Effects of Raised Safety Platforms (RSPs) on Travel Time and Traffic Delay at Roundabouts

by

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ABSTRACT

Raised safety platforms (RSPs) are vertical deflection devices that utilise vertical acceleration to slow vehicle operating speeds down to safe systems-compliant speeds. These devices are not as jarring for drivers as a traditional judder bar and are specifically designed for motorist comfort when traveling at a safe and appropriate speed. RSPs have been specifically identified through the Austroads Guide to Traffic Management and New Zealand Transport Agency (NZTA) Standard Safety Intervention Toolkit as a key safe systems safety intervention.

RSPs are also part of best practice guidance and are designed to slow vehicle speeds enough so that when people make mistakes, they have time to react and avoid a crash. If a crash were still to happen it is kinetic impact energy which determines the severity outcome of a crash is lower. At lower speeds the likelihood of a death or serious injury occurring as a result is drastically reduced.

Safe Systems is a road safety philosophy that requires industry practitioners to provide a more forgiving road system reducing the harm to the human body in the event of a crash. Safe systems have four key pillars safe roads and roadside, safe speeds, safe vehicles, and safe road users. Safe speeds are the areas within which RSPs sit.

Although there are proven safety benefits of RSPs through various literature sources there is still a common user perception that these devices cause a decrease in operational efficiency. Literature is also light on this topic and in cases where past literature is available, they seem to contradict with each other. Some user arguments are that RSPs create congestion at intersections resulting in an increased travel time.

The aim of this thesis report was to provide data-based clarity on the effects of the RSP on travel time and traffic delay at roundabouts to help clarify this area of knowledge gap. This report also seeks to understand effects on traffic speed, crashes, queue lengths, and LOS at roundabouts as a result of RSPs.

This report specifically focuses on roundabouts due to a lack of roundabout-related operational literature as the majority of RSP applications have been at signalised intersections. It should be noted that RSPs are still a new and emerging idea for Australia and New Zealand (NZ). RSPs are a widely used safety intervention in European countries such as the Netherlands.

Investigation in this paper has been done through a review of the literature and quantitative assessment of a sample of sites through microsimulation traffic modeling using Multimodal Traffic Simulation Software. Based on the findings of this paper it is identified that there is a negligible change in traffic delay and a decrease in travel time as a result of RSPs at roundabouts.

The findings of this research shows that RSPs create smoother traffic flow, and safer and better gap selection for vehicles entering a roundabout resulting in improved or the same efficiency for the intersection when compared to pre RSP operation. Some increases in queue lengths was evident on the approach to RSPs and this could relate to driver perception of an increase in congestion. There is no evidence from this paper that supports this as the overall LOS remains unchanged or is improved.

This paper also found that speeds dropped notably on approach to RSPs which resulted in a change in driver psychology where drivers were yielding more at the slower speed. Crash data also showed a decreasing trend in the number of crashes and their severity following RSP installation across all the sites studied. These finding also support past literature on RSP speed and crash reductions.

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Declaration of Authorship

I, Dharmendra Singh, hereby declare that the content of this Masters thesis document represents solely my own work. Any materials or contributions from other authors, when utilised, have been appropriately cited and duly acknowledged. I further declare that I have not submitted this thesis at any other institution in order to obtain any other qualifications.

1. INTRODUCTION TO THE THESIS

1.1 Purpose

The primary purpose of this thesis is to provide evidence-based findings on the effects of RSPs on Travel Time and Traffic Delay at roundabouts. This thesis uses traffic microsimulation modelling and real-time bluetooth data comparisons for site investigations.

As a secondary outcome, the thesis investigates into vehicle operating speed and crash changes that occur as a result of RSPs. The inclusion of speed and crash in this thesis provides safety-based evidence in relation to RSPs. A robust literature review was also completed as part of this paper, which looks into the safety, operational, environmental, design and construction effects of RSPs.

The expected audience of this thesis report is industry practitioners and technical decision-makers who have a knowledge of vehicle traffic and non-motorised active user safety and operational aspects.

1.2 Scope

The extent of this research is limited to the jurisdiction of Hamilton, NZ. Hamilton City's roading network has a number of complying roundabout sites that have recently been treated with RSP and met the site selection criteria.

The study is limited to RSPs on approach to and across the full leg of roundabouts. Midblock RSP and signalised intersections RSP including traditional vertical devices such as speed humps, speed cushions are outside the scope of this paper.

Initially, the intent for this paper was to investigate a spread of sites from across NZ, but due to a low number of relevant sites and a lack of site monitoring and evaluation data required for traffic microsimulation, fewer sites were chosen.

Initial discussions with road controlling authorities identified that even though the number of relevant sites across NZ is currently low, there are plans underway from various councils to retrofit more roundabouts with RSPs. Hence, it is assumed that in the next three to five years, there will be more sites across NZ for a more widespread analysis to be conducted.

Secondly, source quantitative data gathering, analysis and intersection based traffic micro simulation was part of the scope of this report. Scope of works excluded a network model.

Limitations of this thesis are listed in the section below.

1.3 Limitations

There have been several limitations to this thesis. The fundamental limitations are described below:

1. Funding was a fundamental limitation of this paper. As a result of this majority of the data investigations have been based on pre-existing secondary source data sourced from Road Controlling Authoritys (RCAs). Where possible, some site data has been collected by the author.

2. Availability of relevant before and after traffic data at roundabouts RSP sites. This limitation restricts the traffic microsimulation and can result in inaccuracies. A reason for this limitation could be that generally only base traffic data, i.e. volume and speed are monitored on projects. More in-depth data, such as traffic gap selection, driver behaviour, traffic turning counts, site videos, etc., are required to create a robust and accurate before and after microsimulation model.

3. Time has been another significant limitation, i.e., time pressure to complete this thesis within a set time frame, which meant that any known site survey that was in progress at the conclusion of this report could not be included in this paper.

4. Availability of technical resource to support a more robust and in-depth microsimulation model calibration, validation and auditing. It should be noted that the author was a new user of the chosen PTV Vissim microsimulation software and used the best available knowledge to learn this tool within a short period of time. Through the process of this study, some consultants have been reached out for support, but it should be noted that only brief discussions and quick high-level checks have been run due to funding limitations.

5. Each site has variabilities due to adjacent land use, geometric layout, road hierarchy, operating speeds, traffic volumes, active user access to the site, other nearby intersections and their influence on the selected sites. It should be noted that there can be a number of variabilities between selected sites and that the author has used their best engineering judgment to identify these through the study process and make assumptions based on the information available at the time of this project.

6. The extent of other improvements works in conjunction with the installation of RSPs. I.e. slip lane removals, reduction in the number of circulating lanes, traffic lane width reduction, the introduction of priority and non-priority active user crossing points and associated supporting infrastructure such as footpaths, shared paths, on-road separated cycle lanes, etc. It should be noted that these added works have an effect on traffic operation, safety and driver behaviour. It is a common practice for intersection improvements to have other works completed at the time of installing RSPs under the same temporary traffic management (TTM) for reduced user disruption and cost savings.

7. Inconsistent traffic flow pattern due to population growth, new roads commissioning, Christmas/New Year and school holiday periods. It should be noted that some of the data collection and site observations have been carried out in the lead-up to and straight after the holiday periods. Note any data from over these holiday periods has been excluded from this study. Population and traffic growth are limitations outside the control of this study.

8. Low availability of a larger complying sample size for a better spread across NZ. This was partly because RSPs are still a new and emerging idea for NZ. Through communication with RCAs, it is noted that future projects are planned in other parts of the country but will be outside the timelines of this report. Any future sites that get treated with RSPs are subject to Road Controlling Authority (RCA) funding availability and the Central Government's future strategic direction. It should be noted that the inclusion of a larger sample size shouldn't necessarily change the findings from this report but more so reinforce the findings of this work.

9. Wider network activities such as TTM on other parts of the road network can have an effect on traffic flow and behaviour at the study sites. It is unknown which road works were

happening on the network at the time of data collection and how this could have exactly affected the collected data. Note that there will always be improvement, maintenance and renewal activities undertaken on the road network, and generally, data collection periods outside of close proximity work sites are chosen by practitioners so that any effects of these are negligible.

10. Traffic flow patterns have been affected due to the coronavirus (Covid 19). Harantova, V. Hajnik, A. Kalasova, A. and Figlus, T (2022) state that the demand for transport has fallen sharply as a result of the pandemic. The changes have been a result of more people working from home. Projects that were built before the coronavirus pandemic are likely to have differences in base-case data following the pandemic. All but one of the sites within this study are outside this period. As a result, the impact of this limitation is minimal.

1.4 Methodology Summary

The main aim of this paper was to measure the changes in operational efficiencies as a result of RSPs at roundabouts. The paper also looked into how RSPs at roundabout affected speeds and crashes. This was investigated through three main parts of this report as follows:

Stage one: Literature Review

An in-depth national and international literature review focusing on RSP safety, operation, emissions, design and construction was carried out through stage one of this paper. Literature sources used were published, unpublished, technical reports and operational documents. Contractor and practitioner meetings were had in cases where literature was light. Further details on literature review methods are provided in Section 3.1.

Stage Two: Site Investigation

Under stage two of this work, a detailed mixed method of investigation was undertaken for sites that met the site selection criteria. A similar method of investigation has been used by a previous Austroads Research Report (2020), "Effectiveness and Implementation of Raised Safety Platforms".

A total of seven sites were selected through the site section process, two of which were put through the traffic microsimulation. Quantitative data was used for the analysis of sites and was sourced through a secondary source, i.e. from local Road Controlling Authorities. Data from the NZTA Crash Analysis System (CAS) was used for crash analysis.

For a detailed methodology of site investigation, method of data collection, and data analysis, refer to section 11 (Methodology for Site Investigation) of this report.

Stage Three: Traffic Micro Simulation and Discussion

In the third stage of this paper, traffic modelling using PTV Vissim microsimulation software was completed to examine the likely impacts of RSPs on travel time and traffic delays. Intersection-based modelling was completed, and it should be noted that a network model was not undertaken as part of the assessments as it was deemed unnecessary.

Site observations for the calibration of the traffic model and validation of pre-existing data were carried out. For a full traffic micro-simulation methodology, refer to section 11.4

2. BACKGROUND TO THE THESIS

RSPs were pioneered in South Holland, Netherlands, and they've been successfully trialled in Victoria, Australia. NZ's first RSP was installed at the Thomas/Gordonton intersection in Hamilton at the beginning of 2013 and has been successful.

RSPs are elevated sections of roads intended to reduce vehicle speeds at high-risk locations such as intersections and fall under the vertical deflection devices category. One of the notable differences between the RSPs and conventional speed humps (Watts Profile Humps) is that the RSPs use a much gentler ramp slope to achieve the desired speed reduction and can be designed for user comfort.

Existing literature shows strong consensus on the safety benefits of RSPs through speed and crash reductions at high-risk locations. On the contrary existing literature also shows some knowledge gaps and contradiction with one another in the area of the operational effects of RSP.

Literature review has shown that RSPs results in improved traffic efficiency, whereas some others state that RSPs result in a drop in efficiency. There is also a driver perception that RSPs create congestion at intersections, resulting in an increased travel time. This is resulting in public pushback on the installation of RSPs regardless of the significant proven safety benefits.

These factors make this research topic of interest, and this paper aims to provide quantitative data-based traffic micro simulation results and comparisons with real-time travel time data to provide clarity on the operational effects of the RSP in particular travel time and traffic delay at roundabouts.

Based on current statistics, on average, at least one person is killed, and seven people are reported seriously injured in road crashes every day in Aotearoa, NZ, according to the NZ Standard System Intervention Toolkit. This makes this research of further importance as there is a need for data-based evidence if RSPs were to survive the growing dislike from some user groups. This paper tries to bring into light other external factors, such as population growth, traffic growth etc which have an impact on the operational efficiency of the transport network.

Through a case study, it is stated by NZTA that speed is the biggest determining factor of harm caused in a crash and that RSPs are substantially different to conventional speed humps as they have a much gentler ramp specifically designed to achieve the desired speed reduction. The relationship between speed and road trauma is well-established internationally, and that is why managing speed is one pillar of the Safe System approach to road safety. Refer to section 5.1 for more information on safe systems.

This paper seeks to add to the existing knowledge base on RSPs and identify current RSP related areas of knowledge gaps and potential further areas of study that need to be undertaken.

3. INTRODUCTION TO THE LITERATURE REVIEW

3.1 Purpose

RSPs are new and emerging treatments in Australia and NZ. Several research studies have been carried out to improve our understanding of the safety, design, and operational factors associated with RSPs.

This literature review aims to evaluate the available literature on RSPs from NZ and international sources and identify areas of knowledge gaps for further research. The general focus of this literature review has been on the following key areas:

- Safety
- Operational
- Environmental Emissions and Human Health
- Design
- Construction, Maintenace and Monitoring

This review's primary area of interest has been the safety, design and operational effects. Literature specific to RSPs at roundabouts is a bit light, hence, RSPs at signalised intersections and midblock situations are included in the review. The inclusion of these helps broaden the current understanding of RSPs.

3.2 Methodology

Literature review is stage one of this paper and utilises data gathered through the internet and database search primarily published research, journals and guides, e.g. Austroads. Discussions with industry experts and some unpublished literature were also included in the review. The following is a list of databases that were searched through this literature review:

- Australasian College of Road Safety (ARCS)
- Global Road Safety Facility (GRSF)
- Google Chrome Search Engine
- Google Scholar
- Scopus
- The University of Waikato Library Online
- Transport Research International Documentation (TRID)

Literature from the 1980s was included in this review, primarily focusing on recent research information from the last ten years. A combination of the following keywords were used in the search process:

- Raised safety platforms
- Vertical deflection devices
- Raised intersection
- Speed
- Hump
- Traffic calming
- Noise and Vibration
- Vehicle emissions and health

4. LITERATURE REVIEW FINDINGS

4.1 Raised Safety Platforms

RSPs are vertical deflection devices that utilise vertical acceleration to slow vehicle operating speeds down to safe systems-compliant speeds. At slower speeds, the crash kinetic energy, which determines the severity outcome of a collision, is lower. RSPs can be designed for a range of speeds, road hierarchy and operating environments to manage comfort of the vehicle passengers driving over them. They can also be placed in series in high-speed environments to bring operating speeds down to safe levels at conflict points.

Corben (2018) RSPs have been pioneered by the province of South Holland and are widely used across the Netherlands and other European countries. RSPs are referred to in the Netherlands as Raised Stop Lines (RSL). These were developed as conventional designs needed to provide the level of protection sought by the Dutch Sustainable Safety road safety vision. Evaluation conducted by the Netherlands showed that injury-producing crashes fell by a reliable 40 to 50 per cent.

These devices are not as jarring for drivers as a traditional judder bar and are designed explicitly for motorist comfort when travelling at a safe and appropriate speed. RSPs have explicitly been identified through the Austroads Guide to Traffic Management and NZ Transport Agency Standard Safety Intervention Toolkit as a vital safe systems safety intervention.

VicRoads (2019) findings state that RSPs are speed management devices that can reduce the maximum comfortable operating speed for a vehicle to a Safe System collision speed. This means that in the event of a crash resulting forces of the impact are within human tolerance.

RSPs consist of an approach and departure ramp to a flattop-raised section of the road. As per the Austroads Guide to Road Design part 4 (2023), the RSP height should ideally be between 75 mm and 100 mm. The Ramps can be formed in either concrete or asphalt and on bus routes, a height of 75mm and 1:20 ramp grade is recommended. Based on VicRoads(2019) trials, a 1:35 grade is considered appropriate for the departure ramp to provide a smooth exit from an RSP.

4.2 Purpose of Raised Safety Platforms

Austroads research report AP-R560-18 states that speed is the fundamental principle to a safe system. The maximum safe systems speed for a vehicle vs vehicle side impact collision is less than or equal to 50km/h and for crashes involving pedestrians and cyclists, this is less than or equal to 30km/h. These safe systems speed reduce crash severity to survivable levels. The probability of severe or fatal injury crashes increases significantly past these identified safe systems speeds. These figures are supported by several Austroads guides and other published research reports.

Austroads research report AP-R556-17 (2017) mentions that safety platforms will be helpful to where the key objective of the project is to reduce crash severity and its likelihood at lower costs. E. Coulson and D. Cassar (2018) highlight that RSPs are safety interventions capable of reducing the maximum comfortable vehicle operating speed to safe systems collision speeds.

Candappa et al. (2013) identified that RSPs can provide safety benefits for active users at intersections and that intersections should be raised to provide speed reduction benefits to pedestrians. Austroads AGRD Part 7 (2023) also identifies that RSPs can be used to slow traffic speeds and to emphasize the presence of active road users such as pedestrians and cyclists.

4.3 Applications of Raised Safety Platform

Austroads AGRD Part 7 (2023) identifies RSPs as new and emerging treatments in Australia and NZ. Mackie et al. (2020) have identified that RSPs have been extensively used in the Netherlands and that in Australia and NZ a community of practice is developing. Candappa et al. (2013) identified that raised intersections are commonly used in many European countries and less frequently in Australia.

VicRoads (2019) recommends that higher speed environments of ≥ 80km/h use RSP in conjunction with other supporting treatments. RSPs can be used in the following situations:

- On approach to intersections referred to as **approach RSPs**
- At an intersection by raising the whole intersection referred to as **raised intersection**
- At a midblock location to help slow speeds and or improve pedestrian safety referred to as **midblock RSPs.**

Pedestrian priority and non-priority facilities can get included with RSP for added safety through reduced speeds. More information on how these crossings works as follows:

- Priority crossings for pedestrians are also known as zebra crossings in NZ and wombat crossings in Australia. Pedestrians have priority at these crossings, i.e. vehicles are legally required to give way.
- Non-priority crossings, also known as courtesy crossings and generally get placed on RSPs. Non-priority means active users do not have priority, i.e. legally, cars still have the right of way at these sites. This relies on courtesy between drivers and active users on who goes first. These are placed in slow-speed environments (30km/h). This results in more opportunities for active users to get across the road, as drivers are more likely to yield to pedestrians at lower speeds.

On approach to roundabouts, these platforms can moderate approach and entry speeds in a similar way that approach curves and a large central island would do at a conventional roundabout.

Austroads research report AP-R560-18 states that if 90 degree cross road geometry cannot be changed, supporting safety treatments such as RSPs on approaches can compensate for the non-favourable configuration at a lower cost.

4.3.1 Rounabouts and Signalised Intersections

Candappa et al. (2005) state that roundabouts are significantly safer than the standard cross-intersection treatment of signals. Approach speeds and angle of impact at roundabouts are generally lower, with fewer conflict points in the event of a crash. Up to 80% fewer cross-traffic crashes occur at roundabouts than cross intersections.

Austroads AGTM03-20 states that Australian and NZ practices for assessment of the capacity of roundabouts and the delays to traffic is based on gap acceptance theory. Traffic entering the roundabout gives way to all traffic to the right while accepting gaps.

Gap acceptance for drivers in different roundabout entry approaches will be different based on traffic conditions on that approach, i.e., the length of time the driver has been in the queue, actual queue length plus approach road, and roundabout geometry. In summary, lanes with higher flows have a shorter gap acceptance and higher capacity.

Roundabout entry flow and circulating flow on all approaches have a high level of interaction at sites with a higher saturation of approximately 0.85. If the entry flow is oversaturated, capacity constraints can apply, which can result in downstream circulation flow reduction.

Austroads (2020c) The modelling should also take into account other traffic control devices, such as RSPs in close proximity to the roundabout when assessing the performance. Some past literature suggests that RSPs can improve the operational efficiency of roundabouts, see section 6 of this report.

Roundabouts generally have a low angle of entry through careful horizontal deflection design, meaning slower speeds on approach to the roundabout as drivers are forced to slow down before negotiating the roundabout. Hence, if a crash were to occur the angle of impact and force of impact would likely be low, reducing the likelihood of high severity/crash energies.

Signalised intersections, on the other hand, have a high entry angle of around 90 degrees, which results in high-speed, high-severity crashes. RSPs help manage the speed of vehicles entering the signalised intersection, reducing the likelihood of crashes and reducing trauma associated with any crashes that do occur. Traffic signals can provide the ability to remotely manage traffic from the traffic operation centre (TOC) during peak periods.

Corben (2014) looked into criteria for elevated stop lines (ESLs) or RSP in an NZ context at traffic signals in the Netherlands. This work established that two main criteria are used, which are “on roads of 80 km/h or higher, or with either a history of or concern about the potential consequences of red-light running and/or speeding through the intersection”. Once this criterion is met, the recommended package of treatment is as follows:

- RSPs
- a speed limit reduction
- Red-light running and speed safety cameras

5. SAFETY

5.1 Safe Systems

Speed is one of the key pillars of the safe systems solution. In NZ, road safety for every user is guided by the safe systems. Safe Systems is a road safety philosophy based on the principle that road users will make mistakes and are vulnerable to injury when involved in crashes and should not have to pay for this through loss of life or serious injuries.

Safe Systems brings human tolerance to vehicle crash impact energy to the centre of the discussion, requiring industry practitioners to create a more forgiving road system that reduces the price people pay for human error. There are four key pillars of safe systems which are:

- safe roads and roadside
- safe speeds
- safe vehicles
- safe road users.

The relationship between speed and road trauma is well-established internationally, and that is why managing speed is one pillar of the Safe System approach to road safety.

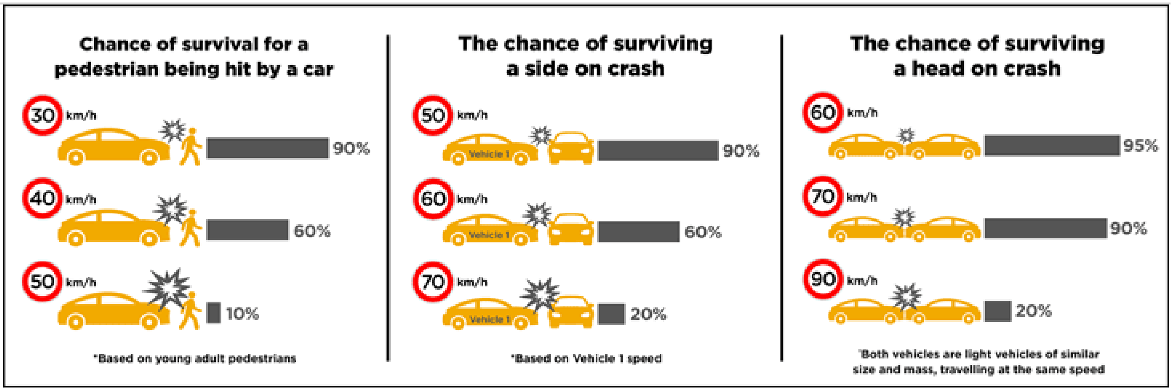
Safe System was endorsed in Australia in 2003 by the Australian Transport Council through the National Road Safety Strategy and adopted by Austroads in 2006. New Zealand Ministry of Transport adopted safe systems in 2010 through the 2010 to 2020 'Safer Journeys' road safety strategy. This has since been replaced with the 2020-2030 Road to Zero safety strategy. This strategy is responsible for providing vision and guidance towards achieving zero deaths and serious injuries on NZ roads. This new strategy still utilises the safe systems approach as its basis.

According to the Global Status Report on Road Safety 2023, the number of road traffic deaths has fallen slightly to 1.19 million per year from 1.2 million per year based on the previous 2015 *Global Status Report on Road Safety, suggesting* safety efforts in recent years have saved lives. This still corresponds to a rate of 15 road fatalities per 100,000 population, putting a huge impact on health and development. The price paid for mobility remains far too high, with the hardest hit being low and middle-income countries.

Based on world data, road traffic-related crashes are the top cause of death and disability among people aged between 5 and 29, surpassing other causes such as drowning, self-harm, etc. When all ages are considered, road injury ranks as the 12th leading cause of death, hence an important health and development challenge. From a NZ context*, "Currently, on average, at least one person is killed, and seven people are reported seriously injured in road crashes every day in Aotearoa NZ", adopted from the NZ Standard System Intervention Toolkit.*

Under a safe systems road safety philosophy, a big difference in the number of deaths and serious injuries can be made by implementing a good speed management programme. The maximum safe systems speed for a vehicle vs vehicle side impact collision is ≤ 50km/h, and vehicle crashes involving pedestrians and cyclists are ≤ 30km/h. The probability of fatal and serious injury crashes increases significantly past these identified safe systems speeds. Refer to Figure 1.

Figure 1. Chance of human survival when hit at different speeds and collision types.



Note. Illustrates how the chance of surviving various types of crashes is heavily influenced by the speed of the vehicles involved. Sourced from Transport for NSW.

5.2 New Zealand Standard Safety Interventions (SSI) Toolkit

There are a variety of tools available to help manage speeds on the transport network. A Standard Safety Interventions Toolkit (SSI Toolkit) has been developed by NZTA and is used to help guide infrastructure investment decisions in NZ and contributes to embedding the national Road to Zero vision. This was published in February 2019.

NZTA SSI Toolkit sets out the range of interventions and notes that the selection of treatment measures should start with the objective of implementing primary Safe System interventions, which are most likely to eliminate the occurrence of fatal and serious injuries. It is through this document RSPs and a number of other treatments have been identified to as primary safe systems interventions:

The SSI Toolkit also has detailed information on each of the above treatments and indications of typical price ranges and expected reductions in deaths and serious injuries as a resulting from implementing these treatments.

5.3 Speeds and Raised Safety Platforms

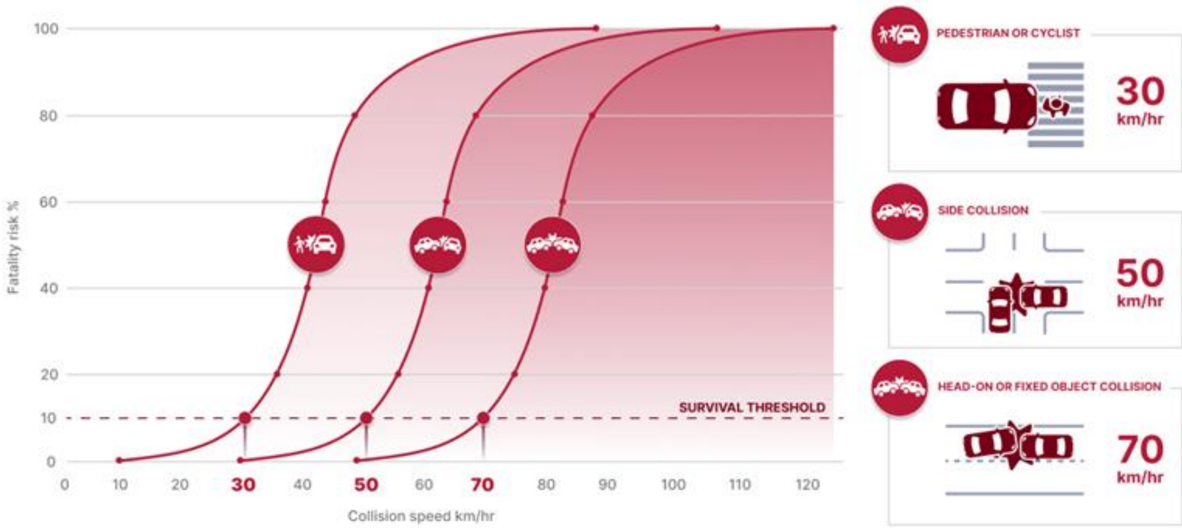
The NZ Trasport Agency speed management guide (2022) states that speed is a major differentiating factor in a crash: "It affects a driver's ability to react. Regardless of the cause of a crash, speed is the difference between someone being unharmed or being seriously injured or killed". Journal of Australasian College of Road Safety (Vol 28 - 2017) states, "Even a small difference in your speed can make a big difference to the likelihood and severity of a crash."

The New Zealand Trasport Agency Standard Safety Intervention Toolkit (2021) acknowledges the importance of safe speeds on road user safety. It supports the streamlined delivery of the Road to Zero Speed and Infrastructure programme for both the NZ Transport Agency and local authorities.

Job & Mbugua (2020) states that reducing speeds is one of the most effective ways to improve safety and save lives. Lower speeds are also fundamental for sustainable mobility. Austroads Research Report AP-R498-15 (2015) suggests that RSPs significantly impact the reduction of vehicle speeds and road crashes in the vicinity of the device.

VicRoads (2019) found that RSPs reduce vehicle speeds to safe systems collision speeds. Under safe systems, roads are designed to reduce injury severity when crashes occur. Figure 2 below is taken from Abley (2023) and aligns well with historical studies and above VicRoads literature. It shows exponentially increase in the probability of deaths and serious injuries with an increase in speed.

Figure 2. Probability of Fatality Injury as a function of Collision Speed

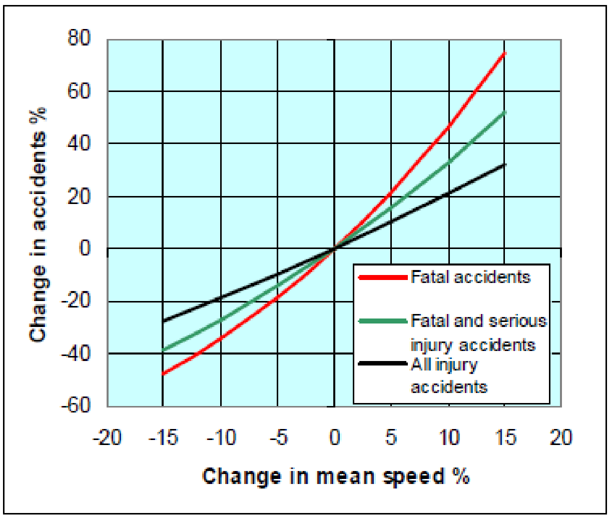


Note. Sourced from Abley insights, Road safety: Making the case for raised safety platforms.

Pratt et al. (2015) research indicated that speeds of over 50 km/h dramatically increase the risk of death and severe injury in the event of vehicle vs vehicle side impact crash. When vehicle speeds are kept at or below 50 km/h through intersections, the chance of death is less than 10%. The likelihood of injury due to side impact crashes increases significantly above 50 km/h.

Nilsson's "Power Model" shows the relationship between mean speed and fatal and injury crashes as cited in the Organisation for Economic Co-operation and Development (OECD) European Conference of Ministers of Transport (2006). This model indicates that reducing speed by a few km/h can significantly reduce the risks of crashes as well as mitigating the consequences of an crash, see Figure 3.

Figure 3. Nilsson's "Power Model"



Note. Sourced from OECD ECMT – 2006.

Makwasha and Turner (2017) RSP lead to 85th percentile speed reduction between 5km/h and 8km/h. H.A. H. Mahdy (2012) concludes that traffic calming devices can reduce speeds by about 20% of free flow speed. Austroads (2009) claims that flat-top road humps produce an 85th percentile speed reduction of 24% at the treatment.

JASIŪNIENĖ et al. (2017) state speeding is one of the most common causes of crashes and also affects the crash severity. Coulson and Cassar (2018) highlighted that RSPs are safety interventions that reduce the maximum comfortable vehicle operating speed to safe systems collision speeds.

Lawrence et al. (2021) showed 46% and 80% reductions in the likelihood of vehicles exceeding 30km/h and 50km/h, respectively, at a combination of sites with raised intersections and approach raised platforms. Candappa et al. (2013) assert the role that speed plays in creating a safe road network and recognise that humans will continue to make mistakes and should not be expected to use the infrastructure perfectly.

