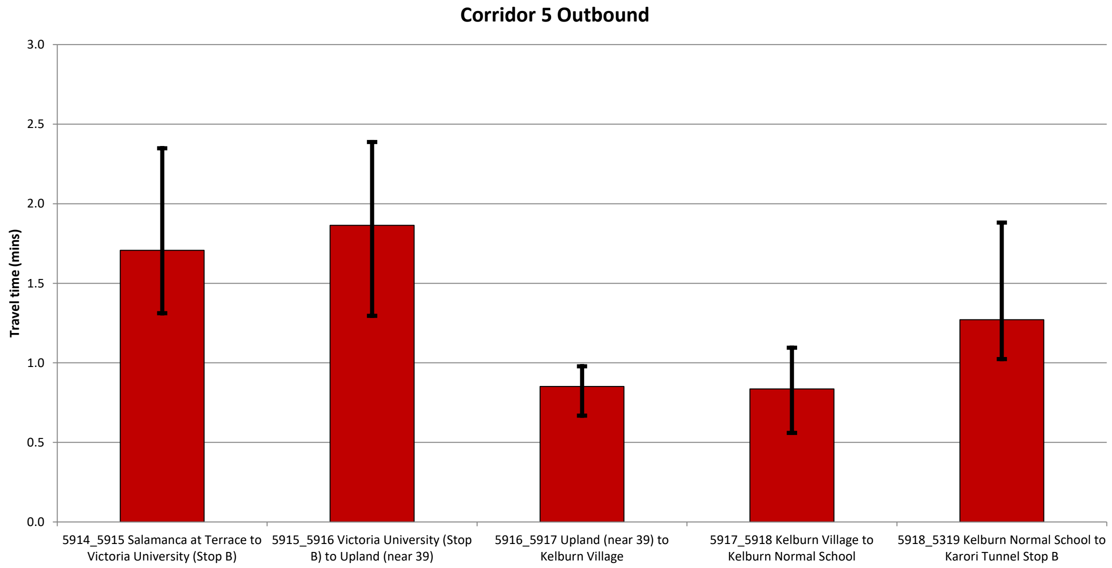
Figure 136: Variation in travel times – Inbound



Outbound

Figure 137 shows the average time it takes for a bus to travel along each segment of the corridor in the outbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

Figure 137: Variation in travel times – Outbound



Bus operating speeds and dwell time delay

The maps below show the average speeds at which buses operate along the corridor and the average time buses dwell at bus stops during the peak hours.

Inbound

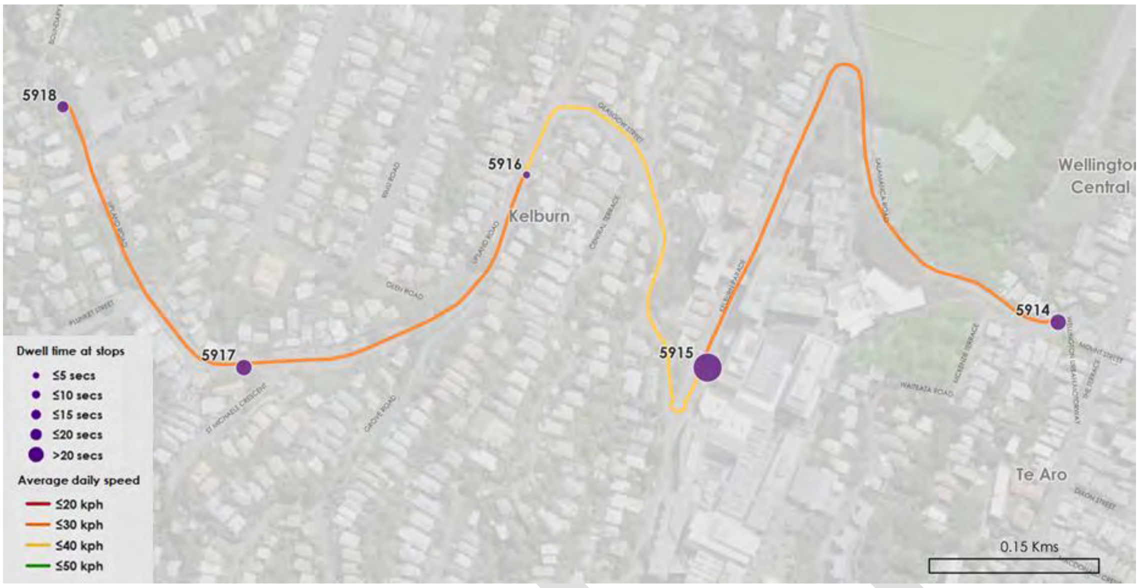
During the morning peak hour in the inbound direction (8am–9am), bus operating speeds on the majority of the corridor are slower than 20km/h.

Figure 138: Operating speeds and dwell times – Inbound morning peak hour (8am–9am)

Outbound

During the slowest hour in the outbound direction (5pm–6pm), bus operating speeds on the corridor are slowest on Upland Road, Kelburn Parade and Salamanca Road.

Figure 139: Operating speeds and dwell times – Outbound afternoon peak hour (5pm–6pm)



2.2. Bus stop audit

There are five inbound bus stops between Karori Tunnel and The Terrace. There are five outbound bus stops between The Terrace and Karori Tunnel.

Of these bus stops, nine are off-line stops, five are not of sufficient length to accommodate a bus, and five do not have sufficient entry and / or exit tapers for buses to easily manoeuvre into and out of the stop. Such issues can lead to increased dwell times as passengers have to make awkward movements to get on and off the bus. This is particularly so for mobility-impaired pedestrians, as well as for the young, elderly, and people with prams or carrying other heavy or bulky items.

Table 70: Bus stop details[48]

	Number of bus stops	
	Inbound	**Outbound**
Total number of bus stops	5	5
Number of offline bus stops	5	4
Number of bus boxes with insufficient length (<15m)	3	2
Number of bus stops missing tapers	2	3

Bus stop walking catchments

The following maps show the areas that are within a five-minute walk of the bus stops on the corridor. The darker blue areas represent where the catchments of multiple bus stops overlap.

[48] Note that the WCC Transport and Infrastructure team is currently working through a list of bus stop improvements, which includes marking out standard bus lengths and entry/exit tapers.

Figure 140: Bus stop catchment – Inbound

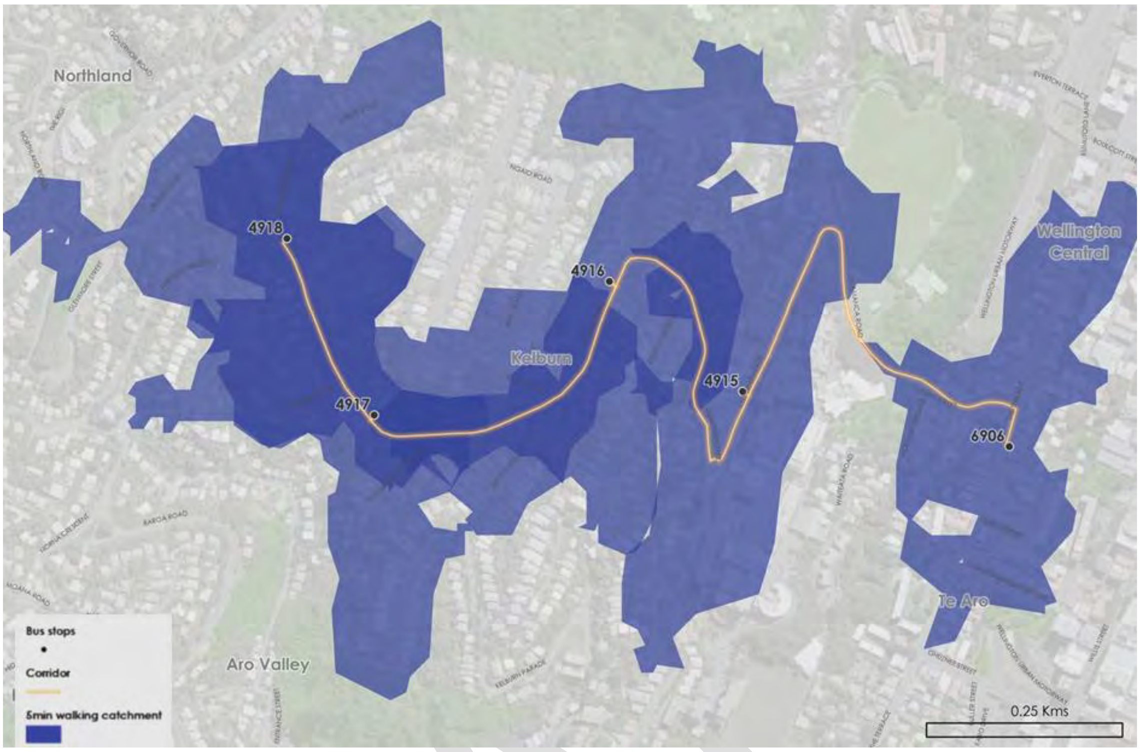
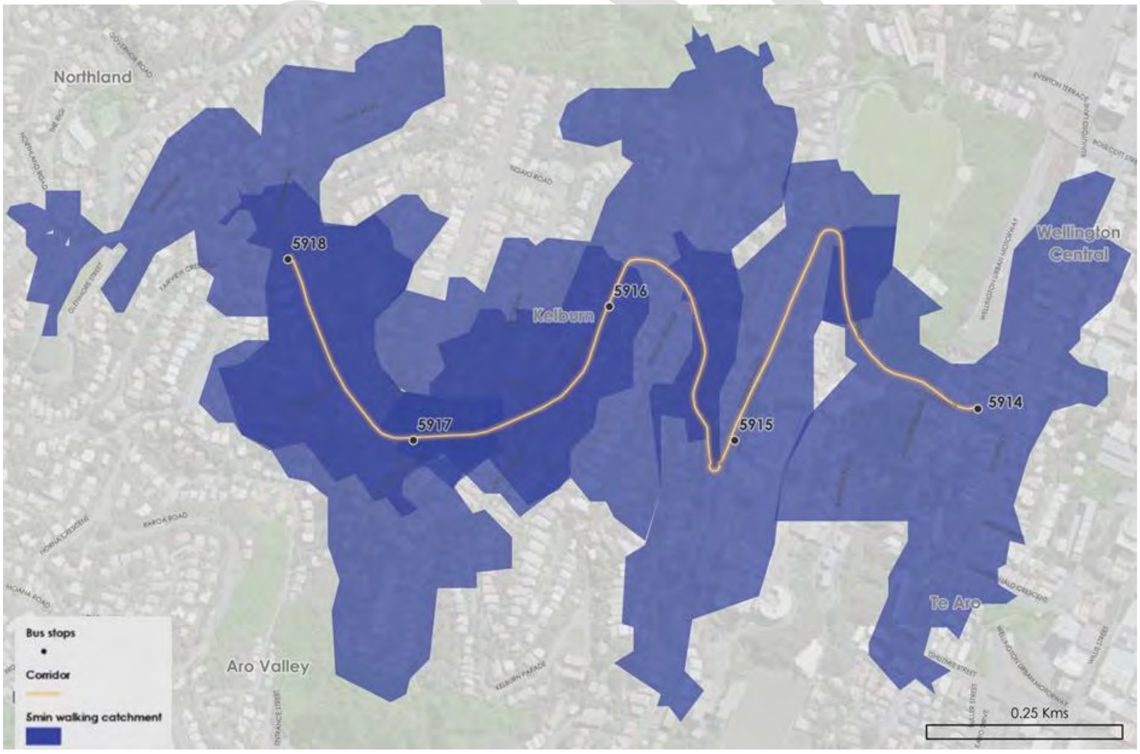


Figure 141: Bus stop catchment – Outbound



2.3. Sources of delay

Percentage delay

The delay that buses experience during the peak hours and slowest hours of travel have been analysed to estimate a breakdown in the sources of delay. Delay is defined as the extra running time of buses, beyond an estimated unimpeded running time. For a full breakdown of how unimpeded running time and delay is estimated, refer to Appendix 2.

To understand the sources of bus delays on the corridor, estimated delays have been decomposed into seven causes:

- long dwell times
- close bus stop spacing
- congestion at bus stops
- congestion at traffic lights
- narrow traffic lanes
- traffic signal delays
- other, which includes delay due to mid-block traffic congestion, un-signalised intersections, hills and corners, roundabouts, and side friction from parking.

Note that in the commentary in the following sections, 'traffic lights' refers to the combination of 'traffic signal delays' and 'congestion at traffic lights'.

Inbound

During the slowest hour in the inbound direction (8am–9am), the delay along corridor 5 results in an average bus travel time that is more than twice as long as the estimated unimpeded running time.

Table 71: Theoretical versus actual travel time – Inbound morning peak hour (8am–9am)

Estimated unimpeded travel time	4.1 minutes
Delay	4.9 minutes
Total travel time	8.9 minutes

During the hour, two-thirds of the delay – 3.2 minutes – is attributable to 'other' reasons. Given the traffic volumes at this time, this is most likely due to mid-block congestion. However, other drivers completing parking manoeuvres or turning into side streets and driveways may also be a contributing factor. The other sources of delay fairly evenly make up the rest of the delay during this hour. A full breakdown of the sources of delay experienced by buses travelling in the inbound direction during the slowest hour (8am–9am) is provided in Figure 142 and Table 72.

Figure 142: Sources of delay – Inbound morning peak hour (8am–9am)

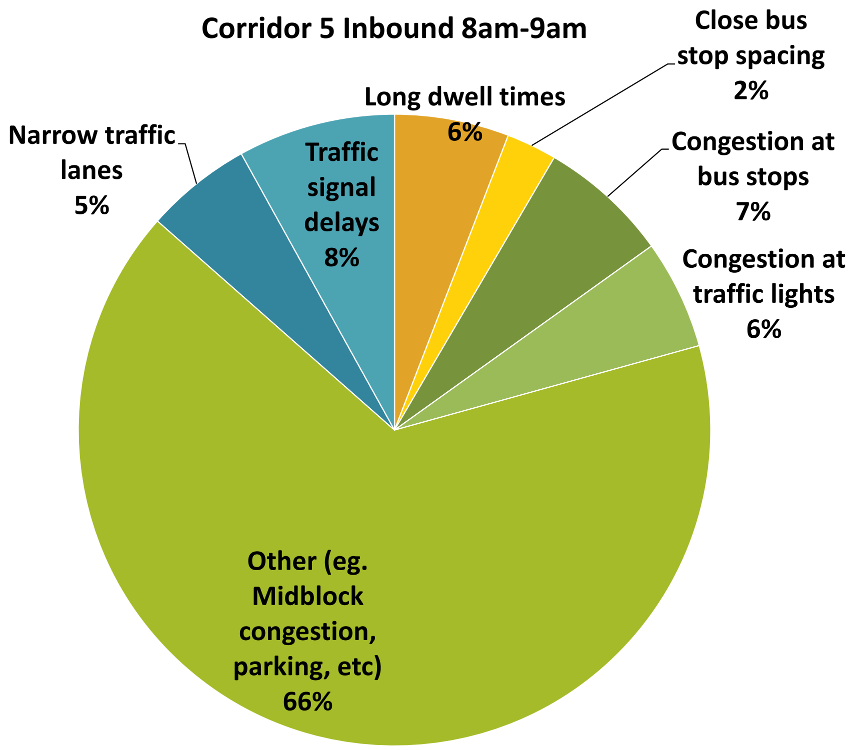


Table 72: Estimated minutes of delay by source – Inbound morning peak hour (8am–9am)

	Minutes added (delay)	Percentage of delay
Long dwell times	0.3	6%
Close bus stop spacing	0.1	2%
Congestion at bus stops	0.3	7%
Congestion at traffic lights	0.3	6%
Narrow traffic lanes	0.3	5%
Traffic signal delays	0.4	8%
Other	3.2	66%

Outbound

During the slowest hour in the outbound direction (5pm–6pm), the delay along corridor 5 results in a bus travel time that is almost twice as long as the estimated unimpeded running time.

Table 73: Theoretical versus actual travel time – Outbound afternoon peak hour (5pm–6pm)

Estimated unimpeded travel time	4.5 minutes
Delay	3.9 minutes
Total travel time	8.4 minutes

During the hour, almost two-thirds of the delay – 3.2 minutes – is attributable to ‘other’ reasons. Given the traffic volumes at this time, this is most likely due to mid-block congestion. However, other drivers completing parking manoeuvres or turning into side streets and driveways may also be a contributing factor. The other sources of delay fairly evenly make up the rest of the delay during this hour. A full breakdown of the sources of delay experienced by buses travelling in the outbound direction during the slowest hour (5pm–6pm) is provided in Figure 143 and Table 74.

Figure 143: Sources of delay – Outbound afternoon peak hour (5pm–6pm)

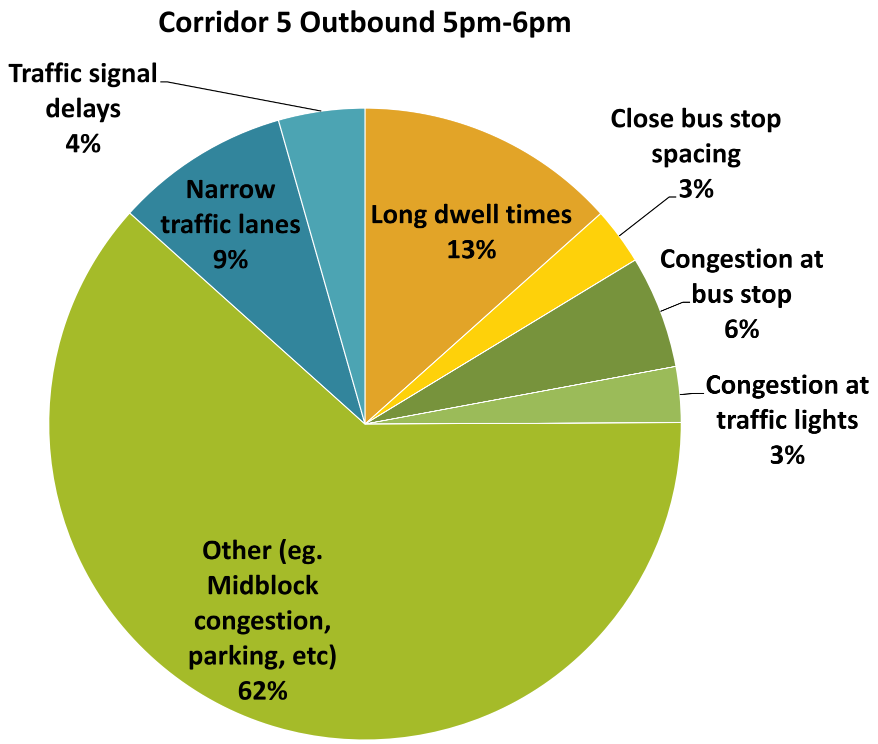


Table 74: Estimated minutes of delay by source – Outbound afternoon peak hour (5pm–6pm)

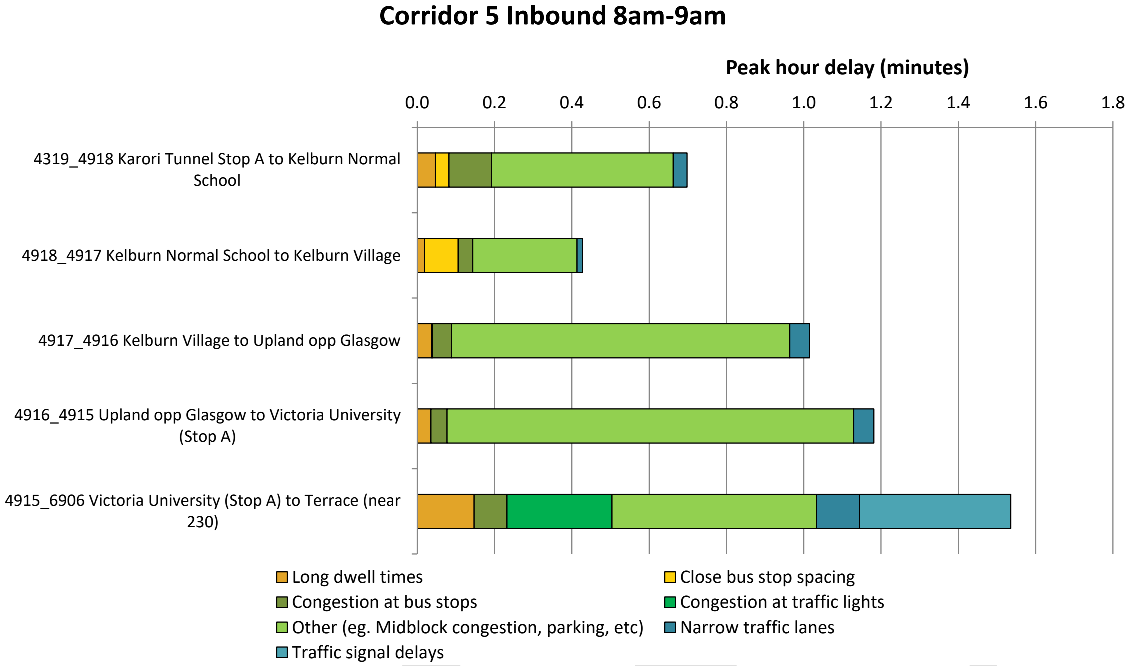
	Minutes added (delay)	Percentage of delay
Long dwell times	0.5	13%
Close bus stop spacing	0.1	3%
Congestion at bus stops	0.2	6%
Congestion at traffic lights	0.1	3%
Narrow traffic lanes	0.4	9%
Traffic signal delays	0.2	4%
Other	2.4	62%

Delay breakdown by segment

Inbound

During the peak hour for buses travelling in the inbound direction on the corridor (8am–9am), the segment experiencing the most delay is on Salamance Road, between Victoria University and The Terrace. Here, buses experience more than 1.5 minutes of delay (over a 720 metre-long segment). Starting from Kelburn village, the delay consistently increases on each segment. Figure 144 provides a breakdown of the sources of delay on corridor 5 by segment for buses travelling in the inbound direction during this hour.

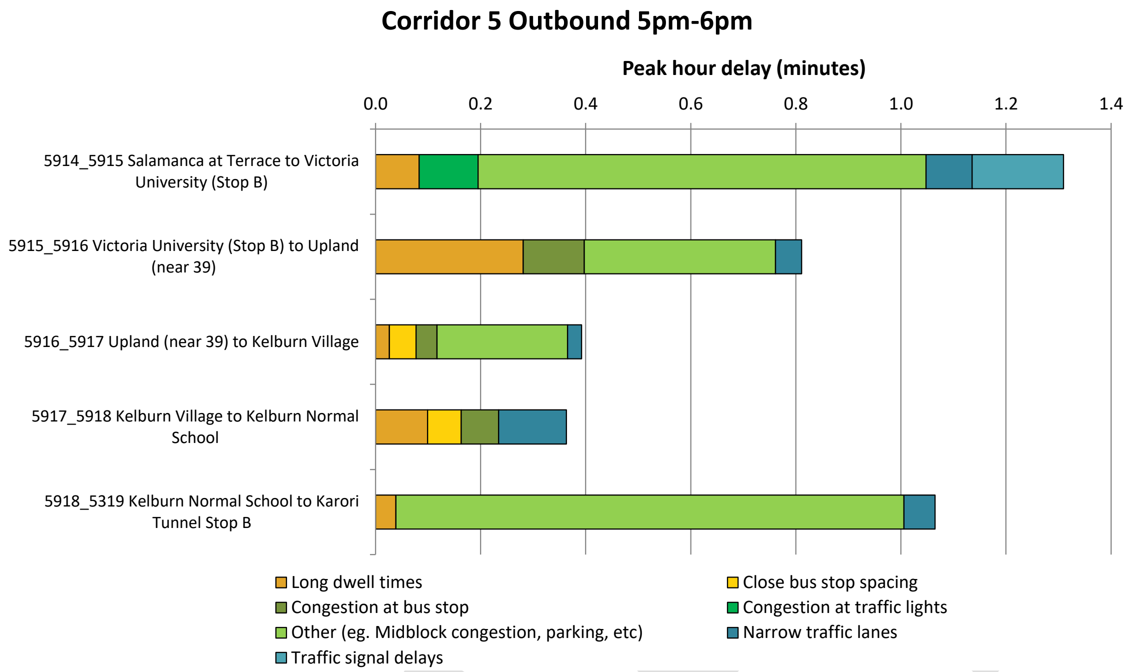
Figure 144: Morning peak hour sources of delay by segment – Inbound



Outbound

During the peak hour for buses travelling in the outbound direction on the corridor (5pm–6pm), the segment experiencing the most delay is on Salamance Road, between The Terrace and Victoria University, where buses experience more than one minute of delay across approximately 720 metres. The section of Upland Road between Kelburn Normal School and Karori Tunnel also experiences more than one minute of delay. Figure 145 provides a breakdown of the sources of delay on corridor 5 by segment for buses travelling in the outbound direction during this hour.

Figure 145: Afternoon peak hour sources of delay by segment – Outbound



2.4. Issues summary

Figure 146 and Figure 147 provide a summary of the key issues across corridor 5, in both the inbound and outbound directions. These issues have been identified as key sources of delay for buses travelling along the corridor.

Figure 146: Key issues – Inbound morning peak hour (8am–9am)

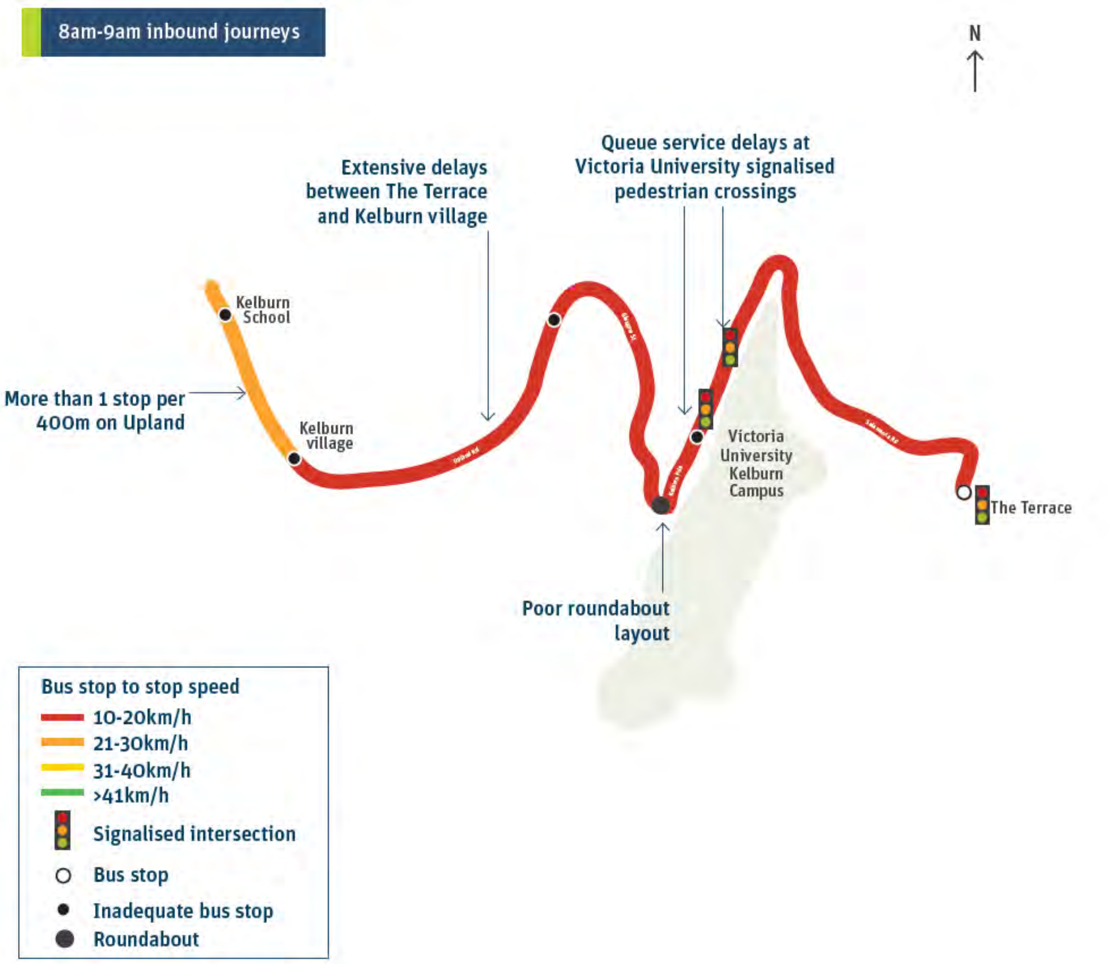


Figure 147: Key issues – Outbound afternoon peak hour (5pm–6pm)

3. Opportunities

For corridor 5, a list of opportunities to improve bus operations has been identified. These opportunities include the implementation of bus priority interventions that would be effective in addressing the documented sources of delay along the corridor and would improve bus travel times.