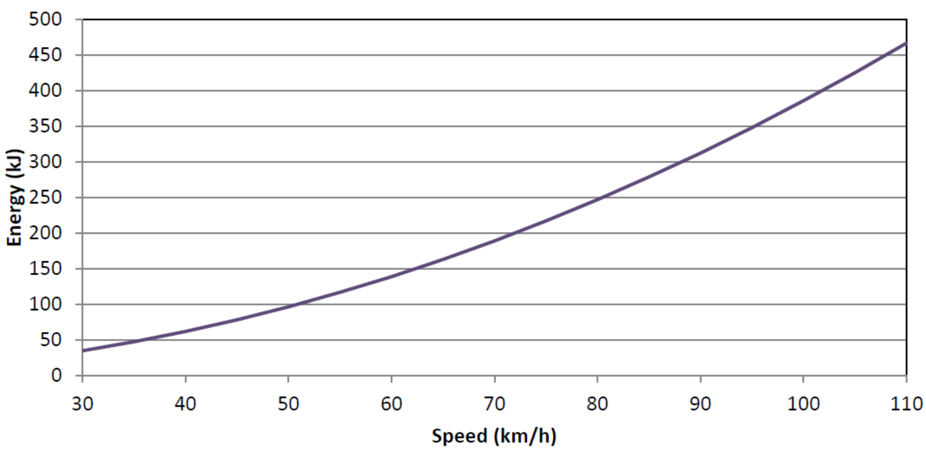
There is a significant amount of literature available, some of which has been captured in this literature review. The literature review all points towards speeding as a primary factor to safe systems compliance and RSPs sometimes also known as vertical deflection devices, being an effective safety intervention to slow speeds down to a safe system compliant level.

5.4 Kinetic Energy and Speed

Austroads Research Report AP-R560-18 (2018) shows that as speed increases, there is a proportionately higher increase in energy. Doubling the speed will result in four times the kinetic energy, and tripling the speed will result in nine times the kinetic energy, see Figure 4. The report concluded that speed changes significantly affect crash kinetic energy.

The above report also stated, "Kinetic energy has a linear relationship with mass, and a doubling of mass doubles the kinetic energy, " meaning that an eight-tonne truck will have eight times the kinetic energy of a one-tonne car.

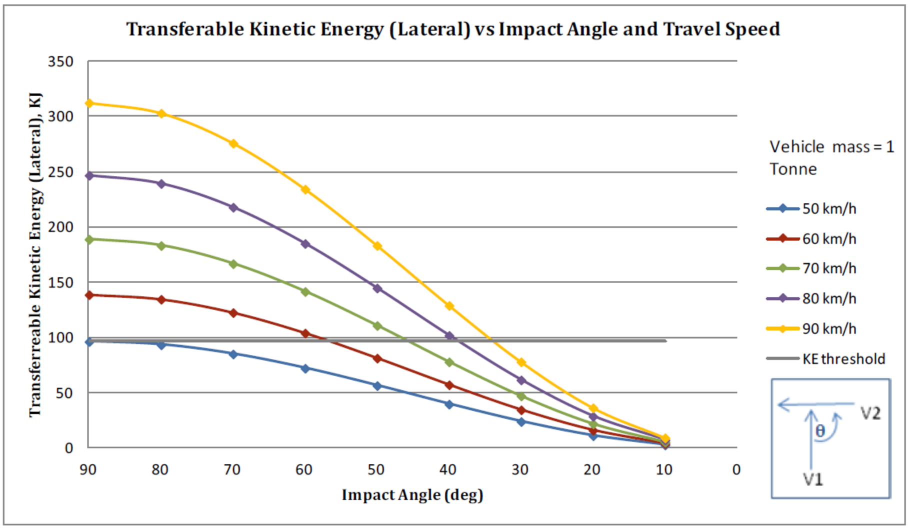
Figure 4. Relationship between Speed and Crash Kinetic Energy



Note. Sourced from Austroads AP-R560-18 (2018)

Candappa et al. (2013) identified that the critical safety principle is creating designs that reduce impact speeds to less than 50km/h. Raised intersections are likely to reduce speeds, and if a crash were to occur, this would happen at a lower speed with minimal vehicle intrusion, meeting the safe systems objective, see Figure 5.

Figure 5. Impact angle and speed effect on the kinetic energy

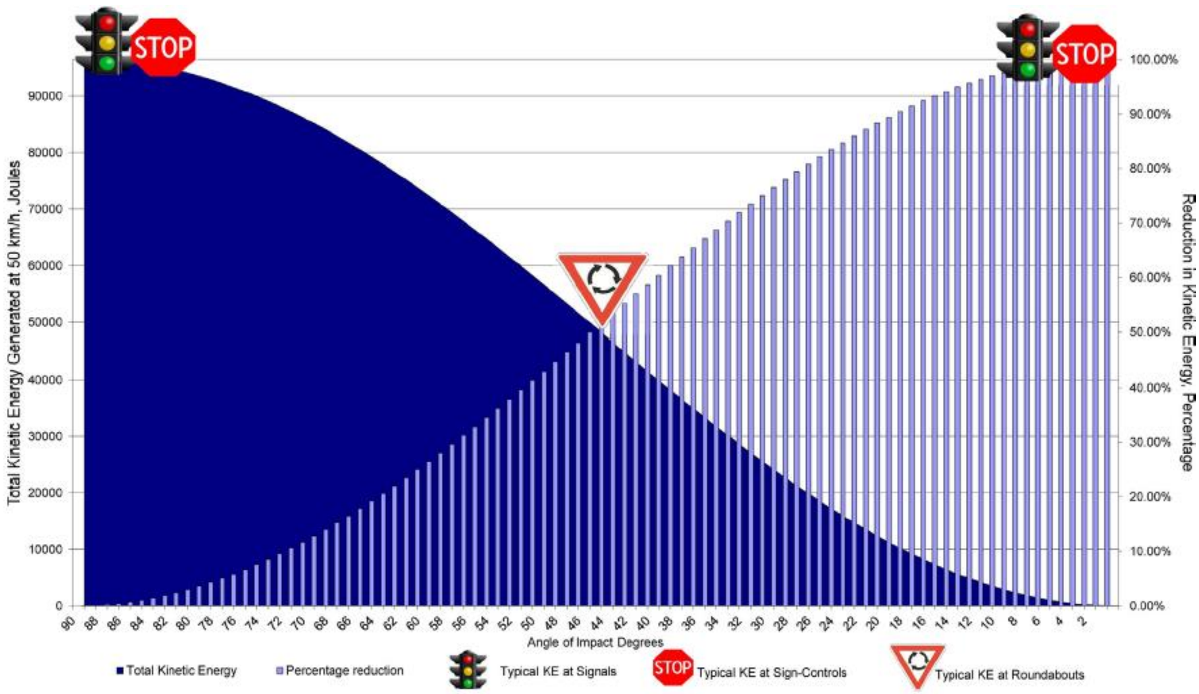


Note. Sourced from An exploration of alternative intersection designs in the context of Safe System (2014)

Candappa and Corben (2011) "It is evident that intersections are designed to secure travel speeds at not more than 50 km/h, as at impacts above this speed, the risk of severe injury to the occupants of vehicles rises rapidly with increasing impact speed".

Candappa et al. (2014) roundabout is a current intersection control that limits the potential of severe collisions. Roundabouts have kinetic energy levels half those at signalised and sign-controlled stop and giveway intersections, see Figure 6. A well-designed roundabout minimises 90-degree collision angles and induces lower operating speed through the intersection.

Figure 6. Effect of Angle of Impact on Kinetic Energy at typical Intersection Controls



Note. Sourced from An exploration of alternative intersection designs in the context of Safe System (2014)

The literature review shows that increased speed, impact angle, and mass increase crash kinetic energy.

5.5 Injury and Crash Causality

Austroads Research Report (AP-R450-14) identified run-off-road and head-on crashes in Australia and NZ of concern. It concluded that road controlling authorities should install appropriate traffic-calming devices to ensure the environment is favourable to vehicles travelling at the appropriate speed.

Austroads (2016) showed that entire intersections RSPs or approach RSPs (also referred to as raised stop bars) and raised pedestrian crossings have a 40% reduction in casualty crashes. Austroads (2017) indicates a 40% reduction in casualty crashes from applying RSPs.

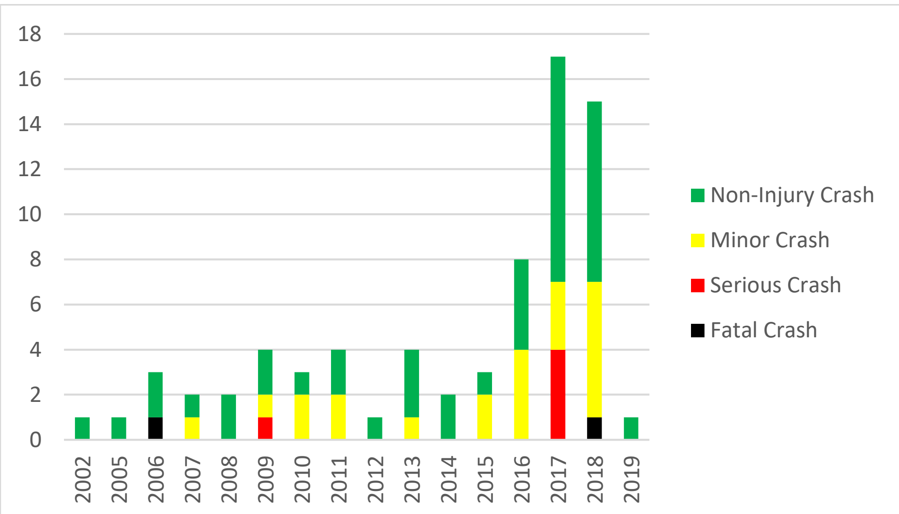
According to Turner et al (2021)**,** raised intersections produce around a 40% reduction in injury crashes and likely higher benefits for vulnerable road users. The International Road Assessment Program (iRAP) Road safety toolkit findings align with this, highlighting that raised intersections can reduce casualty crashes by up to 40%, with this sitting up to 60% for raised midblock pedestrian crossings.

Lawrence et al. (2021) found that speed reduction from RSP resulted in injury crash reduction of around 26% and a reduction in the likelihood of a severe injury due to a crash of between 38% to 57%. Mackie et al.(2019) also concluded that crash risk due to the installation of RSPs is low, and they are likely to reduce crash severity significantly.

Makwasha and Turner (2017) concluded that midblock RSP reduces casualty crashes by 47% and raised intersections reduce casualty crashes by 55%. Makwasha and Turner (2016), in another report before and after results of raised intersections and raised midblock crossings, showed a 53% casualty crash reduction. This report concluded that RSPs were found to lead to safety improvements, regardless of location or treatment type.

Crowther (2019), through the Thomas/Gordonton approach RSP and traffic signals post-construction investigation and identified there have been no reported injury crashes to NZ Police, see Figure 7. Social media comments about poor safety at the intersection have ceased.

Figure 7. Gortondon Thomas Interscetion RSP and Signals crash number and severity plot



Note. Sourced from HCC Content Manager (D-3087741). Trafinz Leadership Award Application 2019.

Abley Limited (2021) reviewed the current SSI toolkit selection criteria and costs with the intention of understanding and confirming the value for money for each SSI. Through this work it it was identified that RSPs (at existing signals and roundabouts) have a 31.3 predicted DSI savings per annum.

Fortuijn et al. (2005) through a study of a substantial number of intersections treated with RSPs showed that physically reducing vehicle speeds at signalised and priority intersections has reduced the number of crashes with casualties by 40-50% and 35% respectively.

There is good consensus in the literature that RSP, either at the midblock, at an intersection or on approach to the intersection, plays a significant role in reducing vehicle speeds, which consequently results in a reduction in injury severity. This area seems to be well-researched, but ongoing monitoring and evaluation would be beneficial as design developments are made to RSPs.

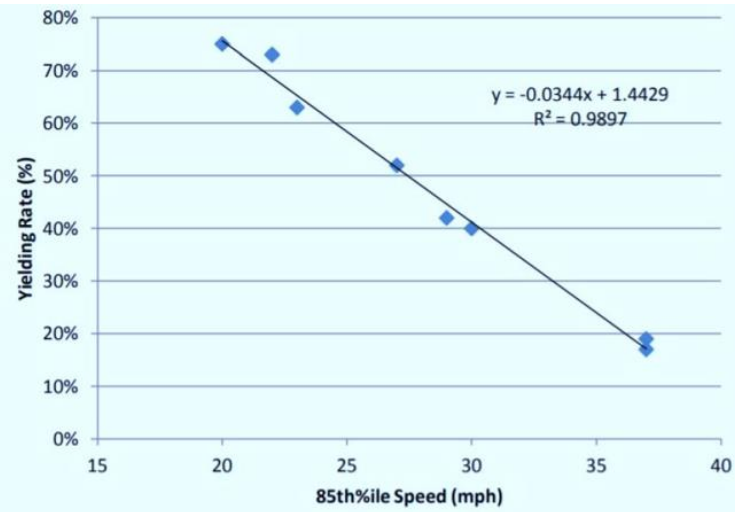
5.6 RSP and Active User

OECD ECMT (2006) Results from investigations of collisions involving pedestrians and vehicles show that 90% of pedestrians survive being hit by a vehicle operating at 30 km/h, whereas only 20% survive at an operating speed of 50 km/h, the chance of survival for a pedestrian or cyclist is nearly zero if hit by a vehicle at a speed of 80 km/h.

Safe Systems Solutions states that "Lower speeds improve road safety, especially for vulnerable road users like pedestrians and cyclists". Lower speeds help to make streets enjoyable places to be and encourage active travel rather than just thoroughfares for traffic.

According to the Global Status Report on Road Safety (2015) issued by the World Health Organization, the risk of death in a crash for pedestrians and cyclists is directly related to operating speed. As operating speeds increase, so does the risk of an crash. Job & Mbugua (2020) As driver speeds increase, the percentage of drivers who yield to pedestrians at marked crosswalks decreases dramatically, highlighting that lower speeds promote safety, inclusion, and equity amongst road users, see Figure 8.

Figure 8. Drivers yielding to pedestrians versus operating speed plot

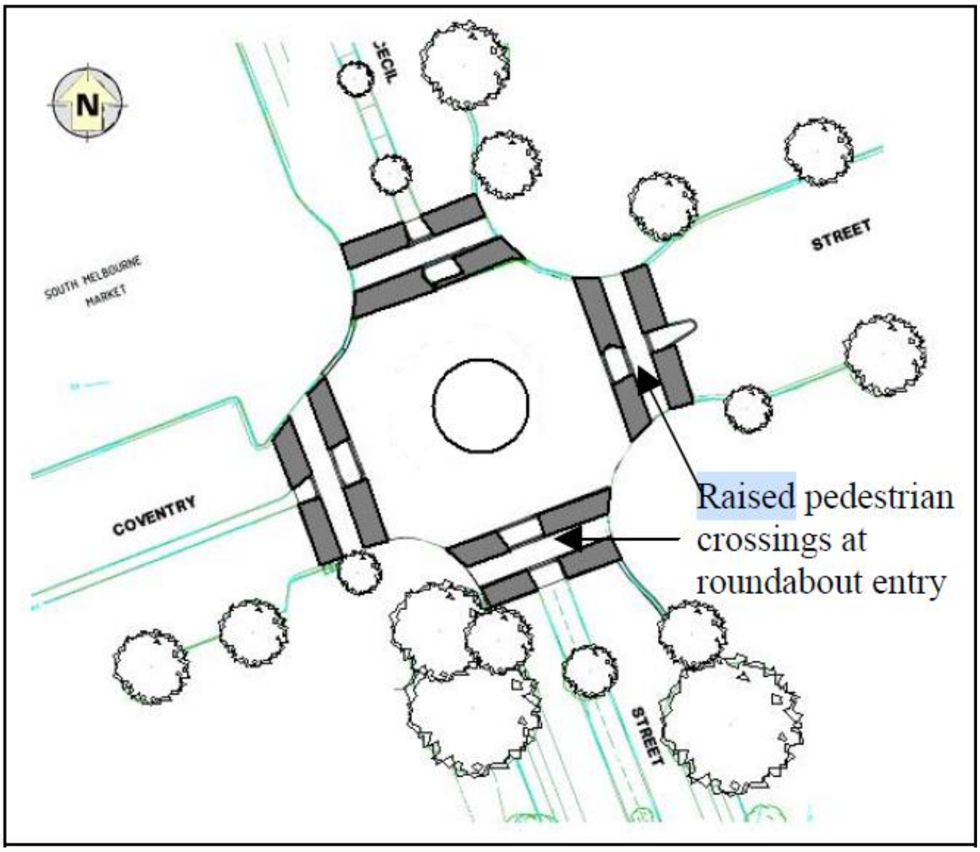


Note. Sourced from Bertulis and Dulaski, 2014. The relationship between the rate of drivers yielding to pedestrians at different speeds.

Candappa & Corben (2011), intersections are designed to achieve travel speeds of at most 30 km/h for pedestrian environments. Design features that help accomplish these speeds are raised platforms within intersections, roundabouts, and speed limits at intersections.

Candappa et al. (2005), through evaluation of the Cecil Street/Coventry Street roundabout in the City of Port Phillip in Melbourne, Victoria, found that retrofitting this roundabout with a raised pedestrian crossing resulted in safety and convenience for pedestrians, see figure 9. There were lower mean vehicle speeds, less confusion and reduced pedestrian crossing times.

Figure 9. Raised pedestrian crossing at roundabout entry.



Note. Sorced from Evaluation of an Alternative Pedestrian Treatment at a Roundabout (2005).

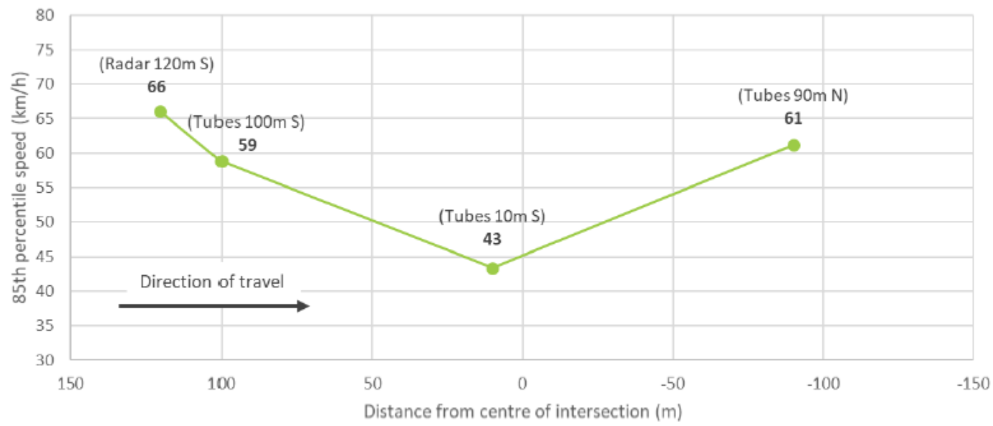
Candappa et al. (2013) identified that RSPs could benefit pedestrians at intersections. RSPs do not reduce the number of conflict points or impact angles at an intersection, but given the speed reduction, these factors are not considered to be a significant concern. This report recommended that intersections should be raised to provide speed reduction benefits to pedestrian crossings.

The literature review has shown consensus that RSPs designed and constructed for 30km/h speeds can provide safety benefits for active road users by lowering the likelihood of deaths and serious injuries in the event of vehicle collision. They also increase the likelihood that a driver will give way to an active user – whether or not the pedestrian crossing is controlled or courtesy.

5.7 Halo Effect of RSP on Speed

Mackie et al. (2019) showed that following RSP works, the 85% speeds at the Gordonton/Thomas Road intersection were well under 50km/h in a 60km/h posted speed limit area. Results showed that 85th percentile speeds were below 60km/h at approx. 80 to 100m back from the intersection on approach, which is the Halo effect from the RSP. Figure 10 shows the speed profile of vehicles as they approach, travel through and depart the intersection.

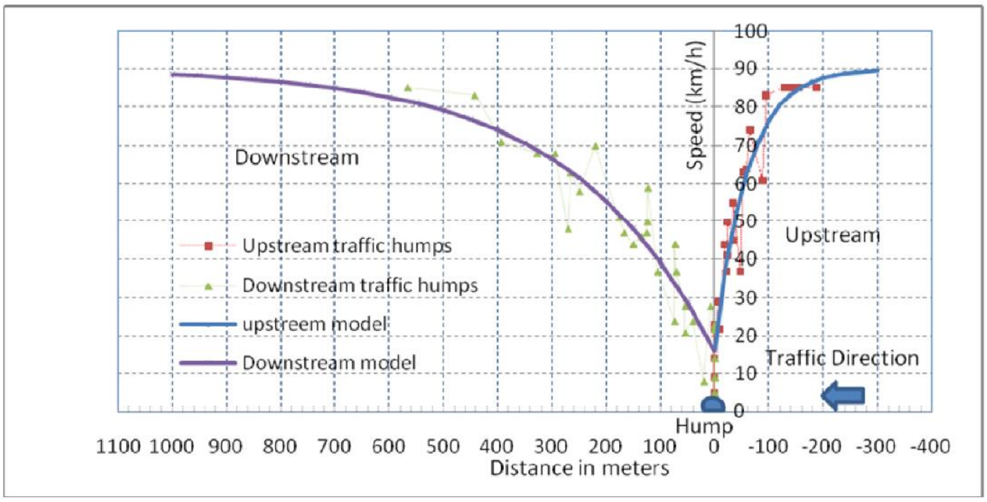
Figure 10. 85th percentile speeds northbound



Note. Sourced from Mackie Research (RSP Evaluation – Gordonton/Thomas Interscetion, Hamilton).

Lawrence et al. (2021) The study identified likelihood of a vehicle exceeding 30 km/h was reduced by 7 percent around 50 – 60 m back from the raised intersection. Mahdy (2012) found that speeds downstream of traffic calming (50 to 100m) were almost half of the upstream speed, see Figure 11.

Figure 11. Speed profile models for up and down stream traffic calming devices on urban streets.



Note. Sourced from Speed calming using vertical deflections in road alignment (2019, May).

Literature shows that RSPs have a halo effect on the speed between 50 and 100 metres. The halo effect on speed from RSP would be an area of interest in planning for traffic calming and warrants further research.

5.8 Case studies of selected Speed and RSP safety interventions

5.8.1 Case Studies within New Zealand

Despite being a low-speed zone, the Church and Victoria Street intersection in Onehunga Auckland had 43 injury crashes between 2014 and 2018 over five years. Urban roundabouts with approach RSPs were added here, and a year after this work, there were zero reported crashes or injuries, see Figure 12. Roundabouts added with RSPs slow vehicles down and introduce safe gaps for cars to merge with other users on the road, improving intersection concentration.

Figure 12. Church and Victoria Street intersection with RSPs in Auckland, NZ.

Note. Sourced from NZTA Safe Systems case study page.

Hamilton's busy Anglesea and Bryce Street signalised intersection got RSP treatment in 2019, aimed at reducing DSI crashes by 25 to 40%. This project was the winner of the 2021 Trafinz Safety Leadership Award.

Figure 13. Anglesea Street Bryce Street raised signalised interscetion in Hamilton, NZ.

Note. Sourced from NZTA Safe Systems case study page.

Taupo District Council upgraded the Napier/Kiddle/Arrowsmith stop control intersection to a single-lane urban roundabout with raised intersection safety platforms, see Figure 15. The speed limit was lowered to 50km/h. Before improvements, there were 18 reported crashes, which included one injury and five minor injury crashes and post-construction, since March 2022, there have been no reported crashes.

Figure 14. Napier/Kiddle/Arrowsmith roundabout with RSPs in Taupo, NZ.

Note. Sourced from NZTA Safe Systems case study page

HCC, in partnership with NZTA, introduced a new signalised intersection with a approach RSP at the Thomas and Gordonton Road intersection. Following the introduction of this treatment, there have been zero DSI crashes at this site. See Figure 15.

Corben (2018) through an RSP assessment report of this site for HCC, highlighted that with any new traffic management device, road user behaviour change is required, and this will be evident to the user. To deliver safety benefits support should be provided to drivers in order to help adjust behaviour to the new speed environment.

Figure 15. Thomas/Gordonton intersection in Hamilton, NZ.

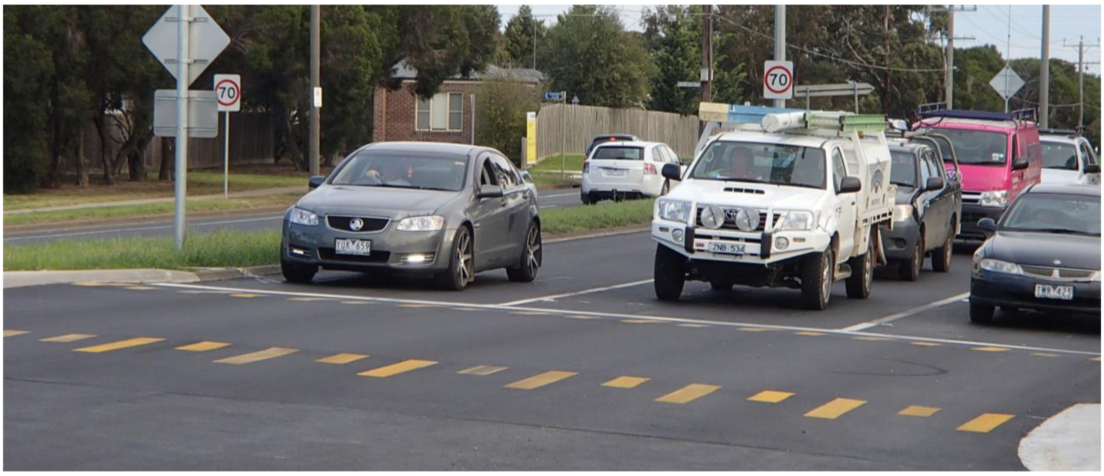
Note. Sourced from HCC Content Manager (D-3087741)

5.8.2 Case Studies Outside of New Zealand

VicRoads in Australia has conducted an RSP trial at its Surf Coast Highway and Kidman Avenue 70km/h signalised intersection (See Figure 16) in Geelong City, Victoria. This was the Australian-first treatment based on innovative Dutch design. Advice from VicRoads is that treatment has been effective in reducing travel speeds through the intersection.

Candappa and Colobong (2015) Through Monash University Accident Research Centre carried out a a trial at the VicRoads intersection of Surf Coast Hwy and Kidman Avenue, Belmont. RSP was combined with traffic signals and posted speed limit change from 70 km/h to 60 km/h and findings showed a significant reductions to travel speed through the intersection.

Figure 16. RSP trial Surf Coast Hwy/Kidman Ave, Belmont, Victoria.



Note. Sourced from Corben,B(2018). Report on assessment of safety platforms proposed for Thomas Road/Gordonton Road, Hamilton.

South Holland in the Netherlands was where the RSPs were pioneered. Fortuijn et al. (2005) study of a number of RSPs in South Holland (Netherlands) indicated significant safety improvement. Figure 17 shows an image of this site.

Figure 17. Photo of a Raised Stop Bar (RSP) site from the Netherlands

Note. For images of more Netherlands examples reference should be made to the original report Proposed trial of elevated stop lines at Surfcoast Highway and Kidman Avenue, Belmont.

6. OPERATIONAL LEVEL OF SERVICE (LOS)

6.1 Traffic Flow, Capacity, Delay and Travel Time

Austroads Research Report AP-R498-15 (2015) suggests that vertical deflection devices could affect signals in a minor way by an increase in inter-green time due to slower clearance time. This research report suggests that capacity and efficiency would be marginally reduced by lower speeds at raised roundabouts but insignificant.

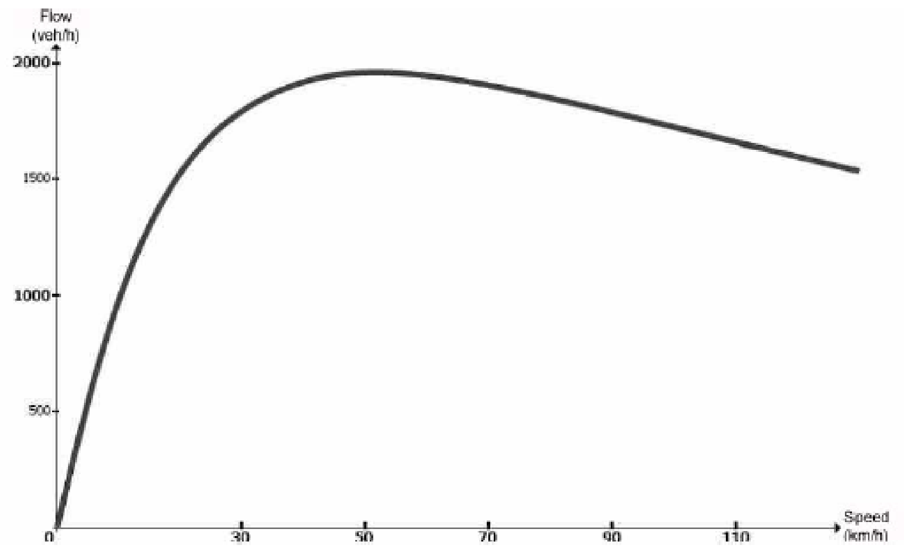
Auckland Transport Practice Note-02 states that RSPs can affect traffic flow, safety and comfort of some users, and emergency services response time. Cairney et al. (2021) on the other hand showed that post-RSP installation capacity was found to increase slightly by 1.4%. This report predicted that it is extremely unlikely there would be an adverse effect on capacity or congestion from RSPs.

Mackie et al. (2019) through the evaluation of the Gordonton/Thomas Road Signalised Intersection RSP found no evidence of a negative impact on traffic efficiency. This report also showed evidence of positive community buy-in with no reports of safety or operational issues. There is little evidence that the RSPs are significantly impacting intersection capacity.

Job & Mbugua (2020) showed that decreasing speeds does not necessarily increase congestion but can improve flow. At higher speeds, drivers generally leave longer gaps and vehicles are further apart and this does not improve congestion as a result of low saturation. Reductions in speed as vehicles reach congested conditions result in a smoother flow of traffic. This produces less stop/start traffic movement, with subsequent benefits on the safety and throughput (flow) of vehicles.

OECD ECMT (2006) states that in an urban built-up context, reducing the average speed from 50 km/h to 30 km/h does not cause a very significant decrease in traffic flow capacity. Traffic flow through specific locations is reduced as speeds increase beyond 50km/h, see Figure 18. Effects of speeds are generally overestimated in the reduction of travel times in urban areas.

Figure 18. Showing traffic flow as a function of speed on an urban road



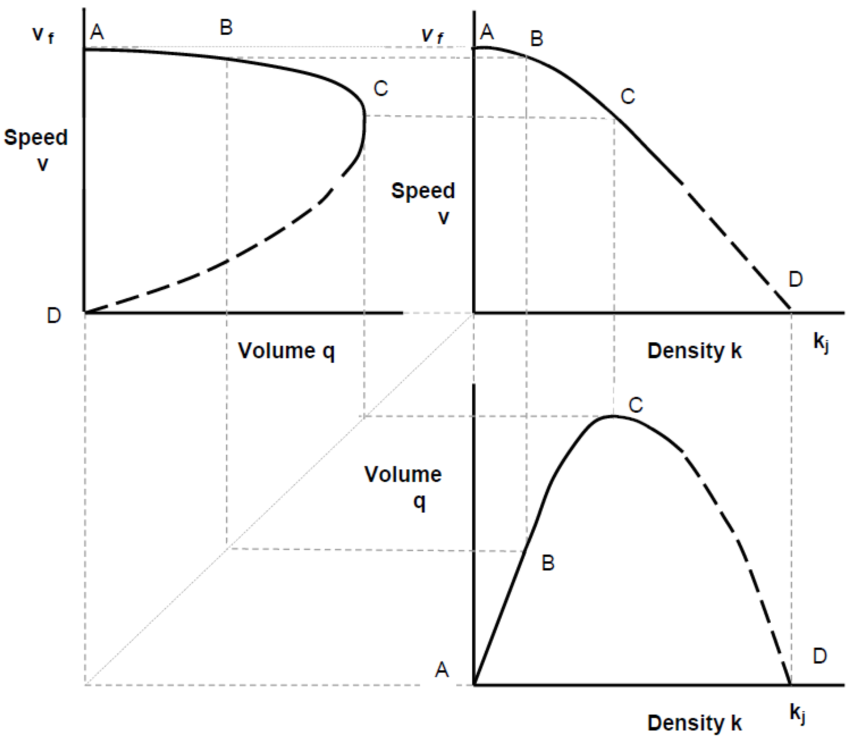
Note. Sourced from OECD, 2006 as sited from Sehier.

Fortuijn et al. (2005) study of 40 signalised intersections that were treated with RSPs in South Holland showed intersection capacity and the ability to negotiate intersections have been enhanced.

Safe Systems Solution (RSP) states that evaluations have shown little evidence of any significant impact on intersection capacity due to RSP installation. “Journey times are hardly affected because speed reductions are focused on a short length of road (the point of risk) rather than over a wide area.”

Ogden and Bennett (1989) show that Traffic Speed, flow (volume) and concentration (density) are the principal variables used to describe a stream of traffic. A different combination of these variables can give rise to different traffic conditions. Austroad AGTM- Part 2 (2020) agrees; see Figure 19 for the relationship.

Figure 19. Graphical relationship between speed, flow (volume) and density (concentration)



Note. Sorced from AGTM02: 2020: Traffic Theory Concepts.

The above graph can also be found in Traffic Engineer Practice (Fourth Edition – 1989). The fundamental relationship between these variables can be described mathematically, and for more detailed information on this, reference to the Austroads Guide to Traffic Management should be made.

There are varying conclusions in the literature on traffic flow and capacity from RSPs. The majority of the literature cited concludes that RSP doesn't reduce traffic capacity or create congestion but instead creates smoother traffic flow and better gap selection, resulting in reduced travel time. There was no literature with evidence around microsimulation modelling or real-time travel time measurements, and it is an area which requires more in-depth analysis.

6.2 Network Operating Plans (NOP)

Hillier et al. (2016) state that “NOPs outline the objectives and relative priorities for different transport modes, network performance, and strategies for guiding the implementation of priorities and performance gap reductions". NOPs encourage a shift in road design from roads aimed at reducing travel time and being more focused on motorised vehicle mobility to planning and designing roads focusing on the safety, access and mobility for all road users.

HCC (2017) NOP has a dual purpose of effectively managing the movement of people and goods and enhancing activity centres. Its focus is getting the right traffic on the right roads while managing demands. Guidance on NOPs is provided in Austroads (2015b). NOP road design considers all road users, particularly vulnerable road users, rather than just motorised vehicles.

Globally, there is a shift towards integrated planning, design, and investment in transport networks to consider the way people travel and interact with their surroundings better. In NZ, the NZTA has developed the One Network Framework (NOF), which is the latest version of NOP and puts people, place and movement at the heart of planning and investment.

The ONF recognises that streets are also places for people to live, work and enjoy. It contributes to improving road safety and building more vibrant and liveable communities. "The ONF is a tool to help establish network function, performance measures, operating gaps and potential interventions for each road and street type." ONF allows land use and transport planning to be integrated.

6.3 Comfort and Vertical Acceleration

Vertical acceleration is where the vehicle accelerates in a vertical direction due to the RSP and gets pulled back down due to the earth's gravitational pull of 9.8 m/s2. This upward and downward pull action induces discomfort to the driver and occupants of the vehicle, resulting in slower speeds. The greater the vertical acceleration, the higher the driver's and passengers' discomfort.

Austroads Guide to Traffic Management Part 8 – LATM (2020) suggests that RSPs are uncomfortable for vehicle passengers and cyclists. Bjarnason (2004), through their thesis, concluded that there is a conflict between driver comfort and speed reduction at vertical devices.

Pratt et al. (2015) identified that vertical acceleration of greater than 0.7g is considered dangerous and can cause damage to the vehicle. Vertical acceleration in the range of 0.5 to 0.7g was seen to achieve noticeable speed reduction without causing damage to the vehicle, see Table 1.

Table 1. Typical driver speed responses to vertical acceleration

Magnitude of vertical acceleration (g)	Typical driver response
0.1 – 0.5	No speed response
0.5 – 0.7	Some speed reduction
0.7+	Possible damage to vehicle (bottoming out)

Note. Sourced from The hurdles of introducing innovative road safety infrastructure solutions – a case study on RSPs.

Blewden et al. (2020) through an extensive literature review on RSPs, had identified consensus between previous studies that 0.4 to 0.7g relate to acceleration levels acceptable for reducing speeds with 0.5g being the comfort level threshold for vertical acceleration. Vertical acceleration of 1.0g and above is regarded as unsafe.

Mackie et al. (2019) analysis showed that speeds of 50-60 km/h are associated with accelerations of approximately 0.4g. Reference should be made to section 3.4.1 of this Austroads Research Report (Ap-R642-20) for more detailed information on vertical acceleration and literature review.

Comfort is a critical criterion for RSP performance effectiveness, and road user discomfort, to a certain extent, can result in reduced vehicle speeds and thus improve overall safety.

6.4 Driver Behaviour

6.4.1 Acceleration and Deceleration at RSP's

Mackie et al. (2019) showed a low risk of erratic or unsafe driver behaviour by introducing raised intersections with only 0.66% of vehicles stopping on the RSP. The community feedback method also provided little evidence that RSPs are perceived as unsafe. This research report concluded that RSPs pose a low crash risk associated with late braking, red-light running and peak acceleration, with vertical acceleration being within acceptable range.

NZTA RSP safe systems case study of approach RSP showed that *"*most drivers braked well in advance of the RSPs and no instances of hard braking were observed". Drivers slowed down as they approached the intersection and were at their slowest speed as they crossed the RSP and moved through the intersection.

Mahdy (2012) concluded that deceleration upstream and acceleration downstream of RSP have different behaviours. Downstream acceleration takes place over a longer distance. Sheykhfard et al. (2023) showed significant speed reduction was observed at humps, and field observations of approaching drivers showed that many braked before reaching the traffic calming measures. This research also concluded that flat-top humps are more comfortable than round humps.

Candappa et al. (2016) VicRoads introduced an Australian-first innovative treatment at the signalised intersection of Surf Coast Highway and Kidman Avenue through RSP. 20% of drivers encroached the stop line at red signals, suggesting some driver confusion and uncertainty about where they are required to stop. Some drivers braked well before necessary, indicating some uncertainty and hesitation.

Literature showed consensus that drivers decelerated on approach and accelerated post the RSP, but some confusion was noted in terms of where drivers are expected to stop.

6.4.2 Red Light Runners

Cairney et al. (2021) Only limited instances of red-light running were recorded. These numbers were too small to conclude the effects of the RSPs on red-light running but sufficient to indicate that red-light running at that site was too infrequent to be of concern. Further research is warranted here, given the small number of events observed. There is limited literature available in relation to red-light running.

6.5 Emergency Vehicles, Buses and Heavy Vehicles

6.5.1 Emergency Vehicles

A recent report (Traffic Calming and effective response time) prepared by MR Cagney (NZ) Ltd for Fire and Emergency New Zealand (FENZ) states that there is limited data available to determine if emergency response access and speeds are likely to be affected through traffic calming. "The existing literature on how emergency response is impacted by traffic calming interventions is quite thin and not convincing."

The evidence that exists is mixed, and as a result, a clear recommendation on right and wrong ways to implement traffic calming was not made. Due to the limited literature and lack of adequate data, this report recommended that FENZ and the roading authorities engage in dialogue around this topic, install pilot/test sites, and monitor setups.

Safe Systems Solution (RSP) states, "Emergency vehicles need to slow down at RSPs. But they must also slow down at roundabouts, traffic lights and other intersections. RSPs on some of Melbourne's busiest emergency vehicle routes do not significantly affect response times."

Boulter and Webster (1997) mention that emergency vehicles do not use fixed routes in the same way as buses. Therefore any additional maintenance costs due to road humps would be challenging to establish. It was assumed that emergency vehicles might exceed the desirable hump crossing speed while responding to an emergency call, and this could lead to damage.

Bulpitt (1995), as cited in Boulter and Webster (1997) suggests that road humps will add 10 seconds to the response time for emergency vehicles. Through an extensive site survey, Mackie et al. (2020) found that inconvenience and delays to buses and emergency vehicles can result from raised intersection treatments and identified a need for close emergency services engagement.

Older literature suggests that some very minor delays and inconveniences may be caused as a result of humps. It is assumed that older literature is referencing traditional style humps and not modern RSPs, which can be designed for comfort. There is a consensus among some literature that there is a need for dialogue between the roading authorities and emergency services. An area which requires more RSP research and development work.

6.5.2 Buses

Austroads (2017) classifies a 1:30 ramp slope as bus-friendly, but this shallower ramp may result in less speed reduction for other vehicles. NZTA, vertical deflection devices guidance, requires consideration of discomfort to bus passengers if placed on bus routes, and that careful design should be undertaken to accommodate buses.

Austroads AP-R556-17 (2017) states that ramp slopes must be carefully selected to balance entry speed reduction with the risk of adverse operational effects such as ‘bottoming out’ by vehicles with lower suspension or discomfort risk of falls for bus passengers. Mackie et al. (2020) identified that a RPS 75mm height for buses might be more suitable for reducing the scraping risk.

Boulter and Webster (1997) state that traffic calmed roads can become unpopular with bus services due to increased journey time and passenger discomfort. Webster and Layfield (1996) as cited in Boulter and Webster, 1997), found that bus companies appear satisfied with 75mm high platforms.

Literature indicates careful design and engagement with bus service providers and operators is required. Public transport service providers might also have an underlying driver education requirement for the appropriate use of RSPs for the safety of all road users and the national/international goal of achieving safe systems compliance.

6.5.3 Heavy Vehicles

Opus Research Report (2018) used computer simulation modelling to investigate RSP effects on a 16m Tractor unit and semi-trailer configuration at Hamilton's Thomas/Gordonton signalised RSP intersection. The report identified that RSP has a negligible impact on changing the critical rollover speed and acceleration from those identified for the same turn without the RSP.

Cairney et al. 2021) undertook desktop simulation to understand the impacts of RSP on heavy vehicle stability. Eight-tonne light rigid trucks, 23-tonne heavy rigid trucks, and 43-tonne semi-trailers were used for simulation runs. Observation of before and after vehicle speeds indicated that the reductions in speed were sufficient to keep vehicles below the rollover threshold.

Austroads AP-R556-17 (2017) mentions that turning heavy vehicles due to the combined horizontal and vertical forces on the axles could lead to an increased risk of overturning. Mackie et al. (2020) found no evidence of truck rollover risk due to RSP implementation and concluded this has been attributed to the careful design.

Austroads Guide to Traffic Management Part 8 – LATM (2020) states that RSPs may adversely affect access for buses, commercial vehicles and emergency vehicles. Mackie et al. (2020) provide design guidance based on more recent investigations and recommend edits to Austroads to factor in buses, heavy vehicles and emergency vehicles and that RSPs can be used subject to careful design and engagement. Mackie et al. (2019) Identified that the heavy vehicle acceleration rate appears to be more of a factor for both RSP and non-RSP sites.

Safe systems solution (RSP) mentions that "RSPs are designed so that large vehicles are not destabilised or damaged. Ramp slopes and height are adjusted to suit the vehicles travelling over them. There is evidence that RSPs are working successfully on major arterial freight routes in Victoria, such as the Surf Coast Highway Belmont and Bass Highway Wonthaggi."

6.6 Vehicle Suspension

Harris and Hall-Geisler (2021) The purpose of the vehicle suspension is to smooth out the ride and to provide safe handling as the vehicle accelerates, decelerates, brakes and negotiates vertical and horizontal road geometry. Vehicle suspension maximises the friction between the road surface and tyres to provide steering stability, handling and vehicle occupant comfort.

Literature on the effects of RSPs on vehicle suspension and maintenance requirements is scarce and is an area of knowledge gap warranting further analysis and data gathering from workshops.

6.7 Noise

Wewalwala and Sonnadara (2011) considered different classifications of vehicles, suggesting that there are effects on noise levels at short distances from speed humps. Maximum increase by 1 to 5dB generally due to larger vehicles and a difference of 1.2dB measured at 20m from the road hump and similar to average road noise levels beyond this point. The radiated noise measured through this work was a function of engine speed (revolutions per minute) and vehicle speed (meters per second).

A recent study outlined by Michael et al. (2020) suggested that noise concerns post-construction were not realised at a compact roundabout in Lance Creek Victoria (W Creek Rd and Korumburra-Wonthaggi Road). Rylander and Bjorkman (2002) suggest that noise level increases due to road bumps are related to aggressive car driver behaviour. This was as the driver regained the speed reduced by the bump.

Austroads Guide to Traffic Management Part 8 – LATM (2020) states that the traffic noise level may increase just before and after RSPs due to braking, acceleration and the vertical displacement of vehicles and their goods.

Velasco (1996), as cited in Boulter and Webster (1997) suggests that traffic calming measures may have significant effects on noise and air pollution reduction.' JASIŪNIENĖ et al. (2017) stated trapezoidal speed humps due to vehicle decelerating and accelerating can cause increased noise and pollution. Safe Systems Solution (RSP), on the other hand, has highlighted that recent tests have shown a decrease in noise, which is mainly a result of resurfacing of RSP approaches.

Mackie et al. (2019) determined that noise levels from RSP probably would be undetectable in comparison to other noise caused by vehicles moving through the intersection, i.e. articulated trucks. Consultation with noise experts suggested that clean baseline data is necessary to measure the noise impacts of the RSPs objectively.

It is currently not a common practice to measure before and after noise changes from the introduction of RSPs. Research findings on noise due to RSPs seem to be limited and an area that needs to be understood more in detail based on the current design/construction, driver behaviour and residents' feedback.

6.8 Vibration

Watts and Krylov (1999) concluded that road humps can produce detectable levels of ground vibration leading to complaints and concerns of building damage but unlikely risk of even minor damage to property. A vehicle model is recommended to aid design such that an appropriate level of in-cab vibration is generated in order to help discourage excessive speeds.

Harris et al. (1999) showed that the 75mm high flat-top humps produced higher noise and vibration levels than the other designs as a result of commercial vehicles operation. JASIŪNIENĖ et al. (2017) Speed humps create potential negative vibrations inside the vehicle and for the neighbouring buildings. In a study for HCC, Cenek (2022) used falling weight deflectometer (FWD) measurements at RSP sites to identify where traffic-induced vibrations from vehicles traversing an RSP. The study concluded that pavement strength is an indicator of the magnitude of ground vibrations induced by traffic.

Further work is required to fully understand the effects of RSPs on vibration based on pavement strength, underlying ground condition, underground three waters infrastructure and separation of buildings from the RSP. There is mixed messaging for existing available literature, some of which are relatively old information and likely to be using traditional hump profiles.

7. ENVIRONMENT EMISSIONS AND HUMAN HEALTH

7.1 Green House Gas Emissions

Austroads research report AP-R498-15 (2015) identified that vehicle emissions would increase marginally due to acceleration and deceleration due to vertical deflection devices. Abbott et al. (1995), as cited in Boulter and Webster (1997) stated that an uneven speed profile may increase fuel consumption and vehicle emissions.

J. Metcalfe (2023) concluded that speed reduction is a critical part of emission reduction. Traffic calming increases vehicle emissions, but the overall impact on greenhouse gas emissions (GHG), ambient air quality, and air pollution health would be small (less than 10%).

Jones and Brunt (2017) lowering urban speed limits from 50km/h to 30km/h reduced emissions by 25%, and analyses show that many lives would be saved through reduced air pollution if urban speeds are lowered to 32km/h (20mph) in addition to savings of crash deaths and serious injuries.

Job & Mbugua (2020) states that managing speeds will reduce greenhouse gas emissions and air pollutants. Lower speeds reduce climate change impacts of road transport and increases efficiency with vehicle fuel consumption and vehicle maintenance. One of the things to note out of this is that economically optimal speeds are lower than expected and typically lower than prevailing speed limits.

Emissions Impossible and EMM (2023) state that speed is a factor that can affect emissions. Emissions are higher at speeds less than 50km/h (due to stop-go) and greater than 80km/h (due to higher load on the engine and resistance due to aerodynamics requiring more fuel). Findings concluded that the type of vehicles in the fleet is the most significant factor on emissions as, over time, the proportion of zero-emission and low-emission hybrid vehicles in the fleet will have a significant impact on average fleet emissions of greenhouse gases and harmful pollutant emissions.

Fang and Volker (2017) identified that VMT deduction could provide co-benefits beyond GHG emissions, such as environmental, human and fiscal health. These co-benefits can be realised directly by lowering air pollutant emissions and indirectly by realising the benefits of alternatives to driving, such as active modes.

The above could mean that RSPs, due to the induced acceleration and deceleration, can result in increased emissions. It is important to note that emissions should not just be assessed independently but in conjunction with other key factors such as social and economic impacts of DSI, mode shifts as a result of safe infrastructure through the introduction of RSPs, vehicle fleet and driver behaviour.

7.2 Health Effects and Air Quality

Anderson et al. (2012) state that higher speeds produce more air pollution, which causes many harmful effects on health, including decreased lung function, cardiovascular disease, increased use of health care services and death. Woodcock et al. (2009) identified that choosing active travel over private motor vehicles in high and middle-income countries will yield essential health benefits and reduction of carbon dioxide (CO_2) emissions.

Metcalfe (2023) states that to reduce the health effects of poor air quality, travel by vehicle will need to be reduced. Speed reduction, which promotes walking and cycling, is critical for emission reduction in NZ. Massar et al. (2021) identified that eco-driving and platooning/flocking vehicles significantly contribute to reducing GHG emissions by 35%.

Every and Holmes (1992), as cited in Boulter and Webster (1997) through modelling, predicted that fuel consumption would increase as a result of flat-top humps. Given the increased consumption, the report suggested that the air quality might deteriorate. Gilbert and Boulter (2022). states through real-world monitoring studies in cities where traffic calming has been widely implemented have identified no significant impact on measured ambient air quality

Based on the existing literature review, choosing active travel and reducing the Vehicle Kilometer Travel (VKT) will significantly benefit human health and air quality. Evidence suggests some disagreement between older and more recent literature and RSPs' effects on human health and air quality, which is an area of knowledge gap that warrants further in-depth modelling and development to increase practitioner understanding.

8. DESIGN

8.1 Design Application and Cost

Austroads AP-R556-17 (2017) mentions that safety platforms will be helpful when the project's key objective is to reduce crash severity and its likelihood at lower costs. Vicroads (2019) provides some essential guidance about site selection and warrants. Although both approach RSP and raised intersections achieve speed reduction, their applicability will depend on site considerations.

Austroads AGRD Part 7 (2023) states pedestrian crossings can be incorporated into the raised platforms to emphasise their presence and slow traffic at conflict points. On approach to roundabouts, RSPs can moderate approach and entry speeds similarly to approach curves and a large central island would do at a conventional roundabout.

Mackie et al. (2020) state that RSPs have been extensively used in the Netherlands. In Australia and NZ, usage is developing. Candappa et al. (2013) raised intersections are commonly used in many European countries and less frequently in Australia.

Vicroads (2019) states that approach platforms are suitable for divided carriageways as median islands enable application in a single direction of travel. Where the platform is installed in an undivided carriageway, the approach and departure ramps have the same slope.

Austroads AP-R556-17 (2017) states that the cost to retrofit RSPs to existing roundabouts is relatively low as platforms should fit within the existing kerbs. Generally, no service relocation is needed, but surface water drainage would require careful consideration. This research report also states, "Cost of a new compact roundabout with safety platforms (and a smaller footprint) is expected to be much lower than the cost of a conventional roundabout or signalised intersection".

8.2 Stakeholder Engagement

Austroads GTM Part 8 (2020) identifies the community as a viable source of information and acceptability. If the community is not content with the proposed outcomes, then all else is secondary. “Therefore, a process for community feedback and a more formal mechanism to obtain community opinions and attitudes may both be required”.

Boulter and Webster (1997) highlighted the importance of consultation with emergency services before traffic calming implementation so emergency service vehicle characteristics can be taken into account during planning, design and construction. Mackie et al. (2020) concluded that public and stakeholder understanding of RSPs is developing, and no significant issues have been identified with RSPs.

Austroads AP-R587-19 (2019) identifies that VicRoads and the NZTA have comprehensive guidelines for community and stakeholder consultation and engagement. There is consensus in the literature that a process of meaningful community engagement and procedure should be in place for the success of traffic calming devices.

8.3 Design Speed

NZTA guidance, Austroads Guide to Road Design part 4 (2023), Coulson and Cassar (2018), VicRoads (2019), Austroads research report AP-R560-18 and Austroads Research Report AP-R642-20 all state that the safe system maximum speed for a side impact crash is 50km/h and where pedestrians are present vehicle collision speed should not be greater than 30km/h.

Coulson and Cassar (2018) state that RSPs can be designed for a range of vehicle types and speeds. For desired outcomes to be achieved, RSP design should also incorporate supporting treatments. VicRoads (2019), For higher speed environments of 80km/h, it is recommended to use RSPs in conjunction with other supporting treatments.

Austroads research report AP-R560-18 states that if 90-degree cross-road geometry cannot be changed, supporting safety treatments such as RSP on approaches can compensate for the unfavourable configuration.

There is a lot of literature available in relation to safe system design speed, and there is a good consensus between independent literature that a design speed of ≤ 50km/h for side impact crashes and ≤ 30km/h for pedestrian and cyclist-related crashes should be employed.

8.4 Road Geometry and Visibility

Austroads GTM Part 8 (2020) states that vertical deflection devices should be clearly visible to drivers on approach. Austroads Research Report (AP-R450-14) identified that limited sight distance, complex curves, steep downhill grades and out-of-context curves are some of the factors for run-off-road and head-on type crashes.

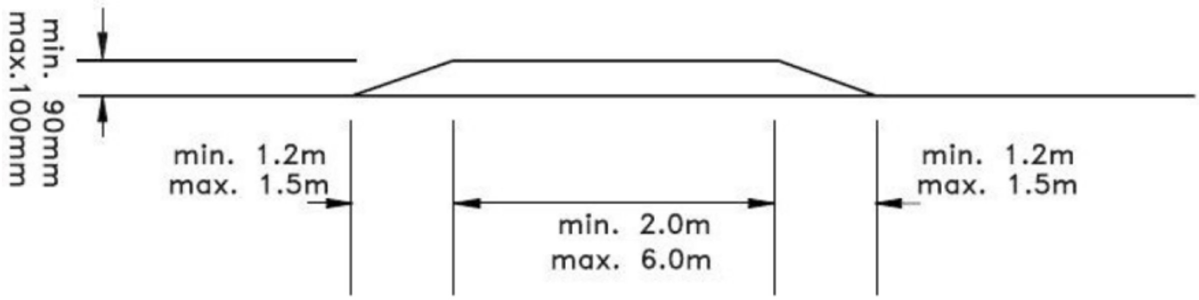
Austroads AGRD Part 4 (2023) identifies that RSPs slow vehicles and increase the visibility of pedestrians due to road surface level increase. Austroads AGRD Part 4A (2023) guides in relation to sight distance requirements at intersections and midblock locations.

Austroads AP-R556-17 (2017) states that vertical deflection devices support low entry speeds onto roundabouts. Some horizontal deflection is still required for acute impact angles, which is generally achieved through the approach splitter and central island.

8.5 Raised Safety Platform Dimensions and Ramp Profile

Austroads GTM Part 8 (2020) states that RSPs are typically two to six meters long with a raised surface of approximately 75 to 100mm. On bus routes, a height of 75mm and a 1:20 ramp grade are recommended, see Figure 20. RSPs should be installed at right angles to the direction of travel. It also states that sharper ramp slopes and higher platforms achieve the most significant speed reduction.

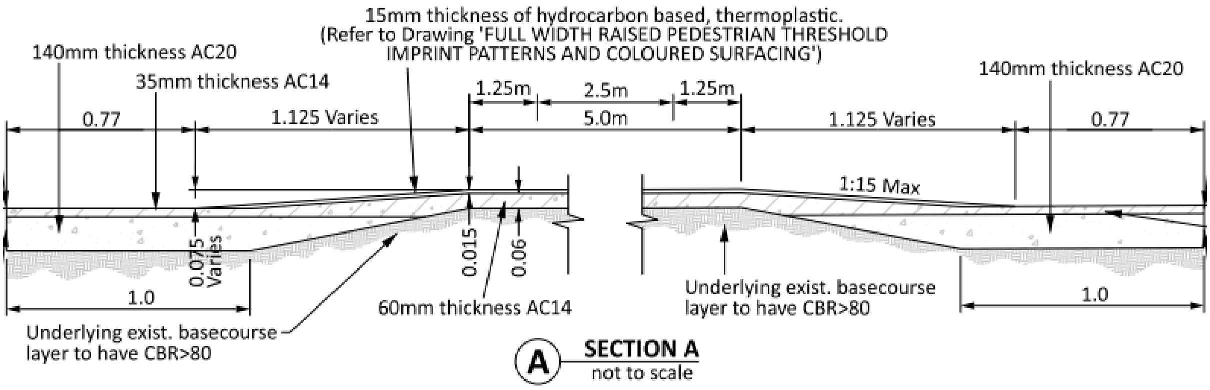
Figure 20. Indicative dimensions of a flat-top road hump



Note. Sourced from Austroads Guide to Traffic Management Part 8 (2020).

Regional Infrastructure Technical Specification (RITS), adopted by nine NZ participating councils from the Waikato Region, specifies that the typical platform height is 75mm, which can vary depending on site constraints, see Figure 21. The usual length is 5m with varying ramp profiles, which are dependent on design speed, road hierarchy, percentage of HCVs, Public Transport route and the required project outcomes.

Figure 21: Asphalt Concrete full width raised pedestrian platform



Note. Sourced from Regional Infrastructure Technical Specification 2021 (D3.10.6)

Vicroads (2019) states a minimum flattop length of 6m with a desirable height of 100mm. At sites with low-height traffic, e.g. heavy commercial vehicle routes, a height of 75mm can be considered. This guidance also claims that heights of less than 75mm are ineffective in speed management.

Vicroads (2019), based on previous trials in Victoria, states that a 1:35 grade is considered appropriate for the departure ramp to provide a smooth exit from an RSP. Austroads Guide to Road Design part 4 (2023) Platform height should ideally be between 75 mm and 100mm. This guide suggests that the ramp grade should range between 1 in 12 to 1 in 20 and that further details can be found in AS 1742.1. ATCOP(2013) specifies RSP ramp grades at a maximum of 1:20 slope and a height not exceeding 75m on bus routes.

JASIŪNIENĖ et al. (2017) state that RSP heights range from 80mm to 120mm, depending on the situation. Through this research, Mackie et al. (2020) recommended ramp slopes from this study, which includes heavy vehicles consideration, see Table 2:

Table 2. Recommended ramp grades for various speeds

Pedestrian/ cyclist activity	Heavy vehicle activity	Speed advisory (km/h)	Divided carriageway		Undivided carriageway
			Approach ramp grade	Departure ramp grade	Approach/departure ramp grade
High (e.g. town or activity centre)	Low (e.g. buses only)	30*	1:15 (6.7%)	1:35 (3%)	1:15 (6.7%)
Medium (e.g. urban arterial)	Low (e.g. buses only)	40*	1:20 (5%)	1:35 (3%)	1:25 (4%)
	Medium		1:25 (4%)	1:35 (3%)	
Low	Medium-high (e.g. truck route)	50^	1:25** (4%)	1:35 (3%)	1:25 (4%)

Note. Sourced from Austroads Research Report, Effectiveness and Implementation of Raise Safety Platforms AP-R642-20 (2020)

There is consensus in the literature reviewed regarding ramp slopes, flat top length and heights. It can be concluded that every site is different, and site-specific assessment must be carried out to confirm ramp dimensions through careful planning and design.

8.6 Signage and Pavement Marking

Coulson and Cassar (2018) RSPs can be painted and paved to increase the conspicuity of the crossing and to raise driver awareness. Mahdy (2012) states that signs and marking upstream of RSPs are essential, particularly for nighttime driving.

Austroads GTM Part 8 (2020) states that RSPs should be illuminated by street lighting for adverse weather conditions and supported through signs, markings and other delineations. VicRoads (2016) states that all RSPs should have warning signs with a recommended safe advisory speed, white line markings, and contrasting pavement colours for increased visibility.

In Australia, the ramps get marked in accordance with AS1742.13, which is the Piano Key layout. A similar design is followed in the Netherlands. In NZ, as per Traffic Control Devices (TCD manual), the ramps are marked in white triangle infill, also known as dragon teeth marking. Pratt et al. (2015) highlight that signs and road markings are required to alert drivers of the treatment ahead so that they slow down accordingly.

There is a consensus in the literature around the need for signs, marking and coloured surfacing for RSPs for improved conspicuity during nighttime and in adverse weather conditions. There are some differences between countries regarding the style of signs and marking.

8.7 Drainage and Pavement

Austroads Guide to Road Design Part 4 (2023), VicRoads (2019) and Austroads Research Report AP-R556-17 (2017) agree that RSPs will introduce high and low surface levels on the carriageway. RSPs act as barriers to existing surface water runoff; hence, evaluating how road drainage and pavement will be impacted through stormwater design and adopting modifications within the design to cater for RSPs is essential.

VicRoad (2019) also states that raised intersections have a more significant impact on drainage and underground services than intersection approaches RSPs.

Pratt et al. (2015) state that pavement and drainage should be considered through the treatment design process. Austroads Guide to Road Design Part 4 (2023) mentions that consideration should be given to additional pavement loading from the installation of a raised platform.

There is a consensus in the literature, and it can be concluded that through the implementation of RSPs, the channel flow path of surface water runoff will be disturbed. This can result in ponding and safety issues if not drained appropriately. Drainage and pavement need careful investigation through the design process.

8.8 Lighting

Austroads Research Report (AP-R498-15) states that the design needs to consider visibility and adequate lighting of vertical deflection devices. VicRoads (2019) highlights that lighting is a crucial element that needs consideration when designing RSPs. This states that all Victorian road RSP treatments should be illuminated in accordance with AS/NZS 1158:2015 - Lighting for roads and public spaces and TCG 006: Guidelines for Street Lighting Design.

AS/NZS1158:2015 is also the standard requirement while designing RSP lighting in NZ. ATCOP (2013) requires all new traffic calming devices to be lit up to Auckland Transports Street lighting guidelines (ATCOP – Chapter 19).

9. CONSTRUCTION, MAINTENANCE AND EVALUATION

9.1 Construction

Austroads GTM Part 8 (2020) suggests that it is desirable to construct the ramp in concrete to minimise scraping, shoving and other deformations but acknowledges that asphalt is also suitable. VicRoads (2019) identifies that it's easier to design and construct RSPs at flater sites. Approach RSPs have a smaller footprint and are easier and less expensive to build than fully raised intersections.