There are multiple levels of interventions that could be implemented across the corridor that would have varying impacts on bus journey times. For this reason, three packages of opportunities for the corridor have been selected. The package options are defined as follows:

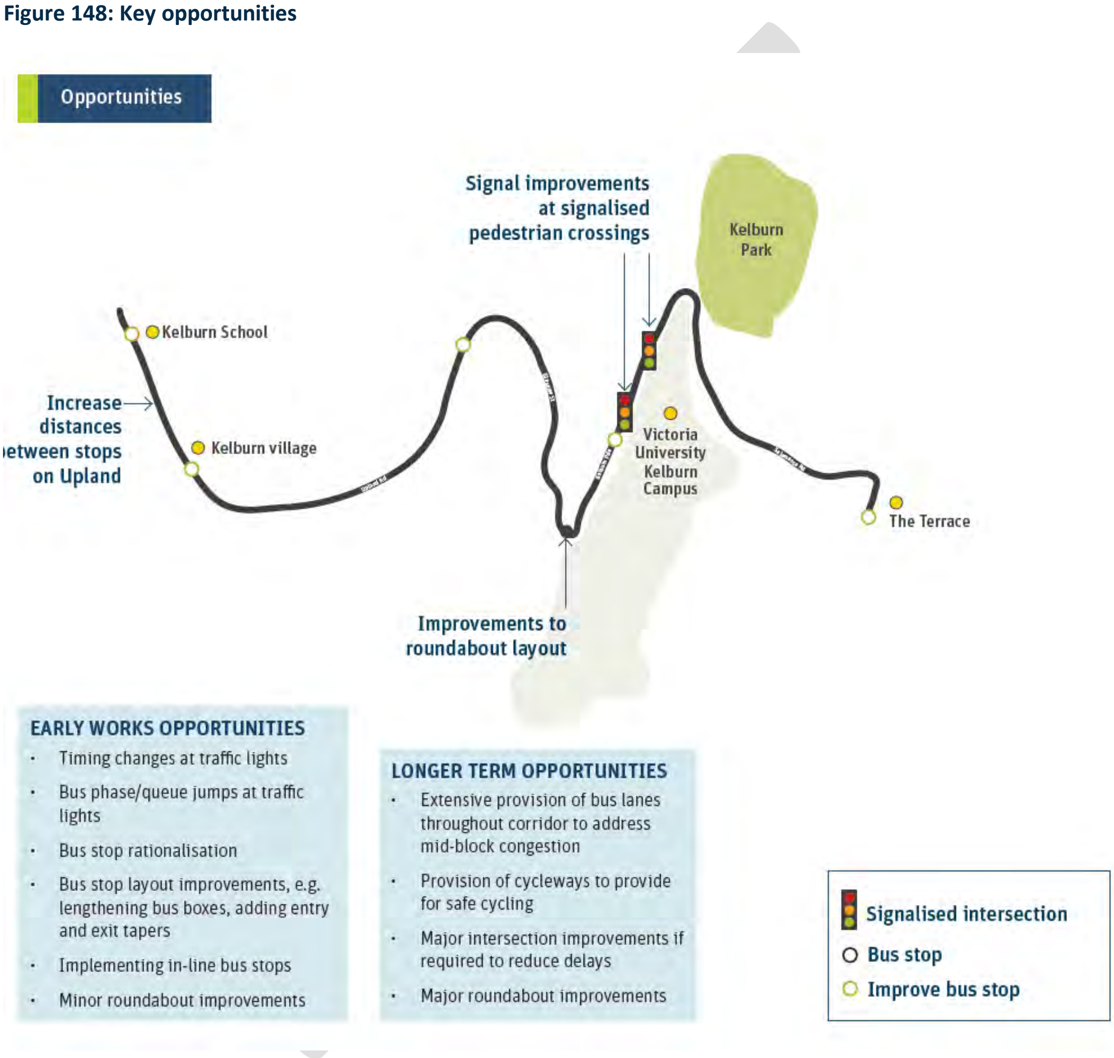
- **Option 1: fix everything**
  This option would address all problems identified on the corridor and implement any of the possible interventions that are effective at addressing the problems that have been identified on the corridor.
- **Option 2: fix the worst problems**
  This option would address only the most severe problems identified on the corridor and only implement interventions that do not involve major reconfiguration of corridor space.

- **Option 3: minimal interventions**
  This option would address only the most severe problems identified on the corridor and implement interventions that involve only minimal reconfiguration of corridor space.

A context map of the location of the key opportunities is provided in Figure 148.

For a full list of the bus priority interventions considered, the package identification process, ad a detailed description of the criteria that was used to identify opportunities on the corridor, refer to Appendix 2.

Figure 148: Key opportunities



Appendix 8 – Kilbirnie to Newtown (corridor 6): corridor analysis summary

1. Corridor overview

1.1. Context

The Kilbirnie to Newtown corridor (corridor 6) is a 2-kilometre-long transport corridor that connects the eastern suburb of Kilbirnie to the southern suburb of Newtown. There are two public bus services and three school services operating on this corridor. On weekdays, there are more than 4000 daily bus passenger trips along the corridor.

When travelling by bus, the journey from one end of the corridor to the other takes seven to nine minutes on average. The inbound peak hour occurs in the morning at 8am–9am, when the average journey time is 11 minutes. The outbound peak hour occurs in the afternoon at 5pm–6pm, when the average journey time is nine minutes.

Table 75: Summary of key facts on the corridor

	Inbound	Outbound
Maximum daily passengers[49]	2,000	2,100
Corridor length (km)	2.0	1.9
Number of bus stops	7	7
Average bus stop spacing (m)	280	272
Average speed (km/h)	14	17
Average travel time (min)	9	7
Minimum travel time (min)	5	5
Maximum travel time (min)	11	9
Slowest weekday hour	8am–9am	5pm–6pm

There are provisions for cyclists on this corridor, on Crawford Road and the eastern end of Constable Street.

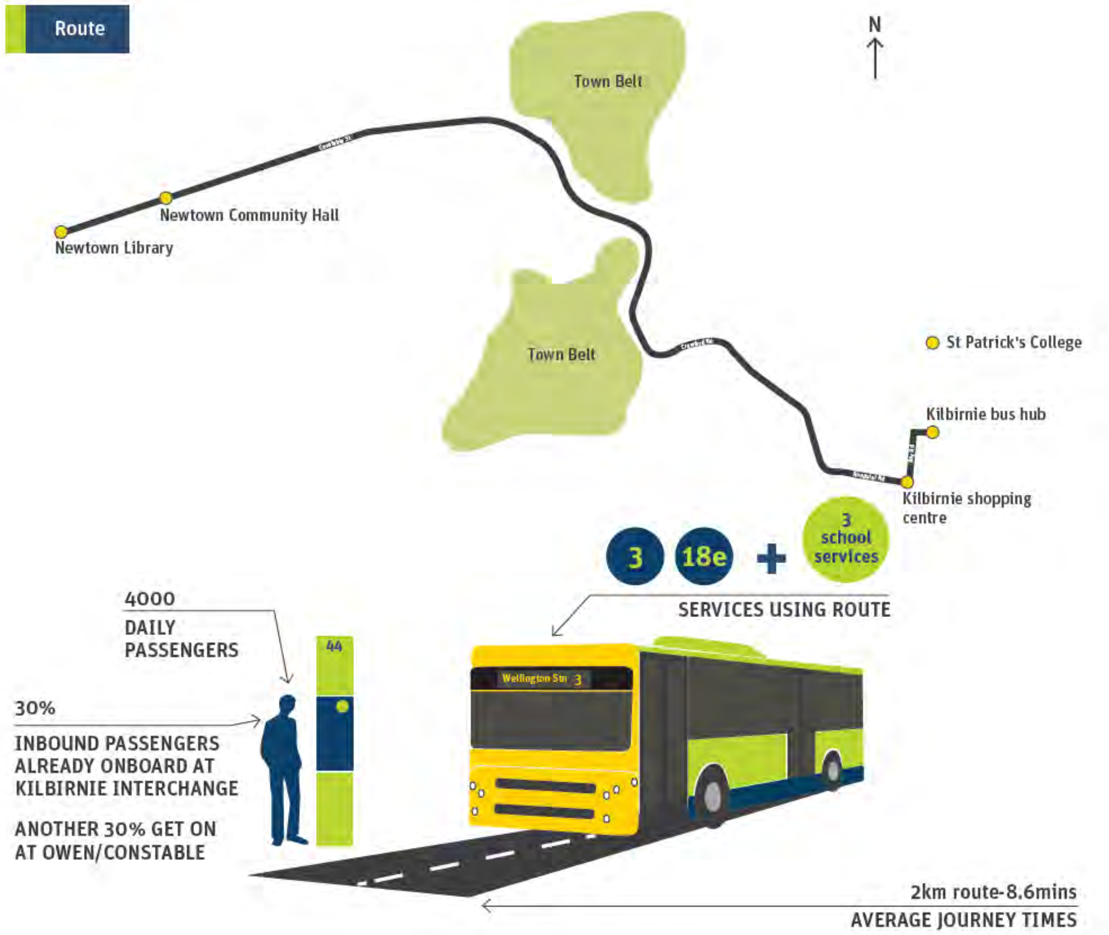
Area

There are several significant destinations along this route, including Kilbirnie town centre, Newtown Library, Newtown Community Hall, and several recreation clubs, including the Wellington and Kilbirnie tennis clubs. The corridor also passes through the Town Belt.

The land use along the corridor is principally inner residential, outer residential, open space, and centre zones.

[49] 'Maximum daily passengers' refers to the maximum number of passengers passing through a point on the corridor. On corridor 6, this occurs on Constable Street.

Figure 149: Corridor context map



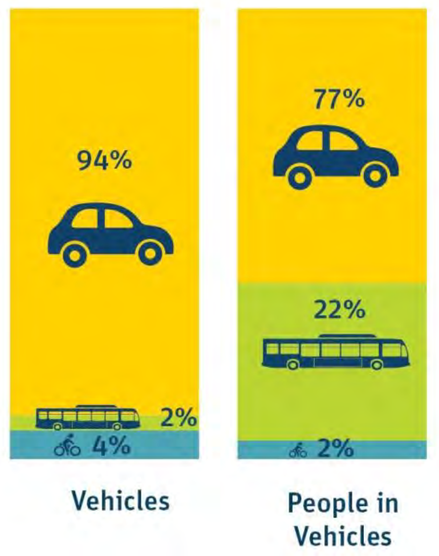
Roads

The Kilbirnie to Newtown corridor is mostly made up of principal roads, with one local road connection, as shown in Figure 150. There are six signalised intersections, one roundabout, and no signalised pedestrian crossings along the corridor.

Figure 150: Road hierarchy map[50,51]

During the morning peak hour (8am–9am), the majority of vehicles on the corridor are private vehicles (94 percent), followed by bikes (4 percent). Buses make up only 2 percent of the vehicles on the corridor. However, they transport 22 percent of the people on the corridor. Figure 151 presents a full breakdown of the modal split on the corridor.

Figure 151: Modal split – Inbound morning peak period (8am–9am)



1.2. Bus operations

There are two public bus services and three school services operating on this corridor. There are seven bus stops in each direction. Most bus stops are located in fare zone two. *Kilbirnie – Stop* A and *Kilbirnie – Stop C* and are part of the Kilbirnie bus hub.

There are no existing bus priority measures in place on this corridor.

[50] Road hierarchy data sourced from WCC District Plan Map 33: Hierarchy of Roads
[51] In the WCC District Plan, the road classifications are defined as follows:

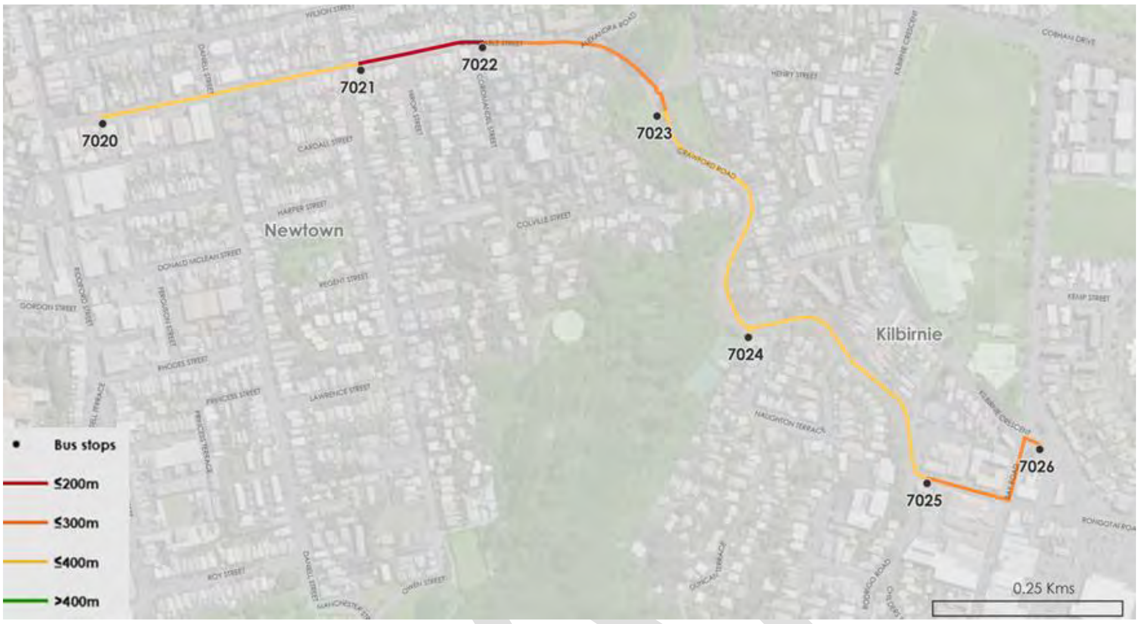
- Principal Road: roads that provide access to motorways and to arterial roads having a dominant through-traffic function and carrying the major public transport routes
- Local Road: roads that provide direct access to properties fronting the road and include both long and short cul-de-sacs

Bus stop spacing

Inbound

The average bus stop spacing along the corridor in the inbound direction is 280 metres. The closest spacing is 163 metres, between two bus stops on Constable Street.

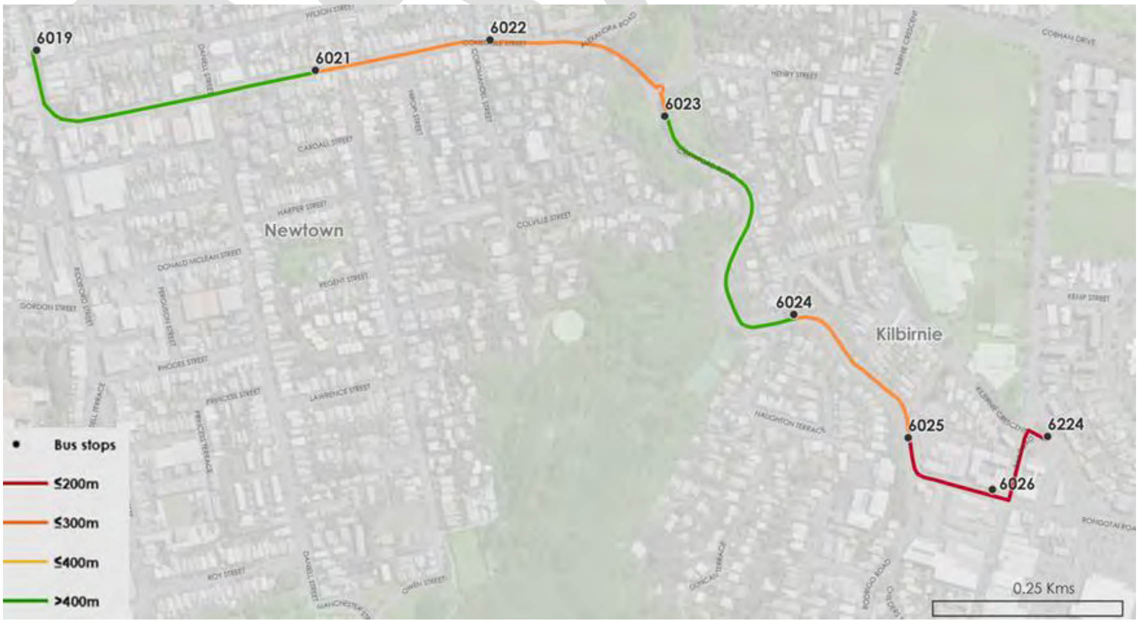
Figure 152: Bus stop locations and spacing – Inbound



Outbound

The average bus stop spacing along the corridor in the outbound direction is 272 metres. The closest spacing is 146 metres, between the Kilbirnie shops and the Kilbirnie bus hub.

Figure 153: Bus stop locations and spacing – Outbound

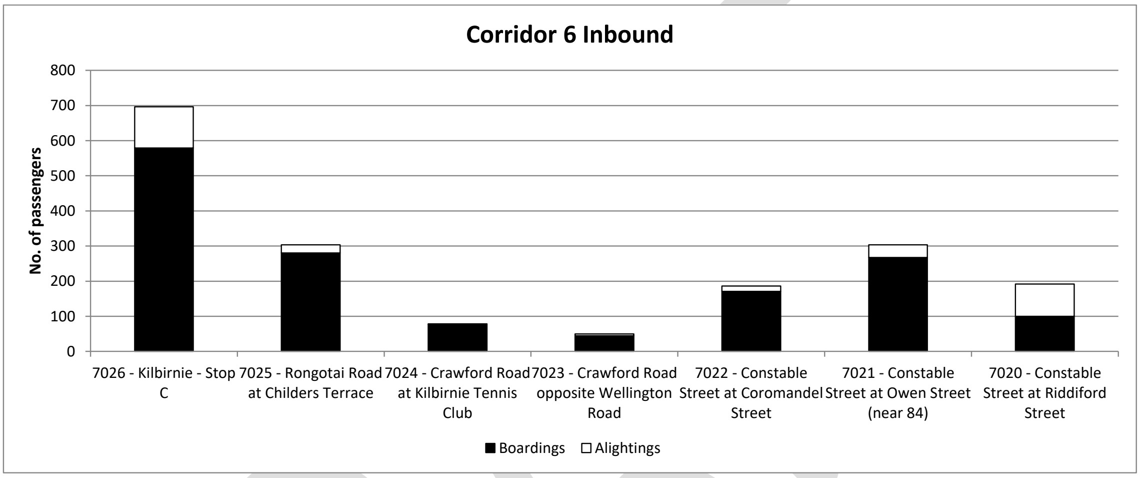


Boardings and alightings

Inbound

The busiest bus stop along the corridor in the inbound direction is *Kilbirnie – Stop C*, with approximately 700 daily boardings and alightings. This is likely due to a large number of passengers transferring between bus services at the Kilbirnie bus hub.[52] There are two bus stops with less than 100 daily boardings and alightings, both located on Crawford Road, where there are smaller walking catchments. Figure 154 shows the daily number of people boarding and alighting at each bus stop along the corridor in the inbound direction. This includes all bus routes that service each bus stop.

Figure 154: Daily boardings and alightings – Inbound

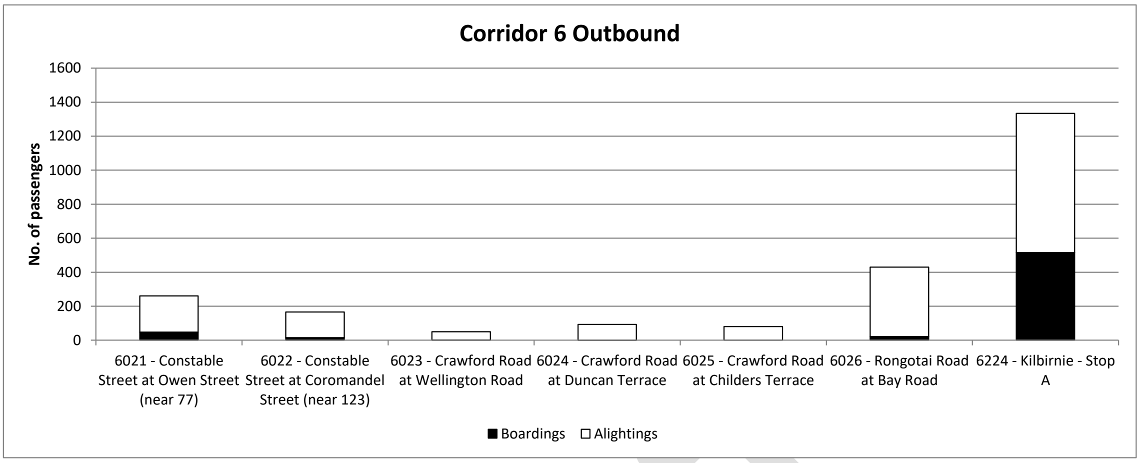


Outbound

The busiest bus stop along the corridor in the inbound direction is *Kilbirnie – Stop A*, with more than 1300 daily boardings and alightings. This is likely due to a large number of passengers transferring between bus services at the Kilbirnie bus hub. There are three bus stops with less than 100 boardings and alightings throughout the day, and one with less than 50. All of these bus stops are located on Crawford Road, where there are smaller walking catchments. Figure 155 shows the daily number of people boarding and alighting at each bus stop along the corridor in the outbound direction. This includes all bus routes that service each bus stop.

[52] There are two inbound bus stops located at the Kilbirnie bus hub: Kilbirnie – Stop B and Kilbirnie – Stop C. Only Kilbirnie – Stop C data has been included in the corridor 6 analysis. The bus services that use Kilbirnie – Stop B travel along the Miramar to city corridor (corridor 3) and have been included in the corridor 3 analysis (refer Appendix 5).

Figure 155: Daily boardings and alightings – Outbound

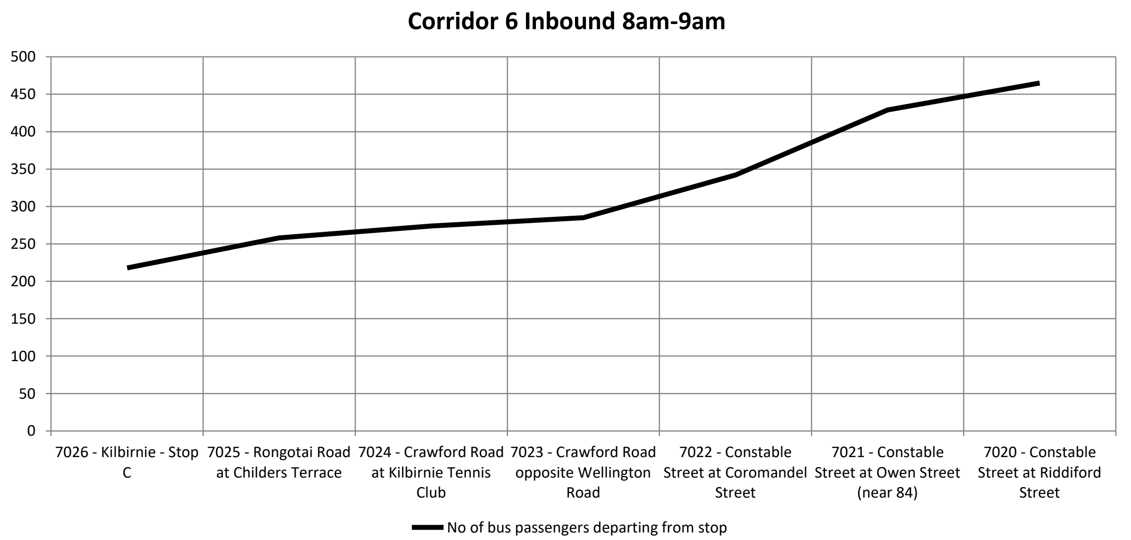


Cumulative passenger numbers

Inbound

During the inbound peak hour on the corridor (8am–9am), bus passenger numbers increase steadily as the bus travels towards Newtown. Figure 156 shows the average number of bus passengers on the bus departing from each bus stop during the morning peak hour.

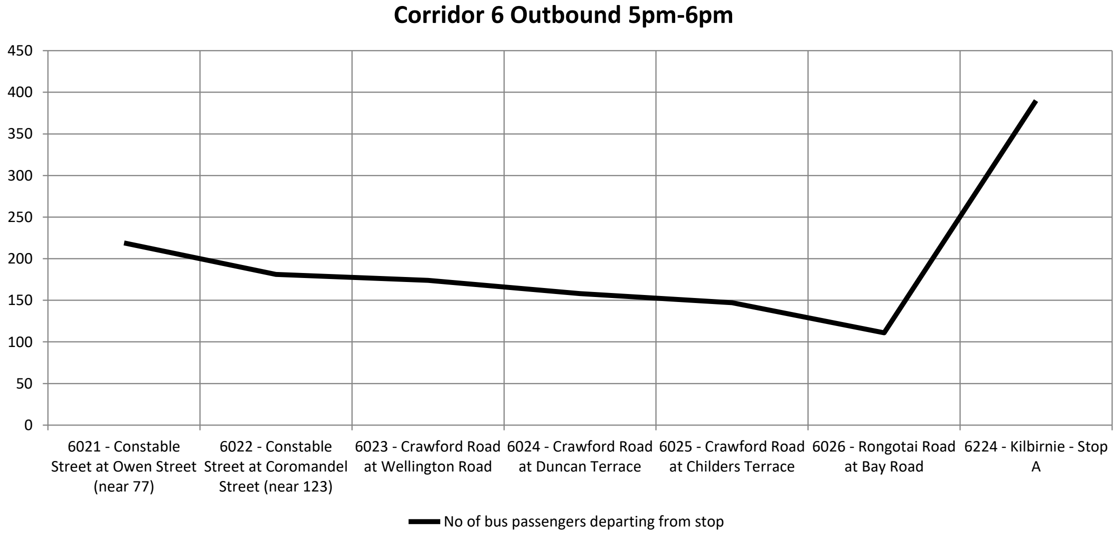
Figure 156: Cumulative bus passenger load – Inbound morning peak hour (8am–9am)



Outbound

During the outbound peak hour on the corridor (5pm–6pm), the number of bus passengers gradually declines as services travel towards Kilbirnie, until the bus stop at the Kilbirnie bus hub, which serves more bus routes than other parts of the corridor. Figure 157 shows the average number of bus passengers on the bus departing from each bus stop during this hour.

Figure 157: Afternoon peak hour cumulative passenger numbers – Outbound



2. Issues

2.1. Travel time

The average travel times along corridor 6 in the inbound direction are slightly faster than travel times in the outbound direction. However, there is more variability in the inbound travel times, with a 5.6-minute difference between the fastest and slowest times compared to less than four minutes between the outbound travel times. Table 76 provides a summary of the average travel times on the corridor and the travel times during the slowest and fastest hours in each direction.