(a) Asphalt versus concrete RSPs

There seems to be some debate across NZ regarding what works best, concrete or asphalt ramps, with different roading authorities using different materials. Through a meeting with Gareth Bellamy (HCC), pavement and RSP construction expert, on 7 February 2024. It was identified that Hamilton City in NZ historically used concrete ramps for platform construction, but due to premature pavement failure immediately adjacent to the ramps and ongoing maintenance requirements, all raised platforms retrofitted to existing roads in Hamilton are now constructed in asphalt. Some of the issues with using concrete over asphalt are listed below:

1. Asphalt pavement, where it joins with concrete RSP, is subject to differential settlement/rutting. This is a result of compaction targets failing to meet specifications due to the need for hand laying and plate compaction of asphalt at the joint to prevent concrete damage.
2. Concrete requires extended curing times and needs to remain un-trafficked for extended periods, resulting in extended traffic management, road closures/ possible lane closures, additional costs, and traffic delays.
3. Concrete requires specialist crews/sub-contractors, leading to coordination issues and resource availability.
4. In the long term, if cracks form in concrete, the whole RSP would need to be dug out and redone.
5. Given its rigid nature, concrete can have a more significant impact on pavement damage than asphalt ramps.

An asphalt ramp, on the other hand, has an asphalt key that forms part of the raised pavement and helps distribute traffic loading. Asphalt ramps can be cost-effective compared to concrete ramps, save curing time, and reduce the complexity of construction and temporary traffic management, including detours.

Even if using Asphalt for RSPs, this is not without issues. RSPs are relatively small projects, resulting in small batches of hot-mix asphalt. Maintaining QA material temperature and access constraints for required compacting machinery often results in asphalt being laid outside QA requirements and hand-laid. Specifically, the compaction of air void seldom meets targets when these methods are used.

On routes with HCV traffic, these compaction deficiencies appear in shallow ruts/ shoves relatively soon (from around 12 months) and deteriorate further over the following 3- 5 years, resulting in costly interventions. Therefore, design and construction coordination is essential to identify the potential of not fulfilling QA, particularly compliance.

(b) How to construct Asphalt RSPs

Through discussion with a contractor, if no additional pavement strengthening works are needed, asphalt ramps are generally constructed by digging about 170 to 200mm deep for the keying in by about 1.0m wide, allowing a one-meterone-meter-wide drum roller into this trench for compaction. Apply tack coat followed by AC20 structural asphalt and an AC14 wearing course (35mm). The ramp and flattop are hand-laid to get the correct slope on the approach and departure ramps. Ideally, Asphalt compaction is undertaken through approximately a 4-tonne roller. However, as noted previously, specified compaction is critical to avoid interface pavement issues such as rutting.

If pavement works are needed, then the standard detail within the RITS document, which is based on an Austroads Pavement design for “urban roads” and includes a standard construction utilising a 170mm M4 Basecourse, based on an achieved Sub grade CBR Value >7 and compacted GP65 sub-base 240mm. This standard construction covers an “all roads scenario” within Hamilton by considering - 20,000 AADT, 5% HCVs, 1% Growth factor and an Asphalt surfacing of <40mm.

Based on a discussion with HCC staff, the Anglesea Street/Bryce Street intersection in Hamilton was closed entirely for construction, which improved worker safety and delivered exceptional value to the community faster. Works were completed within three weeks from start to finish under full road closure, with some remedial works on the shoulder for one week after the closure. This work was projected to take 16 weeks if construction was carried out using partial road closure due to bus movements. Both full and partial road closures have their benefits and disadvantages, and the form of a Traffic Management Plan (TMP) is chosen on a site-by-site basis.

Using asphalt, the key can be undertaken quite easily using like-for-like products. There is also a lower rate of differential settlement (slumping of AC) while the same crew and contractor can be used. It is identified that there is some debate about the most suitable material for RSP construction, and this is an area identified needing further investigation backed by operational and maintenance data through discussions with different councils across the country.

9.2 Maintenace and Renewals

Austroads research report AP-R498-15 (2015) suggests vertical deflection devices on approach to signals would potentially increase operational maintenance costs (drainage/debris, line marking, low parts of vehicles gouging hump/platform). Austroads AP-R556-17 (2017) highlighted knowledge gaps in the maintenance of ramps, for example, rutting. Mackie et al. (2020) suggested that consideration should be given to the whole-of-life costs and any ramp failures resulting from heavy vehicles.

Due to a lack of available literature (published or unpublished) about RSP maintenance and renewal requirements, a meeting (9 February 2024) was had with Wayne Bowden, Maintenance Operations Manager at Connect Hamilton, which is a maintenance and renewal alliance between HCC and Downer.

Through this process, it was determined that it’s usually the pavement on the approach to the RSP that fails due to regular breaking from vehicles in places that were not subject to regular breaking forces in the past. Through increased breaking, pavement is subjected to additional traffic loading/stresses, resulting in failures that require maintenance to hold the road in place.

Drainage is a critical component of RSPs and must be dealt with properly during design and construction. It is best to connect catch pits to existing stormwater system through manholes, but if a stormwater line is unavailable, a bubblup draiange system works quite well. Stormwater grated channels are another option but are susceptible to blockage and more challenging to maintain.

The pavement approach to RSP needs to be investigated as part of the design process. How far back this investigation extends to also needs to be carefully considered. There has been an increase in the frequency of pavement maintenance, i.e. mill and fill type measures on approach to the RSP to hold the pavement together.

On the other hand, there is some evidence that road construction and maintenance projects significantly affect the operational performance leading to an increase in congestion and delay during the construction period. At peak travel times, these work zones turn into bottlenecks since an increased number of vehicles need to pass through the work zone at lower operational speeds. This strongly affects driving comfort and increases stress.

RSP maintenance and renewal is an area that needs to be better researched and has knowledge gaps. It is the understanding that the information is out there with contractors and needs to be brought into the literature and published for industry us

9.3 Monitoring and Evaluation

Austroads Research Report (2016) showed a lack of robust treatment monitoring and evaluation data on speed and crash reduction. Monitoring should include crashes, DSI's, traffic flow, travel time and vehicle movements at intersections.

Austroads (2012b) and Austroads (2015e) provide details on monitoring and evaluation methods and approaches. It states that robust data will help with enhancing practitioner knowledge. VicRoads (2019) states that RSP performance monitoring and evaluation is important to ensure required benefit realisation and future guidance.

Mackie et al. (2019) undertook a detailed evaluation of the Thomas/Gordonton raised intersection in Hamilton through tube counts, traffic cameras, and HCC provided traffic flow information. It concluded an evaluation framework for baseline data collection as part of further developments.

P G Boulter and D C Webster (1997) highlighted the importance of post-construction evaluation for heavy vehicles to refine the measure if required. Austroads GTM Part 8 (2020) identifies critical parameters in the monitoring programme: speeds, crashes, traffic volumes, delays, resident's attitudes and effects on other road users such as bus operators, cyclists and commercial drivers.

Monitoring and evaluation is identified as a key element in the success of RSP and to help boost practitioner knowledge. Some RCAs can make monitoring and evaluation data available, but this information is not very readily available.

10. CONCLUSION OF LITERATURE REVIEW

A literature review carried out as part of this research has identified that RSPs are an effective and approved safety intervention through the NZ Standard Safety Intervention Toolkit and Austroads. RSPs are vertical deflection devices that utilise vertical acceleration to slow vehicle operating speeds down to safe systems-compliant speeds. RSPs are new and emerging treatments in Australia and NZ but are more commonly used in the Netherlands.

Through this literature review, it has been identified that speed is a primary factor for safe systems compliance. Speed and vehicle mass are directly related to crash kinetic energy, which determines the severity/outcome of a collision. Severity gets worse as vehicle mass and speeds increase.

The maximum safe systems speed for a vehicle vs vehicle side impact collision and one involving pedestrians and cyclists is ≤ 50km/h and ≤ 30km/h, respectively. The probability of severe and fatal injury crashes increases significantly past these identified safe systems speeds. RSPs can also emphasise the presence of active road users through improved conspicuity of crossing points.

Literature has identified traffic travel time improvements through the utilisation of RSP, with some sources suggesting minor delays and inconveniences to emergency and heavy vehicles may be caused as a result of vertical deflection devices. Careful design, education and engagement need to run in parallel to minimise any adverse effects of RSPs and improve user knowledge of these leading safety interventions. The following nine areas of knowledge gaps have been identified through this review:

1. Monitoring and evaluation are critical areas that need further research and development if RSPs are to survive community pushback.
2. There are varying conclusions from different literature sources regarding the effect of RSPs on traffic flow, travel time, traffic delay and capacity.
3. Existing literature on how traffic calming interventions impact emergency services response is light, and it is unclear how raised RSPs affect emergency services response times.
4. Research on the maintenance and renewal of RSP and its effect on longer-term pavement life is almost nonexistent.
5. There is a grey area between roading authorities around RSP construction materials (concrete vs asphalt) and the construction methodology for reduced user disruption.
6. Emissions as a result of vehicle deceleration and acceleration at RSPs and effects of this on Human health and its social cost.
7. Literature about noise and vibration induced by flat-top style RSPs is scarce, and it is not a common practice to measure before and after noise changes.
8. Effects of RSPs on vehicle suspension and maintenance requirements.
9. The halo effect of RSP due to different ramp speed profiles.

The Effects of RSP on Travel Time and Traffic Delay at Roundabouts is the topic identified for further research in this paper.

11. METHODOLOGY FOR SITE INVESTIGATION

In this second stage of this research report, the selection of suitable sites, their investigation, microsimulation modelling, and results analysis were carried out. A series of site visits were undertaken to capture post-RSP construction site observations for model set-up and calibration purposes. Several roading authorities have also been contacted through the site selection process.

11.1 Purpose and Objectives

The purpose of site investigations was to identify complying roundabouts within NZ that would have relevant before and after traffic data for travel time, traffic delay, and operational efficiency analysis via the preferred traffic microsimulation method. The site investigation also considers safety comparisons such as speed, crash numbers, and crash severity changes.

The objectives of site investigations were to:

1. Select a sample of complying existing roundabouts with RSP treatments.
2. Collect available RSP traffic data from respective roading authorities and understand any shortcomings and limitations, including site visits, to understand general user behaviour, such as gap acceptance, for modelling purposes.
3. Traffic Micro Simulation Modeling and appropriate software selection.
4. Result analysis to compare before and after travel time, traffic delays, levels of service (LOS), speeds and crashes.
5. Identify any further investigation required that is outside the scope and timelines of this thesis.

11.2 Site Selection

Sites across NZ were identified by contacting the NZTA and local RCAs. RCAs with higher populations across the country were chosen with the addition of a few lower population RCAs to provide a reasonable spread across the country. Results show a higher number of sites in jurisdictions that have higher populations.

NZ has approx. 67 road controlling authorities, and not all of them have been contacted due to time limitations. A total of 13 RCAs were approached, and 20 sites were identified through this process. See Table 3 for more information on RCAs contacted and comments.

Table 3. Table of RCA reached out to in NZ.

	RCA	RCA Contact Name	Title	Potential Sites
1	NZ Transport Agency	Junine Stewart	Area Programme Manager (Waikato/Bay of Plenty)	Two sites completed
2	Auckland Transport	Irene Tse	Team Leader, Road Safety Engineering	Six sites built
3	Wellington City Council	Joe Hewitt and Zack Moodie	NA	One site was treated with one raised zebra on approach.
4	Hamilton City Council	Simon Crowther	Transport Safety Lead	Eight plus others in the planning and design

				phase
5	Dunedin City Council	Ian Martin	Principal Advisor Road Safety	No existing roundabouts have been retrofitted with RSPs.
6	Central Otago District Council	Paul Fleet	Roading Manager	No roundabouts with RSP treatment.
7	Queenstown Lakes District Council	Ben Greenwood	Roading Operations and Contract Manager	No existing roundabouts have been retrofitted with RSPs.
8	Kāpiti Coast District Council	Mark Martin	Team Leader Roading Asset Management	No existing roundabouts have been retrofitted with RSPs.
9	Timaru District Council)	Gillian Catchpowle	Land Transport Project Delivery Coordinator	No existing roundabouts have been retrofitted with RSPs. But there are plans to complete three sites 23/24 FYR.
	Other Road Controlling Authorities contacted:			
10	Invercargill City Council			
11	Tauranga City Council			
12	Taupo District Council			
13	Christchurch City Council			

Key criteria for site selection were that sites had to be pre-existing roundabouts that had been retrofitted with RSPs. Some additional guidance used for site selection is listed as follows:

- RSPs can be either on approaches or across the approach and departure legs.
- RSPs can either priority or non-priority crossings such as a Zebra/cycle (paired crossing) or courtesy crossing, respectively.
- The roundabout site can be either single or multilane type.
- Roundabouts should have higher saturation levels of around 0.85. This was checked through visual observations.

The initial approach for site selection was to identify approximately thirty existing roundabout sites from across NZ that have been retrofitted with RSPs for investigation in this study. However, following correspondence with NZTA and selected local RCAs, only 20 sites were identified in total. Some of these identified sites were in the design phase and were not progressed further.

Further to this given the complexity of data requirements and time/funding constraints for this thesis, sites from HCC jurisdictions were chosen for further investigation. The writer of this report was based in Hamilton, meaning sites within the local area would be more accessible for observation and data capture purposes.

It is assumed that although the sample size is from one roading authority in NZ, the findings of this study are likely to be consistent across NZ. This is due to consistency of Traffic Control Devices (TCD), and environment being fairly consistent across the country. There is no evidence to back this assumption, and further investigation with sites spreading across wider NZ regions will be required to understand similarities in travel time and delays, etc.

11.3 Data Collection Methods and Analysis

The purpose of before and after monitoring is to assess changes in traffic behaviour, traffic turning count, flow (volume), speed, crash occurrence and severity. These factors help determine whether the treatments are achieving the intended safety objectives and are required for microsimulations. The main methods of data collection used for this study through a secondary source were as follows:

- Pneumatic tubes (MetroCount Tubes)
- Radar device
- 180-degree temporary camera
- Addinsight blue tooth data
- Gap Acceptance data
- Crash Data

More information on these methods of data collection, how they compare and their limitations are listed through the sub-sections below.

11.3.1 Pneumatic tube Counters – Speed and Volume data

Commonly known as “rubber tubes” or MetroCount tubes as, MetroCount is the most common manufacturer and method of traffic speed and volume data collection for NZ roads. MetroCount tubes have two tubes running parallel and a calculated dwell time (the time between when a vehicle hits the first tube and then the second tube). If this time is too short or too long, it could result in an error.

Pneumatic tube counters are very susceptible to wear and tear/damage from traffic going over them and are not preferred for permanent counting. They can break during the survey period, resulting in loss and reduced accuracy of data. Recent findings also suggest that these tubes are less accurate at lower speeds, i.e., under 30km/h, as they can fail to identify individual vehicles and their speed.

The acceptable quality range for MetroCount data is between 95% and 105%, as set by the Waikato Road Asset Technical Accord (RATA). This means that 5% of vehicles can either be missed or over-reported, resulting from errors in the tube. This could be due to faulty tubes or vehicles breaking and stopping on the tubes.

The supplier of the metrocount tube data runs a quality check on the reports before the data is sent through to the RCA (Client). HCC comment: “Comparing MetroCount tube with radar, it’s worth noting that tubes underperformed in both of our traffic counting trials so far. They missed about half of the heavy vehicles on Ellis St, and the data quality check failed. On Hukanui Road, they undercounted by 5-10% in the peaks. A few of our new technologies provide more accurate volume and vehicle class data and can be supplemented with radars for speed data“.

MetroCount data collection is still widely used in the industry. Data gathered through the MetroCount tube was also used for before and after speed and volume analysis at some of the sites in this paper. The data obtained from HCC was classified as secondary source data as it’s the RCA who commissioned service providers to carry out these surveys, and these are RCA-owned information.

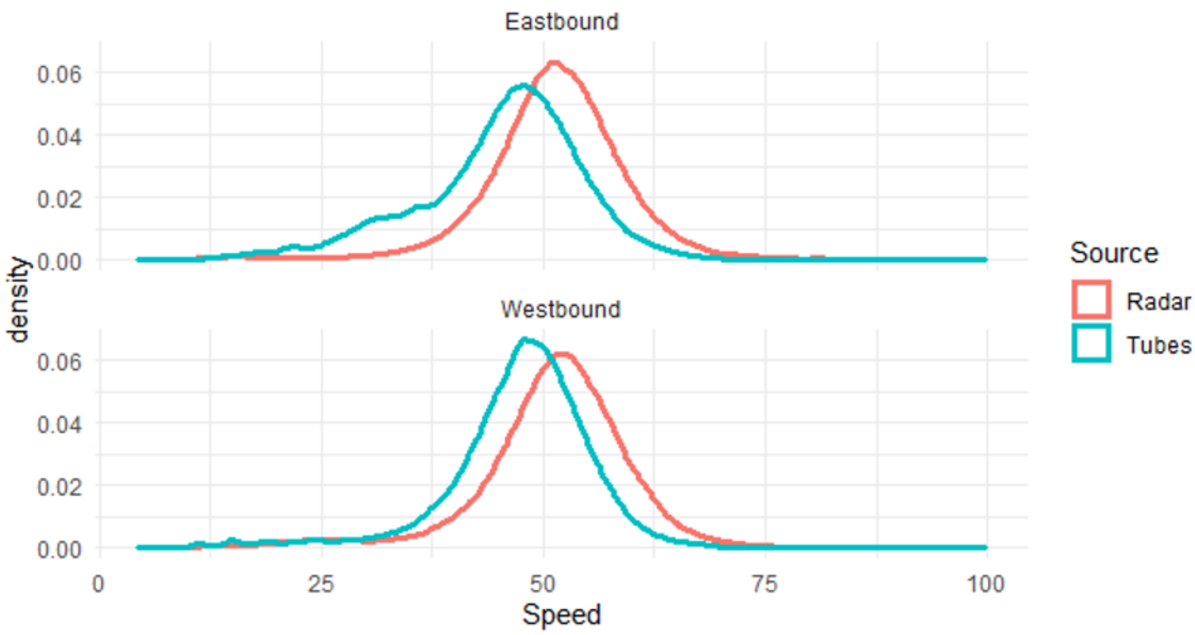
11.3.2 Radar – Speed and Volume

Radars are another form of device that can be used to gather speed and volume data but need calibration against the tube data. These are good devices to use for speed encounters if set up properly, but it is possible for them to be wrongly calibrated.

They need to see the entire vehicle. If these are mounted high enough, then this really isn't a problem as it can see both lanes, but if mounted low with median and planting, this can only see the tops of vehicles; hence, it can't draw a box around the vehicle to classify it. A video survey, in comparison to radar, will actually classify this as a vehicle - discussed further under the 180-degree temporary camera section below.

Volume data gathered through radar was tested against the tube volume data, and radar speeds were tested against the police radar data by HCC. What this showed was that the difference between the radar and tubes was 4.3km/h (average of both directions), consistently, with radar recording higher speeds than the tubes in both directions, see Figure 22.

Figure 22. Graph of radar versus tubes speed distribution



Note. Sourced from HCC provided study Information. Study site located on Ruakura Road, Hamilton, NZ.

One of the limitations of radar is that traffic can be obscured by the median planting. In this situation, the far side of the road on dual lanes is not captured by radar. Radars have worked well at single-lane mid-block sites for recording speed and traffic volume with no obscuring. Radars can't classify vehicles where, whereas tube data can be classified. Radar provides a length instead, which can be converted to classification but is not as accurate currently and requires further validation work.

11.3.3 180-Degree Temporary Camera

These are used for traffic survey videos for a short duration and are also known as PTZ (pan-tilt-zoom) cameras. Site-mounted PTZ cameras basically mean that they can be moved remotely from the traffic operation centre. These can run off a battery and are installed on-site, generally on street light poles, through a contractor. This includes batteries and solar panels.

PTZ can record video footage for up to two days due to storage limitations. These then get taken down, taken back to the office, and run through a video analytics tool that identifies vehicle volumes, speeds, safety, etc. They can give pedestrian desire lines, pedestrian and cyclist count numbers, vehicle count numbers, etc. This information is then displayed on a suitable user interphase.

The other type of camera is the 360-degree fixed camera used for long-term surveillance, and this needs to be a permanent installation due to the permanent power supply required.

11.3.4 Addinsight Bluetooth Data

Addinsight is an Intelligent Transport System (ITS) that collects vehicle Bluetooth data from hardware/sensors deployed on the road network. This then works out the travel time calculation of individual vehicles through vehicle re-identification.

Vehicle re-identification is done through sensors mounted along the road where each vehicle can be detected, reporting its unique " Bluetooth serial number" (a source identifier). When the same vehicle is re-identified at a different location, the travel time and speed can be calculated by comparing the time at which both sensors detected the vehicle.

Based on this, Addinsight can identify real-time travel time based on historical data from several different vehicles. This is a well-utilised tool with many clients across Australia and NZ.

Based on information received from HCC, Bluetooth data represents approximately 25% of traffic on the road, which is a reasonable volume for travel time. This percentage has been identified based on a comparison with the Sydney Coordinated Adaptive Traffic System (SCATS) used to manage traffic signals, which is assumed to be the total number of vehicles. The volume represented through Bluetooth divided by SCATS volume gives the percentage of traffic represented. On average, it shows a 25% representation of the overall traffic volume.

The percentage of Bluetooth data slowly increases over time as new vehicles with Bluetooth come into the vehicle fleet. There is a good spread of vehicles with Bluetooth across Hamilton City, meaning travel times are unlikely to be biased based on varying socio-economic areas.

The survey period used for travel time through the intersections within this study was as follows:

- 7 am to 9 am to cover the morning school and commuter peak traffic.
- 3 pm to 5:30 pm to pick up the afternoon school and commuter peak traffic.

Intersection travel time was based on volume weighted average. That is, legs with a higher traffic volume have a higher weighting as these are more likely to reach oversaturation over the other legs at that intersection. Oversaturation of traffic at an intersection is once the traffic flow has reached the maximum capacity (maximum flow) of that site.

11.3.5 Gap Acceptance Data

Gap acceptance is where a user waits for a suitable time gap in the stream of traffic, which they must give before proceeding. It is measured in seconds and is the time difference between two consecutive vehicles in a stream of traffic at a gap acceptance point, which occurs following the arrival of non-priority traffic. For example, pedestrians giving way to vehicles at non-priority crossing points, traffic at unsignalised intersections giving way to traffic that has priority, or traffic on major roads. Gap acceptance depends on approach road geometry, traffic characteristics (ie, volume, speeds, queue lengths and delays experienced) and experience and risk acceptance by the driver.

Post-construction gap acceptance per approach leg for this study has been measured on-site as part of the manual traffic observation method. Any available video data have been used for pre-construction gap acceptance at sites that were constructed before this study.

A minimum gap value acceptable to a minor traffic stream is known as a critical gap. Guidance from Austroads AGTM02 Part 2 should be sought for more details on gap acceptance. Site visits and observations were also undertaken to understand driver behaviour, such as acceleration and deceleration.

11.3.6 New Zealand Crash Data

Crash data from the NZTA CAS database has been analysed for before and after crash numbers, severity, and involvement of active road use, including common crash patterns. CAS is a system for processing, storing and presenting data about crashes reported to NZ Police since 1 January 1980. The NZ police send crash data to the NZTA. This data is collected in two ways:

- On a handheld device by a Police officer attending a crash or
- On a form (paper or electronic) filled in at the front counter of a Police station.

Following the receipt of this data, the NZTA staff code the data and save it in a data warehouse. CAS system receives the data from the data warehouse when a query is made; this then gets presented as per the requester's preference in the form of maps, reports and extracts on a user interphase.

A five-year period was used for before-crash analysis, and the analysis period was from the date of RSP installation to December 2023. It should be noted that a full five-year after data is unavailable for these sites as RSP has only recently been installed at most of these roundabouts.

A 50m to 100m radius from the centre of the roundabouts has been used for the extent of crash data collection. This was dependent on the size of the roundabout. For the CAS user guide, reference should be made to the NZTA CAS webpage. More information about the crash data used in this paper refer to section 12 of this report. For more detailed information on crash data, reference should be made to the CAS database.

11.4 Traffic Modelling

There are three main types of traffic simulation methods: macroscopic, mesoscopic and microscopic models. These are used for solving complex modelling problems where analytical methods that utilise mathematical equations are impossible or deemed too slow.

11.4.1 Traffic Modelling Methods

Macroscopic Model is a planning stage strategic model, also known as the strategic/network model and considers the aggregate behaviour of traffic flow, providing models with an aggregate representation of traffic flow. These create transportation models that provide insights into long-term strategic planning. The accuracy of this model reduces when focusing on a specific route or site. Macroscopic models are generally used by planners. Some examples of these macroscopic modelling software are EMME, CUBE, TransCAD and Cube Voyager.

Mesoscopic Model is suitable to assess the impact of transport policies on the overall network performance. These are simulations where vehicles are represented as a traffic stream or platoon. These can provide insight into queues and intersection delays but are limited to vehicle-to-vehicle interaction. Some examples of this modelling software are SATURN, TRANSYT, SYNCHRO and LINSIG.

Microscopic Model also known as microsimulation, explicitly represent vehicle-to-vehicle interaction and behaviour of individual drivers, which is not possible in macrosimulation. These models are best suited for complex traffic problems, such as complex intersections, to represent timings and delays accurately. The greater 'realism' gained from representing individual vehicles and drivers in this model introduces a higher level of complexity into the modelling process and data requirement. Hence, it takes time and effort to calibrate and validate these types of models. Some examples of microscopic modelling tools are PTV VISSIM, AIMSUN, SIDRA TRIP and PARAMICS.

More details on the above and other modelling techniques can be found in AGTM03-20-Part 3 – Section 8.1. For summary and features of these applications see Appendix A.

11.4.2 Modelling Method Selection

Given that this thesis looks at investigating travel time and traffic delay at an intersection interaction level, it was identified that traffic microsimulation is the most appropriate modelling simulation type for this study. This type of modelling takes into account the movement of individual vehicles travelling on the road network and any crossings etc, located at the RSPs. It produces a more accurate microscopic-level result. Additional details about the Microscopic/micro-simultation traffic Modelling software are discussed below:

1. PTV VISSIM is a multi-modal traffic flow simulation package developed in Karlsruhe, Germany, by PTV Planung Transport Verkehr AG. It was first developed in 1992 and runs on a Microsoft Windows operating system. PVT VISSIM was initially designed as a single intersection analysis tool and then expanded outwards. In contrast, other tools were generally designed initially to analyse more extensive networks and then had detail applied through time. For example, in a give-way situation, PARAMICS uses just a single value as a gap acceptance value to determine whether a vehicle yields or not. In contrast, VISSIM uses a similar gap acceptance value but can also use a more complicated method where clearance distances/times can be provided between subsequent vehicles.
2. PARAMICS is a multi-modal traffic simulation software developed by Quadstone Paramics and established by the UK Department of Transport in the 1990s. Paramics can simulate individual vehicles at a micro level and the impact of future travel patterns.
3. AIMSUM is a multi-modal traffic simulation software part of Yunex Traffic Group. This has a robust mobility ecosystem and has been used worldwide for approx. 26 years now.
4. SIDRA Intersection, according to SIDRA Solutions, is a powerful tool for designing and evaluating single and network of intersections. SIDRA is a micro-analytical traffic evaluation software which is widely used in the transportation industry.

In discussion with industry experts, it was identified that all of this software treats the movement of vehicles differently and suggests that VISSIM is probably the "gold standard" in terms of dealing with detail. Based on the findings above, PTV VISSIM 2024 multimodal traffic Simulation software was chosen as the preferred traffic model as this digitally reproduces the traffic patterns of all road users. A meeting was also held with the PTV Asia-Pacific Pty Ltd (Australia) Director to discuss the thesis topic, expected outputs and deliverables before finalising the preferred modelling software.

11.4.3 Traffic Model Development

It should be noted that “a model is only as good as the algorithms used in the model, and some simpler models can give excellent results” R.J. Troutbeck, W.Brilon. Only two of the seven selected sites have been modeled due to turning count data limitations. The two sites that were modeled are Wairere and Gordonton Road Roundabout and Wairere and Resolution Drive Roundabout. The micro simulation model was set up for the following three scenarios:

(a) Base Model (Before RSP Installation)

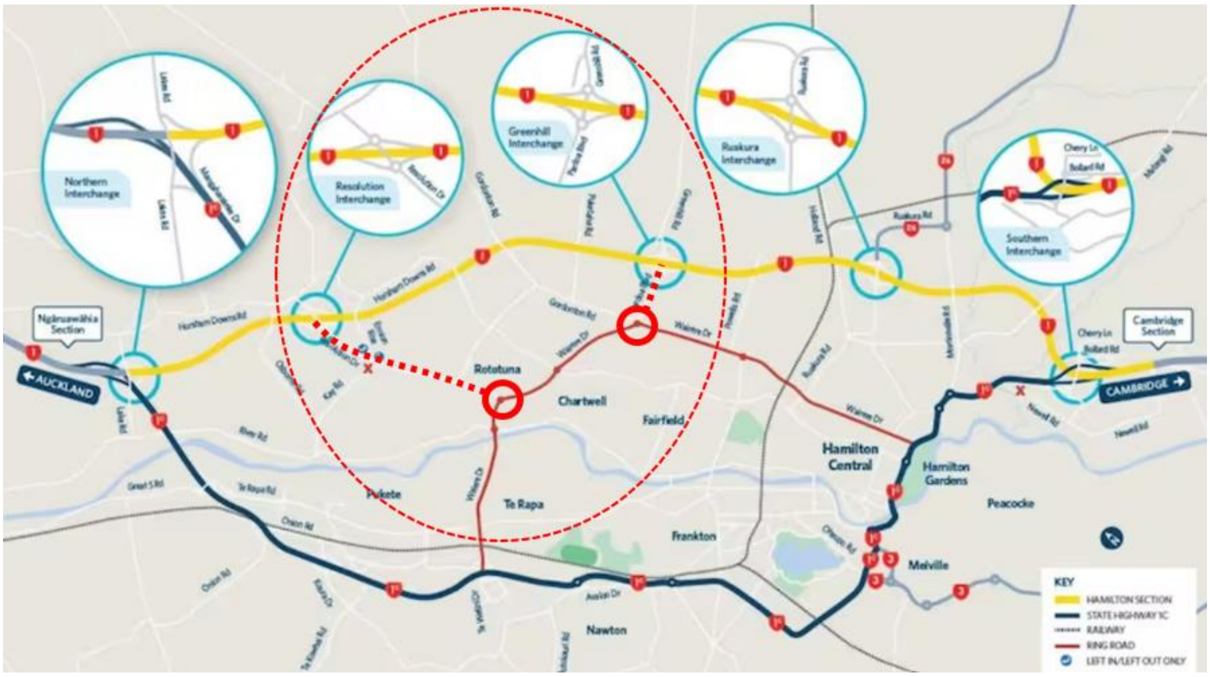
Based on Austroads and modelling guidance, modelling of the base case (pre-construction) is essential. A base case is needed to verify, calibrate, and validate model parameters accurately. The base case provides a benchmark against which the post-construction operational efficiencies will be compared.

(b) Intermediate Model – Post Construction with flow volume changes only

This is where the base-case model was updated with post-construction flow volumes but with no changes to gap acceptance time and reduced speed areas that would have resulted from the RSP addition. Essentially, this was the scenario without the RSP features to give a second base point so that any flow volume changes following construction can be isolated when measuring the effects of RSPs.

The reason for this intermediate model was flow volume changes due to the opening of the Waikato Expressway and population growth. The Waikato Expressway Hamilton Section (SH1), located east of the Wairere Resolution and Wairere Gordonton roundabout site, opened to traffic in July 2021, see Figure 23. This general area is also experiencing steady population growth and major road construction work. As a result, the traffic patterns and volumes can change significantly on some legs.