Table 76: Summary of travel times on the corridor

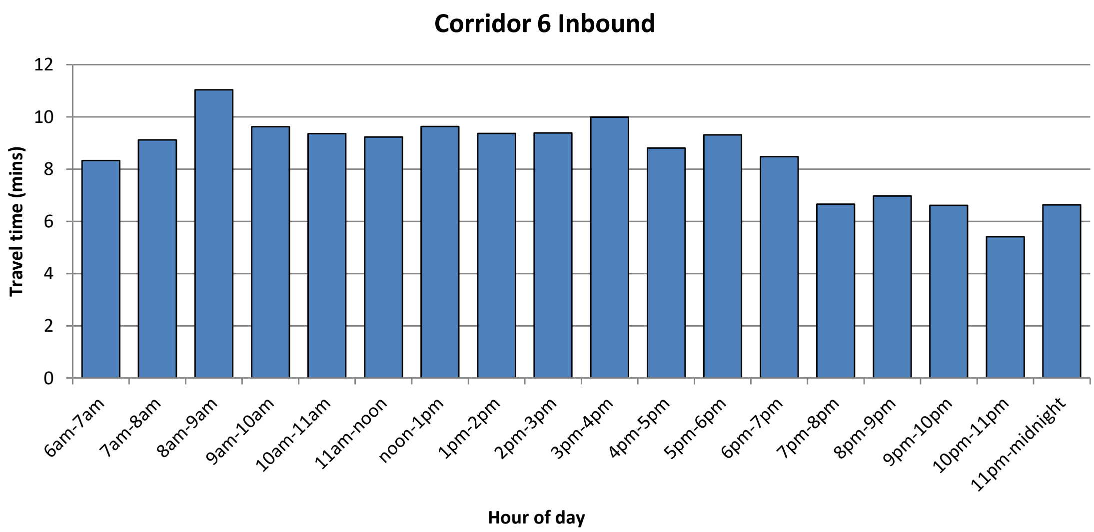
	Inbound	Outbound
Corridor length (km)	2.0	1.9
Average travel time (min)	8.6	6.8
Slowest hour	8am–9am	5pm–6pm
Travel time at slowest hour (min)	11	8.6
Fastest hour	10pm–11pm	6am–7am
Travel time at fastest hour (min)	5.4	4.9

Travel time by hour

Inbound

On corridor 6 in the inbound direction, the slowest hour for buses is 8am–9am, when it takes an average of 11 minutes to travel between the Kilbirnie bus hub and Newtown town centre. This is 2.4 minutes longer than the average travel time and twice as long as travel times during the fastest hour of the day (10pm–11pm). Figure 158 shows the average time it takes for a bus to travel the length of the corridor in the inbound direction for every hour between 6am and midnight.

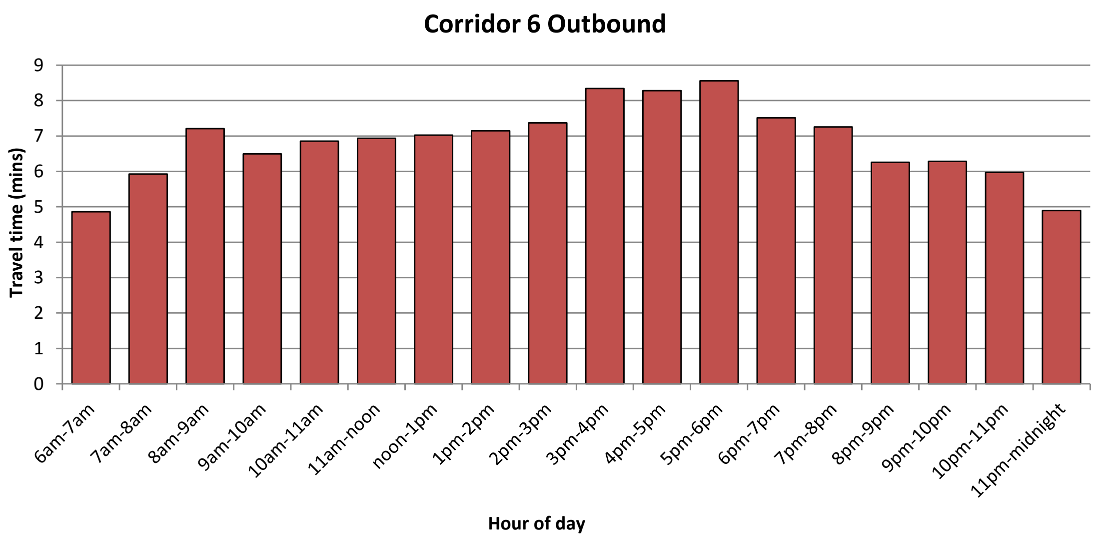
Figure 158: Travel times by hour – Inbound



Outbound

On corridor 6 in the outbound direction, the peak period is more spread out than in the inbound direction. The slowest hour for buses is 5pm–6pm, when it takes an average of 8.6 minutes to travel between Newtown town centre and the Kilbirnie bus hub. This is approximately two minutes longer than the average travel time and almost twice as long as travel times during the fastest hour (6am–7am). Figure 159 shows the average time it takes for a bus to travel the length of the corridor in the outbound direction for every hour between 6am and midnight.

Figure 159: Travel times by hour – Outbound

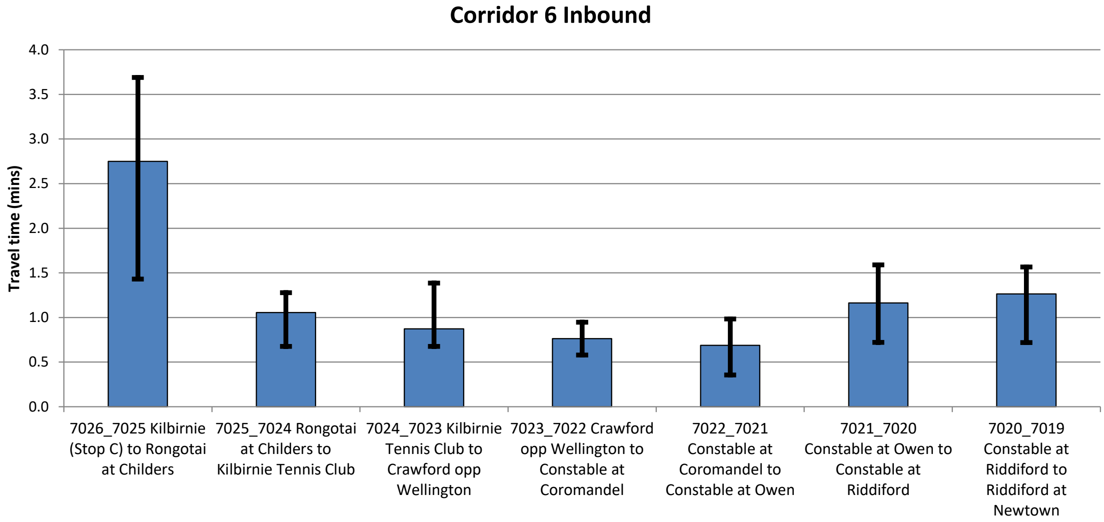


Travel time variability

Inbound

Figure 160 shows the average time it takes for a bus to travel along each segment of the corridor in the inbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

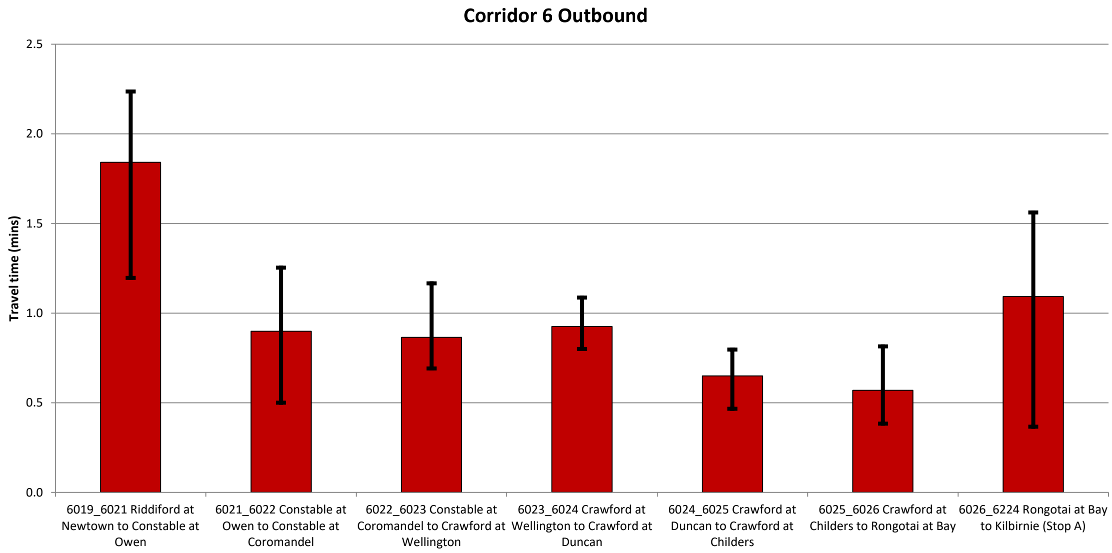
Figure 160: Variation in travel times – Inbound



Outbound

Figure 161 shows the average time it takes for a bus to travel along each segment of the corridor in the outbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

Figure 161: Variation in travel times – Outbound



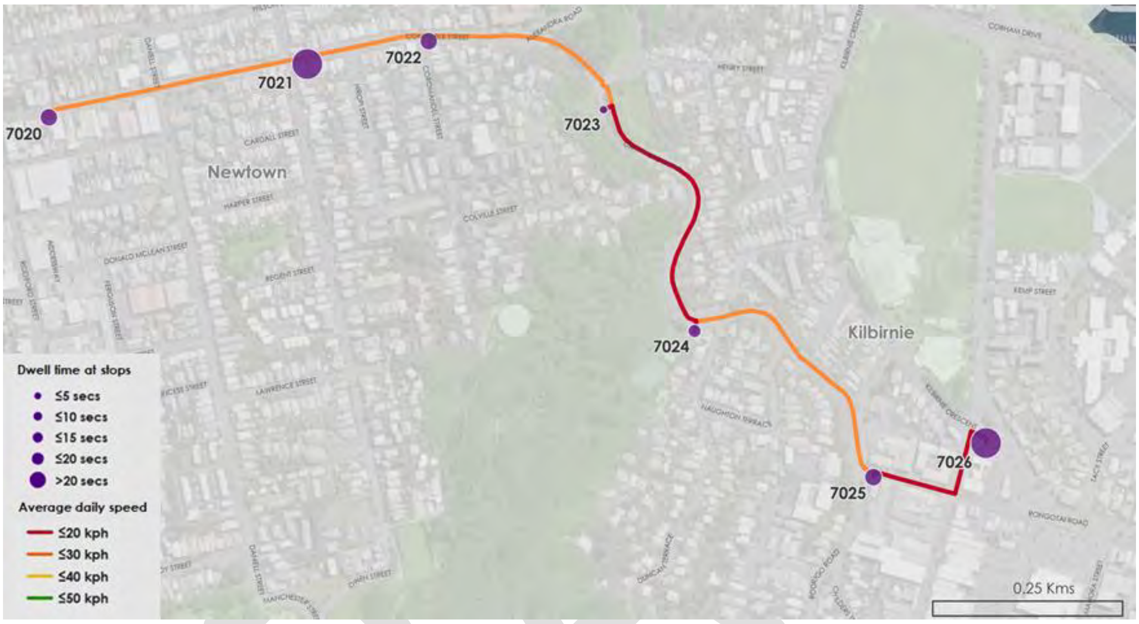
Bus operating speeds and dwell time delay

The maps below show the average speeds at which buses operate along the corridor and the average time buses dwell at bus stops during the peak hours.

Inbound

During the morning peak hour in the inbound direction (8am–9am), bus operating speeds on the corridor are slowest on parts of Crawford Road and heading into the Kilbirnie bus hub.

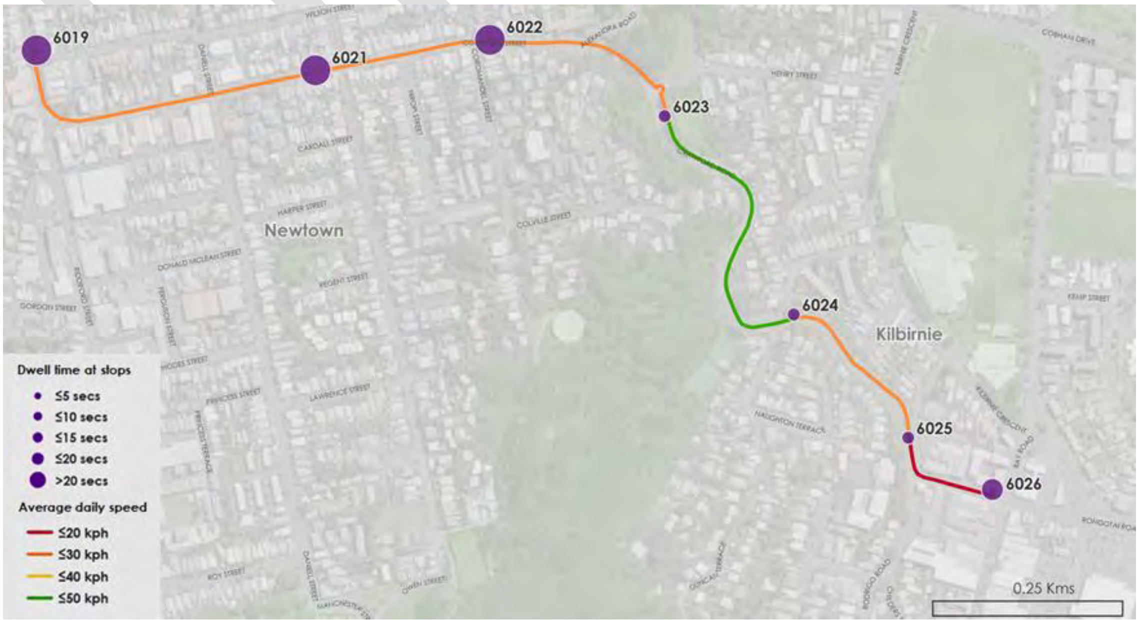
Figure 162: Operating speeds and dwell times – Inbound morning peak hour (8am–9am)



Outbound

During the slowest hour in the outbound direction (5pm–6pm), bus operating speeds on the corridor are slowest departing the Kilbirnie bus hub.

Figure 163: Operating speeds and dwell times – Outbound afternoon peak hour (5pm–6pm)



2.2. Bus stop audit

There are seven inbound bus stops between the Kilbirnie bus hub and Newtown town centre. There are seven outbound bus stops between Newtown town centre and the Kilbirnie bus hub.

Of these bus stops, all are off-line stops, all are of sufficient length to accommodate a bus, and nine do not have sufficient entry and / or exit tapers for buses to easily manoeuvre into and out of the stop. Such issues can lead to increased dwell times as passengers have to make awkward movements to get on and off the bus. This is particularly so for mobility-impaired pedestrians, as well as for the young, elderly, and people with prams or carrying other heavy or bulky items.

Table 77: Bus stop details[53]

	Number of bus stops	
	Inbound	Outbound
Total number of bus stops	7	7
Number of offline bus stops	7	7
Number of bus boxes with insufficient length (<15m)	0	0
Number of bus stops missing tapers	4	5

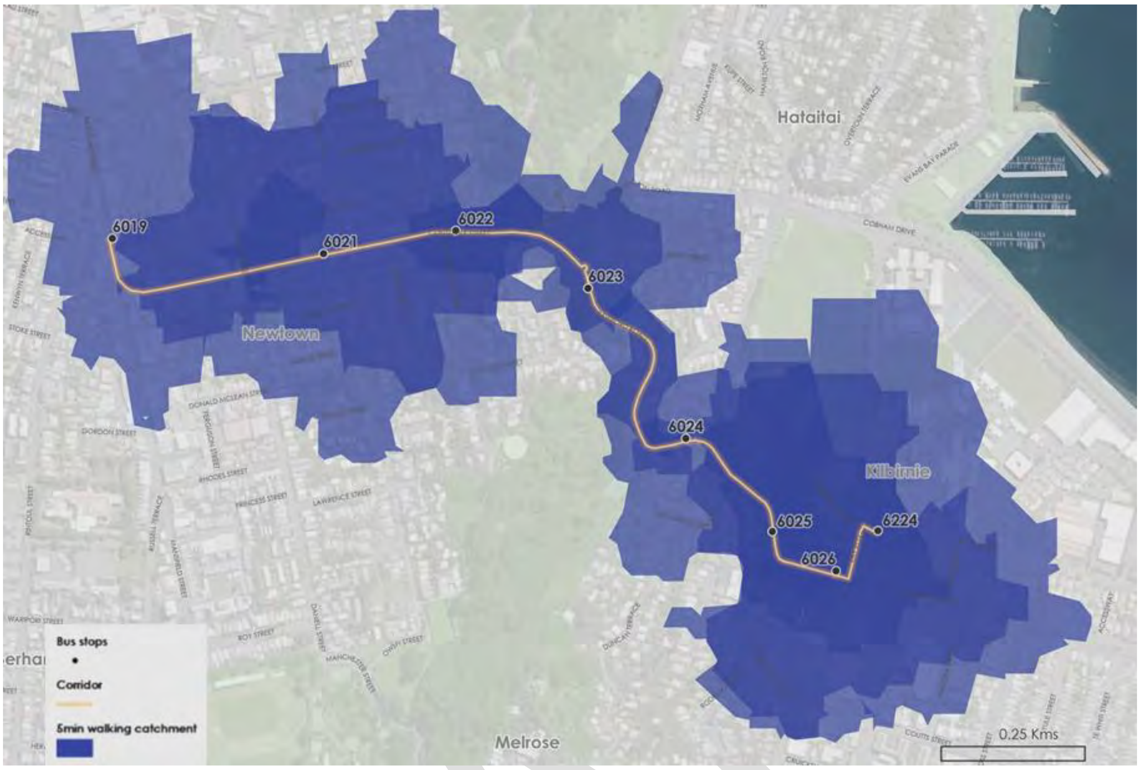
Bus stop walking catchments

The following maps show the areas that are within a five-minute walk of the bus stops on the corridor. The darker blue areas represent where the catchments of multiple bus stops overlap.

Figure 164: Bus stop catchment – Inbound

[53] Note that the WCC Transport and Infrastructure team is currently working through a list of bus stop improvements, which includes marking out standard bus lengths and entry/exit tapers.

Figure 165: Bus stop catchment – Outbound



2.3. Sources of delay

Percentage delay

The delay that buses experience during the peak hours and slowest hours of travel has been analysed to estimate a breakdown in the sources of delay. Delay is defined as the extra running time of buses, beyond an estimated unimpeded running time. For a full breakdown of how unimpeded running time and delay is estimated, refer to Appendix 2.

To understand the sources of bus delays on the corridor, estimated delays have been decomposed into seven causes:

- long dwell times
- close bus stop spacing
- congestion at bus stops
- congestion at traffic lights
- narrow traffic lanes
- traffic signal delays
- other, which includes delay due to mid-block traffic congestion, un-signalised intersections, hills and corners, roundabouts, and side friction from parking.

Note that in the commentary in the following sections, 'traffic lights' refers to the combination of 'traffic signal delays' and 'congestion at traffic lights'.

Inbound

During the slowest hour in the inbound direction (8am–9am), the delay along corridor 6 results in an average bus travel time that is almost three times as long as the estimated unimpeded running time.

Table 78: Theoretical versus actual travel time – Inbound morning peak hour (8am–9am)

Estimated unimpeded travel time	4 minutes
Delay	7.1 minutes
Total travel time	11 minutes

During the hour, most of the delay is attributable to 'other' sources and traffic lights. One-third of the delay – 2.7 minutes – is attributable to 'other' reasons. Given the traffic volumes at this time, this is most likely due to mid-block congestion. However, other drivers completing parking manoeuvres or turning into side streets and driveways may also be a contributing factor. Another third of delay is caused by traffic lights, adding 2.6 minutes to the delay. A full breakdown of the sources of delay experienced by buses travelling in the inbound direction during the slowest hour (8am–9am) is provided in Figure 166 and Table 79.

Figure 166: Sources of delay – Inbound morning peak hour (8am–9am)

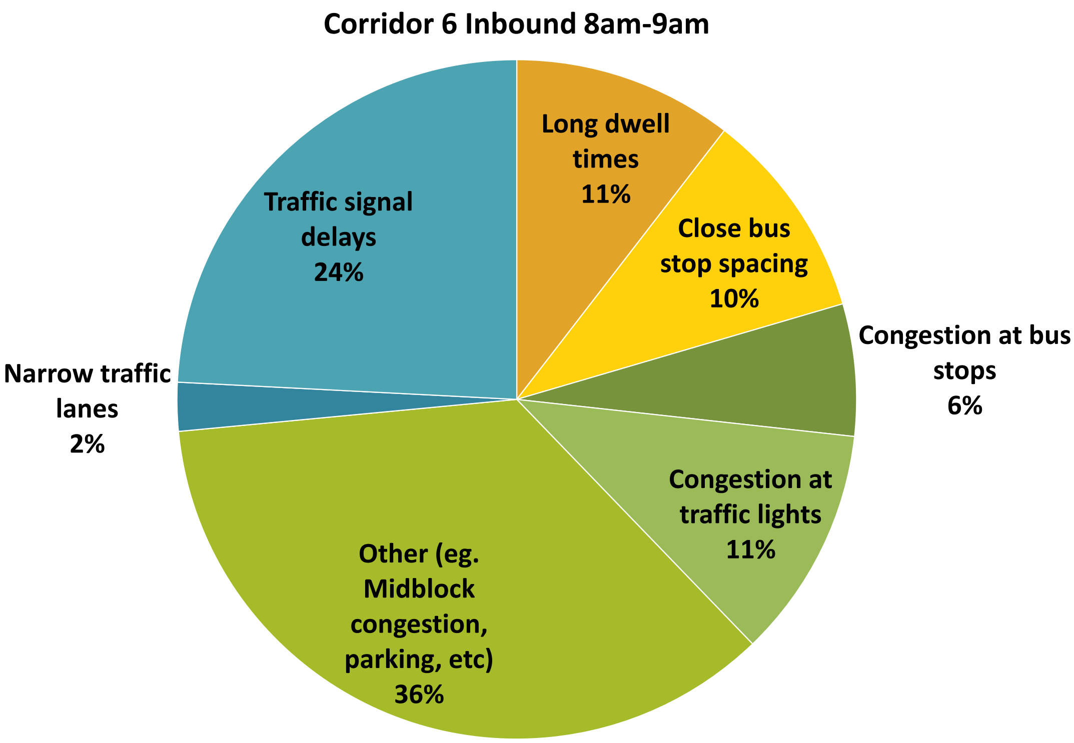


Table 79: Estimated minutes of delay by source – Inbound morning peak hour (8am–9am)

Inbound 8-9am	Minutes added (delay)	Percentage of delay
Long dwell times	0.8	11%
Close bus stop spacing	0.7	10%
Congestion at bus stops	0.5	6%
Congestion at traffic lights	0.8	11%
Narrow traffic lanes	0.2	2%
Traffic signal delays	1.8	24%
Other	2.7	36%

Outbound

During the slowest hour in the outbound direction (5pm–6pm), the delay along corridor 6 results in a bus travel time that is more than twice as long as the estimated unimpeded running time.

Table 80: Theoretical versus actual travel time – Outbound afternoon peak hour (5pm–6pm)

Unimpeded travel time	4 minutes
Delay	4.6 minutes
Total travel time at slowest hour	8.6 minutes

During this hour, the sources of delay affecting the bus running times are much more varied than during the morning inbound peak hour. The largest source delay is traffic lights, contributing 1.7 minutes of delay to the travel time. The second largest source of delay is long dwell times, which adds 1.1 minutes of delay. A full breakdown of the sources of delay experienced by buses travelling in the outbound direction during the slowest hour (5pm–6pm) is provided in Figure 167 and Table 81.

Figure 167: Sources of delay – Outbound afternoon peak hour (5pm–6pm)

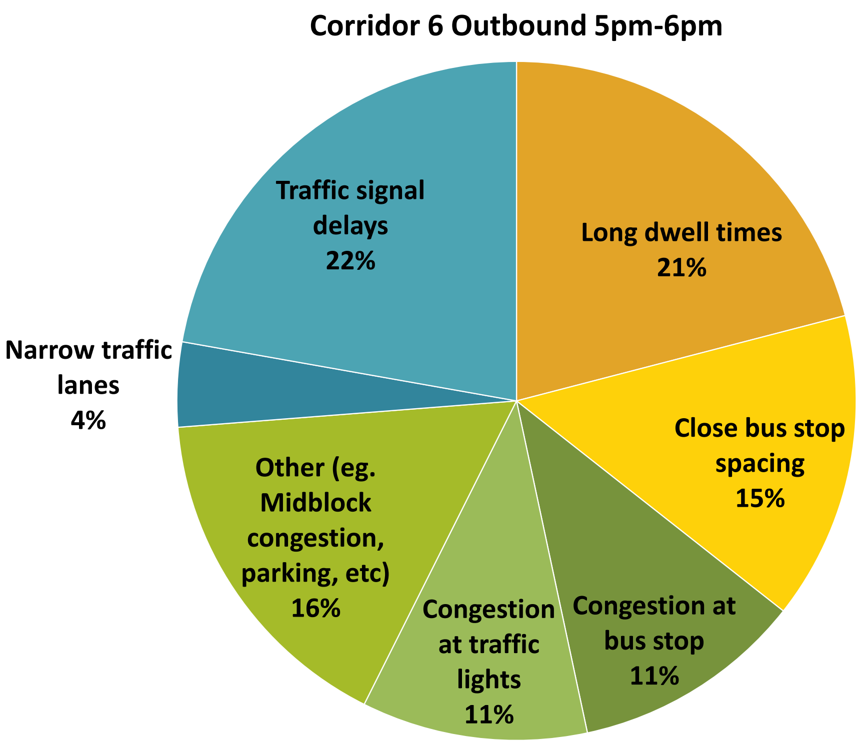


Table 81: Estimated minutes of delay by source – Outbound afternoon peak hour (5pm–6pm)

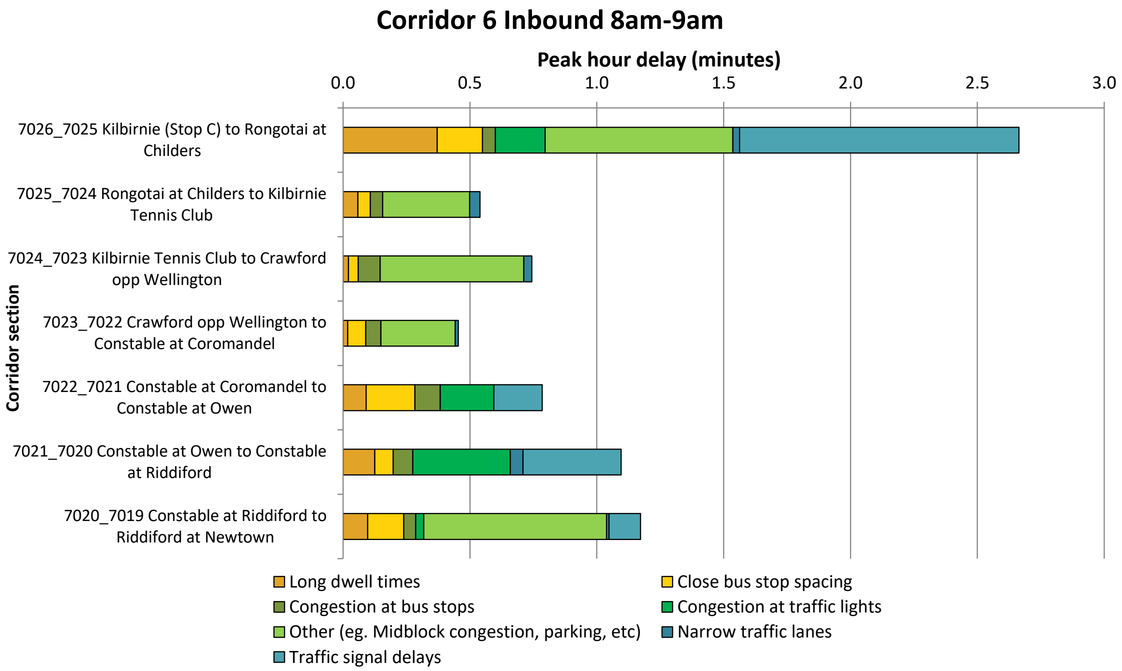
	Minutes added (delay)	Percentage of delay
Long dwell times	1.1	21%
Close bus stop spacing	0.8	15%
Congestion at bus stops	0.6	11%
Congestion at traffic lights	0.6	11%
Narrow traffic lanes	0.2	4%
Traffic signal delays	1.1	22%
Other	0.8	16%

Delay breakdown by segment

Inbound

During the peak hour for buses travelling in the inbound direction on the corridor (8am–9am), the segment experiencing the most delay is on Evans Bay Parade and Rongotai Road, on the departure from the Kilbirnie bus hub. Here, buses experience more than 2.5 minutes of delay. There are two traffic signals in this segment, which together add more than one minute of delay on average. Figure 168 provides a breakdown of the sources of delay on corridor 6 by segment for buses travelling in the inbound direction during this hour.

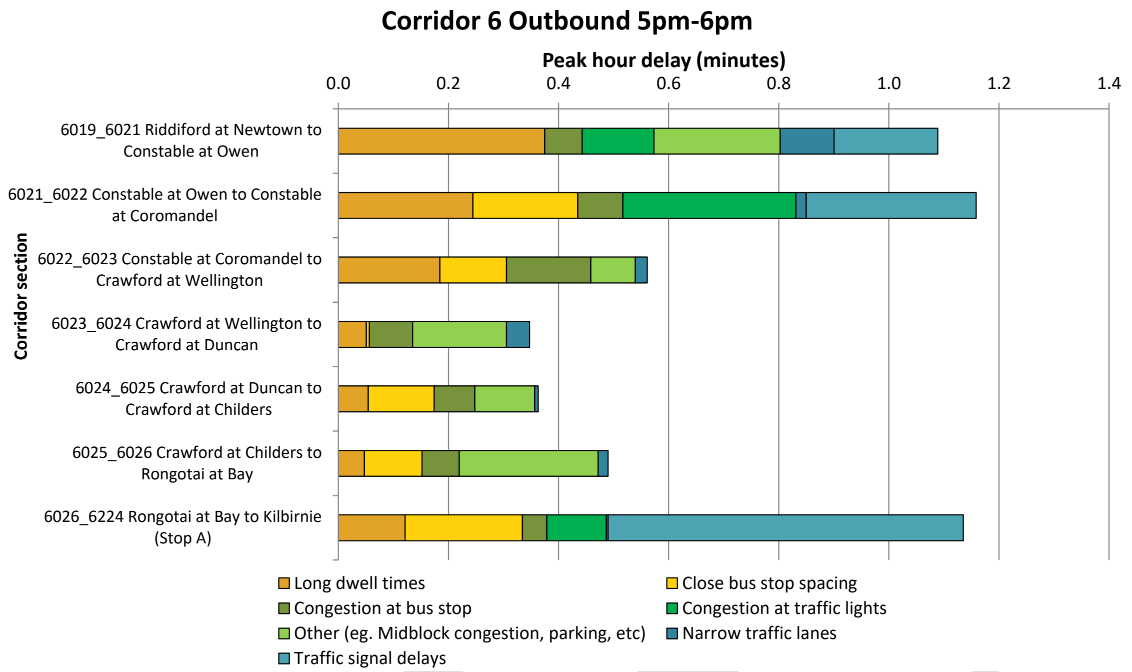
Figure 168: Sources of delay by segment – Inbound morning peak hour (8am–9am)



Outbound

During the peak hour for buses travelling in the outbound direction on the corridor (5pm–6pm), the segments experiencing the most delay are on Constable Street between Riddiford Street and Owen Street, on Constable Street between Owen Street and Coromandel Street, and on Rongotai Road and Evans Bay Parade, on the approach to the Kilbirnie bus hub. More than one minute of delay is experienced by buses on each of these segments. Figure 169 provides a breakdown of the sources of delay on corridor 6 by segment for buses travelling in the outbound direction during this hour.

Figure 169: Sources of delay by segment – Outbound afternoon peak hour (5pm–6pm)



2.4. Issues summary

Figure 170 and Figure 171 provide a summary of the key issues across corridor 6, in both the inbound and outbound directions. These issues have been identified as key sources of delay for buses travelling along the corridor.

Figure 170: Key issues – Inbound morning peak hour (8am–9am)

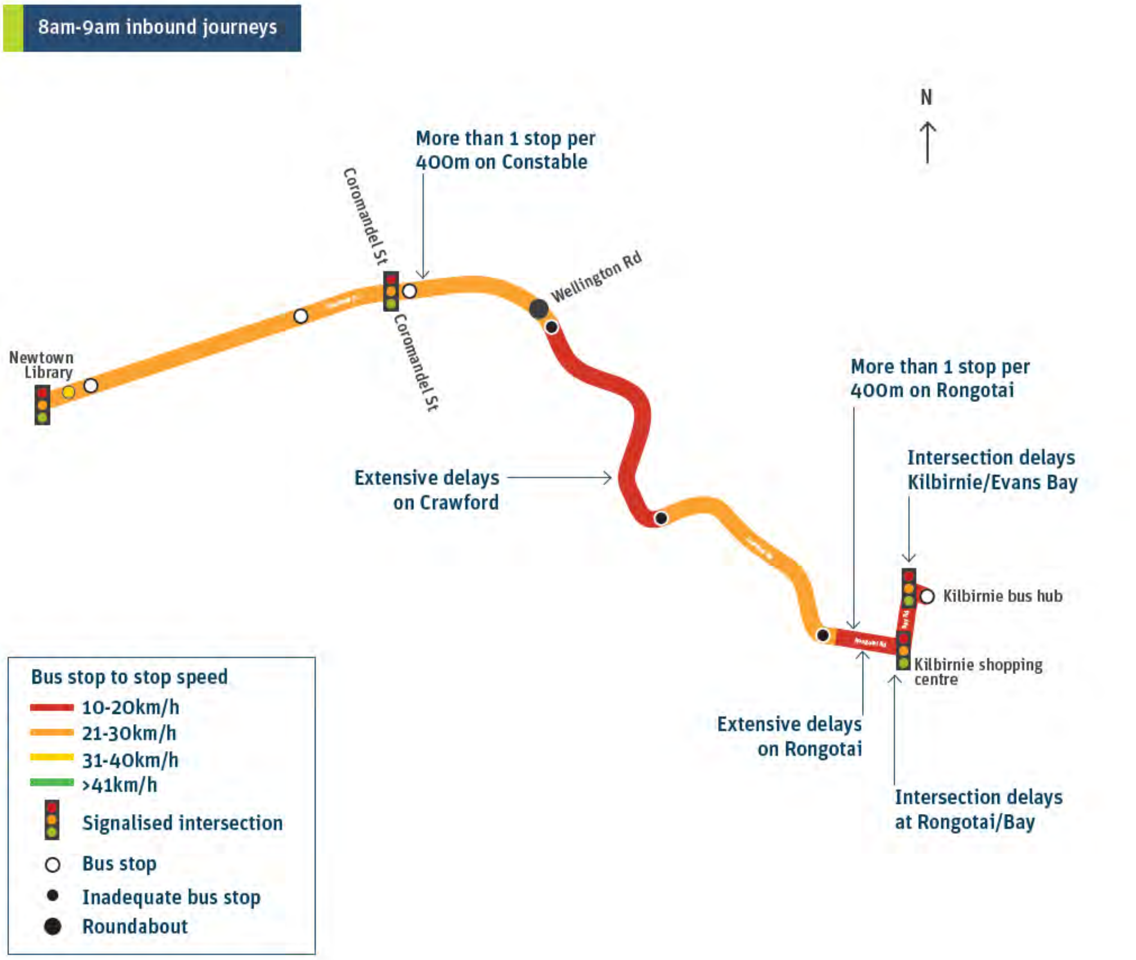
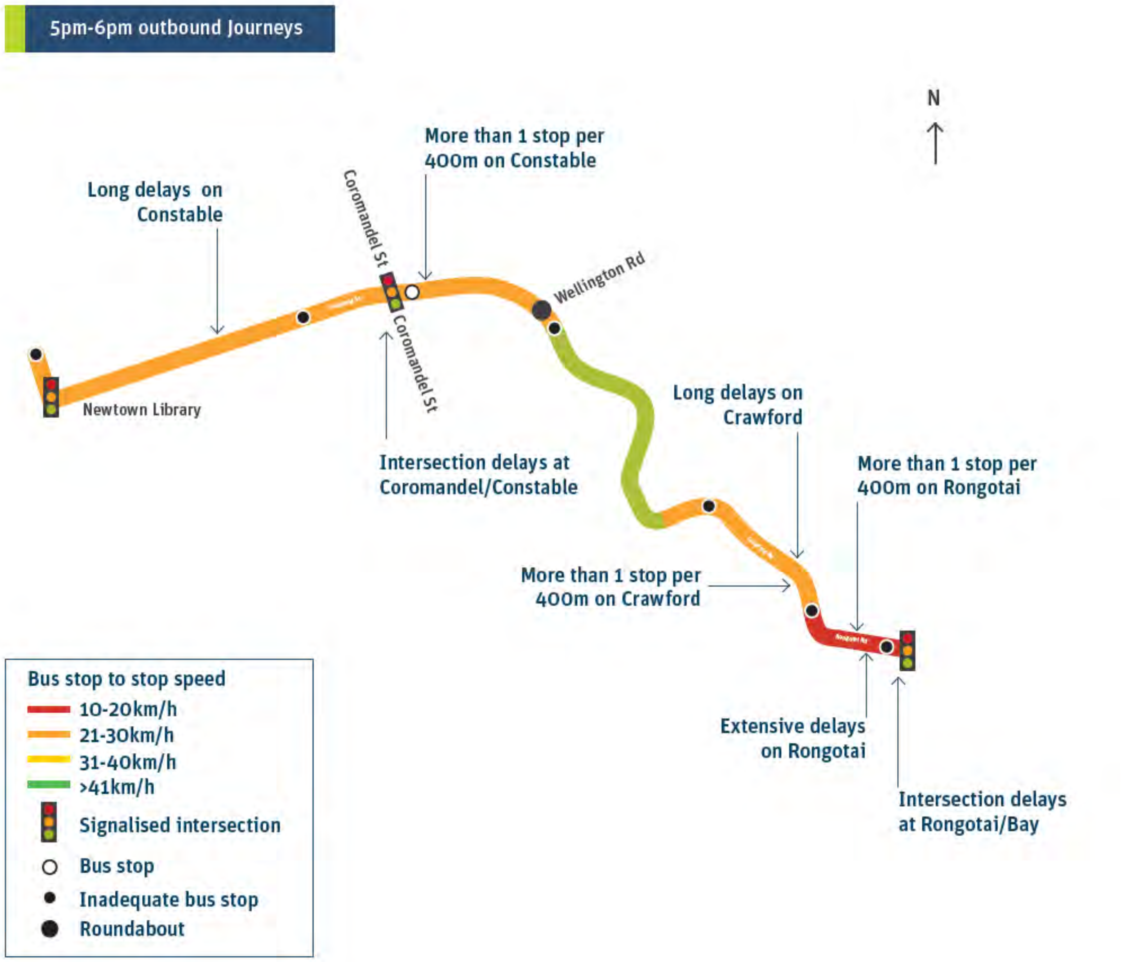


Figure 171: Key issues – Outbound afternoon peak hour (5pm–6pm)



3. Opportunities

For corridor 6, a list of opportunities to improve bus operations has been identified. These opportunities include the implementation of bus priority interventions that would be effective in addressing the documented sources of delay along the corridor and would improve bus travel times.

There are multiple levels of interventions that could be implemented across the corridor that would have varying impacts on bus journey times. For this reason, three packages of opportunities for the corridor have been selected. The package options are defined as follows:

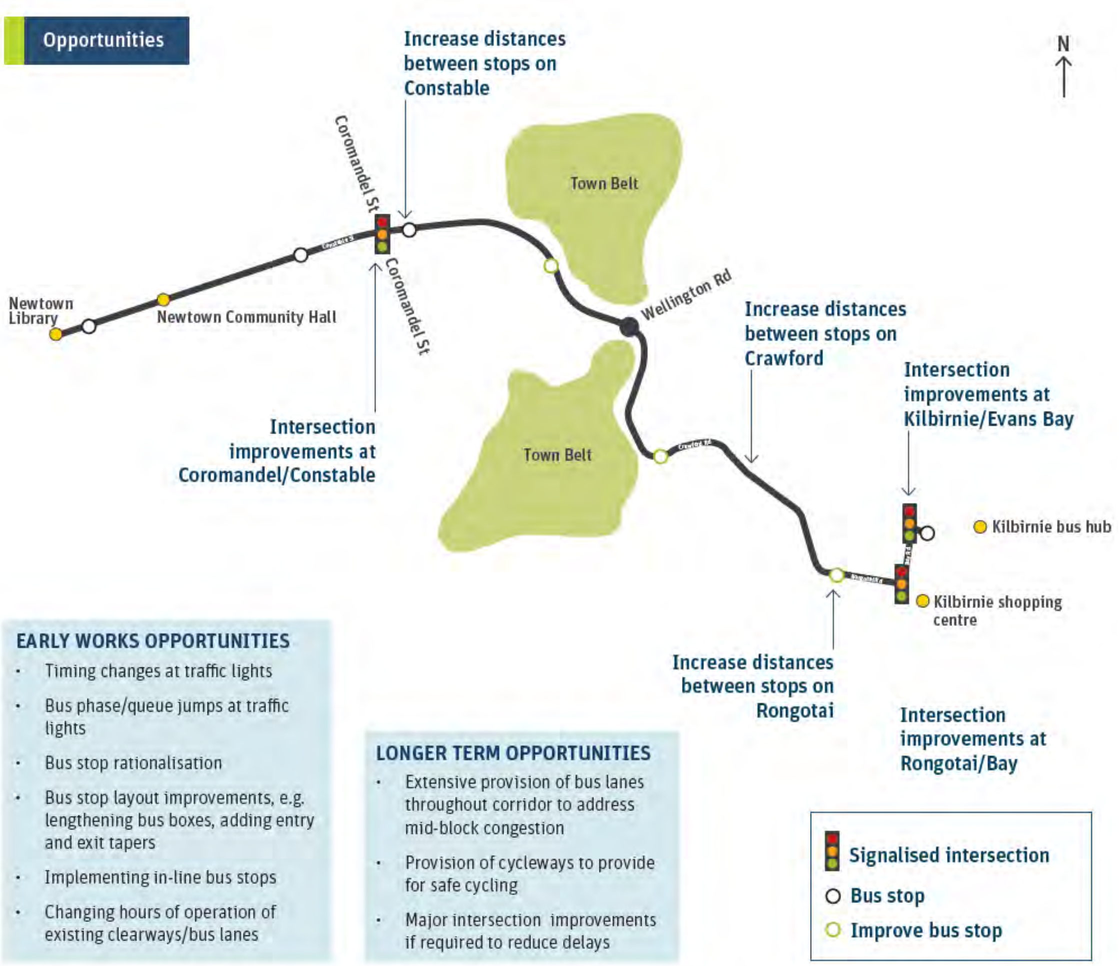
- **Option 1: fix everything**
  This option would address all problems identified on the corridor and implement any of the possible interventions that are effective at addressing the problems that have been identified on the corridor.
- **Option 2: fix the worst problems**
  This option would address only the most severe problems identified on the corridor and only implement interventions that do not involve major reconfiguration of corridor space.

- **Option 3: minimal interventions**
  This option would address only the most severe problems identified on the corridor and implement interventions that involve only minimal reconfiguration of corridor space.

A context map of the location of the key opportunities is provided in Figure 172.

For a full list of the bus priority interventions considered, the package identification process, ad a detailed description of the criteria that was used to identify opportunities on the corridor, refer to Appendix 2.

Figure 172: Key opportunities



Appendix 9 – Brooklyn to city (corridor 7): corridor analysis summary

1. Corridor overview

1.1. Context

The Brooklyn to city corridor (corridor 7) is a 2.6-kilometre-long transport corridor that connects the suburb of Brooklyn to the central city. There are three public bus services and one school service operating on this corridor. On weekdays, there are approximately 3500 daily bus passenger trips along the corridor.

When travelling by bus, the journey from one end of the corridor to the other takes 10 to 11 minutes on average. The inbound peak hour occurs in the morning at 8am–9am, when the average journey time is 14 minutes. The outbound peak hour occurs in the afternoon at 5pm–6pm, when the average journey time is 15 minutes.

Table 82: Summary of key facts on the corridor

Corridor 7: Brooklyn to city	Inbound	Outbound
Maximum daily passengers[54]	1,900	2,500
Corridor length (km)	2.6	2.6
Number of bus stops	10	10
Average bus stop spacing (m)	263	256
Average speed (km/h)	15.3	14.7
Average travel time (min)	10	11
Minimum travel time (min)	7	7
Maximum travel time (min)	14	15
Slowest weekday hour	8am–9am	5pm–6pm

There is an existing section of on-road cycleway on upper Victoria Street, between Ghuznee Street and the Wellington inner city bypass. The section between Vivian Street and Abel Smith Street is protected. There is an associated bike priority signal at the intersection of Victoria Street and Abel Smith Street.

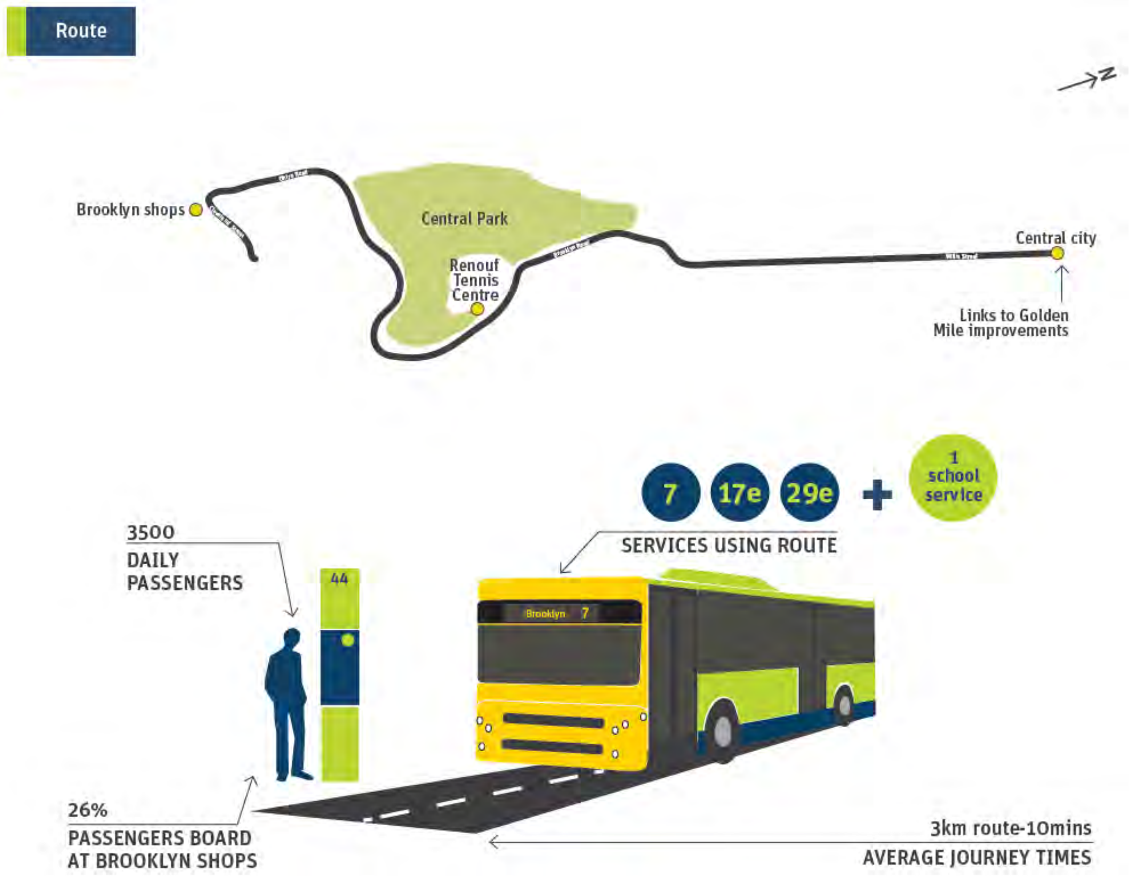
Area

There are several significant destinations along this route, including the Brooklyn town centre, Renouf Tennis Centre, and Central Park, and Willis Street and Victoria Street through the central city.

The land use along the corridor is a mixture of central area, open space, inner residential, outer residential, and centre zones.

[54] 'Maximum daily passengers' refers to the maximum number of passengers passing through a point on the corridor. On corridor 7, this occurs on Willis Street in the inbound direction and on Victoria Street in the outbound direction.

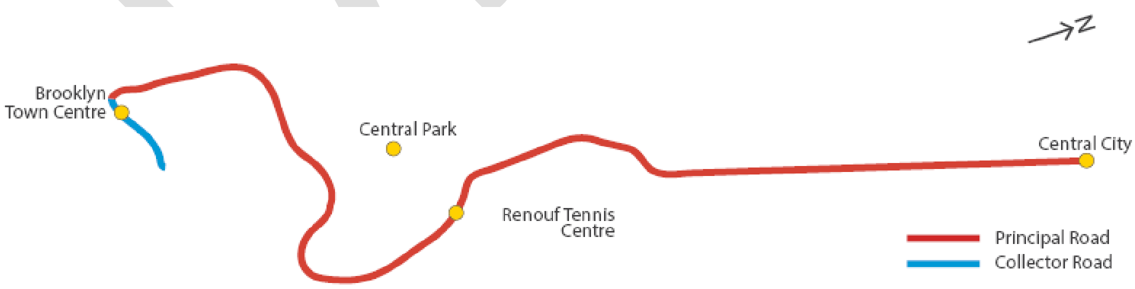
Figure 173: Corridor context map



Roads

The Brooklyn to city corridor is made up primarily of principal roads, with one collector road, as shown in Figure 174. There are seven signalised intersections and no signalised pedestrian crossings or roundabouts along the corridor. Inbound journeys on this corridor travel via Willis Street to access the central city, while outbound journeys to Brooklyn are via Victoria Street.

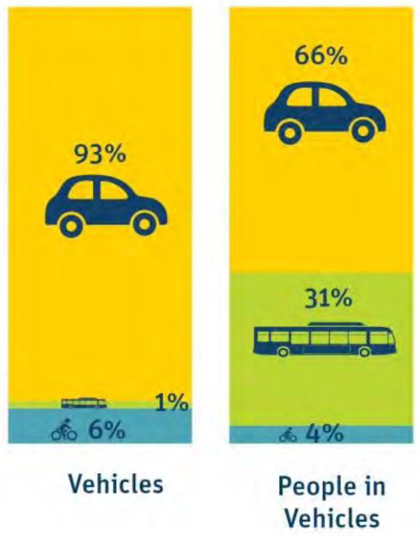
Figure 174: Road hierarchy map[55,56]



[55] Road hierarchy data sourced from WCC District Plan Map 33: Hierarchy of Roads
[56] In the WCC District Plan, the road classifications are defined as follows:
- Principal Road: roads that provide access to motorways and to arterial roads having a dominant through-traffic function and carrying the major public transport routes
- Collector Road: roads that distribute traffic between and within local areas and form the link between principal and secondary roads

During the morning peak hour (8am–9am), the majority of vehicles on the corridor are private vehicles (93 percent), followed by bikes (6 percent). Buses make up only 1 percent of the vehicles on the corridor. However, they transport almost one-third of the people on the corridor (31 percent). This is indicative of the 'heavy lifting' that buses are doing to move people on this corridor. Figure 175 presents a full breakdown of the modal split on the corridor.

Figure 175: Modal split – Inbound morning peak period (8am–9am)



- **Bus operations**

There are three public bus services and one school service operating on this corridor. There are 10 bus stops in the inbound direction and 10 in the outbound direction. All of the bus stops are located in fare zones 1 or 2. The bus stops *Brooklyn – Stop A* and *Brooklyn – Stop C* are part of the Brooklyn bus hub.

There are no existing bus priority measures on the corridor.

Bus stop spacing

Inbound

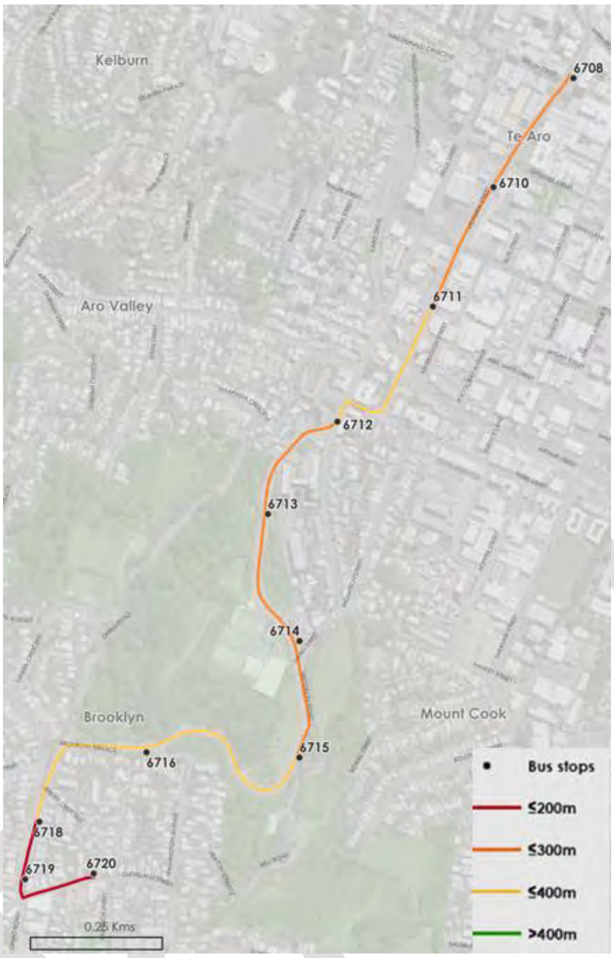
The average bus stop spacing along the corridor in the inbound direction is 263 metres. The closest spacing is 154 metres, between two bus stops in Brooklyn town centre.

Figure 176: Bus stop locations and spacing – Inbound

Outbound

The average bus stop spacing along the corridor in the outbound direction is 256 metres. The closest spacing is 112 metres, between two bus stops on Ohiro Road close to Brooklyn town centre.

Figure 177: Bus stop locations and spacing – Outbound

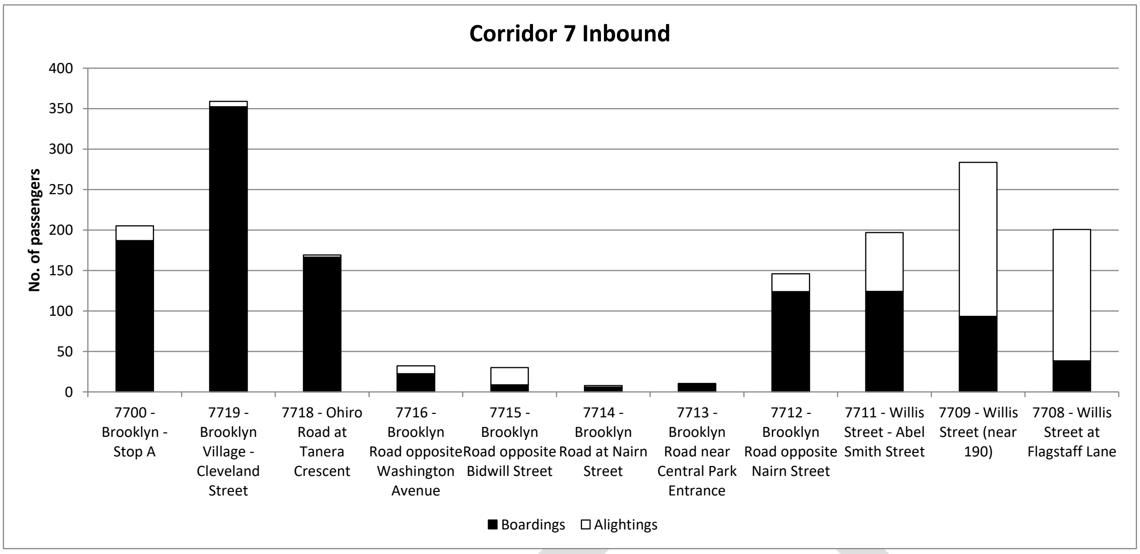


Boardings and alightings

Inbound

The busiest bus stop along the corridor in the inbound direction is *Brooklyn Village – Cleveland Street*, with just over 350 daily boardings and alightings. Four bus stops located on Brooklyn Road are very low-use, with less than 50 boardings and alightings per day. Figure 178 shows the daily number of people boarding and alighting at each bus stop along the corridor in the inbound direction. This includes all bus routes that service each bus stop.