Figure 23. Waikato Expressway connections to the two traffic microsulated sites under investigation.



Note: Modelled sites are shown by solid red circles. Connection of these to Waiakto expressway are shown by the broken red lines. The overall site extent is shown by the broken lines red circle. Hamilton section of the Waikato Expressway is shown by the solid yellow lines.

(c) Post Construction Model with flow changes and RSP features

This is where the model developed in b above was updated with RSP features, such as changes to gap acceptance time and reduced speed areas, etc, that would have resulted from the RSP addition. This is the current scenario and gets compared with models a and b above through results analysis and discussion sections of this report.

11.4.4 Demostration of Modelling Concept

Vissim base data was set to left-hand drive under network settings to suit NZ driving conditions. This is set as the right-hand drive as the default setting. If left at the default setting, the microsimulation would be incorrect.

Key steps to use the PTV VISSIM model setup are listed below:

1. Loading and installing VISSIM (ACADEMIC Version) – set parameters, units, vehicle types and composition;
2. Loading a project area, drawing links and connectors to replicate onsite traffic control layout and setting up lane change distance vehicle input (volume, gap acceptance), static vehicle routes, and vehicle composition;
3. Adding desired speed and reducing speed areas;
4. Adding controls, priority markers, and priority rules;
5. Adding 3D models and running simulations;
6. Generating results lists such as Travel time, queue lengths, LOS, delays, etc, under results evaluation using both the node evaluation and travel time evaluation methods.

It should be noted that different practitioners may use different model setup techniques. There is no right or wrong way of setting up the model subject to the model passing the calibration, validation and sanity checks.

More information on model calibration, validation and auditing is provided below:

Model Calibration: This is where parameter values in a model are changed to provide accurate alignment between what's observed on-site and the modelling results. "The objective of calibration is to improve the model's ability to reproduce driver behaviour and traffic performance characteristics such as travel time, delay or queue length by varying model parameter values from the default values supplied by the software supplier (Austroads AGTM03-20)". Proper calibration ensures that the results are trustworthy and gives confidence to the decision-makers.

Model Validation: This is the comparison of model outputs with observed data (This data must be independent of the data used during the calibration process above. If, through validation, inaccuracy in the model is identified, then the model returns to the calibration stage such that concerns can be analysed and parameters adjusted.

Model Auditing: this is a peer review for a sanity check on the model. This is where error checking is carried out. Given the lack of funding for this study, only a very high-level audit of the model has been taken independently.

For a description of traffic modelling-related terminologies such as gap acceptance, queue lengths, etc, refer to the glossary at the back of this report.

11.4.5 Modelling Deliverables

With reference from Austroads *AGTM03-20: Transport Study and Analysis Method*, the following modelling deliverables are expected:

1. Data Collected – data collection procedure, quality assurance, summary of data collection results
2. Model Development – Coded model and software input files
3. Calibration and Validation - Calibration results, adjusted parameters and rationale, achievement of calibration and validation targets.
4. Auditing – broad-level checking (Sanity check), alternative analysis result.
5. Final Model Output – results and software input files.

11.4.6 Micro Simulation Model Results

Vehicle Travel Times results have been generated using the VISSIM Travel Time Measurement tool. This was set up for each approach leg and all its respective departure routes. Data collection was set to start 15 minutes into the simulation. This is to help warm up the model because at time zero, there is no traffic on your network, and when a model starts, it starts to generate vehicles from the start of the static route. Hence, the best practice is to let the model run for a while before collecting data for any analysis so that the results are correct.

Node Evaluation technique in VISSIM was used to collect modelling data such as traffic delay, LOS, Queue lengths, etc. This is done by drawing a polygon around the roundabout and using the same time parameters as vehicle travel time results were generated.

12. RAISED SAEFTY PLATFORM SITE INVESTIGATION

Seven roundabout sites had been identified through the site selection process to be investigated further – refer to site selection under section 11.2 of this report. These sites are listed as follows:

1. Wairere Drive and Resolution Drive Roundabout
2. Wairere Drive and Gordonton Road Roundabout
3. Thomas Road and Horsham Downs Road Roundabout
4. Tristram Street and Collingwood Street Roundabout
5. Te Rapa Road and Church Road Roundabout
6. Tristram Street and Cobham Drive Roundabout
7. Grey Street and Te Aroha Street Roundabout

12.1 Wairere Drive and Resolution Drive Roundabout

12.1.1 Description and Characteristics of Intersection

The intersection of Wairere Drive and Resolution Drive is a three-legged dual-lane roundabout which is located in Hamilton's northern suburb of Harrofield, see Figure 24. Both these roads are major Transport Corridors on the Hamilton Ring Road linking to the Waikato Expressway and regional significant places and industries.

Figure 24. Wairere Drive and Resolution Drive Intersection Location (Hamilton, NZ)

Note. Pre construction image from HCC GIS City Viewer

There is an existing underpass on the western leg of Wairere Drive for active usage. A shared path also runs along Wairere Drive on the southern side of this roundabout. There is residential activity backing onto all three corners of this roundabout with no direct access from this roundabout.

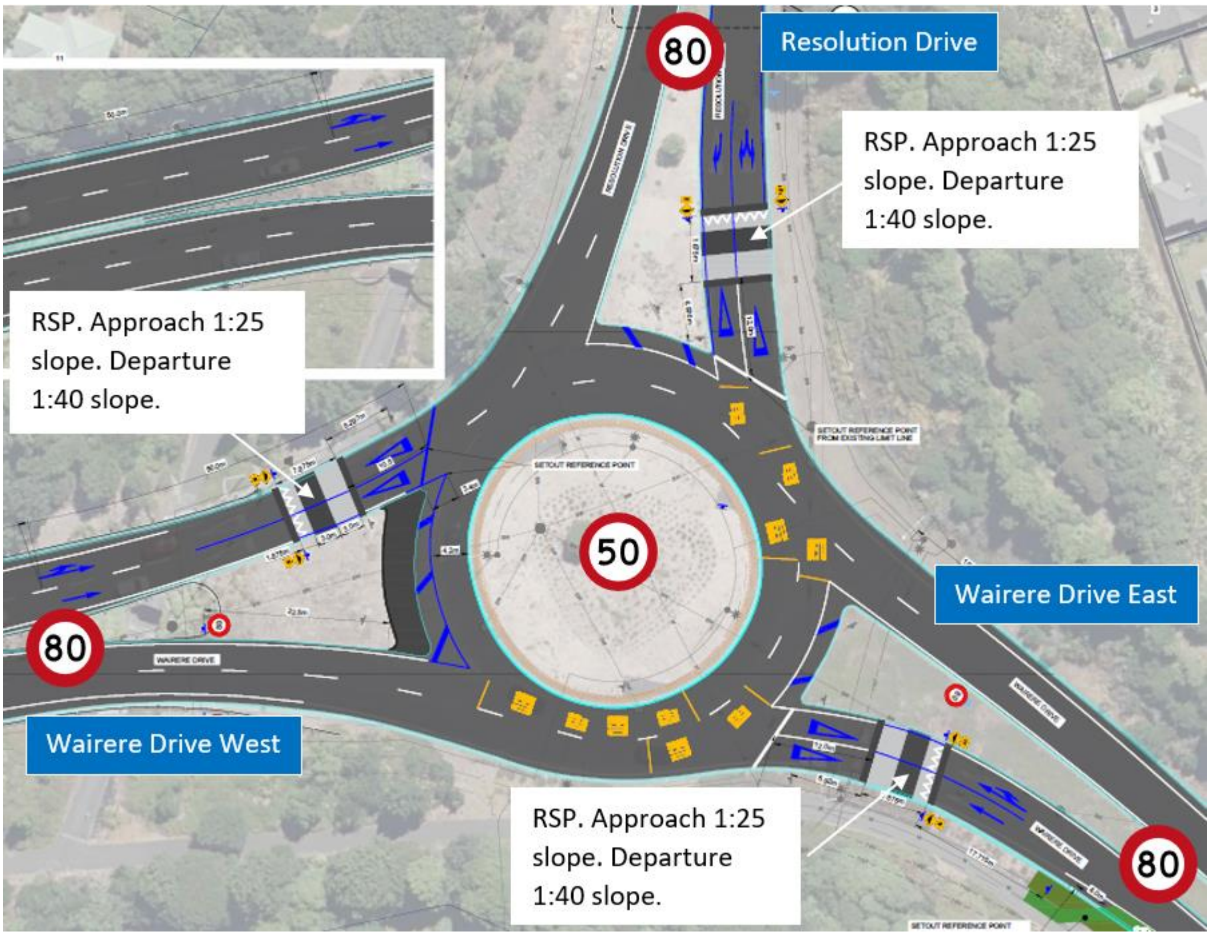
Pretreatment posted speed limit through this intersection was 80km/h. Road hierarchy as per the HCC Operative District Plan, traffic volumes and percentage of Heavy Commercial Vehicles (HCVs) as per mobile roads for this site are listed as follows:

- Resolution Drive is a divided Major Arterial Transport Corridor carrying 21,270 vehicles per day (VPD) of which 2% are HCVs southbound and 10% HCVs northbound.
- Wairere Drive is also a divided Major Arterial with:
  - Eastern leg carrying 26000 vpd (ADT) of which 6% are HCVs.
  - Western leg carrying 33700 vpd (ADT) of which 3% are HCVs.

12.1.2 Raised Safety Platforms and Key Design Features

This site was treated with approach RSPs in April 2023. Approach ramp slopes were designed and built to 1:25 for a 50km/h design speed profile and the departure ramps were set at 1:40 shallow ramps to cater for the high volume HCV usage on this road. The RSPs are set back a minimum of one car length from the new limit lines at a height of 75mm and are constructed out of asphaltic concrete. There has also been an extension of the western splitter island to restrict right-turning traffic into Resolution Drive to single-lane circulating. Posted speed limit was dropped to 50km/h as part of the RSP works, see Figure 25.

Figure 25. Wairere Drive and Resolution Drive RSPs General Layout Information



Note. Sourced from HCC Issue for Construction Drawing. CM Document Reference (D-4662184).

12.1.3 Before and After Crash Evidence

Approach RSPs were introduced at this roundabout in April 2023. Using the NZTA CAS system and a 100 m radius from the roundabout, there have been a total of 33 reported crashes over the five years (April 2018 to April 2023) prior to the RSP installation. The result showed a total of 1 minor injury and 32 non-injury crashes over this period. No fatal or serious injury crashes have been reported at this roundabout over this period, see Table 4.

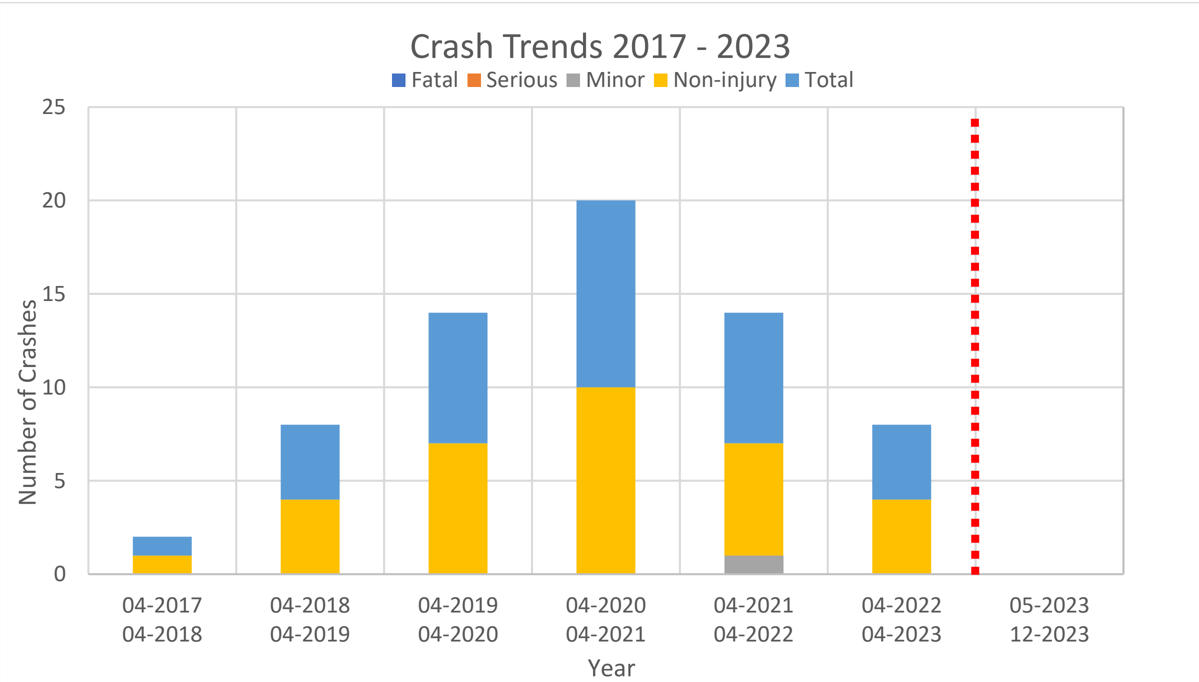
Table 4. Before and after crash history at Wairere Drive and Resolution Drive Roundabout

	Before			After		
Severity of Crash	**Number of Crash**	**Pedestrian involved**	**Cyclist involved**	**Number of crash**	**Pedestrian involved**	**Cyclist involved**
Fatal	0	0	0	0	0	0
Serious	0	0	0	0	0	0
Minor Injury	1	1	1	0	0	0
Non injury	32	0	0	0	0	0
TOTAL	**33**	**1**	**1**	**0**	**0**	**0**

Note. Data sourced from NZ Transport Agency Crash Database (December 2023)

Post construction crash analysis was carried out in December 2023. After crash data for a eight month period from May 2023 to December 2023 was retrieved. Data showed no reported crashes at this intersection over this period hence a decline in crash numbers are evident. It should be noted that ideally 12 months of after-data is required to start confirming the effectiveness of the treatment. Figure 26 is a plot of crash numbers and severity over time at this site:

Figure 26. Before and after crash and severity bar graph



Note. Data sourced from NZ Transport Agency Crash Database (December 2023). Broken red line shows the time of RSP Installation.

For further detail about crash data and collision diagram reference should be made to the NZTA CAS system.

12.1.4 Traffic Speed

Traffic speed data were collected through MetroCount tube and fixed radar over a seven-day period by HCC on all three approaches to this roundabout. Survey periods are listed as follows:

1. Before, data was surveyed using MetroCount tubes between 11 August 2022 and 17 August 2022.
2. After data was surveyed using fixed radar between 14 February 2024 and 20 February 2024.

The MetroCount tubes and fixed radar were positioned to gather traffic data on the approach to the roundabout approximately at the location of the new approach RSP, see Table 5 for apeed data.

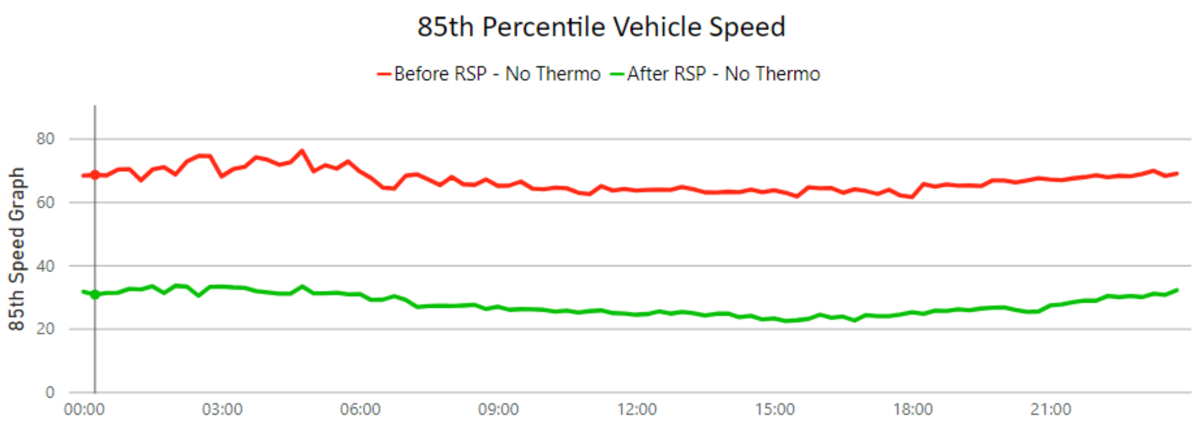
Table 5. Before and after traffic operating speed data

	85th Percentile Speeds before RSP Installation	85th Percentile Speeds after RSP Installation	Percentage speed change
Wairere Drive East (WB)	38.5km/h	No data	N/A
Wairere Drive West (EB)	69.0km/h	32.06km/h	**53% Reduction**
Resolution Drive (SB)	51.93km/h	26.60km/h	**49% Reduction**

Note. Shows the percentage change in vehicle operating speeds on approach to the RSP.

Before and after 85th percentile speed data comparison has shown between 49 to 53% reduction in operating speeds on Wairere West and Resolution Drive approaches. See Figure 27 for a 24-hour speed distribution.

Figure 27. Before and after Speed changes on Wairere Drive West approach



Note. Graph shows speed distribution over a 24 hour period.

12.1.5 Traffic Modelling

Basis of Assessment

Traffic model development, calibration, performance measurement, and comparison techniques were used as the basis of traffic operational assessment. An incremental approach to traffic modelling was used whereby three models were developed as follows:

1. Base-case operational condition AM peak model (Before RSP case).
2. Intermediate case operational condition AM peak model with flow volume changes only.
3. Post Construction operational condition AM Peak Model with flow volume and RSP features (After RSP case)

For more details on the above refer to modelling development section 11.4.3 of this report.

Survey Data

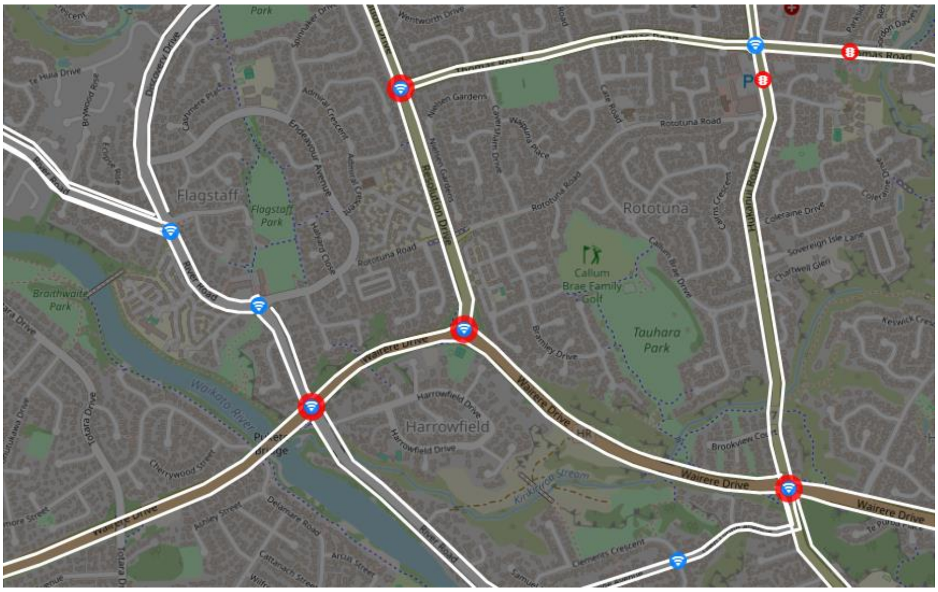
- **Traffic Turning Counts**

Due to lack of data , the best estimate for turning counts was made using the real-time Bluetooth Addinsight data. This approach was deemed suitable for this site due to Bluetooth count stations on all three approach intersections to this site. The same method was used to identify after RSP turning count peak period flows for data consistency and compatibility reasons. The Bluetooth count stations are located at the following locations:

- Wairere Drive and Hukanui Road Roundabout
- Wairere Drive and River Road Signalised Intersection
- Resolution Drive and Thomas Road Roundabout.

The Wairere Drive and Resolution Drive Roundabout, which is under investigation, also has Bluetooth count stations. See Figure 28 for Bluetooth sensor stations.

Figure 28. Real Time Bluetooth sensor location



Note. Bluetooth sensors used for turning count data are circled in red.

Through a check of the Bluetooth data profile, the AM and PM peak periods were identified. AM peak was identified to be between 7:45 am to 8:45 am and the PM peak between 4:30 pm to 5:30 pm. Bluetooth data used for the turning count was an average of three consecutive days. Wednesday through Friday was used for this as these days had similar traffic profiles. The Bluetooth data period used was from 8 to 10 February 2023 for before and 7 to 9 February 2024 for after analysis.

This data was compared against the available tube and radar data for the same time period and scaled up to give an estimated turn-count volume. It was identified that Bluetooth identified 17% percent of the actual vehicles at this site. AM and PM before and after turning count summary data for this site are listed in Table 6 below as provided by HCC.

Table 6. Before and after installation traffic flow volume counts

	AM Peak Period (Before) – 7:45AM to 8:45AM		
	Wairere Drive West	**Resolution Drive**	**Wairere Drive East**
Wairere Drive West	13	329	1010
Resolution Drive	714	10	261
Wairere Drive East	833	78	9
PM Peak Period (Before)– 4:30PM to 5:30PM			
Wairere Drive West	13	441	906
Resolution Drive	453	6	157
Wairere Drive East	880	276	11
AM Peak Period (After) – 7:45AM to 8:45AM			
Wairere Drive West	12	320	886
Resolution Drive	700	10	378
Wairere Drive East	759	151	9
PM Peak Period (After)– 4:30PM to 5:30PM			
Wairere Drive West	11	353	780
Resolution Drive	422	6	175
Wairere Drive East	837	296	11

Note. AM and PM peak period turning counts. PM peaks were not modelled but included for future research.

- **Reduce Speed Area (RSA)**

A site drive-over was carried out on 16 February 2024 (7 pm to 8 pm) to calculate the comfortable approach and circulating speed at this roundabout. This data was used to set the Reduce speed area parameter in the traffic model. Reduce speed area slows traffic on approach to roundabouts and RSPs to mimic the real-life situation as closely as possible.

This survey showed that the safe circulating speed post-construction at this roundabout is 30km/h. A floating car survey was used to identify the circulating speed of other vehicles at this roundabout. This was also showing results close to 30km/h. The same 30km/h reduced speed area circulating speed was used for the before (Base Case) scenario. Based on the post-construction site drive over 30km/h is identified as the safe circulating speed and the same is assumed for the base case situation. Note no before raised safety installation site speed check through a floating car survey was completed.

It was also noted that intersection approach geometry and visibility restrictions have an impact on the approach speeds. See Table 7 for reduce speed area modelling values.

Table 7. Reduced speed area data for cars and LGV's

	Base Case (Before RSP)		**Post Construction (After RSP)**	
	Approach RSA (km/h)	Circulatory RSA (km/h)	Approach RSA (km/h)	Circulatory RSA (km/h)
Wairere West (EB)	50	30	40	30
Resolution (SB)	50	30	40	30
Wairere East (WB)	50	30	40	30

Note. Data based on site drive over. Circulatory speed for HCV's and buses was set at 25km/h for both the before and after scenarios. Approach speed for buses and HCVs was set at 10km/h below the values in the table above. All approach and circulatory values above were set for cars and LGV's. Approach RSA before RSP was estimated to be 10km/h above the post-construction RSA vales.

- **Gap Acceptance**

A site visit was carried out on 19 February 2024 (7:00 am to 8:00 am) to measure the postconstruction gap acceptance onsite. Gap acceptance is dependent on approach road geometry, visibility, time in queue on approach to the intersection and type of vehicle a driver is driving ie a motorbike vs a bus. Gap acceptance values before construction was not available. Hence SIDRA was used to work out the headway value by imputing tuning counts.

Gap acceptance values used for the model set up see Table 8 below.

Table 8. Gap acceptance values

	Base Case (Before RSP)	**Post Construction (After RSP)**
	Gap Acceptance (S) by SIDRA	Gap Acceptance (S) by Site Visit
Wairere West (EB)	4.0	4.0
Resolution (SB)	3.0	3.0
Wairere East (WB)	3.5	3.0

- **Site Observations**

Post-construction observations listed as follows:

- River/Wairere signal spillover (Wairere WB) into the Wairere/Resolution Roundabout. This results in queueing on Resolution back to Resolution/Thomas roundabout in the morning peak period. Queueing back onto Wairere East was also seen as a result of this.
- Wairere (EB) traffic had gaps formed in it due to the signal operation at the River/Wairere intersection but these gaps were not able to be optimized by the Resolution (SB) approach due to Wairere (WB) queueing back onto the roundabout.
- Hardly any queueing was noted on the Wairere (EB) approach as low numbers of traffic were turning right from Wairere into Resolution.
- Wairere (WB) traffic was pushing into the roundabout into traffic approaching from the right from Resolution. Traffic merge was happening on the roundabout (WB) outside lane.

No pre RSP construction observations were made at this site.

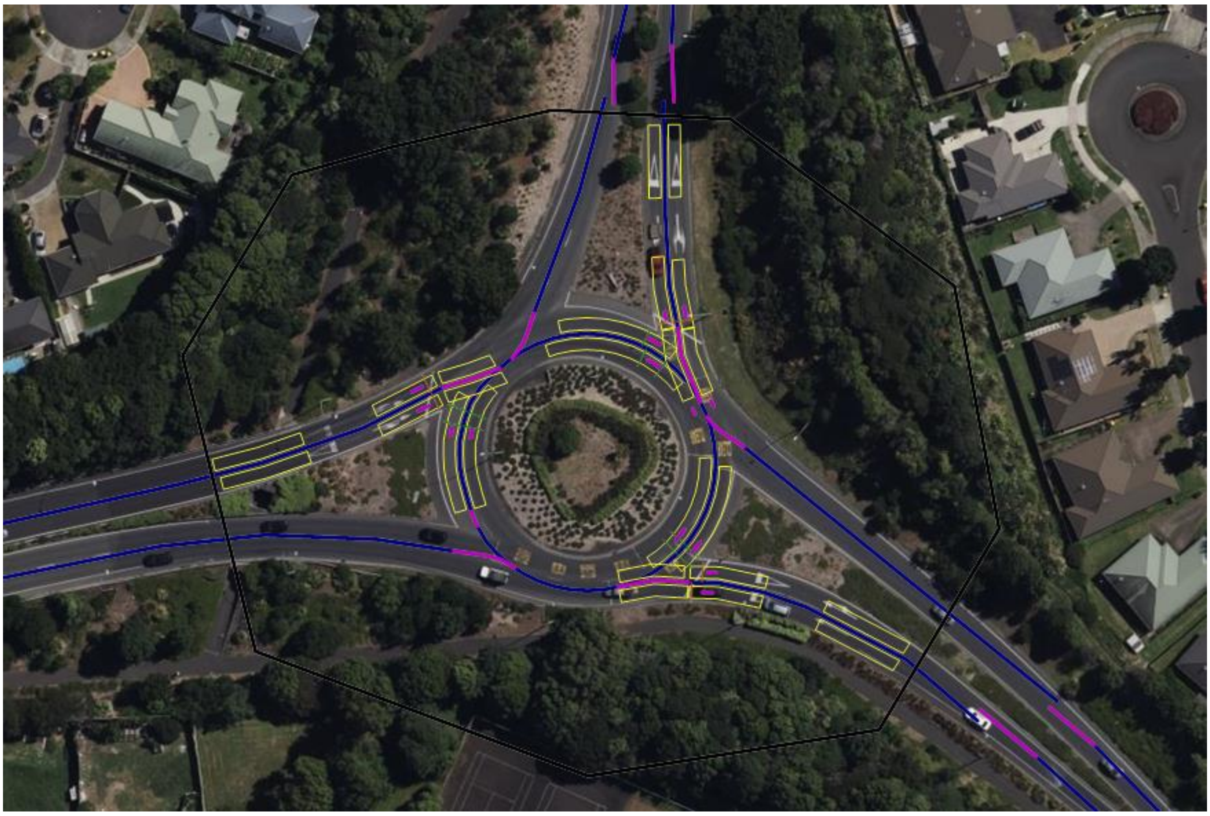
Traffic Model

For more information on the traffic model setup methodology refer to on section 11.4 (Traffic Modelling) of this report. For further modelling guidance reference should also be made to the resource library on the PTV VISSIM website.

Note the model excluded spill-back from Wairere/River signalised intersection. This was so that effects of the RSPs could be measured in isolation of external factors. Roundabout was modelled in isolation rather than in a network scenario.

See figure 29 for the model set up. Reduce speed area set up as shown in yellow rectangles.

Figure 29. Model layout for Wairere Drive and Resolution Drive Roundabout



Note. Snip taken from PTV VISSIM and represents Wairere Resolution model setup. This shows, reduce speed areas, node for data collection points and general model layout.

Desired speed which is generally the operating speed limit was set at 80km/h 500 meters back from the intersection. Another desired speed of 50km/h was set 100m back from the limit line to mimic vehicles naturally slowing down on approach to the roundabout.

Following approach flow volumes were used for before and after model simulation. Wairere West showed a 10% decrease in flow volume post-construction. Resolution Drive showed a 10% increase in flow volumes. Wairere East showed no change, see Table 9.

Table 9. Traffic Flow Volume on approach to Wairere Drive and Resolution Drive Roundabout

Movement	**Base Case**	**Post Construction**	**% Flow change**
1: Wairere West (EB) Approach	1352	1218	**10% Decrease**
2: Resolution (SB) Approach	985	1088	**10% Increase**
3: Wairere East (WB) Approach	920	919	**No Change**

Note. Befora and after flow volume by approach leg. Decrease and no change shown in green. Increase in flow volume shown in red.

A snapshot of the micro simulation is shown in Figure 30.

Figure 30. VISSIM Micro Simulation Model of Wairere Drive and Resolution Drive Roundabout

Note. Snapshot of Micro Simulation Model Layout

Results and Analysis

- Travel Time (s)

Travel time data for all movements were generated and reported. For AM Peak vehicle travel time as taken from PTV VISSIM, see Table 10. U-turn movements are not presented in the table below as this was a minor movement with only 1% of vehicles performing this.