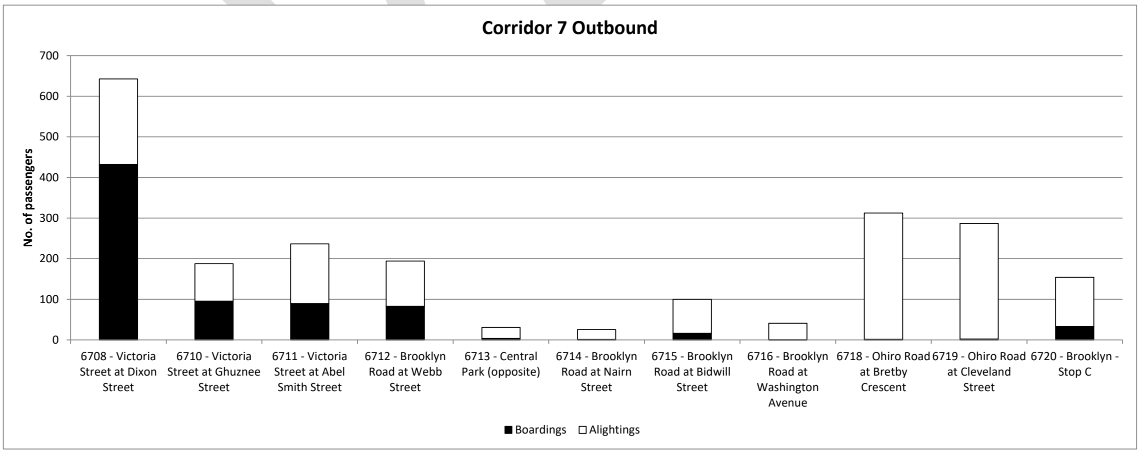
Figure 178: Daily boardings and alightings – Inbound



Outbound

The busiest stop along the corridor in the outbound direction is the first stop, *Victoria Street at Dixon Street*, with more than 600 daily alightings. The busiest stop for alightings is *Ohiro Road at Bretby Crescent*. There are four bus stops with less than 100 boardings and alightings throughout the day, and three with less than 50. Figure 179 shows the daily number of people boarding and alighting at each bus stop along the corridor in the outbound direction. This includes all bus routes that service each bus stop.

Figure 179: Daily boardings and alightings – Outbound

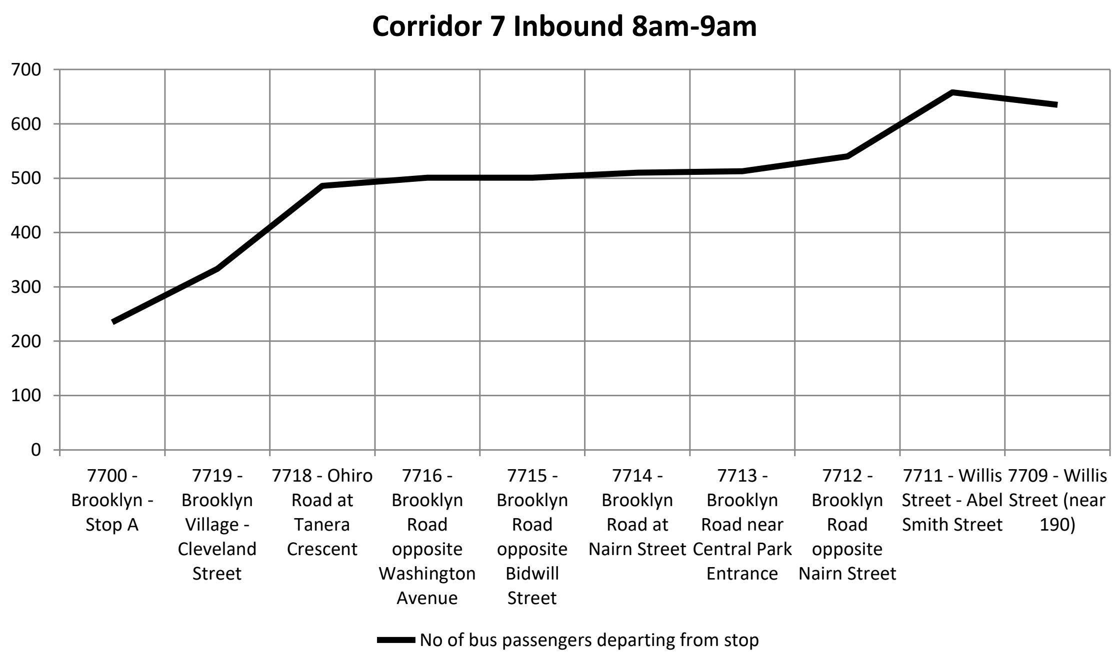


Cumulative passenger numbers

Inbound

During the inbound peak hour on the corridor (8am–9am), the highest bus passenger numbers occur on Willis Street. There is a steady increase in passenger numbers through Brooklyn town centre before plateauing and increasing again at the bottom of Brooklyn Road. Figure 180 shows the average number of bus passengers on the bus departing from each bus stop during this hour.

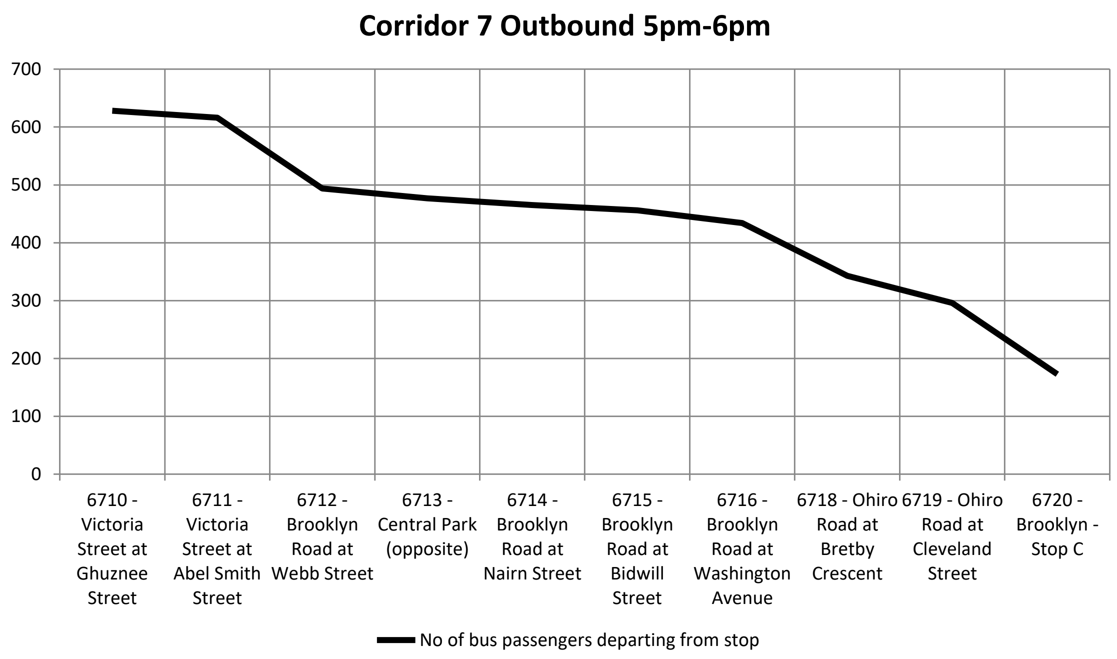
Figure 180: Cumulative bus passenger load – Inbound morning peak hour (8am–9am)



Outbound

During the outbound peak hour on the corridor (5pm–6pm), the highest bus passenger numbers occur on Victoria Street and decrease steadily along the corridor as the service travels outbound. Figure 181 shows the average number of bus passengers on the bus departing from each bus stop during this hour.

Figure 181: Cumulative bus passenger load – Outbound afternooon peak hour (5pm–6pm)



2. Issues

2.1. Travel time

The average travel times along corridor 7 in the inbound direction are faster than travel times in the outbound direction. Travel times in both directions have similar variability, with a 7.2-minute difference between the fastest and slowest travel times in the inbound direction compared to an eight-minute difference between the outbound travel times.

Table 83: S summary of travel times on the corridor

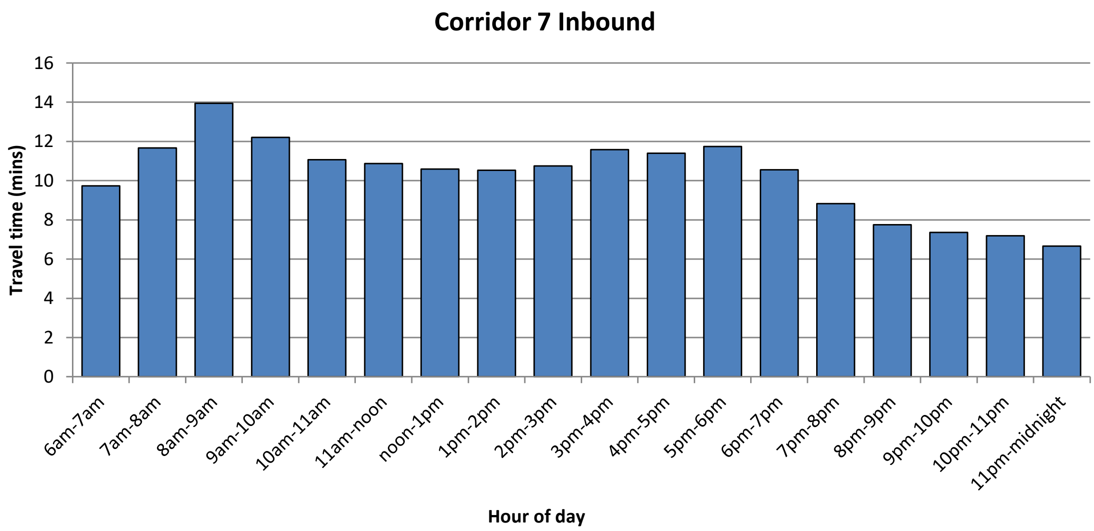
	Inbound	Outbound
Corridor length (km)	2.6	2.6
Average travel time (min)	10.2	10.6
Slowest hour	8am–9am	5pm–6pm
Travel time at slowest hour (min)	13.9	15.4
Fastest hour	11pm–midnight	11pm–midnight
Travel time at fastest hour (min)	6.7	7.4

Travel time by hour

Inbound

On corridor 7 in the inbound direction, the slowest hour for buses is 8am–9am, when it takes an average of 13.9 minutes to travel between Brooklyn town centre and Dixon Street. This is more than twice as long as travel times during the fastest hour of the day (11pm–midnight). Figure 182 below shows the average time it takes for a bus to travel the length of the corridor in the inbound direction for every hour between 6am and midnight.

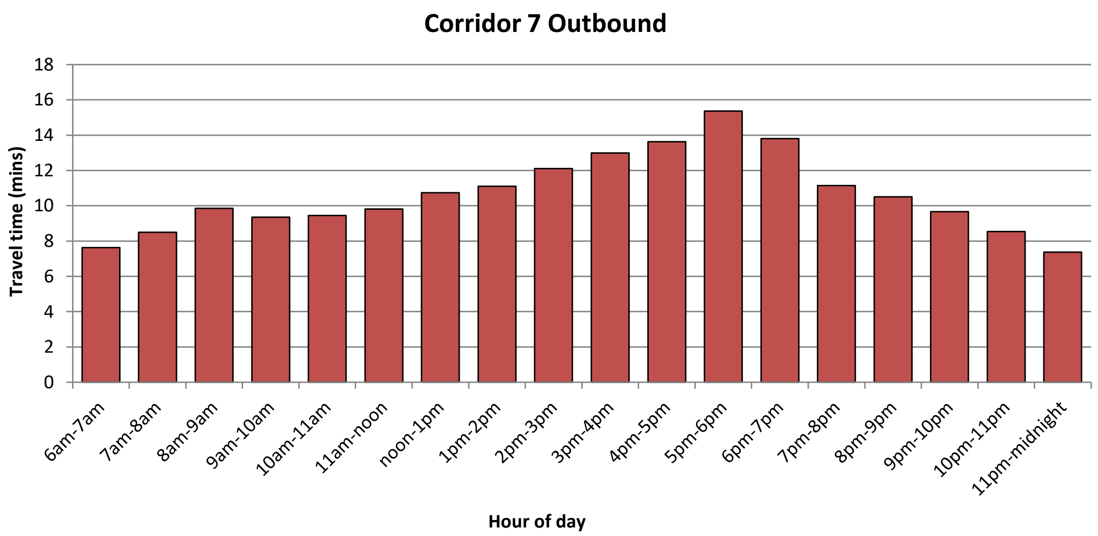
Figure 182: Travel times by hour of day – Inbound



Outbound

On corridor 7 in the outbound direction, the slowest hour for buses is 5pm–6pm, when it takes an average of 15.4 minutes to travel between Dixon Street and Brooklyn town centre. This is more than twice as long as travel times during the fastest hour of the day (11pm–midnight). Figure 183 shows the average time it takes for a bus to travel the length of the corridor in the outbound direction for every hour between 6am and midnight.

Figure 183: Travel times by hour of day – Outbound

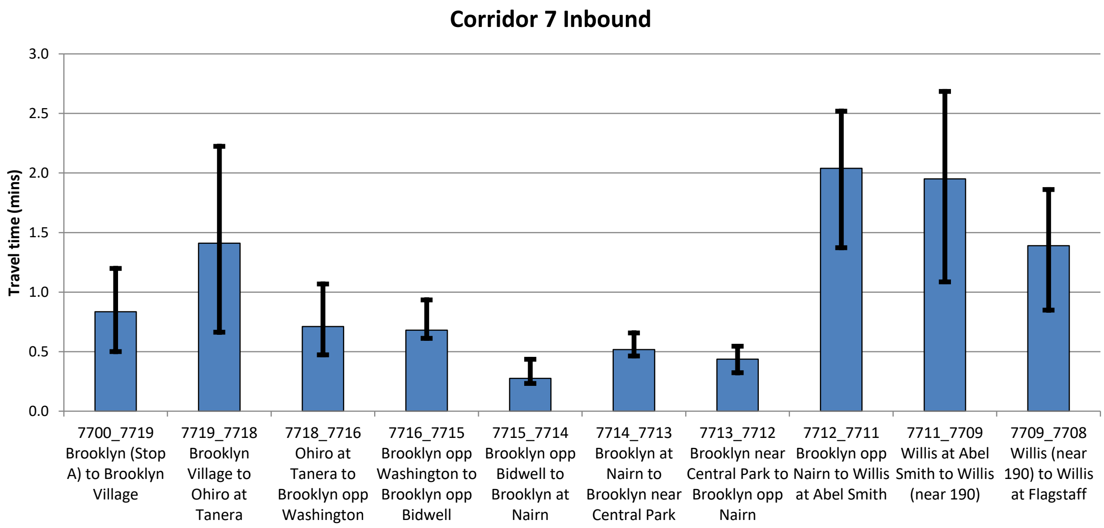


Travel time variability

Inbound

Figure 184 shows the average time it takes for a bus to travel along each segment of the corridor in the inbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

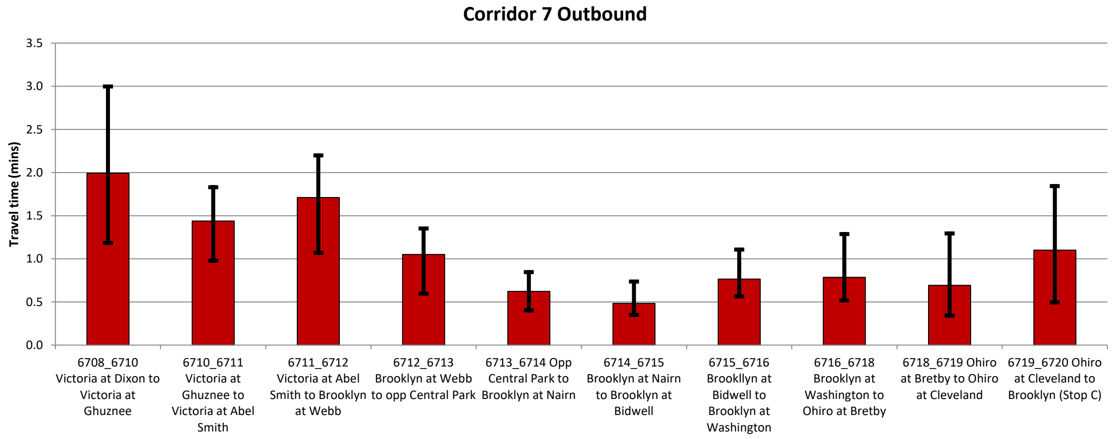
Figure 184: Variation in travel times – Inbound



Outbound

Figure 185 shows the average time it takes for a bus to travel along each segment of the corridor in the outbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

Figure 185: Variation in travel times – Outbound



Bus operating speeds and dwell time delay

The maps below show the average speeds at which buses operate along the corridor and the average time buses dwell at bus stops during the peak hours.

Inbound

During the morning peak hour in the inbound direction (8am–9am), bus operating speeds on the corridor are slowest through Brooklyn town centre and along Willis Street.

Figure 186: Operating speeds and dwell times – Inbound morning peak hour (8am–9am)

Outbound

During the slowest hour in the outbound direction (5pm–6pm), bus operating speeds on the corridor are slowest along Victoria Street.

Figure 187: Operating speeds and dwell times – Outbound afternoon peak hour (5pm–6pm)

2.2. Bus stop audit

There are 10 inbound bus stops between Brooklyn town centre and Dixon Street. There are 10 outbound bus stops between Dixon Street and Brooklyn town centre.

Of these bus stops, 15 are off-line stops, six are not of sufficient length to accommodate a bus, and nine do not have sufficient entry and / or exit tapers for buses to easily manoeuvre into and out of the stop. Such issues can lead to increased dwell times as passengers have to make awkward movements to get on and off the bus. This is particularly so for mobility-impaired pedestrians, as well as for the young, elderly, and people with prams or carrying other heavy or bulky items.

Table 84: Bus stop details[57]

	Number of bus stops	
	Inbound	Outbound
Total number of bus stops	10	10
Number of offline bus stops	8	7
Number of bus boxes with insufficient length (<15m)	3	3
Number of bus stops missing tapers	4	5

[57] Note that the WCC Transport and Infrastructure team is currently working through a list of bus stop improvements, which includes marking out standard bus lengths and entry/exit tapers.

Bus stop walking catchments

The following maps show the areas that are within a five-minute walk of the bus stops on the corridor. The darker blue areas represent where the catchments of multiple bus stops overlap.

Figure 188: Bus stop catchment – Inbound

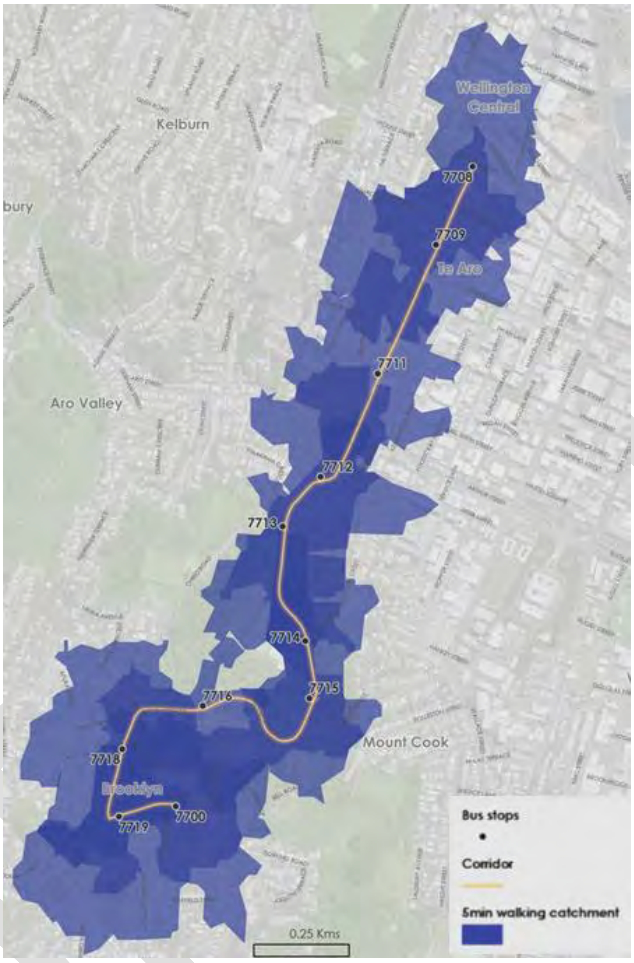
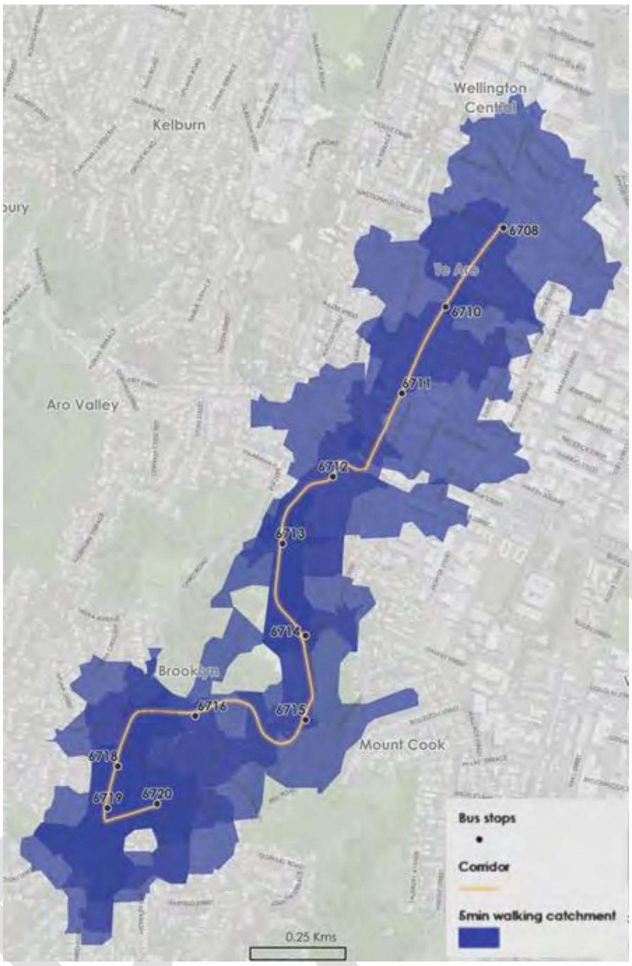


Figure 189: Bus stop catchment – Outbound



2.3. Sources of delay

Percentage delay

The delay that buses experience during the peak hours and slowest hours of travel have been analysed to estimate a breakdown in the sources of delay. Delay is defined as the extra running time of buses, beyond an estimated unimpeded running time. For a full breakdown of how unimpeded running time and delay is estimated, refer to Appendix 2.

To understand the sources of bus delays on the corridor, estimated delays have been decomposed into seven causes:

- long dwell times
- close bus stop spacing
- congestion at bus stops
- congestion at traffic lights
- narrow traffic lanes
- traffic signal delays
- other, which includes delay due to mid-block traffic congestion, un-signalised intersections, hills and corners, roundabouts, and side friction from parking.

Note that in the commentary in the following sections, ‘traffic lights’ refers to the combination of ‘traffic signal delays’ and ‘congestion at traffic lights’.

Inbound

During the slowest hour in the inbound direction (8am–9am), the delay along corridor 7 results in an average bus travel time that is more than two-and-a-half times as long as the estimated unimpeded running time.

Table 85: Theoretical versus actual travel time – Inbound morning peak hour (8am–9am)

Estimated unimpeded travel time	5.3 minutes
Delay	8.6 minutes
Total travel time	13.9 minutes

During the hour, more than one-third of the delay – 3.3 minutes – is attributable to ‘other’ reasons. Given the traffic volumes at this time, this is most likely due to mid-block congestion. However, other drivers completing parking manoeuvres or turning into side streets and driveways may also be a contributing factor. Traffic lights are the second largest source of delay, adding 2.3 minutes of travel time. More than one minute of delay is caused by each closely spaced bus stop (1.2 minutes) and long dwell times (1.1 minutes). A full breakdown of the sources of delay experienced by buses travelling in the inbound direction during the slowest hour (8am–9am) is provided in Figure 190 and Table 86.

Figure 190: Sources of delay – Inbound morning peak hour (8am–9am)

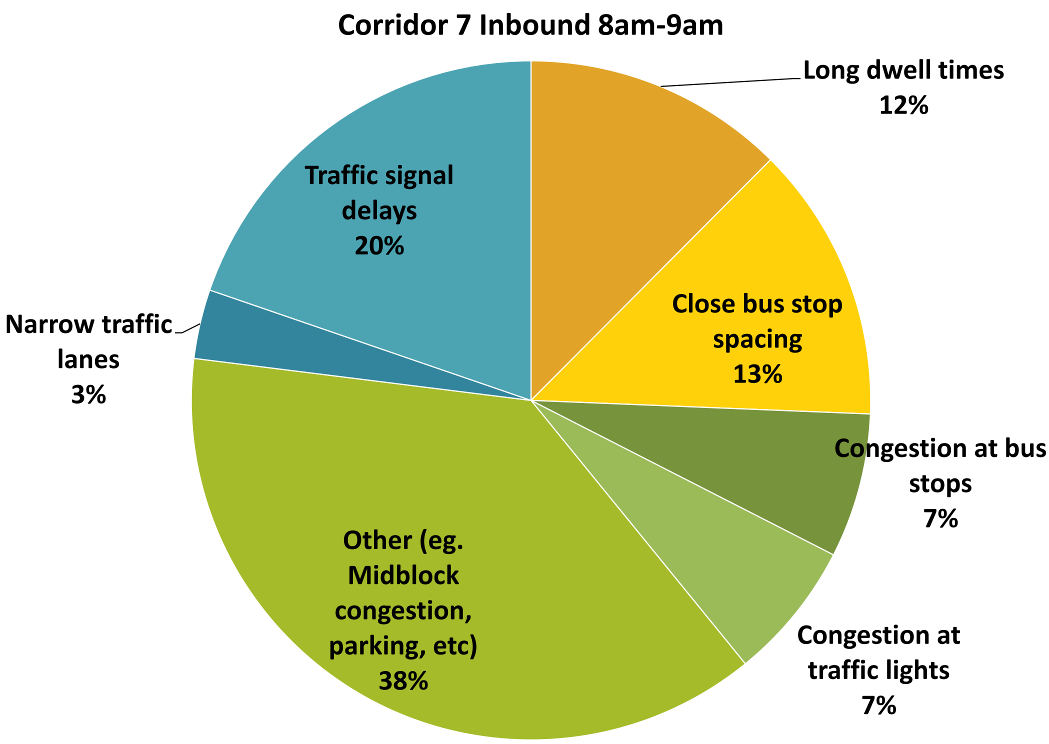


Table 86: Estimated minutes of delay by source – Inbound morning peak hour (8am–9am)

	Minutes added (delay)	Percentage of delay
Long dwell times	1.1	12%
Close bus stop spacing	1.2	13%
Congestion at bus stops	0.6	7%
Congestion at traffic lights	0.6	7%
Narrow traffic lanes	0.3	3%
Traffic signal delays	1.7	20%
Other	3.3	38%

Outbound

During the slowest hour in the outbound direction (5pm–6pm), the delay along corridor 7 results in a bus travel time that is almost three times as long as the estimated unimpeded running time.

Table 87: Theoretical versus actual travel time – Outbound afternoon peak hour (5pm–6pm)

Estimated unimpeded travel time	5.2 minutes
Delay	10.2 minutes
Total travel time (4-5pm)	15.4 minutes

During this hour, the largest source of delay is the 'other' category, contributing to 3.9 minutes of delay. Given the traffic volumes at this time, this is most likely to be traffic congestion, even though bus lanes are in operation on parts of the corridor at this time. Other drivers completing parking manoeuvres or turning into side streets and driveways may also be a contributing factor.

Traffic lights add a total of 2.9 minutes of delay, long dwell times add 1.8 minutes, and close bus stop spacing adds 1.4 minutes. A full breakdown of the sources of delay experienced by buses travelling in the outbound direction during the slowest hour (5pm–6pm) is provided in Figure 191 and Table 88.

Figure 191: Sources of delay – Outbound afternoon peak hour (5pm–6pm)

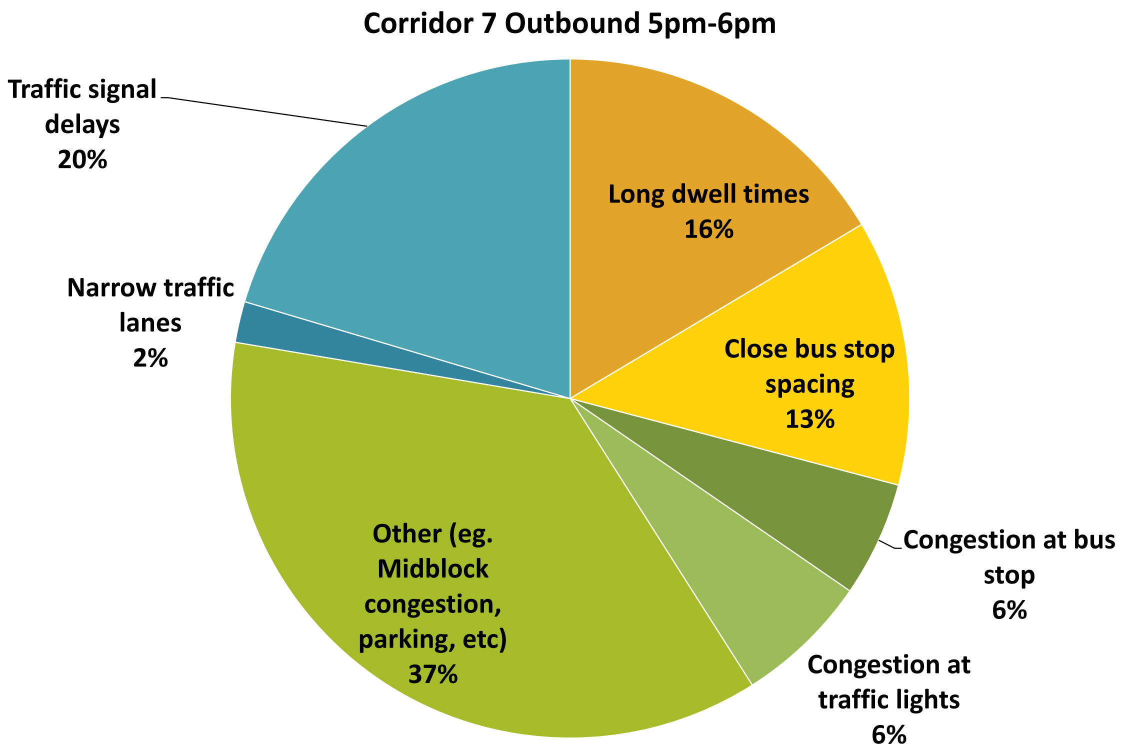


Table 88: Estimated minutes of delay by source – Outbound afternoon peak hour (5pm–6pm)

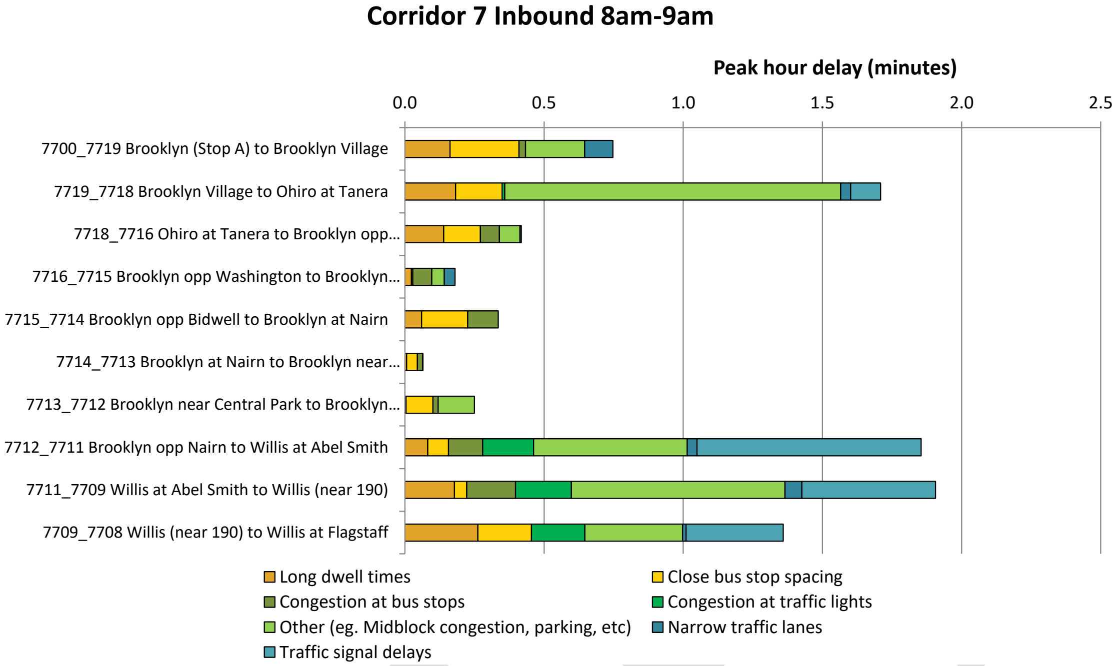
	Minutes added (delay)	Percentage of delay
Long dwell times	1.8	16%
Close bus stop spacing	1.4	13%
Congestion at bus stops	0.6	6%
Congestion at traffic lights	0.7	6%
Narrow traffic lanes	0.2	2%
Traffic signal delays	2.2	20%
Other	3.9	37%

Delay breakdown by segment

Inbound

During the peak hour for buses travelling in the inbound direction on the corridor (8am–9am), there are four segments of the corridor that experience at least one minute of delay. These segments are a section of Ohiro Road and three segments along Willis Street. More than five minutes of delay is experienced on Willis Street alone. Figure 192 provides a breakdown of the sources of delay on corridor 7 by segment for buses travelling in the inbound direction during this hour.

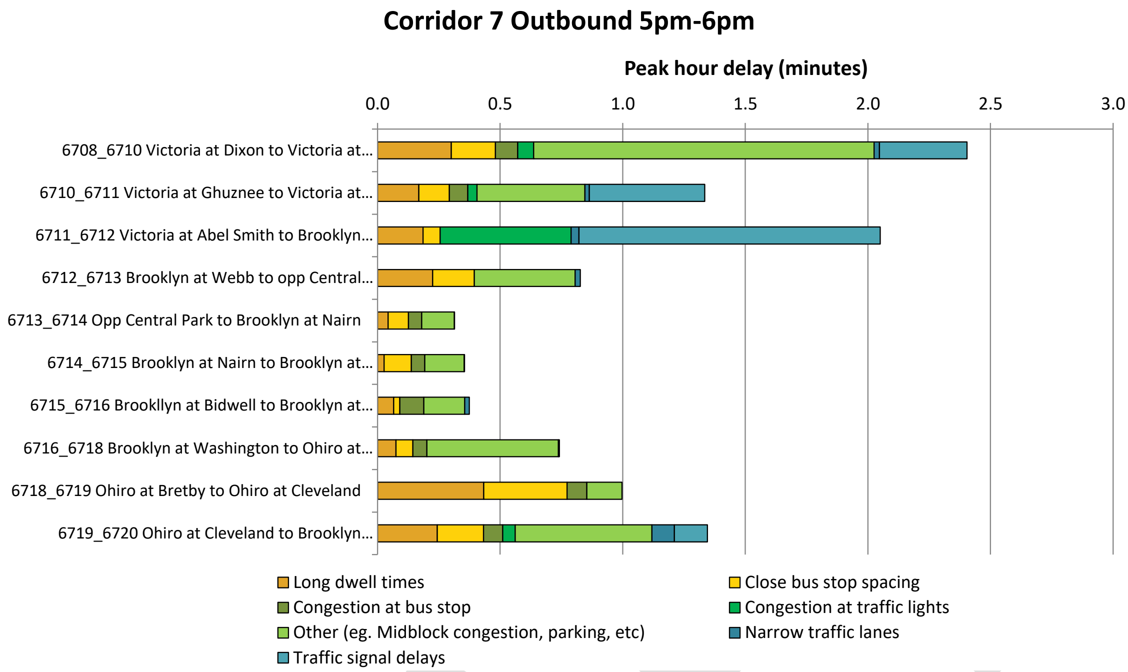
Figure 192: Sources of delay by segment – Inbound morning peak hour (8am–9am)



Outbound

During the peak hour for buses travelling in the outbound direction on the corridor (5pm–6pm), there are two segments on Victoria Street where buses experience at least two minutes of delay. In the segment of Victoria Street between Abel Smith Street and Brooklyn Road, buses experience, on average, almost two minutes of delay due to traffic lights. Figure 193 provides a breakdown of the sources of delay on corridor 7 by segment for buses travelling in the outbound direction during this hour.

Figure 193: Sources of delay by segment – Outbound afternoon peak hour (5pm–6pm)



2.4. Issues summary

Figure 194 and Figure 195 provide a summary of the key issues across corridor 7, in both the inbound and outbound directions. These issues have been identified as key sources of delay for buses travelling along the corridor.

Figure 194: Key issues – Inbound morning peak hour (8am–9am)

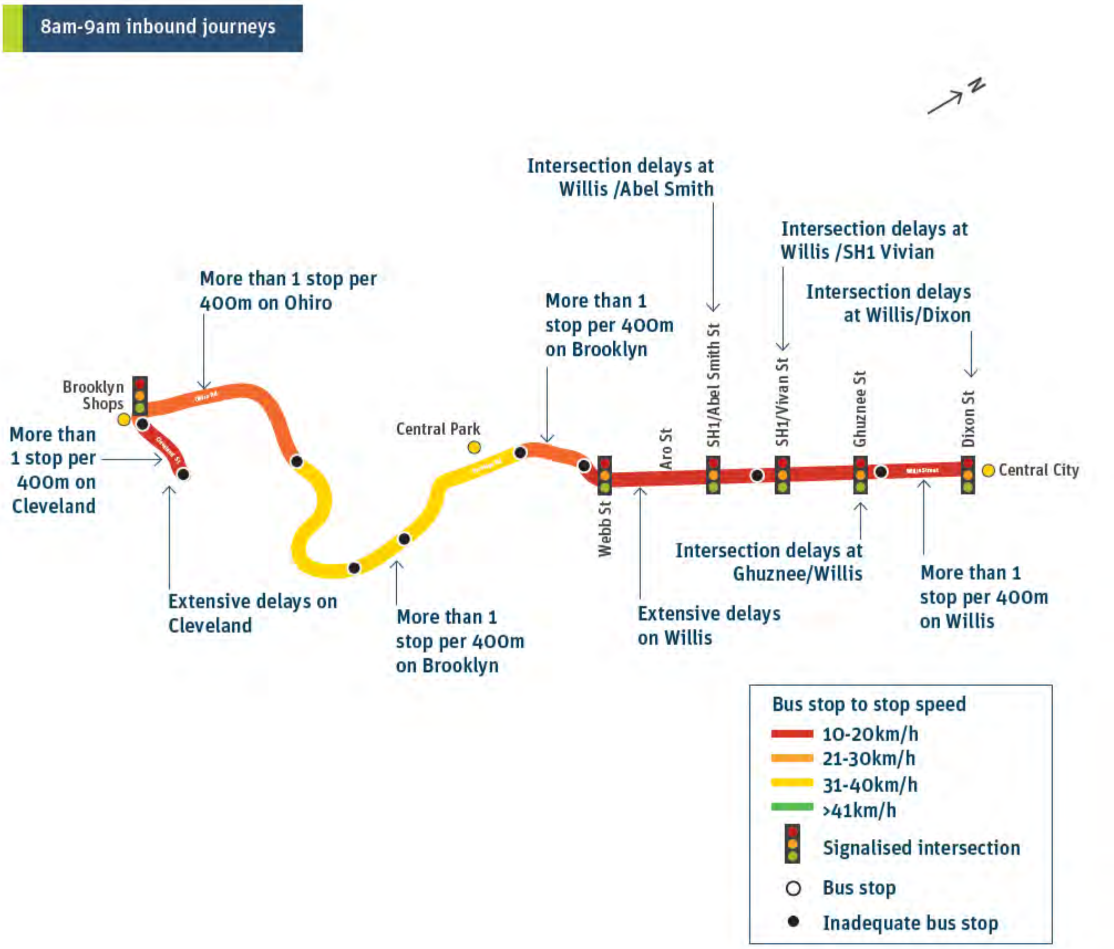
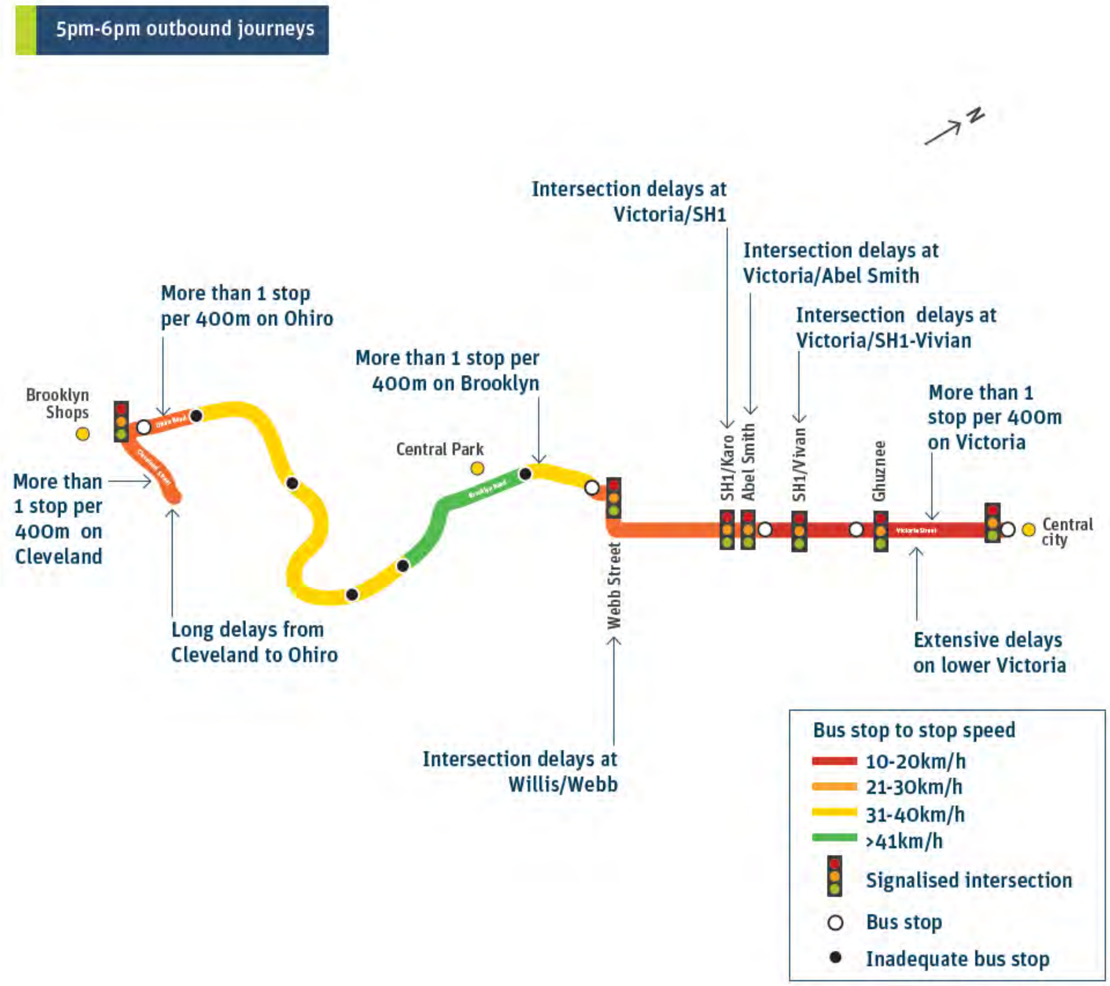


Figure 195: Key issues – Outbound afternoon peak hour (5pm–6pm)



3. Opportunities

For corridor 7, a list of opportunities to improve bus operations has been identified. These opportunities include the implementation of bus priority interventions that would be effective in addressing the documented sources of delay along the corridor and would improve bus travel times.

There are multiple levels of interventions that could be implemented across the corridor that would have varying impacts on bus journey times. For this reason, three packages of opportunities for the corridor have been selected. The package options are defined as follows:

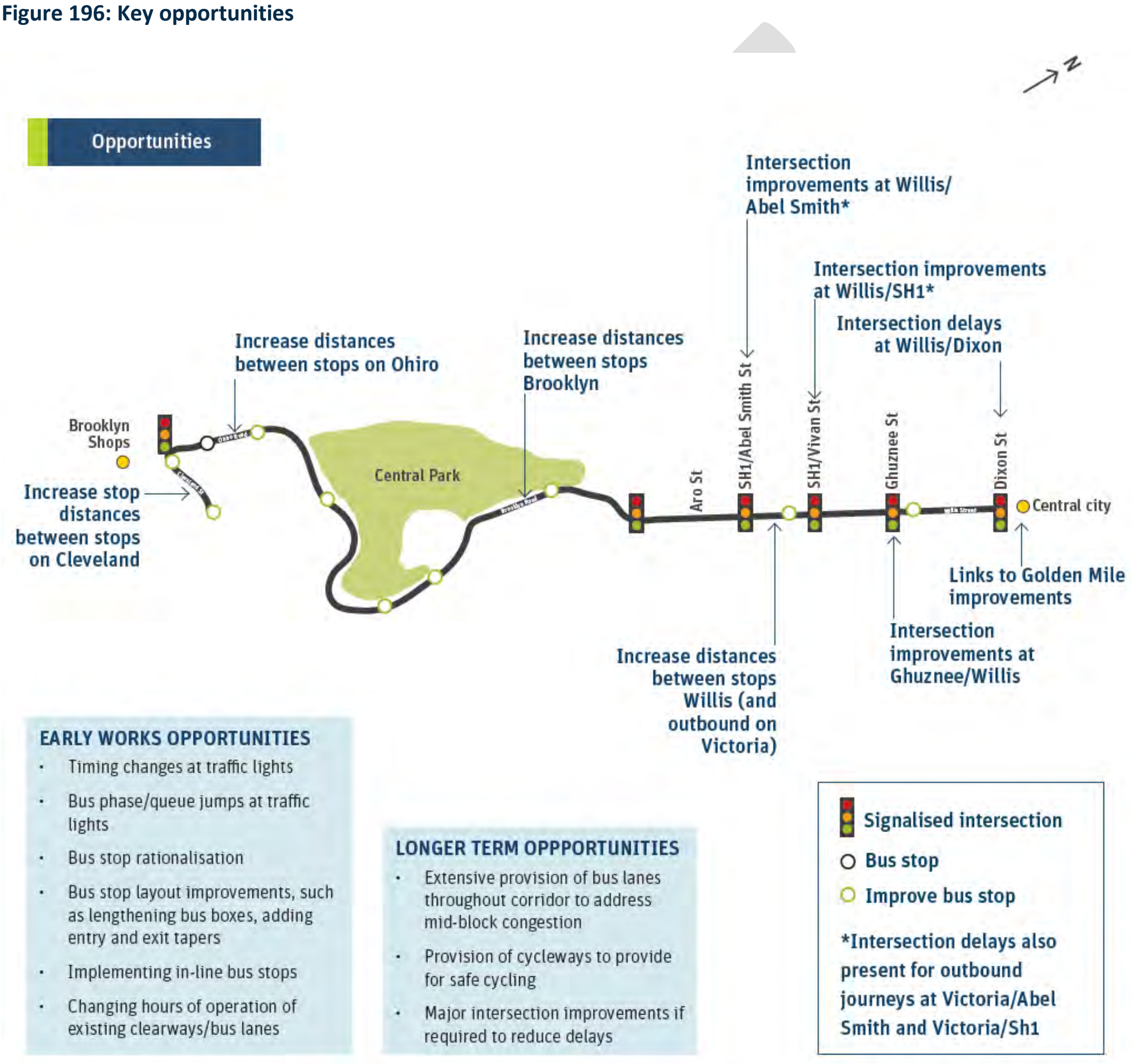
- **Option 1: fix everything**
  This option would address all problems identified on the corridor and implement any of the possible interventions that are effective at addressing the problems that have been identified on the corridor.
- **Option 2: fix the worst problems**
  This option would address only the most severe problems identified on the corridor and only implement interventions that do not involve major reconfiguration of corridor space.

- **Option 3: minimal interventions**
  This option would address only the most severe problems identified on the corridor and implement interventions that involve only minimal reconfiguration of corridor space.

A context map of the location of the key opportunities is provided in Figure 196.

For a full list of the bus priority interventions considered, the package identification process, ad a detailed description of the criteria that was used to identify opportunities on the corridor, refer to Appendix 2.

Figure 196: Key opportunities



Appendix 10 – Johnsonville to city (corridor 8): corridor analysis summary

1. Corridor overview

1.1. Context

The Johnsonville to city corridor (corridor 8) is a 3.6-kilometre-long transport corridor that connects Johnsonville to the central city via Hutt Road. There are three public bus services and no school services operating on this corridor. On weekdays, there are more than 8000 daily bus passenger trips along the corridor.

When travelling by bus, the journey from one end of the corridor to the other takes six to nine minutes on average. The inbound peak hour occurs in the morning at 8am–9am, when the average journey time is 13 minutes. The outbound peak hour occurs in the afternoon at 5pm–6pm, when the average journey time is nine minutes.

Table 89: Summary of key facts on the corridor

	Inbound	Outbound
Maximum daily passengers[58]	4,500	4,100
Corridor length (km)	3.6	3.4
Number of bus stops	4	5
Average bus stop spacing (m)	1,202	842
Average speed (km/h)	24.5	34.8
Average travel time (min)	9	6
Minimum travel time (min)	7	5
Maximum travel time (min)	13	9
Slowest weekday hour	8am–9am	5pm–6pm

There are provisions for cyclists on Hutt Road and Centennial Highway in the form of a shared path.

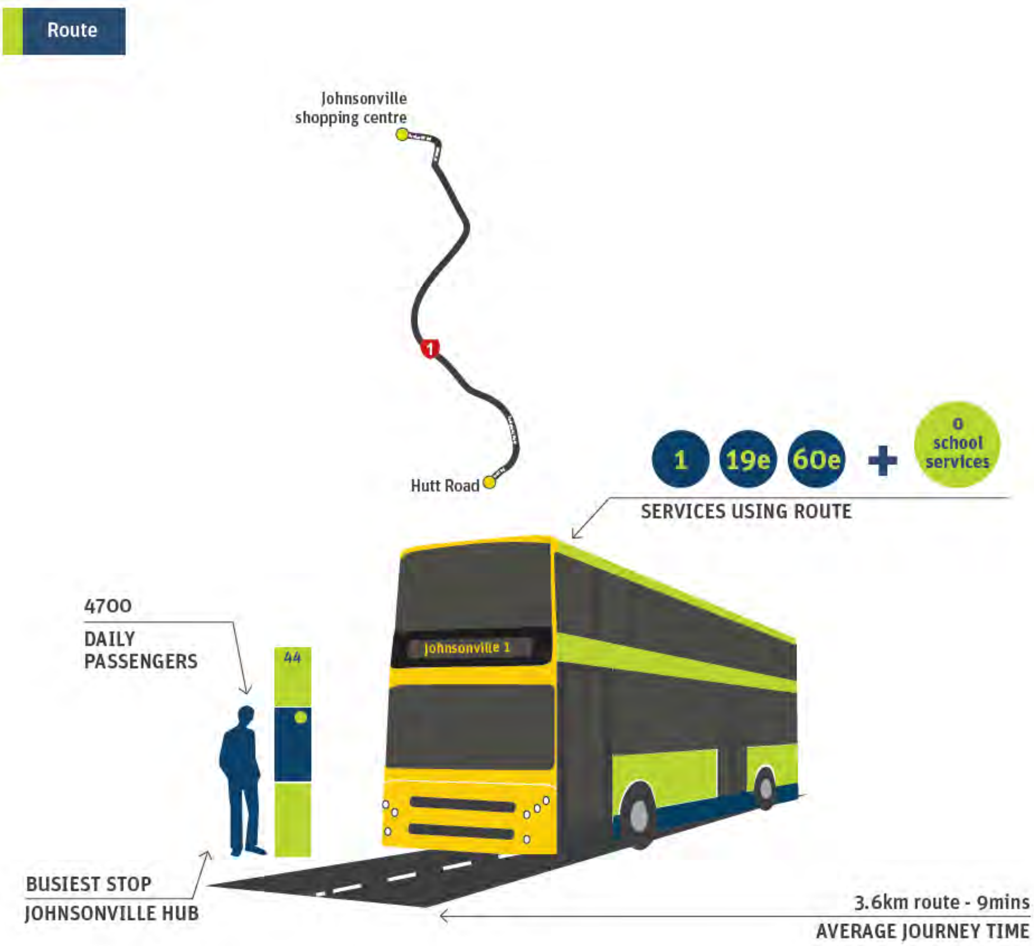
Area

There are several significant destinations located along the Johnsonville to city corridor, including Johnsonville town centre and Johnsonville Library.

The land use along the corridor is primarily business, outer residential, centres, and open space zones.

[58] 'Maximum daily passengers' refers to the maximum number of passengers passing through a point on the corridor. On corridor 8, this occurs along Centennial Highway and Hutt Road, which serves more bus routes than other parts of the corridor.

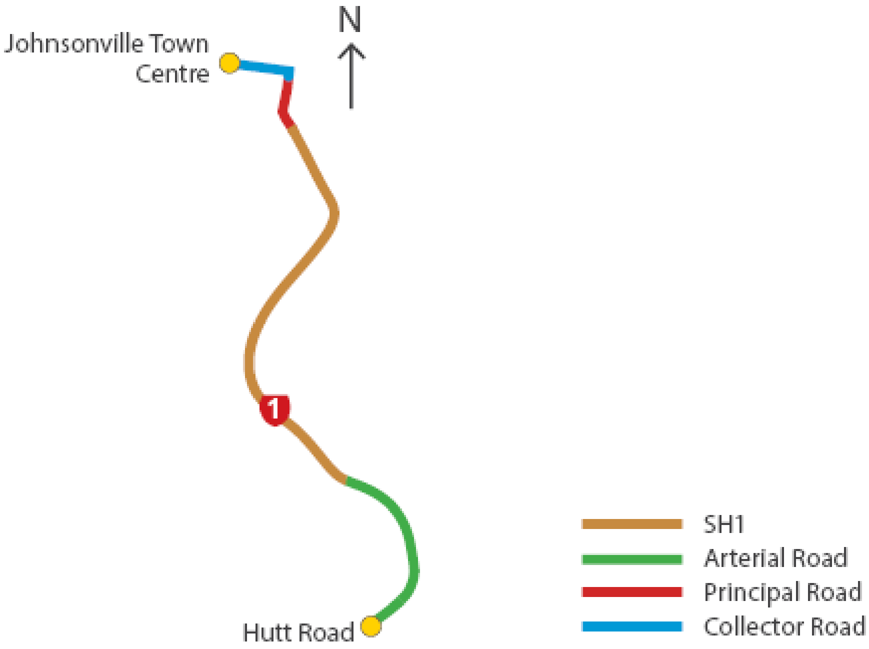
Figure 197: Context map



Roads

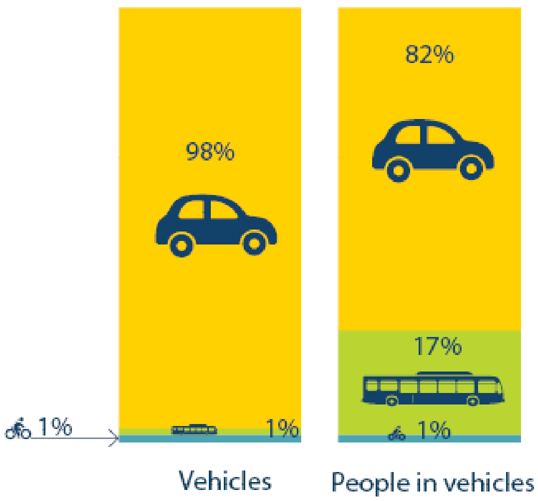
The Johnsonville to city corridor is made up of arterial, principal, and collector roads and also includes a long segment on SH1, as shown in Figure 198. There are five signalised intersections and no signalised pedestrian crossings or roundabouts on the corridor.