Table 10. Travel time data from traffic model

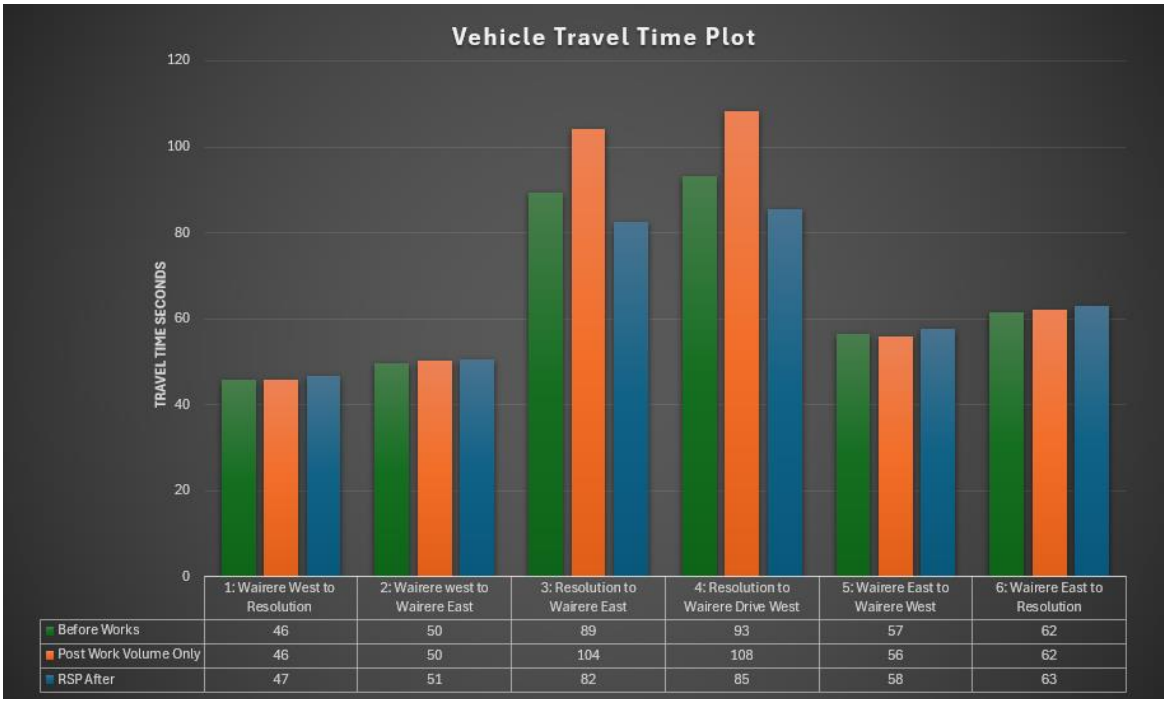
	Travel Time Base Case (Before)	Travel Time After (Volume Only*)	Travel Time After (With volume and RSP RSA**)
1: Wairere West to Resolution	46	46	47
2: Wairere West to Wairere East	50	50	51
3: Resolution to Wairere East	89	104	82
4: Resolution to Wairere West	93	108	85
5: Wairere East to Wairere West	57	56	58
6: Wairere East to Resolution	62	62	63

Note. * volume only excludes after construction reduced speed area for RSP and any change in gap acceptance.
**Includes RSP gap acceptance change and Reduce Speed Area (RSA)

Traffic coming from Wairere West and Wairere East showed a slight increase in travel time of 1 second. Traffic coming from Resolution Drive heading into Wairere Drive legs showed a 15-second increase in travel time when compared to the post-construction flow volume changes. With RSP added to post-construction flow volumes, there was an overall 7 to 8-second reduction in travel time for Resolution Drive (SB) traffic.

See Figure 31 for the travel time plot.

Figure 31. Vehcile Travel time plot at Wairere Drive and Resolution Drive Roundabout



Note. Travel time was graphed using Micro Simulation travel time data. AM peak shown above.

- Level of Service (LOS), Average Delay and Maximum Queue Lengths

Table 11 shows the level of service (LOS), average delay, and maximum Queue length data as generated by the Micro Simulation for base-case and post-construction scenarios. The data showed no change in LOS on Wairere East and Wairere West approaches. Resolution Drive showed an improvement from LOS E to LOS D.

Table 11. Modelling Results for Traffic LOS, Max Queue Length and Average Delay

	Movement	Wairere West (EB Approach)	Resoultion (SB Approach)	Wairere East (WB Approach)
Level of Service (LOS)	Base Case (No RSP)	LOS A	LOS E	LOS B
KEY LOS A C E B D F	After with traffic volume	LOS A	LOS D	LOS B
	After with traffic volume and RSP	LOS A	LOS D	LOS B
Average Delay (sec)	Base Case (No RSP)	4	33	10
	After with traffic volume	4	30	10
	After with traffic volume and RSP	4	22	12
Max Queue Length (m)	Base Case (No RSP)	53	431	160
	After with traffic volume	53	455	171
	After with traffic volume and RSP	52	456	212

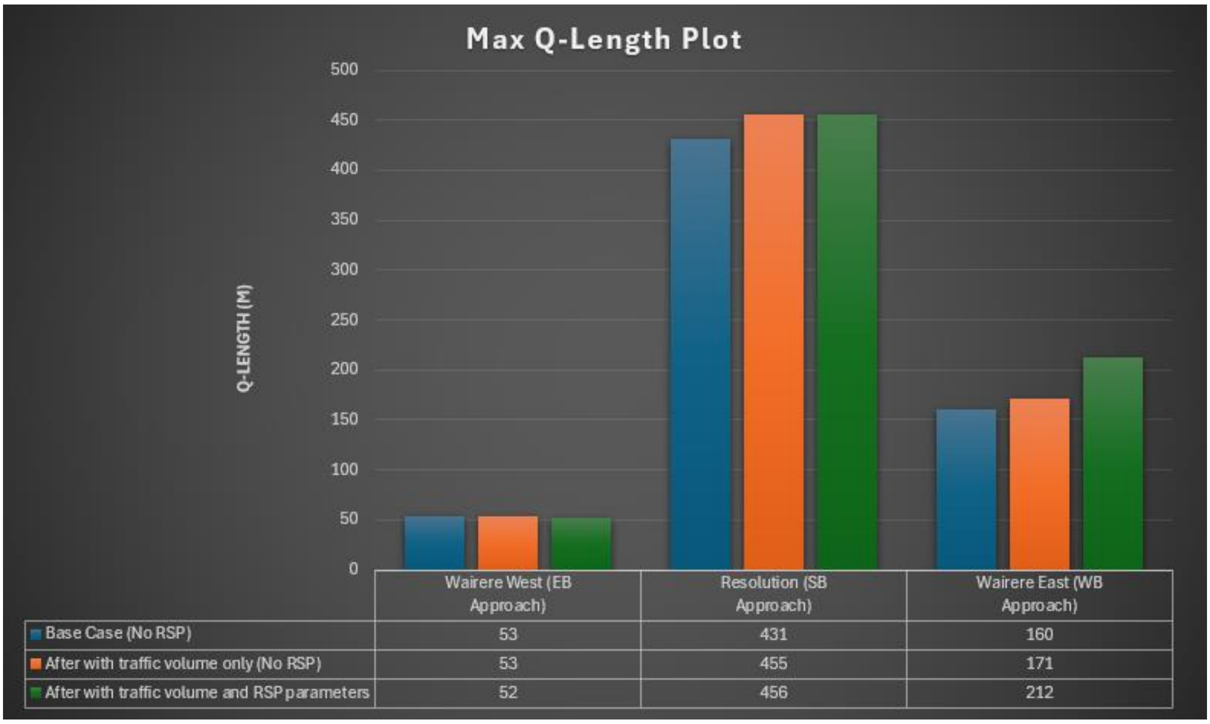
Wairere West (EB) showed no change in delay post construction. Resolution Drive (SB) approach showed an 8-second reduction in delays in comparison to post-construction flow volumes. Wairere East (WB) approach showed a 2-second increase in delay. See Figure 32.

Figure 32. Vechicle delay plot for Wairere Drive and Resolution Drive Roundabout

Note. Traffic delay was graphed using Micro Simulation delay data. AM peak plot shown above

See Figure 33 for the queue length plot.

Figure 33. Vechicle Max Queue Length plot for Wairere Drive and Resolution Drive Roundabout



Note. Queue length was graphed using Micro Simulation data. AM peak shown above

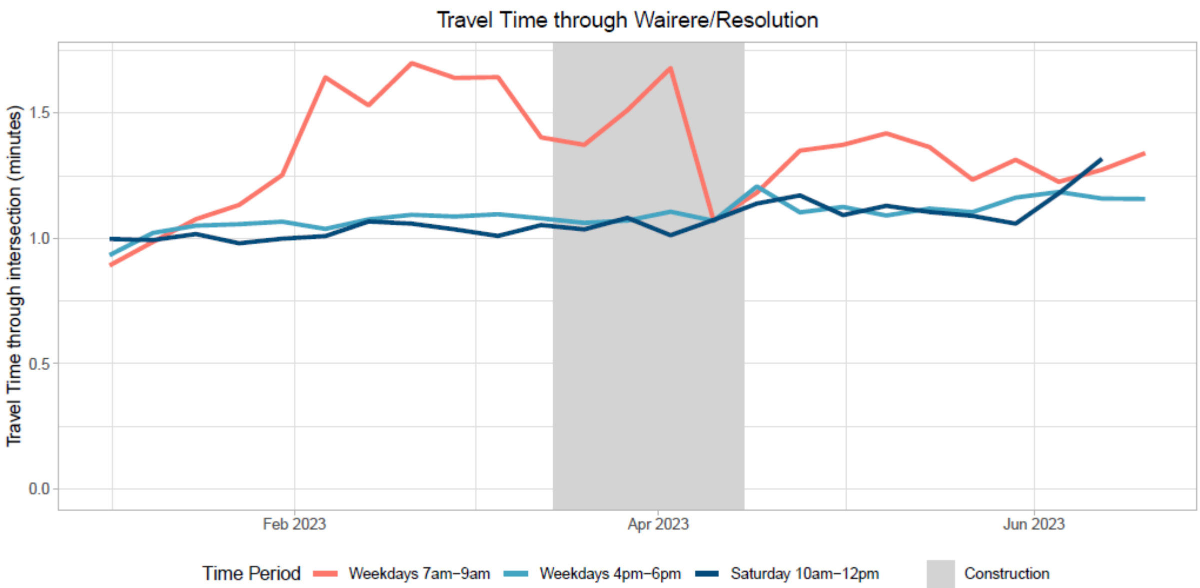
Wairere West (EB) approach showed a very slight decrease in queue length by 1m. Wairere East (WB) direction showed an increase in queue lengths by 11 meters through the introduction of post-construction volumes. This increased a further 41 meters with the addition of RSP. Resolution Drive (SB) approach queue lengths increased by 24 metres with the post-construction flow volumes. RSPs resulted in queue length increase increase by another 1m.

12.1.6 Travel Time by Bluetooth Data

Travel time through the intersection via Addinsight Bluetooth real-time data shows a drop in travel time during the AM peak, see Figure 34. This is primarily the Wairere Drive westbound and Resolution Drive southbound approaches and is likely due to more gaps opening up from their right. Wairere Drive eastbound has seen a small increase in the PM peak but only by about 10 seconds. This could be classified as balancing of flow through the introduction of approach RSP by slowing speeds creating more safe gaps in traffic.

There was no clear evidence of traffic travel time delays during the construction period. This was due to physical works at this site being undertaken as part of night works and outside the peak periods. This has left the peak periods relatively unchanged causing minimal to no delays during times of high demand on the traffic network. Another reason for this could have been due to a reduced scope of work through the installation of approach platforms only ie no departure platforms or other complex TCD or kerb realignment treatments which can be more complex and time-consuming.

Figure 34. Travel time through Wairere Drive and Resolution Drive Roundabout



Note. Source HCC utilising Addinsight Real time Bluetooth data

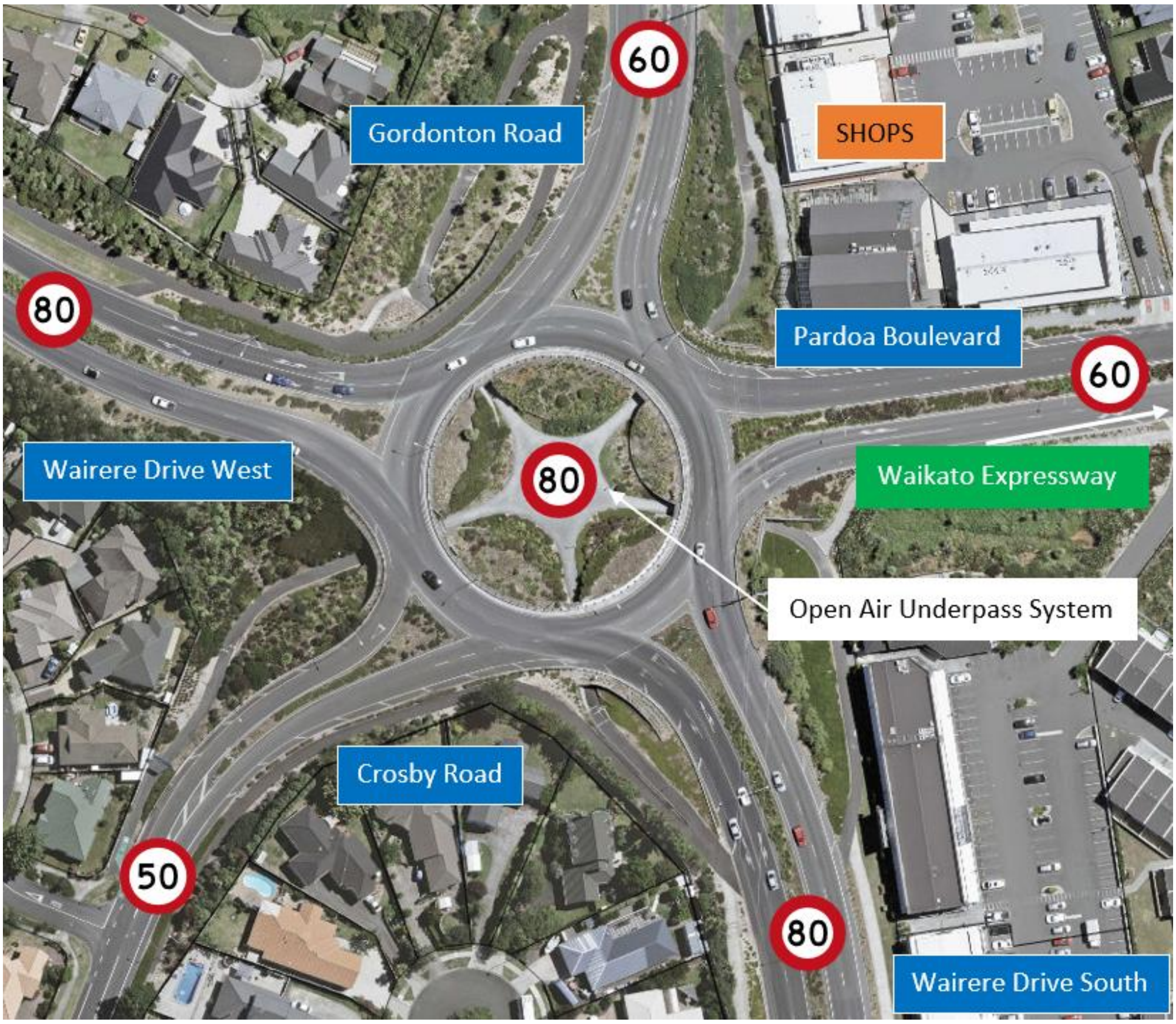
Travel time through real-time Bluetooth data at each leg of the intersection has also been analysed. For more information on this site and sites to follow in this report refer to Appendix B.

12.2 Wairere Drive and Gordonton Road

12.2.1 Description and Characteristics of Intersection

The Wairere Drive and Gordonton Road Intersection is a five-legged dual-lane circulating roundabout located in the northeast of Hamilton within the suburb of Chartwell. There are two approach and departure lanes on each leg of this roundabout except for the Crosby Road which has a single-lane approach leg, see Figure35. The roundabout has a separated underpasses system for pedestrian and cyclist access through this site. No at-grade crossings are provided at this site. The surrounding land use is residential on the western side and commercial on the eastern side.

Figure 35. Wairere Drive and Gordonton Road Intersection Location and Layout Plan (Hamilton, NZ)



Note. Image from HCC GIS City Viewer

Pretreatment posted speed limit through this roundabout was 80km/h along Wairere Drive East and South legs. The posted speed limit on other legs at this roundabout is listed as below.

- 60 km/h on Gordonton Road
- 60 km/h on Pardoa Boulevard
- 50 km/h on Crosby Road

Road hierarchy as per the HCC Operative District Plan, traffic volume and percentage heavy commercial vehicles (HCVs) as per Mobile Roads data, see table 12.

Table 12. Road Hierarchy, traffic volume and % Heavy Commercial Vehciles

	Road Hierarchy	Traffic Volume ADT	HCVs
Wairere Drive (West)	Major Arterial	28,804	4%
Gordonton Road	Minor Arterial	15,000	7%
Pardoa Boulevard	Proposed Major Arterial	3,203	14% eastbound 17% westbound
Wairere Drive (South)	Major Arterial	25,000	4%
Crosby Road	Collector	4,326	0%

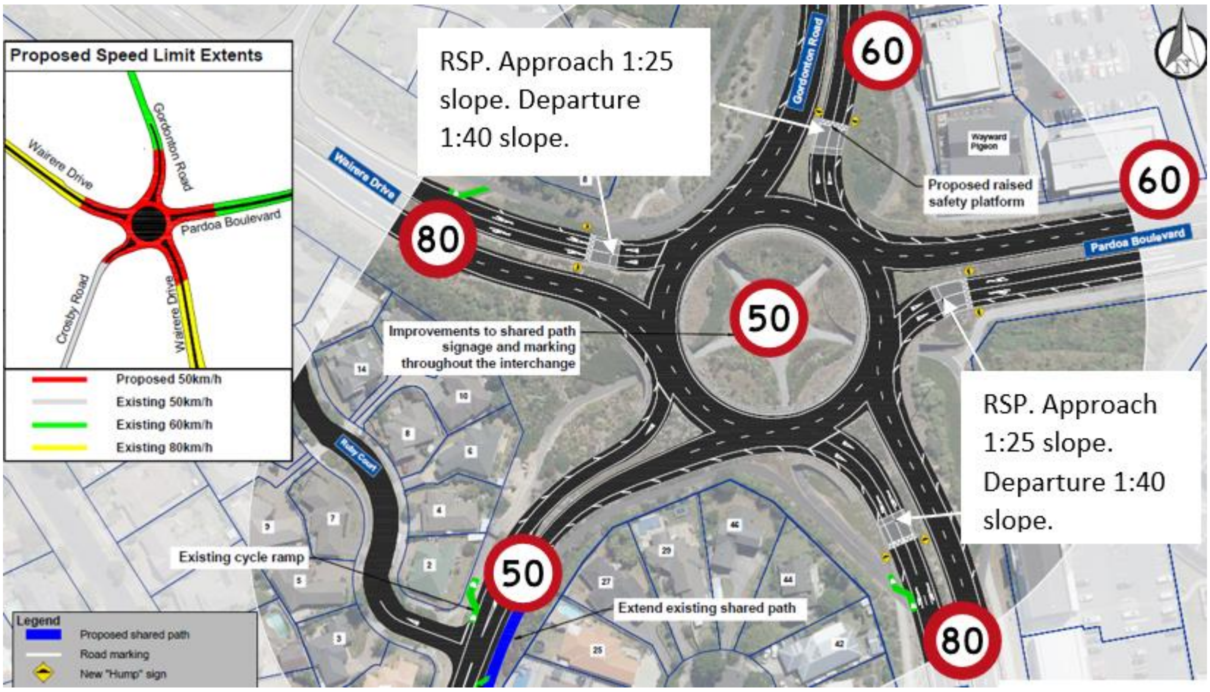
12.2.2 Raised Safety Platforms and Key Design Features

Approach RSPs were added to four of the five legs at this intersection. Crosby Road leg was not treated with a RSP treatment as the operating speeds on this approach leg were already low. This leg is also a key FENZ access point as Chartwell Fire Station which is located halfway down Crosby Road. There were also signage, road marking, shared path and cycling transition improvements works carried out as part of the RSP works.

All of the RSPs at this site were built with asphaltic concrete with an approach ramp slope of 1:25 and a departure ramp slope of 1:40. A shallow departure ramp slope was chosen given the Arterial road hierarchy to provide maximum comfort when exiting the RSP for all vehicles. The RSPs are set back a minimum of one car length from the new limit lines and have a height of 75mm. The roundabout posted speed limit was dropped to 50km/h as part of the RSP works, see Figure 36.

All relevant as-built information for the purpose of this thesis was collected through physical site visits and HCC Issued for Construction (IFC) drawing (Document Link D-4992367). For a copy of the IFC drawing and any additional as-built information, interested parties should contact the relevant RCA.

Figure 36. Wairere Drive and Gordonton RSP Treatment Layout



Note. HCC Concept Plan (CM Document Reference D-4487809)

12.2.3 Before and After Crash Evidence

Approach RSP were introduced at this roundabout in December 2023. Crash data from the NZTA CAS database for a 5-year period between December 2018 to December 2023 within a 100 m radius was obtained. A total of 67 reported crashes were identified. The result showed one serious injury crash, 12 minor injury crashes and 54 non-injury crashes.

It should be noted that not all the crashes get reported to police meaning that there is likely to be a number of non-injury unreported crashes for this site based on the damage to infrastructure that as occurred at this site eg signs and guardrails

The serious injury crash was a result of a vehicle northbound on Wairere Drive which had lost control while turning left hitting the central guardrail systems and ending up over the embankment into the open-air underpass system below. Alcohol and speed were likely factors in this crash.

Common crash trends and factors included incorrect use of lane, night and loss of control crashes, speed, failing to give way and wet road surface.

After treatment crash data search for a two month period from January 2024 to February 2024 was made and revealed no reported crashes at this intersection over this period. More details on the reported crashes are shown in Table 13.

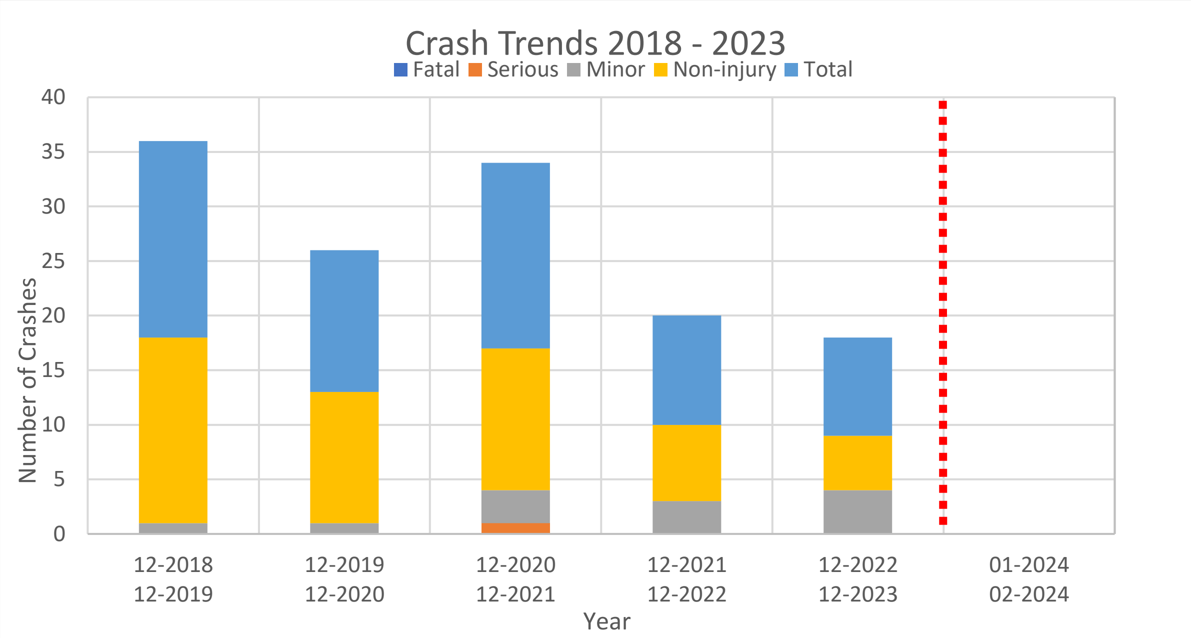
Table 13. Before and after crash history at Wairere/Resolution Drive Roundabout

	Before			**After**		
Severity of Crash	**Number of Crash**	**Pedestrian involved**	**Cyclist involved**	**Number of crash**	**Pedestrian involved**	**Cyclist involved**
Fatal	0	0	0	0	0	0
Serious	1	0	0	0	0	0
Minor Injury	12	1	1	0	0	0
Non injury	54	0	0	0	0	0
TOTAL	**67**	**1**	**1**	**0**	**0**	**0**

Note. Data sourced from NZ Transport Agency Crash Database (February 2024)

Figure 37 is a plot of crash numbers and severity over time at this site.

Figure 37. Before and after crash and severity bar graph



Note. Data sourced from NZ Transport Agency Crash Database (February 2024). Broken red line shows the time of RSP Installation.

12.2.4 Traffic Speed

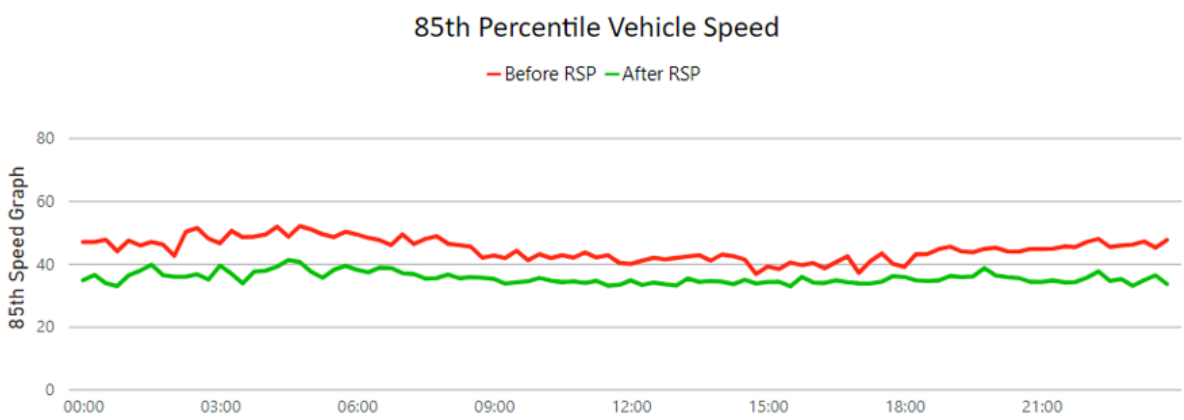
Radar survey was used for before and after speed data collection. Radars were deployed on site for the following period and a full seven day data set was analysed:

1. Before data taken between 02 November 2022 and 10 Novemeber 2022.
2. After data taken between 25 Janurary 2024 and 04 Feburary 2023.

Some of the approaches were obstructed by median planting resulting in an error in the after speed radar data. Radar needs to be able to see the whole vehcile in order to identiy it. Reliable speed information was only available for the Pardoa Boulevard approach.

Before and after 85th percentile speed data comparison has shown a 23% reduction in operating speeds on the Pardoa BLVD west bound approach to the RSP (42.50 km/h to 32.55 km/h). See Figure 38 for a 24 hour speed distribution.

Figure 38. Before and after Speed changes



Note. Showing the northbound approach operating speed distribution over a 24 hour period.

12.2.5 Traffic Modelling

Basis of Assessment

Traffic model development, calibration, performance measurement, and comparison techniques were used as the basis of traffic operational assessment. An incremental approach to traffic modelling was used whereby three models were developed as follows:

1. Base-case operational condition AM peak model (Before RSP case).
2. Intermediate case operational condition AM peak model with flow volume changes only.
3. Post Construction operational condition AM Peak Model with flow volume and RSP features (After RSP case)

For more details on the above refer to modelling development section 11.4.3 of this report.

Survey Data

- **Traffic Turning Count Data**

Three Traffic cameras and three radars were mounted on streetlight poles at this intersection from 7 June 2023 to 14 June 2023. The camera only captured three of the five legs at this roundabout and had a lag on the footage so the video couldn't be processed for before turning count data. Refer to Figure 39 below for camera and radar zones of capture.

Figure 39. Camera and radar zones.

Given the above data limitation pre-construction situation turn count data was not available. As an alternative source similar to the Wairere/Resolution site Addinsight Bluetooth data was used to estimate before/after turning counts at this site. The Bluetooth count stations were located at the following locations:

- Wairere Drive and Hukanui Road Roundabout
- Gordonton Road and Puketaha Road Roundabout
- Pardoa BLVD and Webb Drive Signals
- Wairere Drive and Powells Road Signals
- Crosby Road and Hukanui Road Intersection

The Wairere Drive and Gordonton Drive Roundabout also had Bluetooth count stations. See Figure 40 for Bluetooth sensor stations.

Figure 40. Bluetooth sensor location

Note. Bluetooth sensors used are circled in red.

Through a check of the Bluetooth data profile, the AM and PM peak periods were identified. AM peak was identified to be between 7:45 am to 8:45 am and the PM peak between 4:30 pm to 5:30 pm. Bluetooth data used for the turning count was an average of three consecutive days. Wednesday through Friday was used for this as these days had similar traffic profiles. The Bluetooth data period used was from 11 to 13 October 2023 for before and 7 to 9 February 2024 for after analysis.

This data was compared against the available tube for the same time period and scaled up to give an estimated turn-count volume. A blanket scaling factor could not be used at this site due to the presence of some side roads between the Bluetooth sensors. Scaling factors of between 10 and 20% were used to produce data reflective of actual radar data from this site. For the AM and PM before and after turning count data for this site see Table 14.

Table 14. Before and after installation traffic turning counts

	AM Peak Period (Before) – 7:45Am to 8:45AM				
	Wairere Drive West	Gordonton Road	Pardoa Boulevard	Wairere Drive South	Crosby Road
Wairere Drive West	7	78	220	553	12
Gordonton Road	90	4	77	460	100
Pardoa Boulevard	248	41	4	150	67
Wairere Drive South	395	186	83	6	31
Crosby Road	12	22	40	33	1
	PM Peak Period (Before)– 4:30PM to 5:30PM				
Wairere Drive West	7	51	137	493	10
Gordonton Road	160	5	50	283	47
Pardoa Boulevard	400	83	6	90	65
Wairere Drive South	483	322	55	9	27
Crosby Road	19	24	22	17	1
	AM Peak Period (After) – 7:45Am to 8:45AM				
Wairere Drive West	8	65	178	603	17
Gordonton Road	143	10	77	623	133
Pardoa Boulevard	231	43	5	110	121
Wairere Drive South	326	227	88	7	43
Crosby Road	14	22	52	33	1
	PM Peak Period (After)– 4:30PM to 5:30PM				
Wairere Drive West	7	53	190	430	10
Gordonton Road	180	6	14	343	65
Pardoa Boulevard	447	114	7	107	69
Wairere Drive South	469	290	63	8	14
Crosby Road	19	33	43	37	1

Note. AM and PM peak period turning counts. PM peaks were not modelled but included for future research.

- **Reduce Speed Area (RSA)**

A site drive-over was carried out on 16 February 2024 (8 pm to 9 pm) of peak period to identify the comfortable approach and circulating speed at this roundabout. This data was used to set the reduced speed area parameter in the traffic model.

This survey showed that the safe circulating speed post-construction at this roundabout is 30km/h. A floating car survey identified circulating speed of other vehicles at this roundabout was also around 30km/h. This same 30km/h reduced speed area circulating speed was assumed for the before (Base Case) context. Note no base case speed check through a floating car survey was completed at this site. See table 15 for reduce speed area values that were used for in this traffic model.

Table 15. Reduced speed area data for cars and LGV's

	Base Case (Before RSP)		**Post Construction (After RSP)**	
	Approach RSA (km/h)	Circulatory RSA (km/h)	Approach RSA (km/h)	Circulatory RSA (km/h)
Wairere West (EB)	50	30	40	30
Gordonton (SB)	40	30	40	30
Pardoa BLVD (WB)	40	30	40	30
Wairere South (NB)	50	30	40	30
Crosby (EB)	30	30	30	30

Note. Data based on site drive over. Circulatory speed for HCV'sand buses was set at 25km/h for both the before and after scenarios. Approach speed for buses and HCVs was set at 10km/h below the values in the table above. All approach and circulatory values above were set for cars and LGV's. Approach RSA before RSP was estimated to be 10km/h above the post-construction RSA vales.