Figure 198: Road hierarchy map[59,60]



During the morning peak hour (8am–9am), the vast majority of vehicles on the corridor are private vehicles (98 percent). Buses make up only 1 percent of the vehicles on the corridor. However, they transport 17 percent of the people on the corridor. Figure 199 presents a full breakdown of the modal split on the corridor.

Figure 199: Modal split on the corridor (inbound peak period 8-9am)



[59] Road hierarchy data sourced from WCC District Plan Map 33: Hierarchy of Roads.
[60] In the WCC District Plan, the road classifications are defined as follows:

- Motorway: high standard limited access roads designed to carry long distance through traffic at speed
- Arterial Road: high standard limited access roads designed to carry long distance through traffic
- Principal Road: roads that provide access to motorways and to arterial roads having a dominant through-traffic function and carrying the major public transport routes
- Collector Road: roads that distribute traffic between and within local areas and form the link between principal and secondary roads

1.2. Bus operations

There are four bus stops in the inbound direction and five in the outbound direction. All of the bus stops are located in fare zone 3. The bus stops *Johnsonville – Stop A* and *Johnsonville – Stop B* are part of the Johnsonville bus hub.

There are no existing bus priority measures in place on this corridor.

Bus stop spacing

Inbound

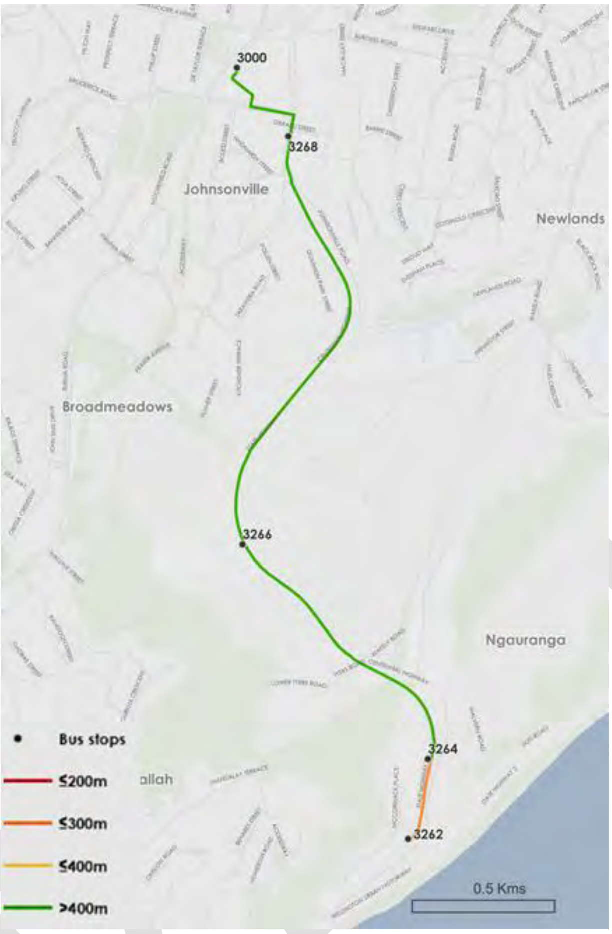
The average bus stop spacing along the corridor in the inbound direction is 1.2 kilometres. This long spacing is due to a long stretch between bus stops on the motorway through Ngauranga Gorge. The closest spacing is 637 metres, between the two bus stops in Johnsonville.

Figure 200: Bus stop locations and spacing – Inbound

Outbound

The average bus stop spacing along the corridor in the outbound direction is 840 metres. This long spacing is due to a long stretch between bus stops on the motorway through Ngauranga Gorge. The closest spacing is 300 metres, between Hutt Road and the Ngauranga commercial centre.

Figure 201: Bus stop locations and spacing – Outbound

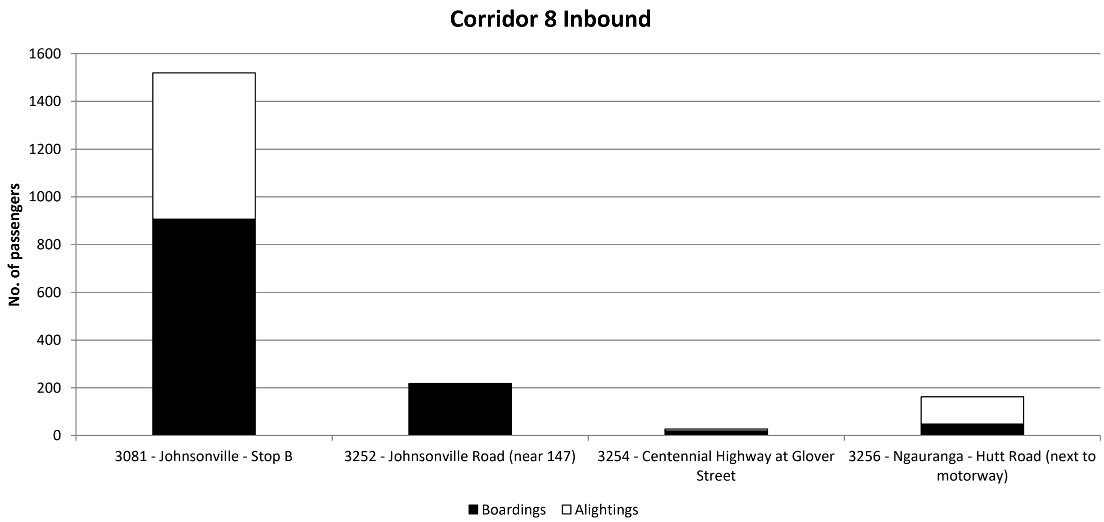


Boardings and alightings

Inbound

The busiest bus stop along the corridor in the inbound direction is *Johnsonville – Stop B*, with just over 1500 daily boardings and alightings. The least busy bus stop is *Centennial Highway at Glover Street*, with less than 30 daily boardings and alightings. Figure 202 shows the daily number of people boarding and alighting at each bus stop along the corridor in the inbound direction. This includes all bus routes that service each bus stop.

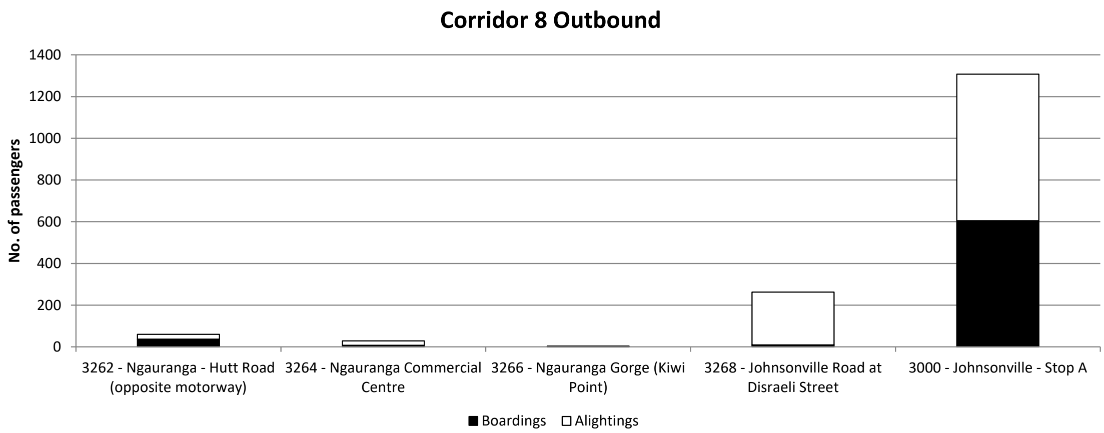
Figure 202: Daily boardings and alightings – Inbound



Outbound

The busiest bus stop along the corridor in the outbound direction is *Johnsonville – Stop A*, with more than 1300 daily boardings and alightings. All of the bus stops before Johnsonville have less than 100 boardings and alightings throughout the day, and *Ngauranga Gorge (Kiwi Point)* has only four boardings and alightings per day, on average. Figure 203 shows the daily number of people boarding and alighting at each bus stop along the corridor in the outbound direction. This includes all bus routes that service each bus stop.

Figure 203: Daily boardings and alightings – Outbound

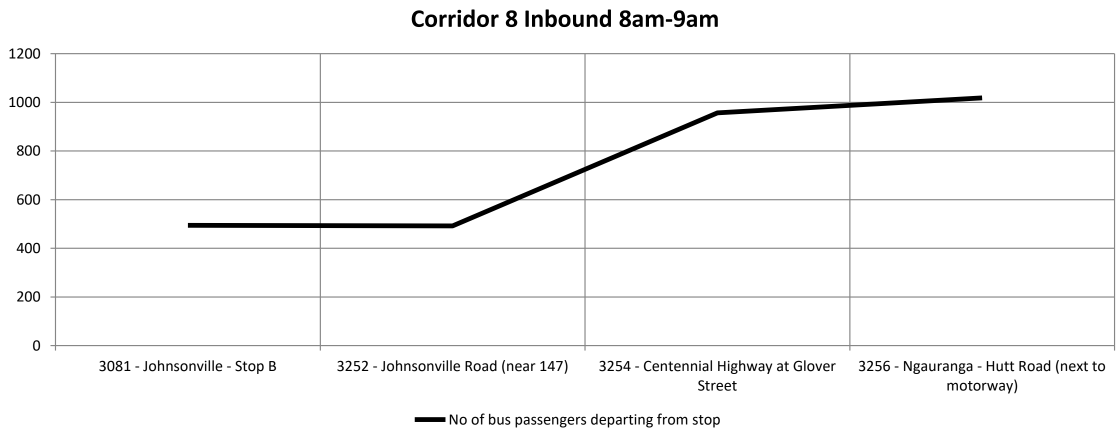


Cumulative passenger numbers

Inbound

During the inbound peak hour on the corridor (8am–9am), the highest bus passenger numbers occur on Centennial Highway and Ngauranga Gorge, which serve more bus routes than other parts of the corridor. Figure 204 shows the average number of bus passengers on the bus departing from each bus stop during this hour.

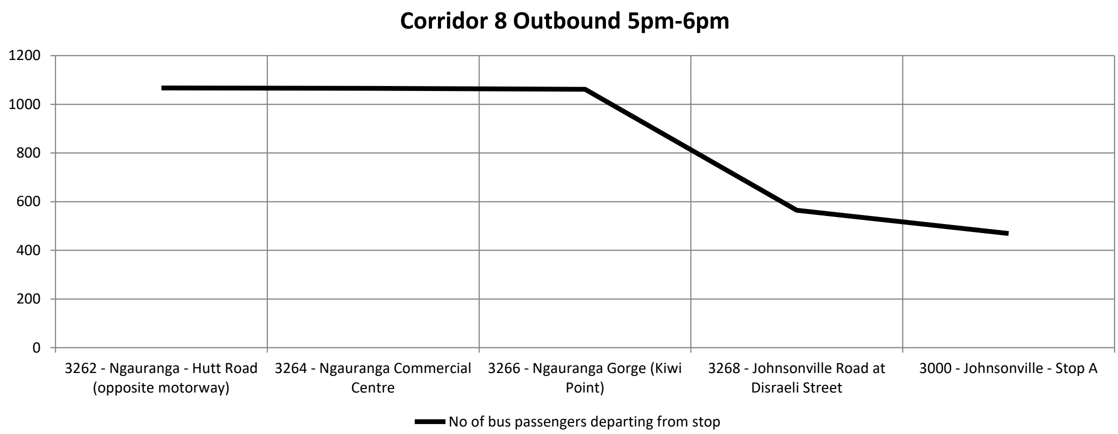
Figure 204: Cumulative bus passenger load – Inbound morning peak hour (8am–9am)



Outbound

During the outbound peak hour on the corridor (5pm–6pm), the highest bus passenger numbers occur on Ngauranga Gorge, which serves more bus routes than other parts of the corridor. Figure 205 shows the average number of bus passengers on the bus departing from each bus stop during this hour.

Figure 205: Cumulative bus passenger load – Outbound afternooon peak hour (5pm–6pm)



2. Issues

2.1. Travel time

The average travel times along corridor 8 in the inbound direction are slower than travel times in the outbound direction. Travel times in the outbound direction also have less variability, with a 3.7-minute difference between the fastest and slowest travel times compared to a 6.6-minute difference between the inbound travel times.

Table 90: Summary of travel times on the corridor

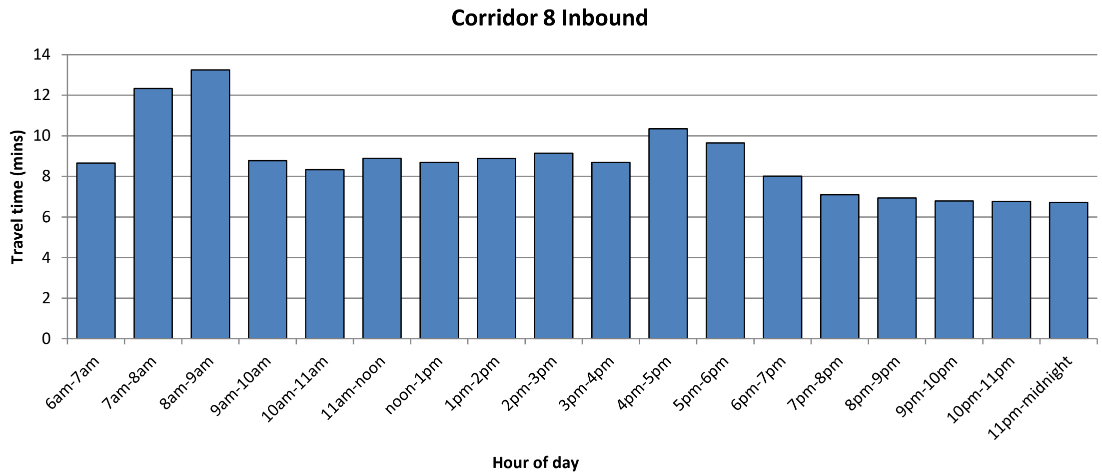
	Inbound	Outbound
Corridor length (km)	3.6	3.4
Average travel time (min)	8.8	6.2
Slowest hour	8am–9am	5pm–6pm
Travel time at slowest hour (min)	13.3	8.9
Fastest hour	11pm–midnight	11pm–midnight
Travel time at fastest hour (min)	6.7	5.2

Travel time by hour

Inbound

On corridor 8 in the inbound direction, the slowest hour for buses is 8am–9am, when it takes an average of 13.3 minutes to travel between Johnsonville town centre and Hutt Road. This travel time is almost twice as long as travel times during the fastest hour of the day (11pm–midnight). Figure 206 below shows the average time it takes for a bus to travel the length of the corridor in the inbound direction for every hour between 6am and midnight.

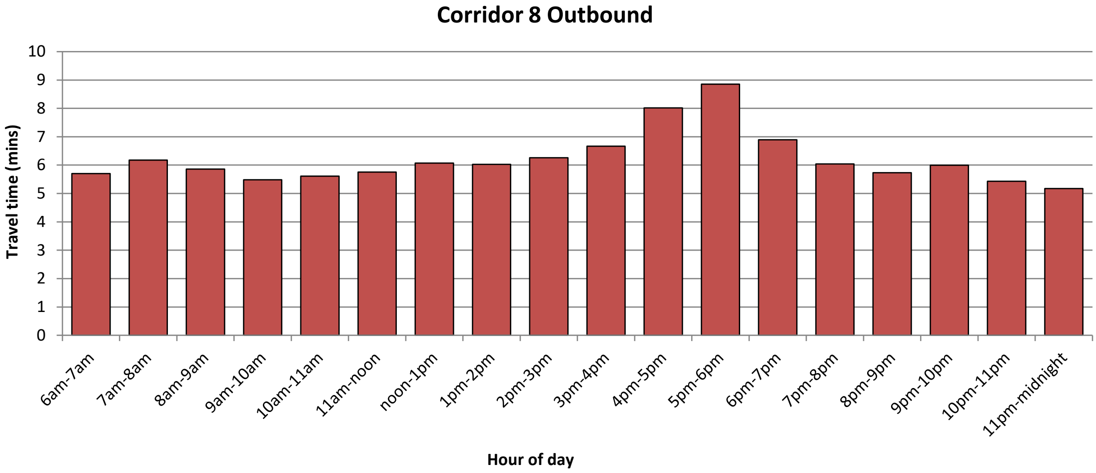
Figure 206: Travel times by hour – Inbound



Outbound

On corridor 8 in the outbound direction, the slowest hour for buses is 5pm–6pm, when it takes an average of 8.9 minutes to travel between Hutt Road and Johnsonville town centre. Figure 207 shows the average time it takes for a bus to travel the length of the corridor in the outbound direction for every hour between 6am and midnight.

Figure 207: Travel times by hour – Outbound

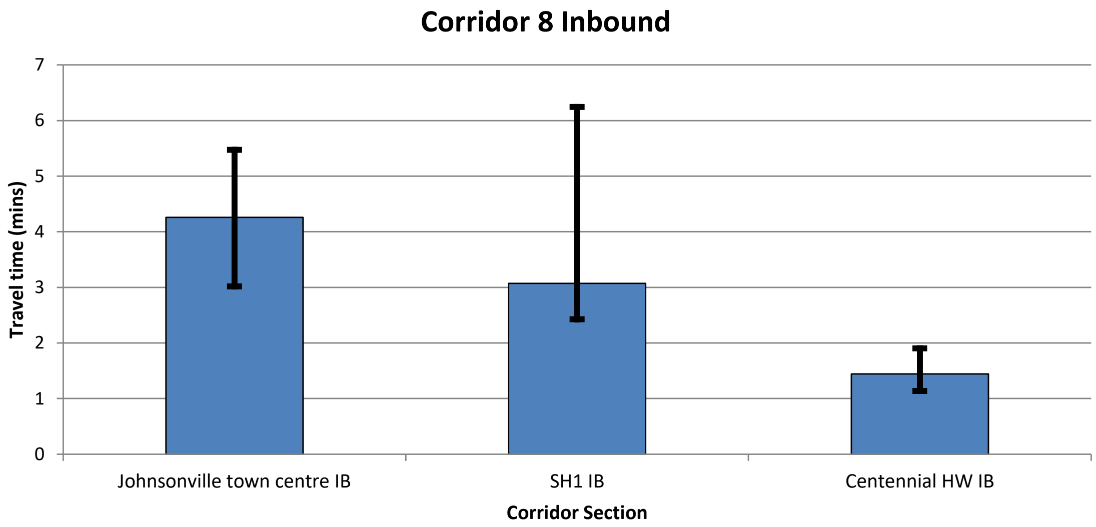


Travel time variability

Inbound

Figure 208 shows the average time it takes for a bus to travel along each segment of the corridor in the inbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

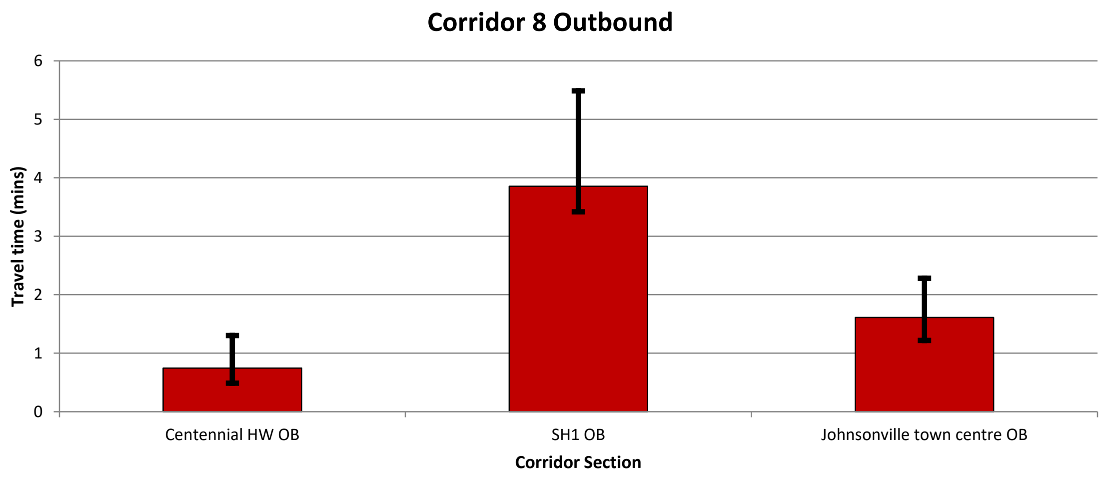
Figure 208: Variation in travel times – Inbound



Outbound

Figure 209 shows the average time it takes for a bus to travel along each segment of the corridor in the outbound direction. The black lines represent the variation between the shortest and longest travel times on each segment, indicating the variability of travel times throughout the day.

Figure 209: Variation in travel times – Outbound



Bus operating speeds and dwell time delay

The maps below show the average speeds at which buses operate along the corridor and the average time buses dwell at bus stops during the peak hours.

Inbound

During the morning peak hour in the inbound direction (8am–9am), bus operating speeds on the corridor are slowest through Johnsonville.

Figure 210: Operating speeds and dwell times – Inbound morning peak hour (8am–9am)

Outbound

During the slowest hour in the outbound direction (5pm–6pm), bus operating speeds on the corridor are slowest through Johnsonville.

Figure 211: Operating speeds and dwell times – Outbound afternoon peak hour (5pm–6pm)

2.2. Bus stop audit

There are four inbound bus stops between the Johnsonville bus hub and Hutt Road. There are five outbound bus stops between Hutt Road and the Johnsonville bus hub.

Of these bus stops, seven are off-line stops, four are not of sufficient length to accommodate a bus, and one does not have sufficient entry and / or exit tapers for buses to easily manoeuvre into and out of the stop. Such issues can lead to increased dwell times as passengers have to make awkward movements to get on and off the bus. This is particularly so for mobility-impaired pedestrians, as well as for the young, elderly, and people with prams or carrying other heavy or bulky items.

Table 91: Bus stop details[61]

	Number of bus stops	
	Inbound	Outbound
Total number of bus stops	4	5
Number of offline bus stops	2	5
Number of bus boxes with insufficient length (<15m)	2	2
Number of bus stops missing tapers	1	0

[61] Note that the WCC Transport and Infrastructure team is currently working through a list of bus stop improvements, which includes marking out standard bus lengths and entry/exit tapers.

Bus stop walking catchments

The following maps show the areas that are within a five-minute walk of the bus stops on the corridor. The darker blue areas represent where the catchments of multiple bus stops overlap.

Figure 212: Bus stop catchment – Inbound

Figure 213: Bus stop catchment – Outbound

2.3. Sources of delay

Percentage delay

The delay that buses experience during the peak hours and slowest hours of travel have been analysed to estimate a breakdown in the sources of delay. Delay is defined as the extra running time of buses, beyond an estimated unimpeded running time. For a full breakdown of how unimpeded running time and delay is estimated, refer to Appendix 2.

To understand the sources of bus delays on the corridor, estimated delays have been decomposed into seven causes:

- long dwell times
- close bus stop spacing
- congestion at bus stops
- congestion at traffic lights
- narrow traffic lanes
- traffic signal delays
- other, which includes delay due to mid-block traffic congestion, un-signalised intersections, hills and corners, roundabouts, and side friction from parking.

Note that in the commentary in the following sections, 'traffic lights' refers to the combination of 'traffic signal delays' and 'congestion at traffic lights'.

Inbound

During the slowest hour in the inbound direction (8am–9am), the delay along corridor 8 results in an average bus travel time that is almost three times as long as the estimated unimpeded running time.

Table 92: Theoretical versus actual travel time – Inbound morning peak hour (8am–9am)

Estimated unimpeded travel time	4.5 minutes
Delay	8.8 minutes
Total travel time	13.3 minutes

During the hour, more than half of the delay – 5.3 minutes – is attributable to 'other' reasons. Given the traffic volumes at this time, this is most likely due to traffic congestion. Traffic lights are the second largest source of delay, increasing travel times by 2.9 minutes. A full breakdown of the sources of delay experienced by buses travelling in the inbound direction during the slowest hour (8am–9am) is provided in Figure 214 and Table 93.

Figure 214: Sources of delay – Inbound morning peak hour (8am–9am)

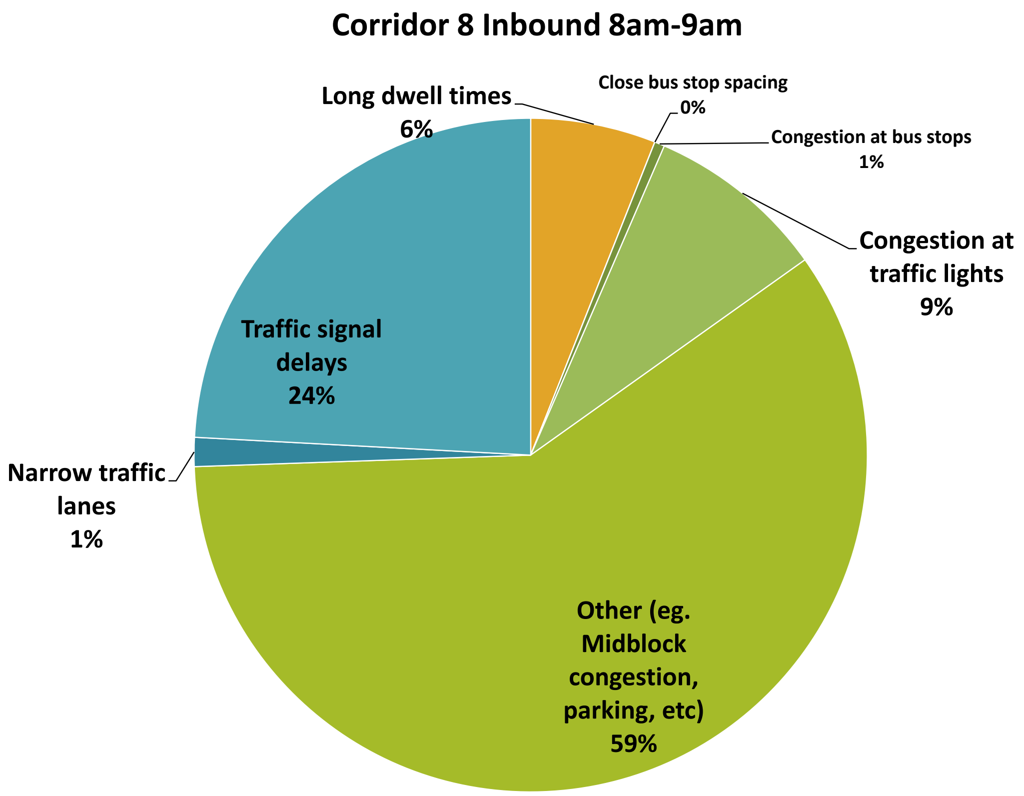


Table 93: Estimated minutes of delay by source – Inbound morning peak hour (8am–9am)

	Minutes added (delay)	Percentage of delay
Long dwell times	0.5	6%
Close bus stop spacing	0.0	0%
Congestion at bus stops	0.04	1%
Congestion at traffic lights	0.8	9%
Narrow traffic lanes	0.1	1%
Traffic signal delays	2.1	24%
Other	5.3	59%

Outbound

During the slowest hour in the outbound direction (5pm–6pm), the delay along corridor 8 results in a bus travel time that is more than twice as long as the estimated unimpeded running time.

Table 94: Theoretical versus actual travel time – Outbound afternoon peak hour (5pm–6pm)

Estimated unimpeded travel time	4.2 minutes
Delay	4.6 minutes
Total travel time	8.9 minutes

During the hour, more than half of the delay – 3.3 minutes – is attributable to traffic light delay. 'Other' sources of delay are the second largest source of delay, increasing travel times by 1.6 minutes. Given the traffic volumes at this time, this is most likely due to traffic congestion. A full breakdown of the sources of delay experienced by buses travelling in the outbound direction during the slowest hour (4pm–5pm) is provided in Figure 215 and Table 95.