- **Gap Acceptance Value**

Gap acceptance is dependent on approach road geometry, visibility, time in the queue on approach to the intersection, and the type of vehicle a driver is driving ie a motorbike vs a bus. Gap acceptance values before construction were measured on-site on 10 November 2023 (7:00 am and 9:00 am) during the morning peak period. Post-construction gap acceptance was measured on-site on 19 February 2024 (8:00 am to 9:00 am). Desktop observations of available site videos before and after construction were also made to help generate an average gap acceptance value. For gap acceptance values used for the Wairere Drive And Gordonton Road refer to the Table 16.

Table 16. Wairere Drive and Gordotnon Road Roundabout Gap Acceptance Values

	Base Case (Before RSP)	**Post Construction (After RSP)**
	Gap Acceptance (s)	Gap Acceptance (s)
Wairere West (EB)	3.0	3.5
Gordonton (SB)	4.0	4.0
Pardoa BLVD (WB)	4.0	4.5
Wairere South (NB)	3.0	3.5
Crosby (EB)	4.0	4.0

Site Observations

Before construction site visit observations are listed as follows:

- Gordonton (SB) queued back to Thomas/Gordonton Signals
- Long queues on Pardoa (WB) legs.
- Wairere Drive west and south were noted as the dominant movements resulting in queues developing on side roads such as Crosby Road, Gordonton Road, and Pardoa Boulevard
- Wairer Drive northbound approach was rarely stopped but more so slowing and rolling through as soon as a gap opened.
- Crosby Road was stopped at the limit line waiting for safe gap with some queueing noted
- Gordonton Road and Pardoa Boulevard saw high delays due to the approach speed on Wairere southbound.

Post Construction site visit observations are listed as follows:

- Gordonton queue back to Thomas/Gordonton in AM peak
- Pardoa BLVD was queued back
- Crosby Road approach traffic slowed approx. 5 meters back from the limit line and slowly rolled towards the limit line after that and took off as a gap became available.
- Wairere west and east flowing well.

Traffic Model

A Micro Simulation model using Vissim was developed to understand the LOS, travel time, delays, and queueing at this roundabout. See Figure 41 for the model setup.

Figure 41. Model layout for Wairere Drive and Gordonton Road Roundabout

Note. Snip taken from PTV VISSIM and represents Wairere Resolution model setup. This shows, reduce speed areas, node for data collection points and general model layout.

Desired speed which is generally the operating speed limit was set at 80km/h 500 meters back from the intersection. There was another desired speed of 50km/h set 100m back from the limit line as vehicles naturally slowed down on approach to the roundabout to get into the roundabout circulating lane.

See Table 23 for the approach flow volumes that were used before and after model runs. Wairere West and Pardoa BLVD showed no change in flow volume post-construction. Gordonton Road and Crosby Road showed a 35% and 13% increase in flows heading onto the roundabout respectively. Wairere South showed a 1% decrease in volume, see Table 17.

Table 17. Approach flows at Wairere Drive and Gordonton Road Roundabout

	Base Case	Post Construction	% Flow change
1: Wairere West (EB) Approach	870	871	No Change
2: Gordonton (SB Approach)	731	986	35% Increase
3: Pardoa BLVD (WB Approach)	510	510	No Change
4: Wairere South (NB Approach)	701	691	1% Decrease
5: Crosby Road (WB Approach)	108	122	13% Increase

Note. Green is decrease in flow and and red is increase in flow.

A snapshot of the micro simulation is shown on figure 42.

Figure 42. VISSIM Micro Simulation Model of Wairere Drive and Gordonton Drive Roundabout

Note. Snapshot of Micro Simulation Model Layout

Results and Analysis

- Travel Time (s)

Travel time data for all movements were generated and reported. For AM Peak vehicle travel time as taken from the model, see Table 18. U-turn movements are not presented in the table below as this was a minor movement with only 1% of vehicles performing this.

Table 18. Travel time data from microsimulation

	Travel Time Base Case (Before)	**Travel Time After (Volume Only*)**	**Travel Time After (With volume and RSP RSA**)**
1: Crosby to Wairere West	41	40	40
2: Crosby to Gordonton	48	50	46
3: Crosby to Pardoa	64	62	60
4: Crosby to Wairere South	66	64	64
5: Wairere West to Gordonton	44	43	45
6: Wairere West to Pardoa	56	57	56
7: Wairere West to Wairere South	63	67	66
8: Wairere West to Crosby	66	72	72
9: Gordonton to Pardoa	333	369	361
10: Gordonton to Wairere South	327	385	387
11: Gordonton to Crosby	337	375	379
12: Gordonton to Wairere West	343	382	387

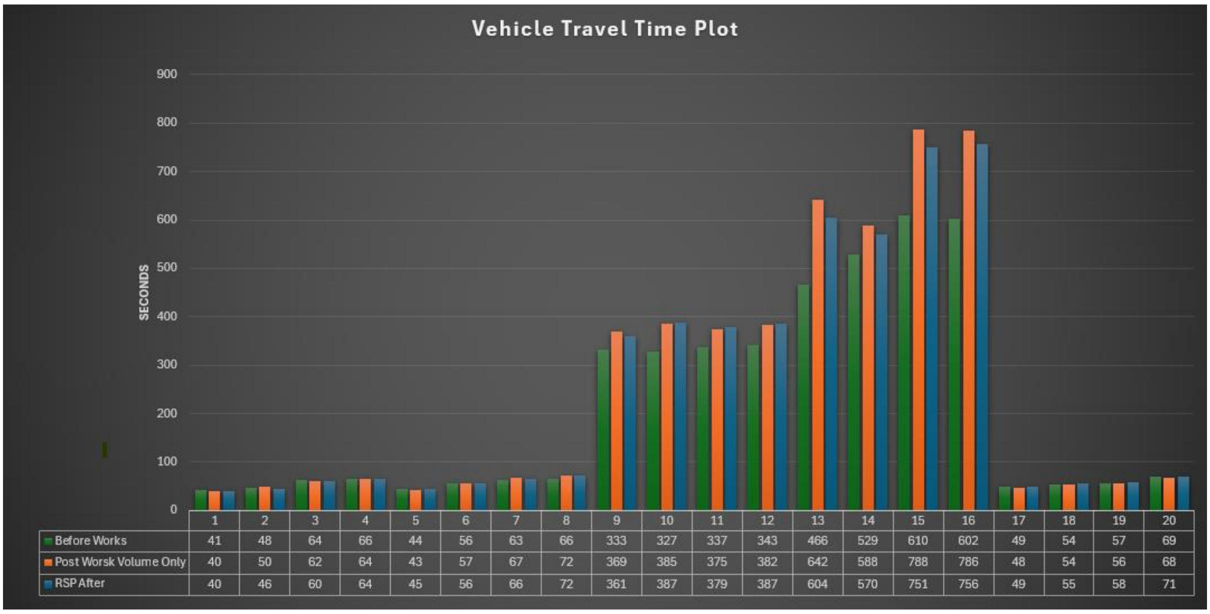
13: Pardoa to Wairere South	466	642	604
14: Pardoa to Crosby	529	588	570
15: Pardoa to Wairere West	610	788	751
16: Pardoa to Gordonton	602	786	756
17: Wairere South to Crosby	49	48	49
18: Wairere South to Wairere West	54	54	55
19: Wairere South to Gordonton	57	56	58
20: Wairere South to Pardoa	69	68	71

Note. * volume only excludes after construction reduced speed area for RSP and any change in gap acceptance.
**Includes RSP gap acceptance change and Reduce Speed Area (RSA)

Crosby Road, Wairere West, and Wairere South showed negligible change in travel time in the range of between zero and six seconds. Some OD increased while the others dropped by a few seconds. Based on this the change in travel time on these legs is negligible. Pardo BLVD saw a large increase in travel time between one to two minutes as a result of post-construction volume changes. Subsequent to this addition of a RSP to the model showed a reduction in travel time by 30 seconds on average. Without the RSP the travel times would have been higher.

Traffic coming from Gordonton Road reported an increase in travel time through the post-construction flow volumes averaging 43 seconds. Following the RSP model three of the OD showed between 2-second to 5-second increase in travel time with one OD showing a reduction in travel time by 8 seconds and these can be classed as neglegiable. See Figure 43 for the travel time plot.

Figure 43. Vehcile Travel time plot at Wairere Drive and Resolution Drive Roundabout



Note. Travel time was graphed using PTV VISSIM Micro Simulation travel time data. AM peak shown above.

- Level of Service (LOS), Average Delay and Maximum Queue Lengths

Table 19 shows the level of service (LOS), average delay, and maximum Queue length data as generated by the Micro Simulation for base-case and post-construction scenarios.

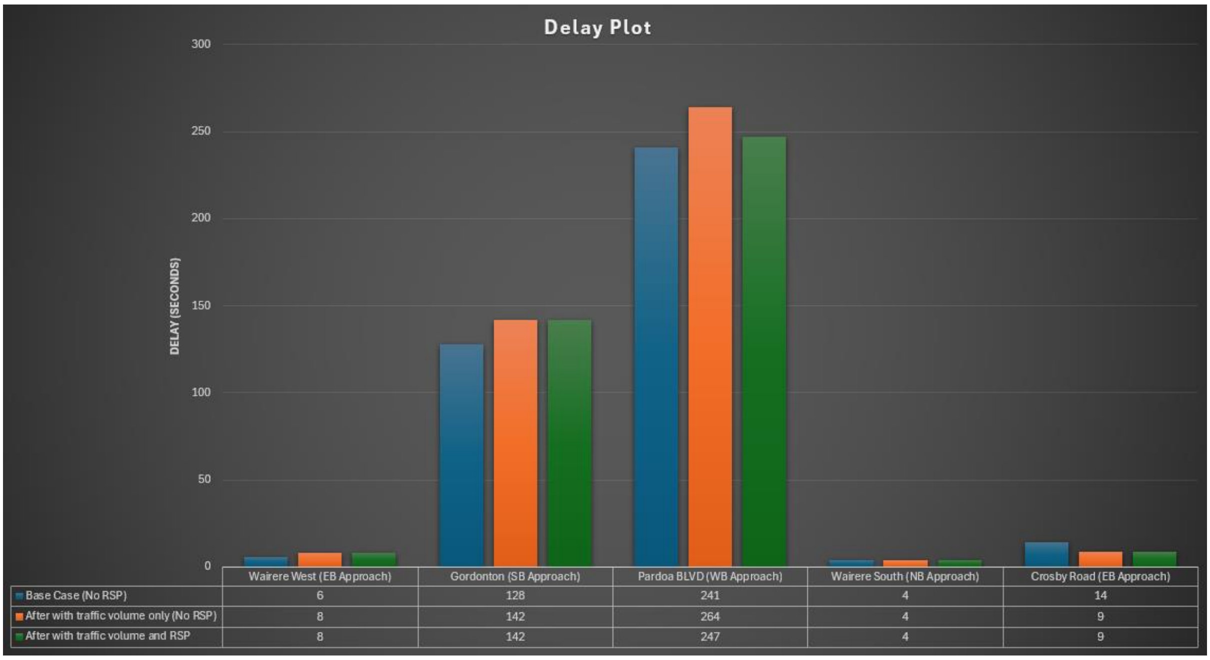
The data showed LOS F Gordonton Road and Pardoa BLVD heading towards the roundabout and this remained unchanged post construction. Wairere should no change in LOS A. Wairere West recorded a drop from LOS A to LOS B. Crosby Road on the other hand showed an improvement from LOS C to LOS B.

Table 19. Modeeling Result

	Movement	Wairere West (EB)	Gordonton (SB)	Pardoa BLVD (WB)	Wairere South (NB)	Crosby Road (WB)
Level of Service (LOS)	Base Case (No RSP)	LOS A	LOS F	LOS F	LOS A	LOS C
	After with traffic volume	LOS B	LOS F	LOS F	LOS A	LOS B
KEY LOS A B C D E F	After with traffic volume and RSP	LOS B	LOS F	LOS F	LOS A	LOS B
Max Queue Length (m)	Base Case (No RSP)	98	506	510	37	24
	After with traffic volume	110	516	499	41	24
	After with traffic volume and RSP	115	516	510	50	19
Average Delay (sec)	Base Case (No RSP)	6	128	241	4	14
	After with traffic volume	8	142	264	4	9
	After with traffic volume and RSP	8	142	247	4	9

Wairere Drive South (NB) showed no change in delay post-construction. Crosby Road (EB) showed a 5-second reduction in delays. Wairere Drive West and Gordonton Road both showed an increase in delay by 2 seconds and 14 seconds respectively following after volume mode. After RSP installation model showed no addional change in delays. Pardoa BLVD showed an increase in delay of 23 seconds when compared to the post-construction volume change. With the RSP these delays dropped by 17 seconds. A net delay increase of 6 seconds. See Figure 44 for the delay plot.

Figure 44. Vechicle delay plot for Wairere Drive and Resolution Drive Roundabout



Note. Traffic delay was graphed using Micro Simulation delay data. AM peak plot shown above

Crosby Road showed a reduction in average queue lengths by 5m. Wairere West, Wairere South, and Gordonton Road all showed an increase in queue lengths in the post-construction model through flow volume change of 2 m, 4 m, and 10 m respectively. Wairere West and Wairere South showed a further increase in queue lengths following the model of RSP parameters by 5 m and 9 m respectively. Gordonton Road on the other hand showed no difference as a result of the RSP model. Pardoa BLVD showed no net difference in queue lengths between before and post-construction RSP condition. See Figure 45 for the queue length plot.

Figure 45. Vechicle Max Queue Length plot for Wairere Drive and Resolution Drive Roundabout

Note. Traffic queue length was graphed using Micro Simulation data. AM peak plot shown above

12.2.6 Travel Time by Bluetooth Data

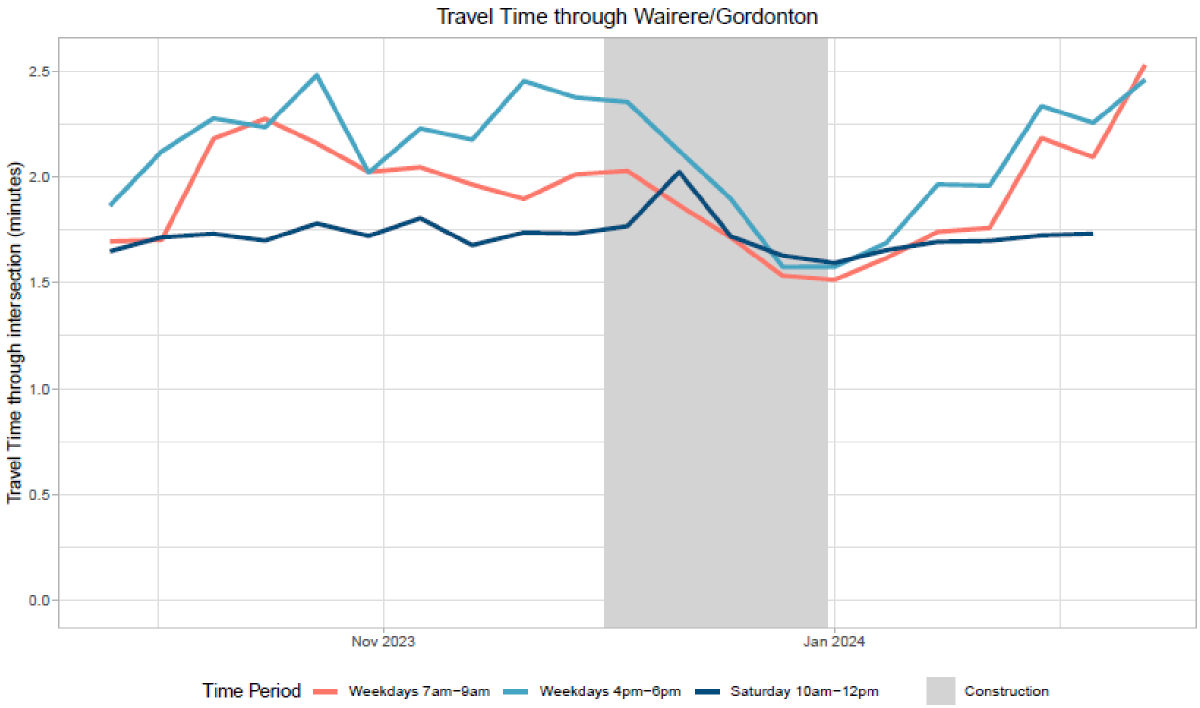
Addinsight Bluetooth data was used to understand travel time delays through this intersection. This data was received from HCC and focuses on morning, afternoon, and weekend peak periods of 7 am to 9 am, 4 pm to 6 pm and 10 am to 12 pm respectively.

Physical works at this site were completed in December 2023 and blue tooth data was recovered on 14 February 2024. This combined with the school holiday period traffic flow fluctuations from December to the end of February it is fair to say that the intersection is still in the settling down phase following the RSP works.

The available data shows before and after travel times remain unchanged for Pardoa Boulevard, Crosby Road, and Wairere Drive East. There seems to be a slight increase on Wairere Drive West and Gordonton Road approaches but due to the short data period. These findings can't be confirmed as these can be attributed to a number of other factors such as school holidays, remedial works taking place post-construction, Christmas/New Year shut, etc.

For travel time through the intersection via realtime Addinsight Bluetooth data source, see figure 46.

Figure 46. Travel time through Wairere Drive and Gordonton Road Roundabout



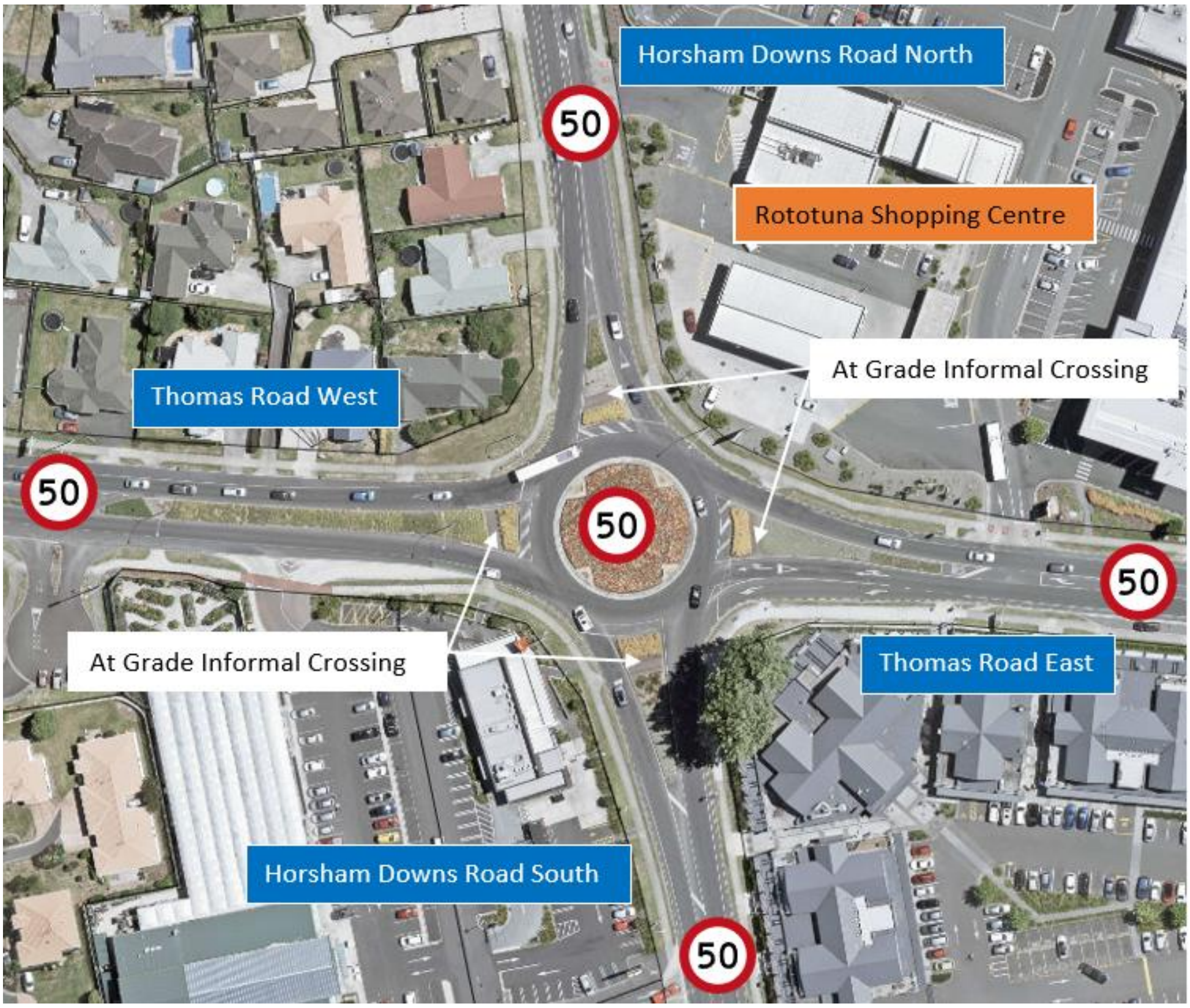
Note. Source HCC utilising Addinsight Real time Bluetooth data

12.3 Thomas Road and Horsham Downs Road Roundabout

12.3.1 Description and Characteristics of Intersection

The Thomas Road and Horsham Downs Road Intersection is a four-legged, single-lane circulating roundabout located in Hamilton's northern suburb of Rototuna, see Figure 47. The adjoining land at the three corners of this roundabout is zoned for business, while the area to the northwestern corner is zoned as residential. There are businesses such as supermarkets, Service Stations and Fast food stores located in this area.

Figure 47. Thomas Road and Horsham Downs Road Intersection Location (Hamilton, NZ)



Note. Pre-construction image taken from HCC GIS City Viewer

Road hierarchy as per the HCC Operative District Plan, traffic volumes and percentage of Heavy Commercial Vehicles (HCVs) as per mobile roads for this site are listed as follows:

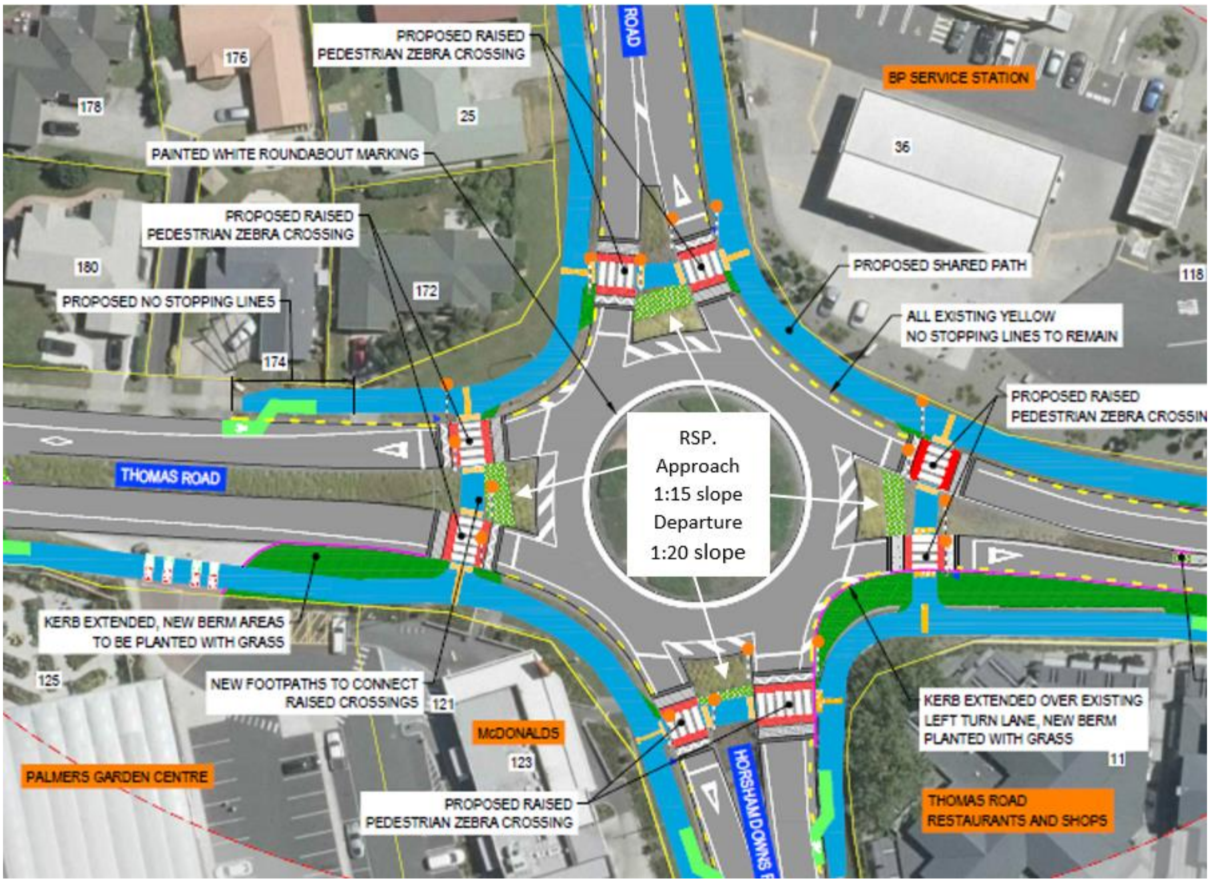
- Thomas Road is a Minor Arterial Road with the;
  - Eastern leg carrying 11,400 vpd (ADT) of which 3% are HCVs and the;
  - Western leg carrying 12,294 vpd (ADT) of which 5% are HCVs.
- Horsham Downs Road southern leg is a minor arterial carrying 11600 vpd (ADT).
- Horsham Downs Road northern leg is also a minor arterial carrying 7400vpd (ADT).

12.3.2 Raised Safety Platforms and Key Design Features

Improvement works at this site comprised of removal of the dedicated left turn slip on the Thomas Road westbound approach and retrofitting of RSPs on all legs to manage entry and exit traffic speeds. New zebra crossings were added to all of the four RSPS to improve active user safety and LOS.

The RSPs are set back one car length from the new limit line. All platform built were 75mm high with the approach slope of 1:15 for a 30km/h speed profile entry given the presence of active users and priority crossing at this site. A 1:20 departure ramp slope was used at this site, see Figure 48. The posted speed limit on all legs of the intersection remained at 50km/h before and after construction.

Figure 48. Thomas Road and Horsham Downs Road Intersection RSPs General Layout



Note. HCC Issue For Construction Drawing (CM Document Reference D-4379382)

12.3.3 Before and After Crash Evidence

RSPs were added to this roundabout in May 2022. Five years before crash data (May 2017 to May 2022) from NZ Transport Agency CAS was recovered to analyse the number, severity and type of crashes pre-installation. A search radius of 100m was used for this site and a total of 9 crashes were reported before installation. Crashes involving pedestrian and cyclist were included in these figures.

After treatment crash data from June 2022 to December 2023 (1.5-year period) recorded one reported non-injury crash over this period. More details on the crashes are listed in Table 20.

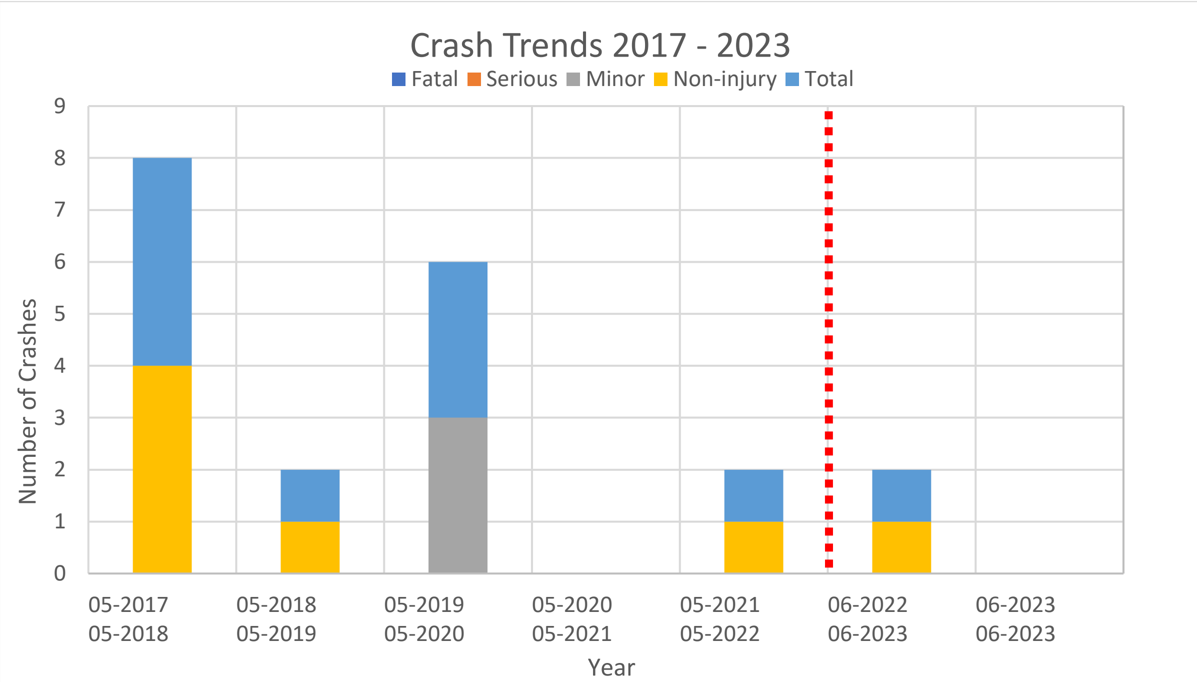
Table 20. Thomas Road and Horsham Downs Road before and after crash information

	Before			**After**		
Severity of Crash	**Number of Crash**	**Pedestrian involved**	**Cyclist involved**	**Number of crash**	**Pedestrian involved**	**Cyclist involved**
Fatal	0	0	0	0	0	0
Serious	0	0	0	0	0	0
Minor Injury	3	1	1	0	0	0
Non injury	6	0	0	1	0	0
TOTAL	**9**	**1**	**1**	**1**	**0**	**0**

Note. Data has been sourced from NZ Transport Agency Crash Database (December 2023)

See Figure 49 for a plot of crash numbers and severity over time at this site:

Figure 49 Before and after crash and severity plot



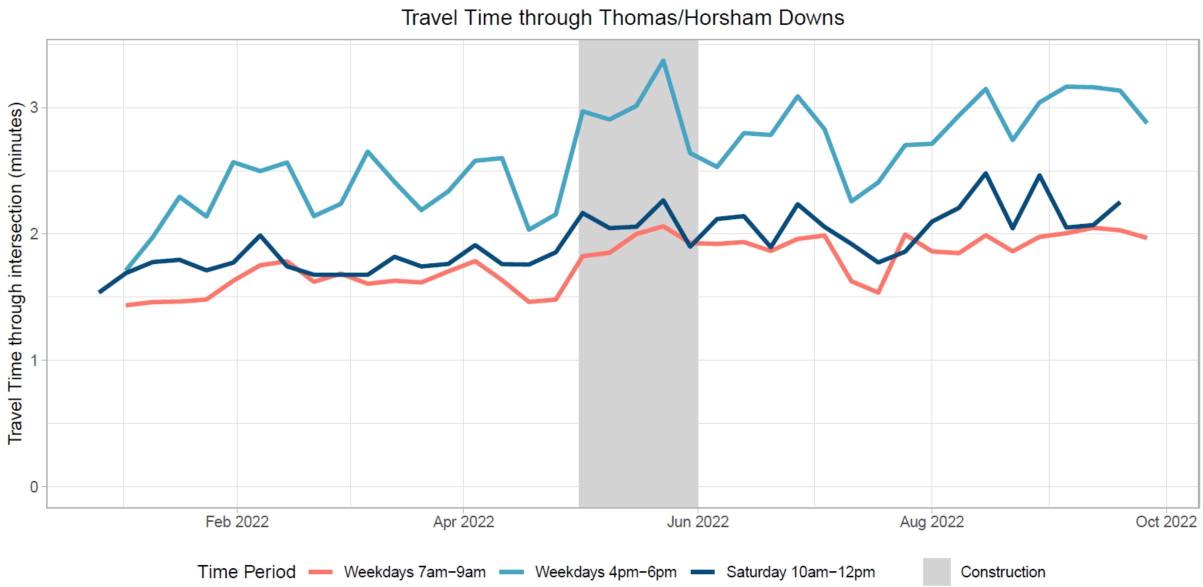
Note. Data sourced from NZ Transport Agency Crash Database (December 2023). Broken red line shows the time of RSP Installation.