Figure 215: Sources of delay – Outbound afternoon peak hour (5pm–6pm)

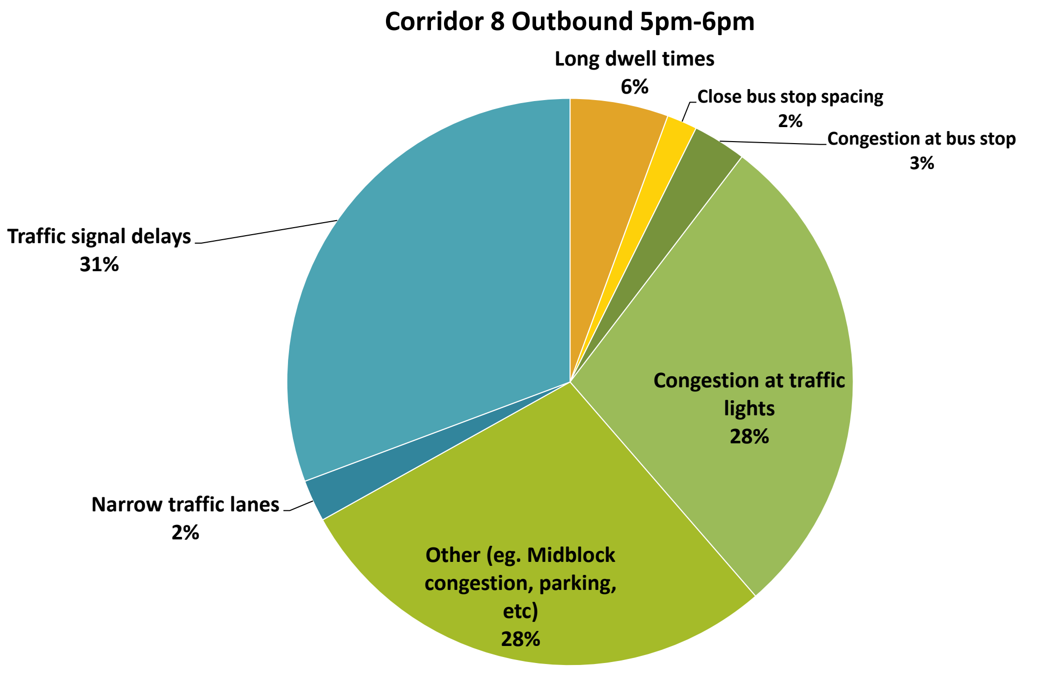


Table 95: Estimated minutes of delay by source – Outbound afternoon peak hour (5pm–6pm)

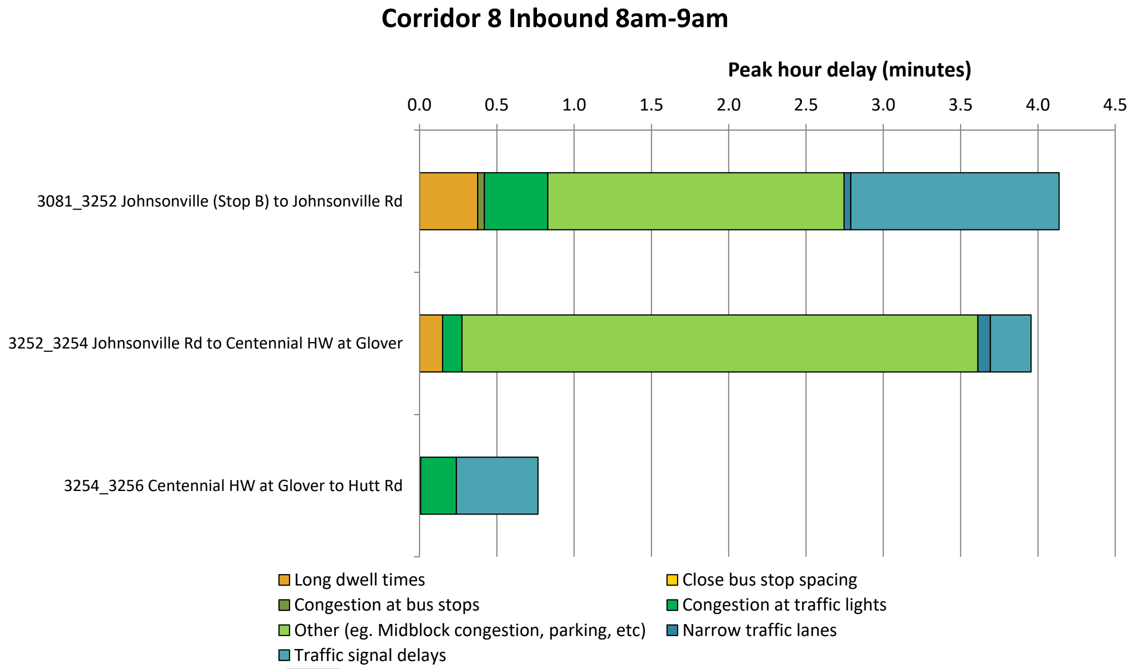
	Minutes added (delay)	Percentage of delay
Long dwell times	0.3	6%
Close bus stop spacing	0.1	2%
Congestion at bus stops	0.2	3%
Congestion at traffic lights	1.6	28%
Narrow traffic lanes	0.1	2%
Traffic signal delays	1.7	31%
Other	1.6	28%

Delay breakdown by segment

Inbound

During the peak hour for buses travelling in the inbound direction on the corridor (8am–9am), buses experience the most delay on the segment through Johnsonville and the segment from Johnsonville to Centennial Highway, each with approximately four minutes of delay. Figure 216 provides a breakdown of the sources of delay on corridor 8 by segment for buses travelling in the inbound direction during this hour.

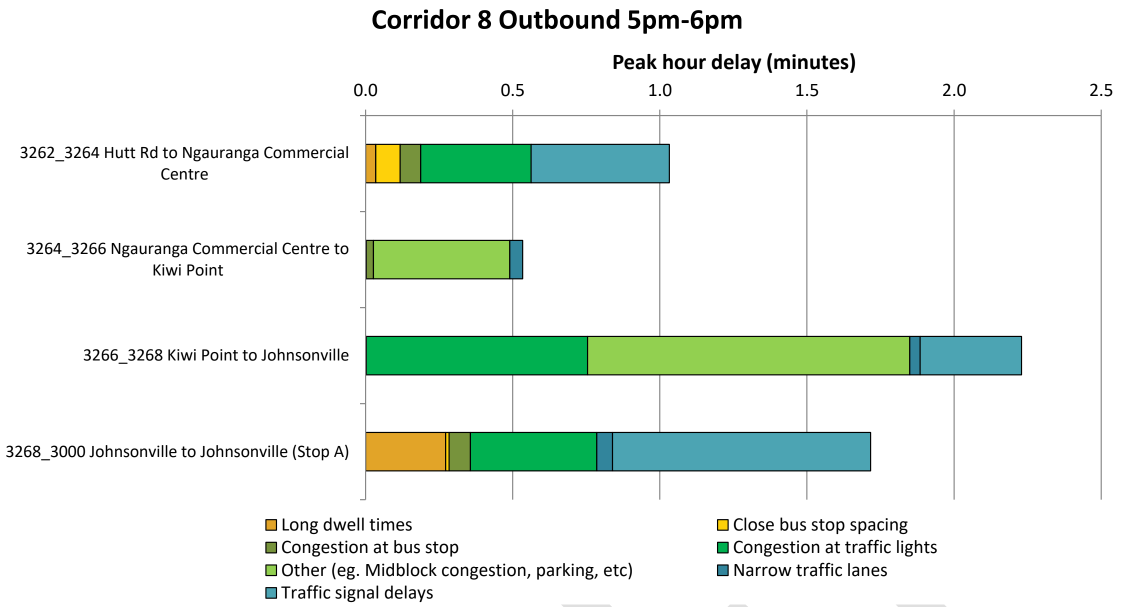
Figure 216: Sources of delay by segment – Inbound morning peak hour (8am–9am)



Outbound

During the peak hour for buses travelling in the outbound direction on the corridor (5pm–6pm), the segment experiencing the most delay is on the motorway, between Kiwi Point and Johnsonville, with more than two minutes of delay. More than 1.5 minutes of delay is experienced through Johnsonville, with more than one minute of delay attributable to traffic lights. Figure 217 provides a breakdown of the sources of delay on corridor 8 by segment for buses travelling in the outbound direction during this hour.

Figure 217: Sources of delay by segment – Outbound afternoon peak hour (5pm–6pm)



2.4. Issues summary

Figure 218 and Figure 219 provide a summary of the key issues across corridor 8, in both the inbound and outbound directions. These issues have been identified as key sources of delay for buses travelling along the corridor.

Figure 218: Key issues – Inbound morning peak hour (8am–9am)

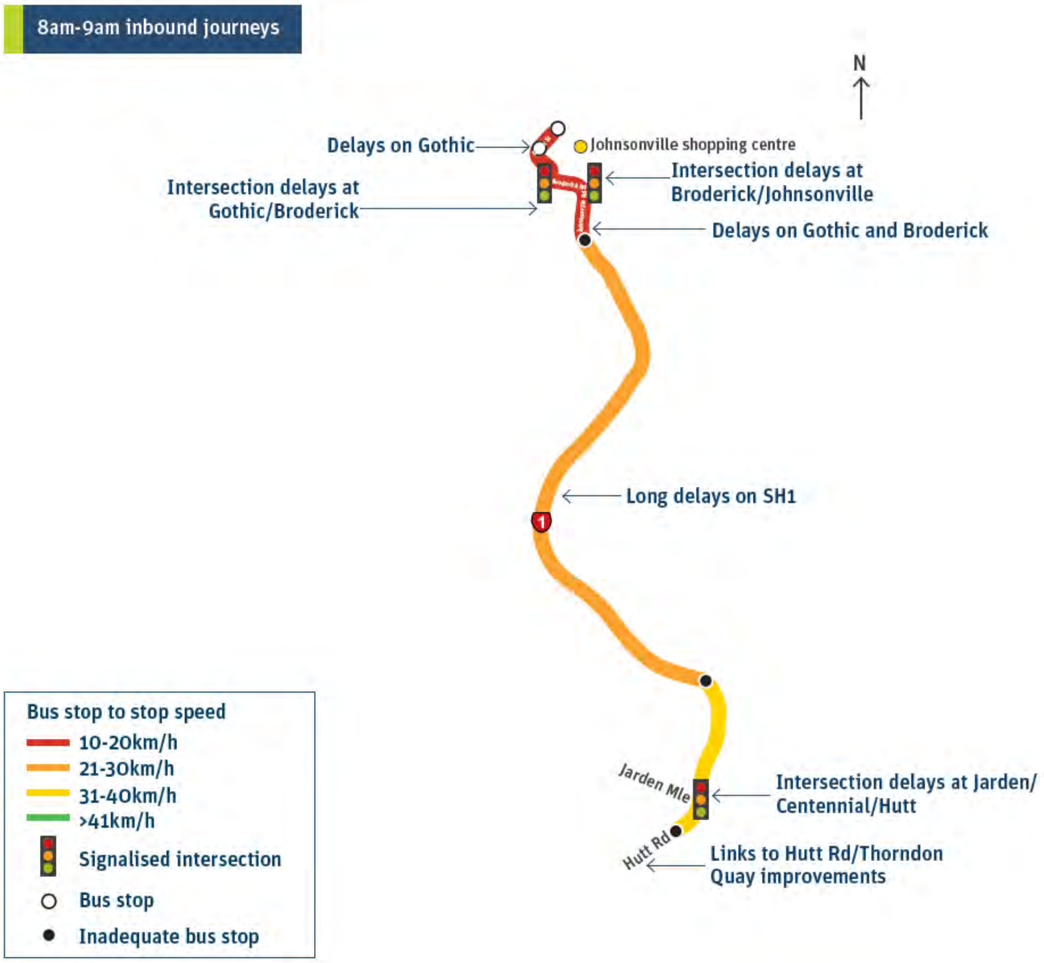
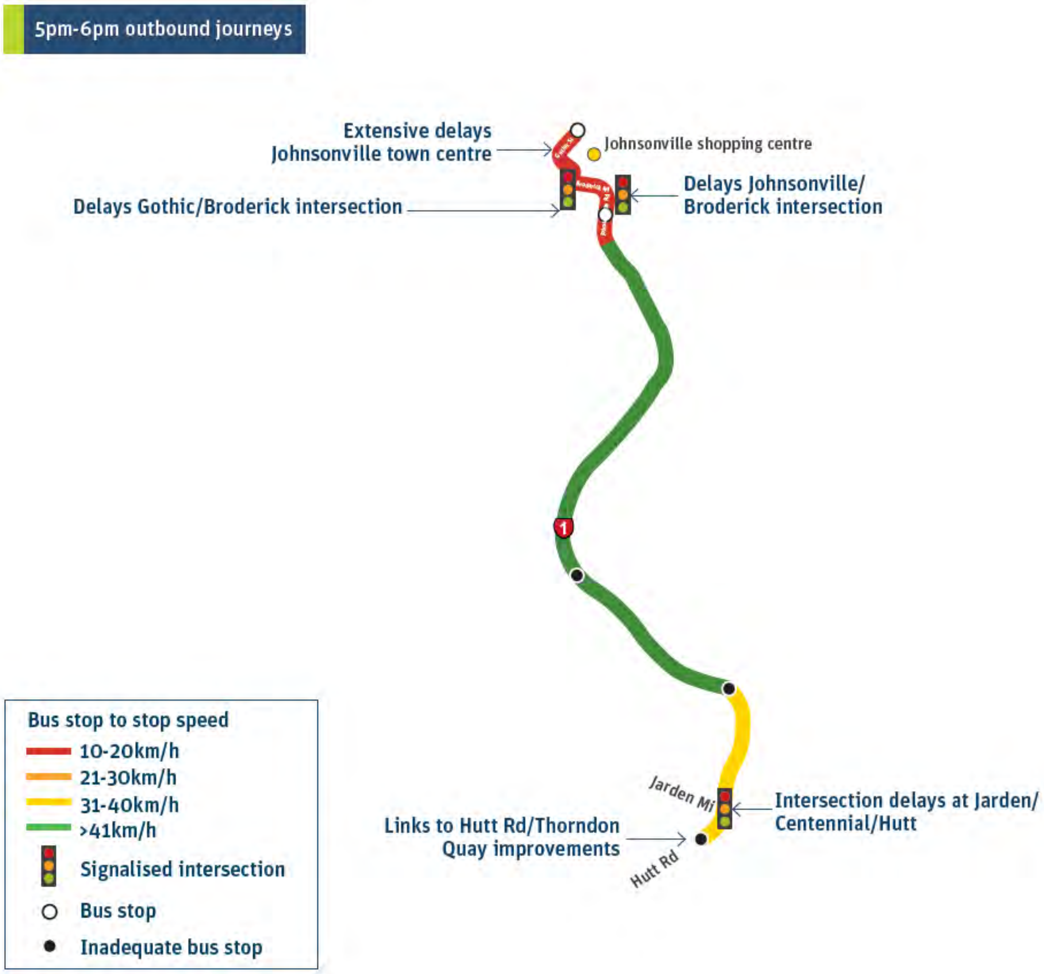


Figure 219: Key issues – Outbound afternoon peak hour (5pm–6pm)



3. Opportunities

For corridor 8, a list of opportunities to improve bus operations has been identified. These opportunities include the implementation of bus priority interventions that would be effective in addressing the documented sources of delay along the corridor and would improve bus travel times.

There are multiple levels of interventions that could be implemented across the corridor that would have varying impacts on bus journey times. For this reason, three packages of opportunities for the corridor have been selected. The package options are defined as follows:

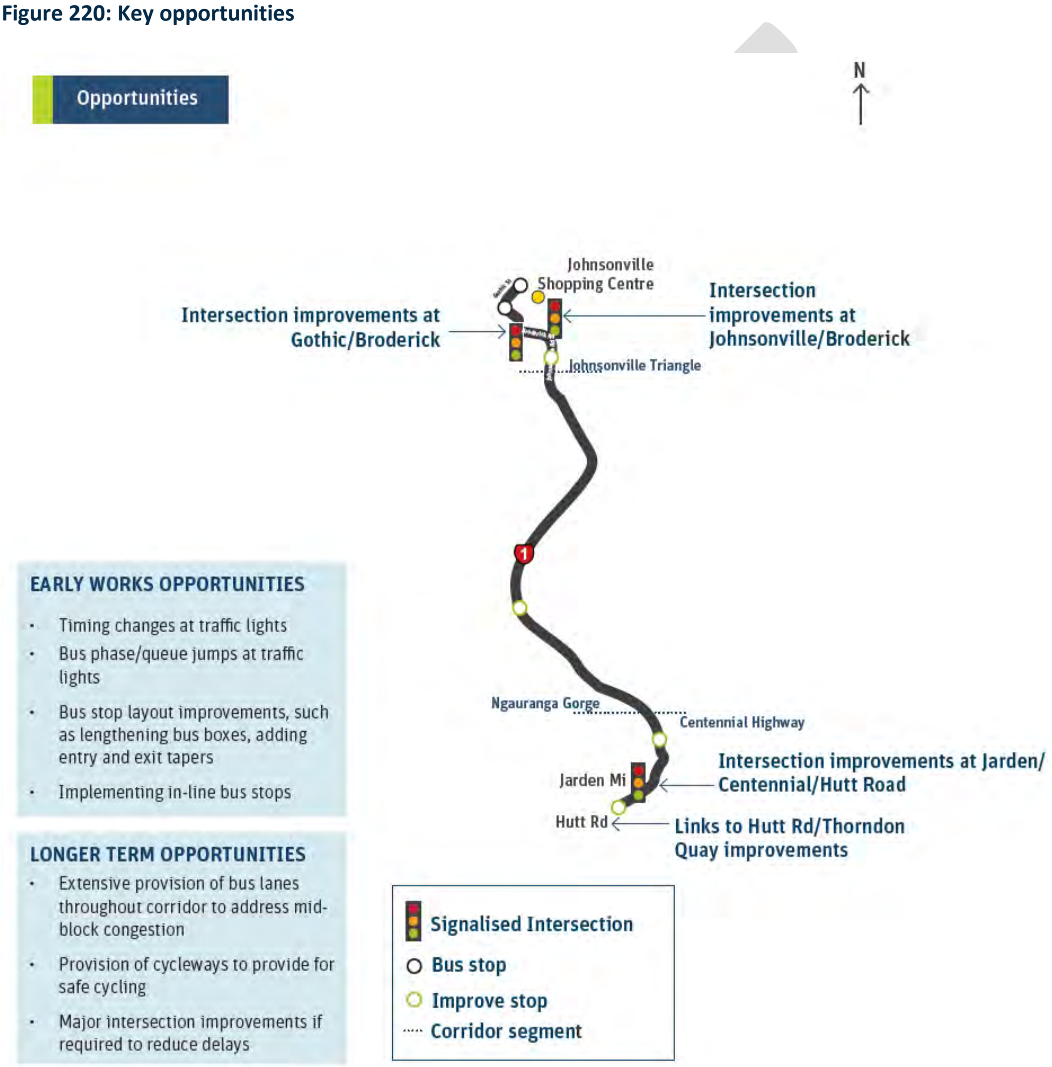
- **Option 1: fix everything**
  This option would address all problems identified on the corridor and implement any of the possible interventions that are effective at addressing the problems that have been identified on the corridor.
- **Option 2: fix the worst problems**
  This option would address only the most severe problems identified on the corridor and only implement interventions that do not involve major reconfiguration of corridor space.

- **Option 3: minimal interventions**
  This option would address only the most severe problems identified on the corridor and implement interventions that involve only minimal reconfiguration of corridor space.

A context map of the location of the key opportunities is provided in Figure 220.

For a full list of the bus priority interventions considered, the package identification process, ad a detailed description of the criteria that was used to identify opportunities on the corridor, refer to Appendix 2.

Figure 220: Key opportunities



Appendix 11 – Early improvements screening

The eight corridors were reviewed to identify the most significant causes of delay. These were tabulated and assessed against the early improvements criteria to identify locations where early improvements are likely to be appropriate. The table below shows the locations that are recommended to be prioritised as part of the early improvements programme, and those excluded.

Table 96: Early improvements short-listing

Corridor	Direction	Period	Location	Issue	Early improvements criteria				Include	Other considerations
					Effective	Quick	Cheap	Flexible		
Newtown to city	Inbound	4-5pm	Riddiford (Hall–Hospital)	~100 sec delay due to congestion	Bus lane					LGWM mass transit, cycle route
	Inbound	4-5pm	Riddiford/Adelaide	~40 sec delay at 1 signal	Bus jump					LGWM mass transit, cycle route
	Inbound	4-5pm	Riddiford @ Constable, Rintoul	~40 sec delay at 2 signals	Bus jumps					LGWM mass transit, cycle route
	Inbound	4-5pm	Adelaide	~60 sec delay due to congestion	Bus lane	Extend bus lane hours				Cycle route
	Inbound	4-5pm	Cambridge	~60 sec delay due to congestion	Bus lane	Extend bus lane hours				Cycle route
	Inbound	8-9am	Cambridge	~60 sec delay due to congestion	Bus lane	Upgrade bus lane				Cycle route
	Inbound	8-9am	Riddiford (Hall–Hospital)	~90 sec delay due to congestion	Bus lane					LGWM mass transit, cycle route
	Inbound	8-9am	Riddiford/Adelaide	~40 sec delay at 1 signal	Bus jump					LGWM mass transit, cycle route
	Inbound	8-9am	Riddiford @ Constable, Rintoul	~40 sec delay at 2 signals	Bus jumps					LGWM mass transit, cycle route
	Outbound	8-9am	Kent @ Courtenay, Elizabeth	~110 sec delay due to congestion	Bus lane	Extend bus lane hours				Cycle route
	Outbound	4-5pm	Kent @ Courtenay, Elizabeth	~70 sec delay at 2 signals	Bus jump	Simple reconfiguration				Cycle route
	Outbound	4-5pm	Basin	~60 sec delay due to congestion	Bus lane					LGWM SH1, cycle route
	Outbound	4-5pm	Courtenay, Kent	~40 sec delay due to congestion	Bus lane	Simple lane reallocation				Cycle route
	Outbound	4-5pm	Kent/Pirie	~40 sec delay at 1 signal	Bus jump	Simple lane reallocation				Cycle route
	Outbound	4-5pm	Basin	~40 sec delay at 3	Bus jumps					LGWM SH1, cycle route

Corridor	Direction	Period	Location	Issue	Early improvements criteria				Include	Other considerations
					Effective	Quick	Cheap	Flexible		
				signals						
	Outbound	4-5pm	Riddiford (Hall–Hospital)	~40 sec delay due to congestion	Bus lane					LGWM mass transit, cycle route
	Outbound	4-5pm	Riddiford @ Mein, Rintoul, Constable	~40 sec delay at 3 signals	Bus jumps					LGWM mass transit, cycle route
Karori to city	Inbound	8-9am	Karori Rd centre to Marsden	~210 sec delay due to congestion	Bus lane					Cycle route
	Inbound	8-9am	Karori Rd Marsden to Standen	~90 sec delay due to congestion	Bus lane					Cycle route
	Inbound	5-6pm	Bowen clearway	~40 sec delay due to congestion	Bus lane	Extend bus lane hours				Cycle route
	Outbound	5-6pm	Glenmore @ Upland roundabout	~90 sec delay due to congestion	Bus lane	Part-time signal on Upland				Cycle route
	Outbound	5-6pm	Bowen @ Lambton, Terrace, Tinakori	~60 sec delay at 3 signals	Bus jumps					LGWM Golden Mile, cycle route
	Outbound	5-6pm	Karori Tunnel	~40 sec delay at 1 signal	Bus jump					Cycle route
Seatoun to city	Inbound	8-9am	Miramar–Cobham–Troy roundabouts	~200 sec delay due to congestion	Bus lane					LGWM mass transit, Cobham crossing, cycle route
	Inbound	8-9am	Kilbirnie Cres	~60 sec delay due to congestion	Bus lane					
	Inbound	8-9am	Kilbirnie Cres @ SH1	~40 sec delay at 1 signal	Bus jump	Reconfigure approach to intersection				LGWM SH1
	Inbound	8-9am	Cambridge	~40 sec delay due to congestion	Bus lane	Upgrade bus lane				Cycle route
	Inbound	8-9am	Elizabeth @ Kent	~40 sec delay at 1 signal	Bus jump	Simple lane reallocation				

Corridor	Direction	Period	Location	Issue	Early improvements criteria				Include	Other considerations
					Effective	Quick	Cheap	Flexible		
	Outbound	5-6pm	Kilbirnie Cres	~60 sec delay due to congestion	Bus lane					
	Outbound	5-6pm	Kent @ Courtenay, Elizabeth	~60 sec delay at 2 signals	Bus jumps	Simple reconfiguration				Cycle route
	Outbound	5-6pm	Troy–Cobham–Miramar roundabouts	~60 sec delay due to congestion	Bus lane					LGWM mass transit, Cobham crossing, cycle route
Mt Cook to city	Inbound	4-5pm	Wallace	~120 sec delay due to congestion	Bus lane					
	Inbound	4-5pm	Taranaki (Wallace–Abel Smith)	~90 sec delay due to congestion	Bus lane	Partial widening on Taranaki				LGWM mass transit, cycle route
	Inbound	8-9am	Riddiford (hospital to John)	~50 sec delay due to congestion	Bus lane					LGWM mass transit, cycle route
	Inbound	8-9am	Wallace	~70 sec delay due to congestion	Bus lane					
	Inbound	8-9am	Riddiford (hospital to John)	~50 sec delay due to congestion	Bus lane					LGWM mass transit, cycle route
	Outbound	5-6pm	Riddiford (John to hospital)	~60 sec delay due to congestion	Bus lane					LGWM mass transit, cycle route
	Outbound	5-6pm	Wallace	~90 sec delay due to congestion	Bus lane					
	Outbound	5-6pm	Taranaki (Webb–Wallace)	~60 sec delay due to congestion	Bus lane	Change clearway to bus lane				
Kelburn to city	Inbound	8-9am	Upland–Glasgow–Kelburn	~110 sec delay due to congestion	Bus lane					Cycle route
	Outbound	5-6pm	Kelburn Normal School–Karori Tunnel	~60 sec delay due to congestion	Bus lane					Cycle route
	Outbound	5-6pm	Salamanca	~50 sec delay due	Bus lane					Cycle route

Corridor	Direction	Period	Location	Issue	Early improvements criteria				Include	Other considerations
					Effective	Quick	Cheap	Flexible		
				to congestion						
Newtown to Kilbirnie	Inbound	8-9am	Bay @ Evans Bay, Rongotai	~70 sec delay at 2 signals	Signal changes	Phasing and timing changes				LGWM mass transit
	Outbound	5-6pm	Bay @ Evans Bay, Rongotai	~40 sec delay at 2 signals	Signal changes	Phasing and timing changes				LGWM mass transit
Brooklyn to city	Inbound	8-9am	Ohiro (Cleveland–Tanera)	~80 sec delay due to congestion	Bus lane					WCC safety improvement, cycle route
	Inbound	8-9am	Willis	~40 sec delay due to congestion	Bus lane					Cycle route
	Inbound	8-9am	Willis @ Webb, SH1	~40 sec delay at 2 signals	Bus jumps					LGWM SH1, cycle route
	Outbound	5-6pm	Victoria (Dixon–Ghuznee)	~90 sec delay due to congestion	Bus lane					Cycle route
	Outbound	5-6pm	Victoria @ Abel Smith, SH1, Webb/Willis	~70 sec delay at 3 signals	Bus jumps					LGWM SH1, cycle route
Johnsonville to city	Inbound	8-9am	SH1	~220 sec delay due to congestion	Bus lane					Cycle route
	Inbound	8-9am	Broderick–Johnsonville roads	~120 sec delay due to congestion	Bus lane					Cycle route
	Inbound	8-9am	Broderick @ Moorefield, Gothic, J'ville	~80 sec delay at 3 signals	Bus jumps					Cycle route
	Inbound	8-9am	Centennial @ Hutt	~30 sec delay at 1 signal	Bus jump	Simple reconfiguration				Cycle route
	Outbound	5-6pm	SH1–Johnsonville	~100 sec delay due to congestion	Bus lane					Cycle route
	Outbound	5-6pm	Broderick @ Gothic, J'ville	~90 sec delay at 2 signals	Bus jumps	Simple reconfiguration on Broderick				Cycle route