12.3.4 Travel Time by Bluetooth Data

Addinsight Bluetooth data showed that the Thomas/Horsham Downs intersection is the only site that has seen a large increase in travel time in comparison to other sites that form part of this study. The most affected period was the weekday PM peak period. This can be affected by a number of factors such as population growth, the removal of the left turn slip lane on Thomas Road westbound approach, roadworks in other areas and potentially through the introduction of priority pedestrian crossings on all legs which balances the LOS and safety between cars and pedestrians. The least affected leg was Horsham Downs Road southbound from Moonlight Drive to Thomas Road.

Traffic travel time delays as a result of physical works were seen at this intersection during the PM peak. Morning and weekend peaks showed only a slight travel time delay during construction. This is shown by the grey hatched area, see Figure 50.

Figure 50. Travel time through Thomas Road and Horsham Downs Road Roundabout



Note. Source HCC utilising Addinsight real time Bluetooth data

12.4 Tristram Street and Collingwood Street Roundabout

12.4.1 Description and Characteristics of Intersection

The Tristram Street and Collingwood Street intersection is a four-legered dual-lane roundabout located in the southwestern quadrant of Hamilton's Central Business District referred to as City Fringe Mix. The adjoining land to this intersection supports major facilities such as WINTEC and businesses such as Service Station, office block and early childhood centre, see figure 51.

The adjoining land at the three corners of this roundabout is zoned for business while the area to the northwestern corner is zoned as residential.

Figure 51. Tristram Street and Collingwood Street Intersection Location (Hamilton, NZ)

Note. Image from HCC GIS City Viewer

Road hierarchy as per the HCC Operative District Plan, traffic volumes and percentage of Heavy Commercial Vehicles (HCVs) as per mobile roads for this site are listed as follows:

- Tristram Street a Major Arterial Road with the;
  - Southern leg carrying 13093 vpd (ADT) of which 2% are HCVs and the;
  - Northern leg carrying 17,700 vpd (ADT) of which 2% are HCVs.
- Collingwood Street eastern leg is a Collector Central City Transport Corridor carrying 5100 vpd (ADT) with 4% HCVs.
- Collingwood Street western leg is a Collector Road carrying 3609 vpd (ADT).

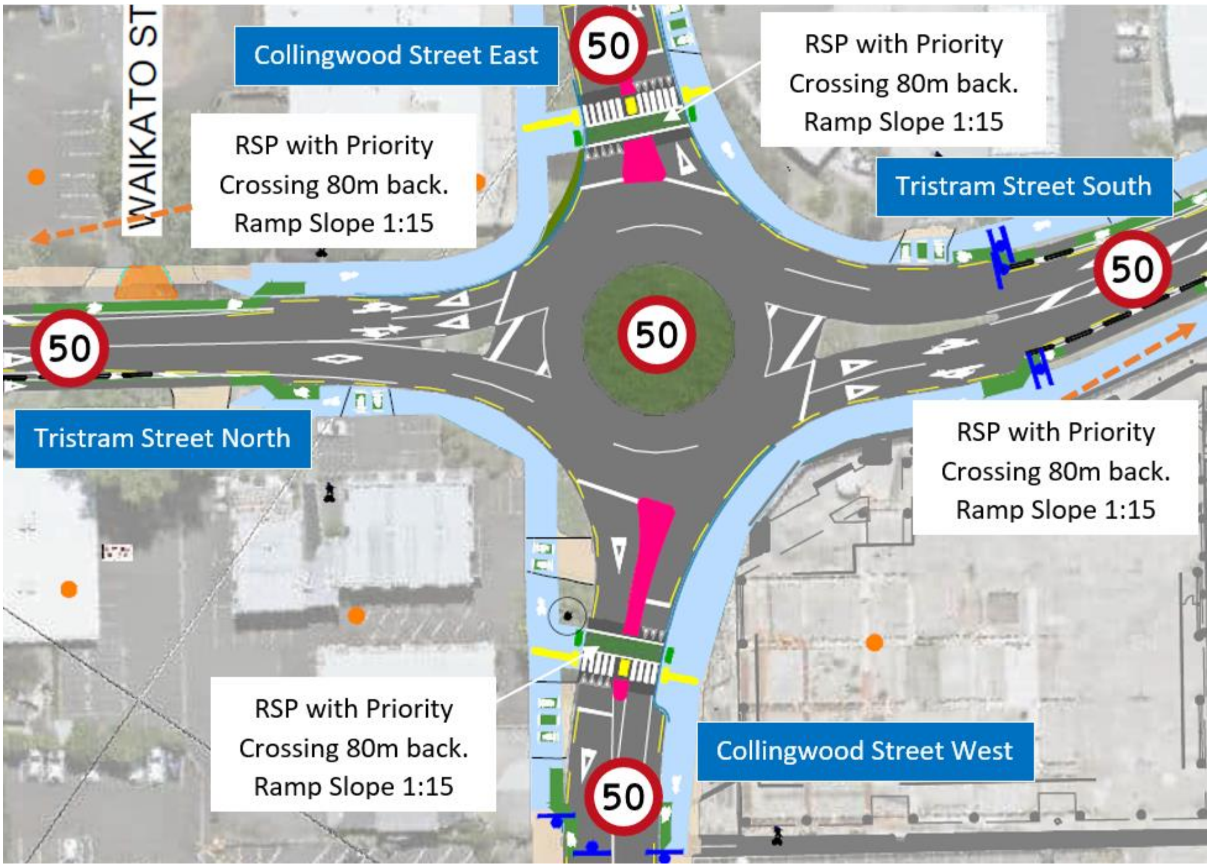
12.4.2 Raised Safety Platforms and Key Design Features

This site has been treated with RSPs on all approach and departure legs to the roundabout with the inclusion of priority pedestrian and cycle crossings also sometimes known as paired crossings. The RSPs on Tristram Street are set back (approx. 80m) to the midblock single-lane section for crossing safety reasons. The RSPs on Collingwood Street are set back a one-car length from the new limit line. All four RSPs have a height of 75mm.

All platform ramp approach slope were designed at 1:15 for a 30km/h speed profile due to the high pedestrian usage of this area and the departure ramps were set at 1:15. All legs of this intersection are posted at 50km/h and remain unchanged from before construction.

The project also included some walking and cycling shared path improvement works, kerb extension works and the addition of cycle lanes and concrete separators as part of the works, see Figure 52.

Figure 52. Tristram Street and Collingwood Street RSPs General Layout Information



Note. HCC Issue For Construction Drawing. CM Document Number (D-4490002)

12.4.3 Before and After Crash Evidence

RSPs were added to this roundabout in November 2022. Five year before crash data (November 2017 to November 2022) from CAS was recovered to analyse the number, severity and type of crashes pre-installation. A search radius of 100m was used for this site and a total of 22 crashes were reported before the RSP installation.

After treatment crash data from December 2022 to December 2023 (12 month period) recorded only one non-injury reported crash. For more details on crashes, refer to Table 21.

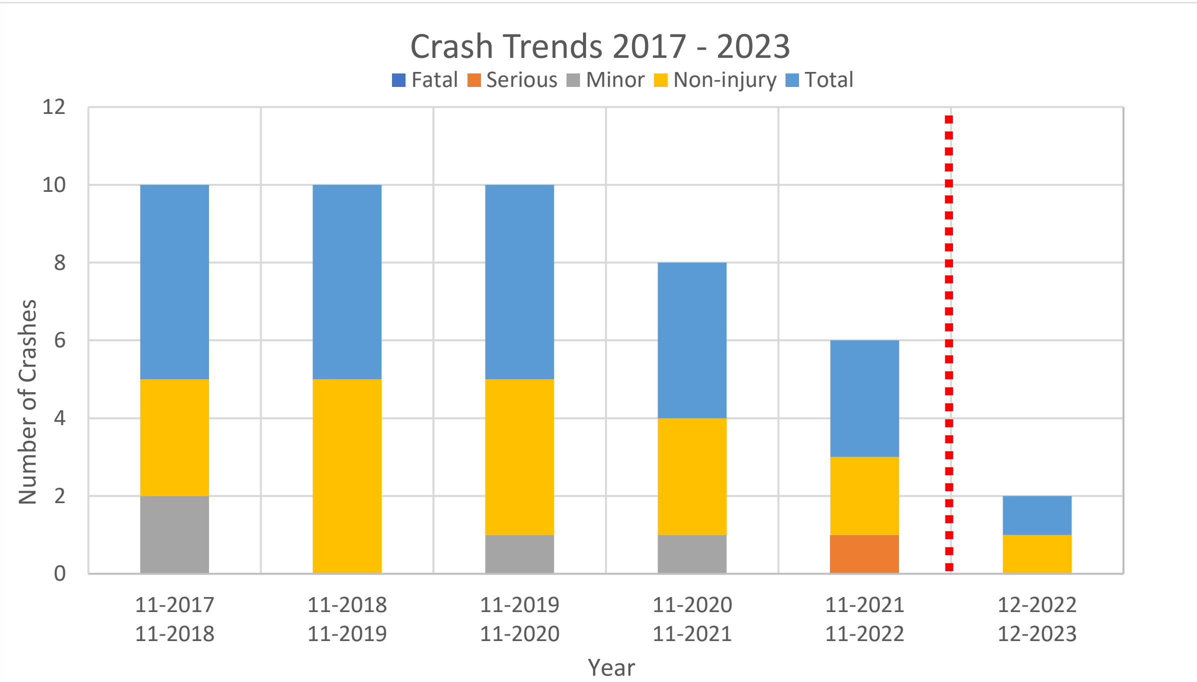
Table 21. Tristram Street and Collingwood Street before and after crash information

	Before			After		
Severity of Crash	**Number of Crash**	**Pedestrian involved**	**Cyclist involved**	**Number of crash**	**Pedestrian involved**	**Cyclist involved**
Fatal	0	0	0	0	0	0
Serious	1	0	0	0	0	0
Minor Injury	4	1	1	0	0	0
Non injury	17	0	0	1	0	0
TOTAL	**22**	**1**	**1**	**1**	**0**	**0**

Note. Data sourced from NZ Transport Agency Crash Database (December 2023)

See Figure 53 for a plot of crash numbers and severity over time at this site:

Figure 53. Before and after crash and severity bar graph



Note. Data sourced from NZ Transport Agency Crash Database (December 2023). Broken red line shows the time of RSP Installation.

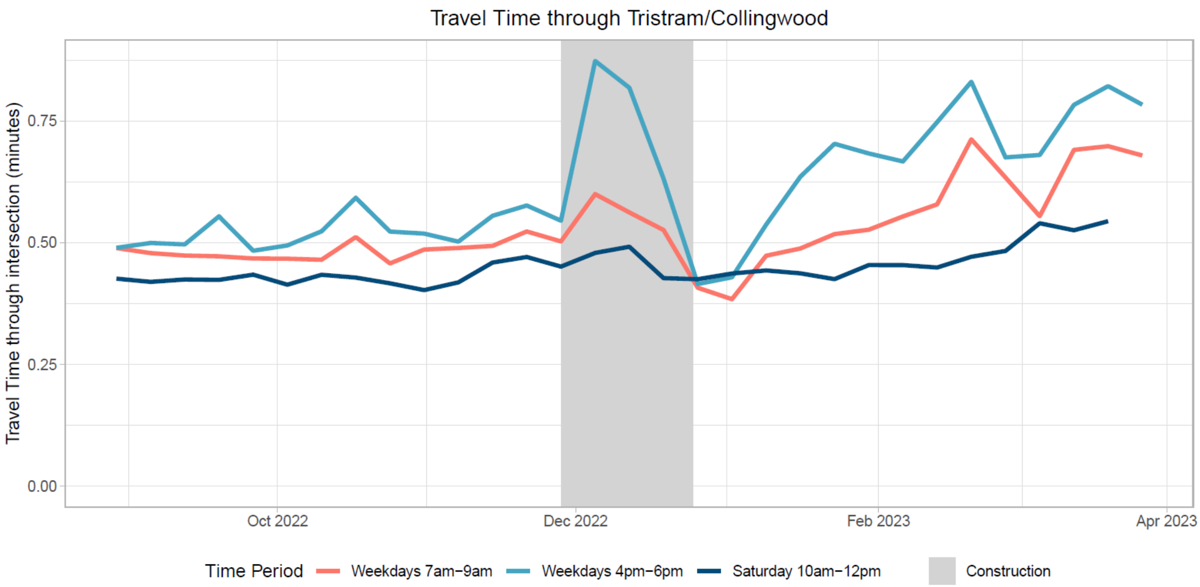
For further detail about crash data and collision diagram reference should be made to the NZ Transport Agency CAS system.

12.4.4 Travel Time by Bluetooth Data

Addinsight Bluetooth data was used to understand real-time changes in travel time through this intersection. This information was received from HCC and focuses on morning, afternoon and weekend peak periods of 7 am to 9 am, 4 pm to 6 pm and 10 am to 12 pm respectively, refer to Figure 40 for more details.

An increase in travel time at Tristram/Collingwood was seen but was mainly from Tristram Street southbound approach (Ward to Collingwood Street via Tristram leg). The increase in travel time is likely associated with other road works in the area such as safety works at the Tristram/Anzac Intersection which which happened around the same time in January 2023. Traffic travel-time delays during construction were noted at this intersection as shown by the grey hatching under Figure 54.

Figure 54. Travel time through Tristram Street and Collingwood Street Roundabout



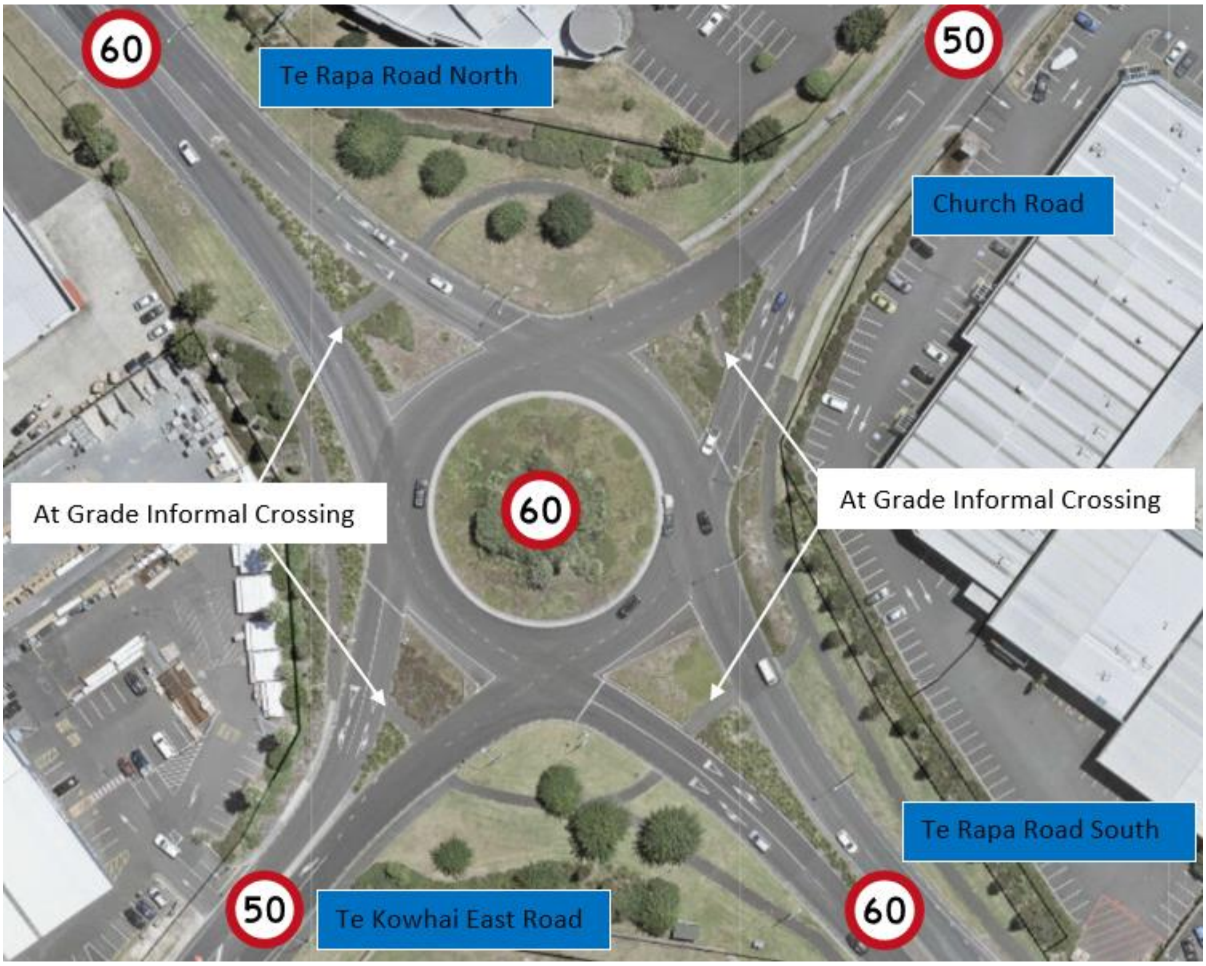
Note. Source HCC utilising Addinsight Real time Bluetooth data

12.5 Te Rapa Road and Church Road Roundabout

12.5.1 Description and Characteristics of Intersection

This intersection of Te Rapa Road and Church Road is a four-legged dual-lane roundabout. It is located in the north-western suburb of Pukete, Hamilton. There are commercial businesses surrounding the intersection and industrial zones beyond this to the north, see Figure 55.

Figure 55. Te Rapa Road Church Road Intersection Location (Hamilton, NZ)



Note. Preconstruction image from HCC GIS City Viewer

Road hierarchy as per the HCC Operative District Plan, pretreatment posted speed limit, traffic volumes and percentage of Heavy Commercial Vehicles (HCVs) for this site are identified as follows:

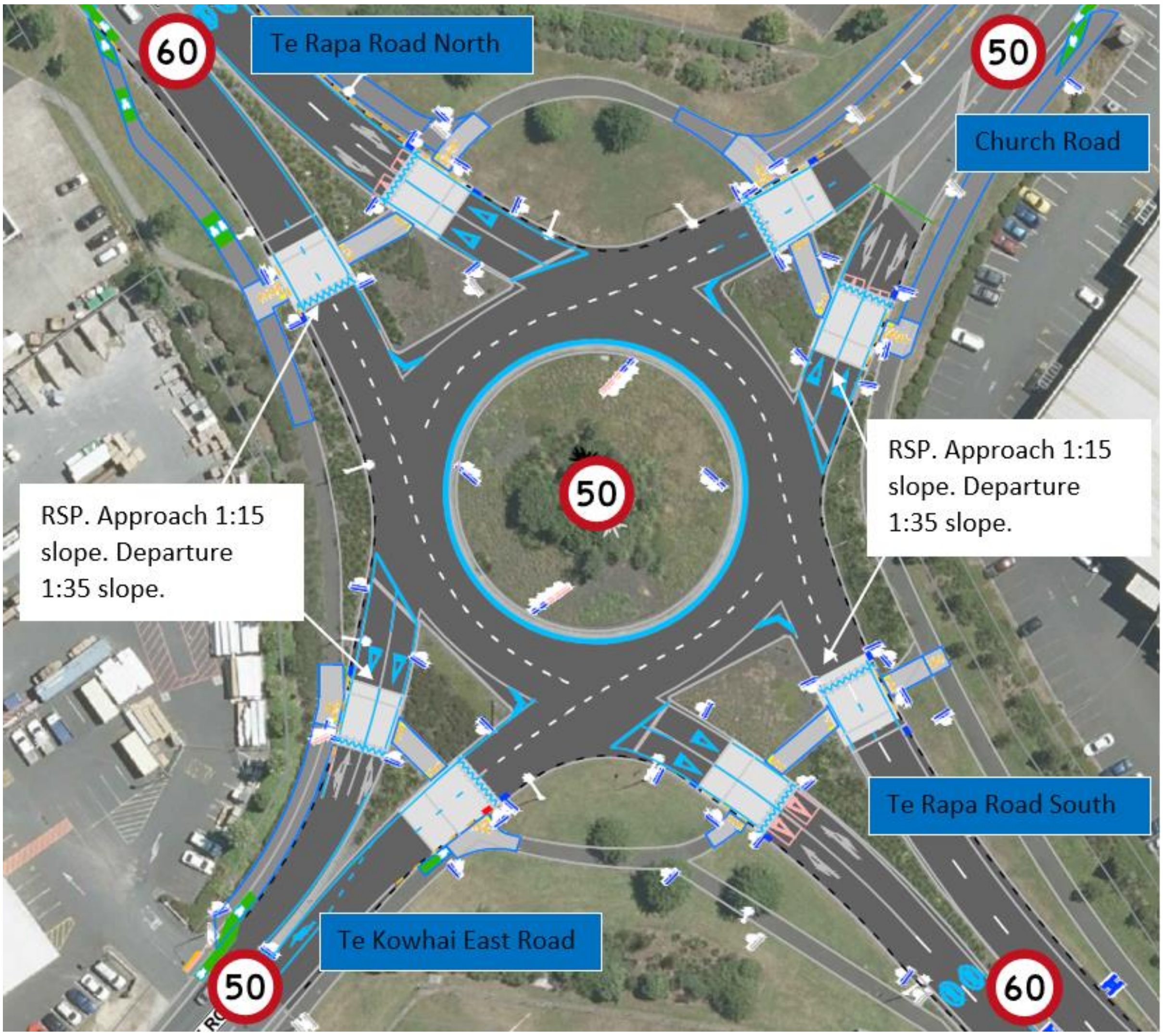
- Te Rapa Road North is a Major Arterial posted at 60km/h carrying 14500 vehicles per day (VPD) of which 7% are HCVs.
- Te Rapa Road South is a Major Arterial posted at 60km/h carrying 22300 vpd (ADT) of which 5% are HCVs.
- Te Kowhai East Road is a Proposed Major Arterial posted at 50km/h carrying 9857 vpd with 4% HCVs.
- Church Road is a Collector road posted at 50km/h carrying 9700 vehicles per day with 4% HCV usage.

12.5.2 Raised Safety Platform Key Design Features

This site was treated with RSP on all approach and departure legs of the roundabout. There are footpaths at all corners of this intersection but the platforms did not include any priority pedestrian or cyclist crossings due to the dual lane shadowing safety concern.

Platform ramp approach slope was designed at 1:15 for 30km/h speed profile and the departure ramps were set at 1:35 shallow Swedish style ramps to cater for the HCV usage. The RSPs were set back a minimum of one car length from the new limit lines and have a height of 75mm. The posted speed limit at this rounabout was dropped to 50km/h as part of the RSP works, see Figure 56. The project also included some walking and cycling shared path improvement works.

Figure 56. Te Rapa Road Church Road RSPs General Layout Information



Note. HCC Issue for Construction drawing. CM Document Reference (D-4596406)

12.5.3 Before and After Crash Evidence

RSPs were added to this roundabout in February 2023. Five years before crash data (February 2018 to February 2023) from CAS was recovered to analyse the number, severity and type of crashes pre-installation. A search radius of 100m was used for this site and a total of 20 crashes were reported before installation.

Post-construction crash data from February 2023 to December 2023 also sourced from CAS showed a total of 2 crashes over this one-year period, one being minor injury and the other being of non-injury severity. More details on the crashes are listed in Table 22:

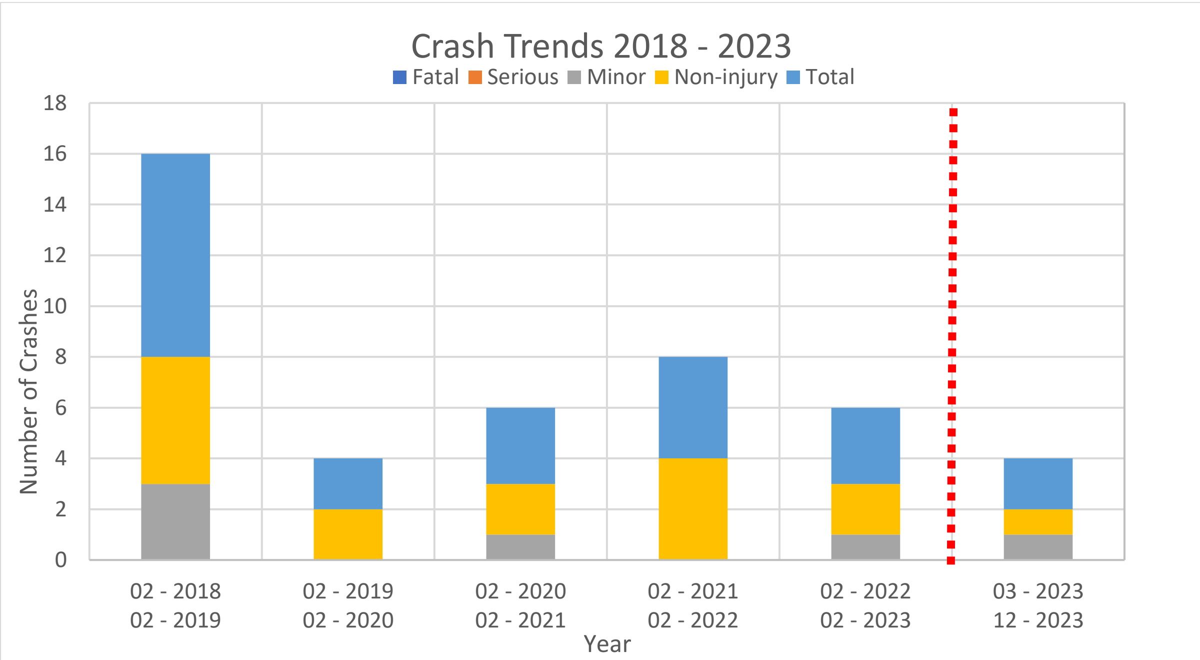
Table 22. Te Rapa Road and Church Road before and after crash information

	Before			After		
Severity of Crash	**Number of Crash**	**Pedestrian involved**	**Cyclist involved**	**Number of crash**	**Pedestrian involved**	**Cyclist involved**
Fatal	0	0	0	0	0	0
Serious	0	0	0	0	0	0
Minor Injury	5	1	1	1	0	0
Non injury	15	0	0	1	0	0
TOTAL	**20**	**1**	**1**	**2**	**0**	**0**

Note. data has been sourced from NZ Transport Agency Crash Database (December 2023)

See Figure 57 for**Error! Reference source not found.** a plot of crash numbers and severity over time at this site:

Figure 57. Before and after crash and severity plot



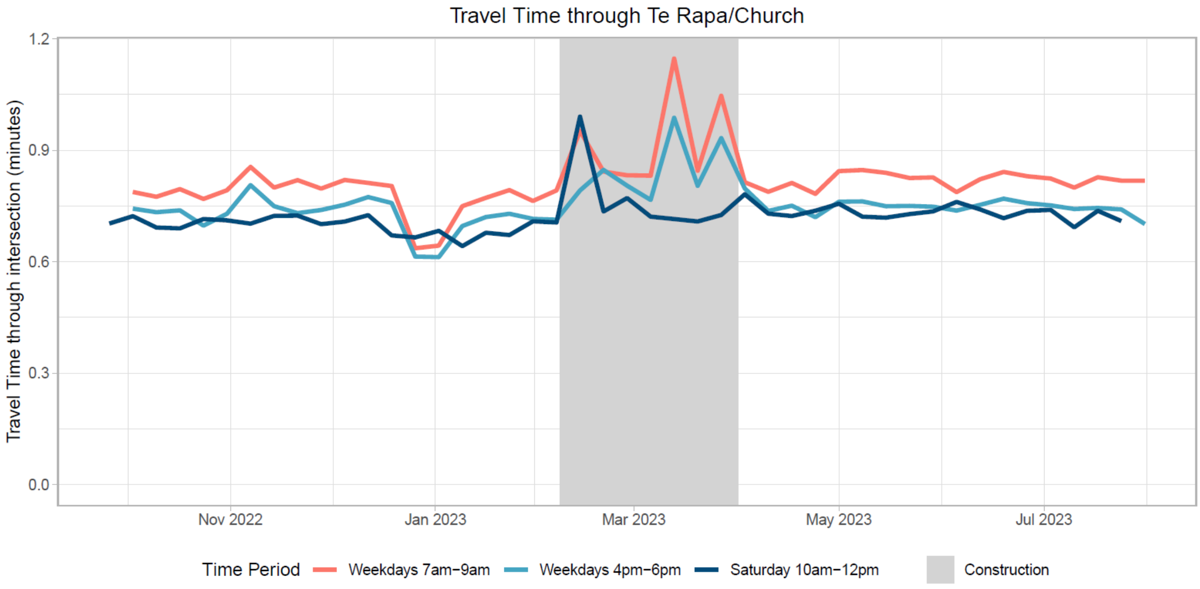
Note. Data sourced from NZ Transport Agency Crash Database (December 2023). Broken red line shows the time of RSP Installation.

For further detail in relation to crash data and collision diagram reference should be made to the NZ Transoport Agency CAS stsyem.

12.5.4 Travel Time by Bluetooth Data

Travel time through the intersection via Addinsight Bluetooth real-time data shows no change in travel time through this intersection following the installation of RSPs, see Figure 58. The travel time was seen to remain within the range of 36 to 54 seconds.

Figure 58. Travel time through Te Rapa Road and Church Road Roundabout



Note. Source HCC utilising Addinsight Real time Bluetooth data

Traffic travel time delays as would be expected during the construction period were seen at this intersection. This is shown by the grey hatched area.

12.6 Tristram Street and Cobham Drive Roundabout

12.6.1 Description and Characteristics of Intersection

This intersection is a four-legged dual-lane roundabout located to the south of the Hamilton Central City area and is one of the main entrances into the city connecting to SH1 through Cobham Drive. The fourth leg of this roundabout is a private access road to a supermarket car park. The adjoining land use to this intersection is zoned as business, residential, open space and central city zones, see Figure 59.

There is a dedicated high speed left turn slip lane located on Cobham Drive east approach to the roundabout and merges back onto Cobham Drive south past the roundabout. This completely bypasses the roundabout and is separated by a planted splitter island which also includes a cycle cut through for cyclists at the roundabout heading south on Cobham Drive.

Figure 59. Tristram Street and Cobham Drive Intersection Location (Hamilton, NZ)

Note. Image from HCC GIS City Viewer – before construction site layout.

Pretreatment posted speed limit through this roundabout was 80km/h and 50km/h on Cobham Drive East and Tristram Street respectively. Cobham Drive south was poasted at 80km/h. Road hierarchy as per the HCC Operative District Plan, traffic volumes and percentage of Heavy Commercial Vehicles (HCVs) as per mobile roads for this site are listed as follows:

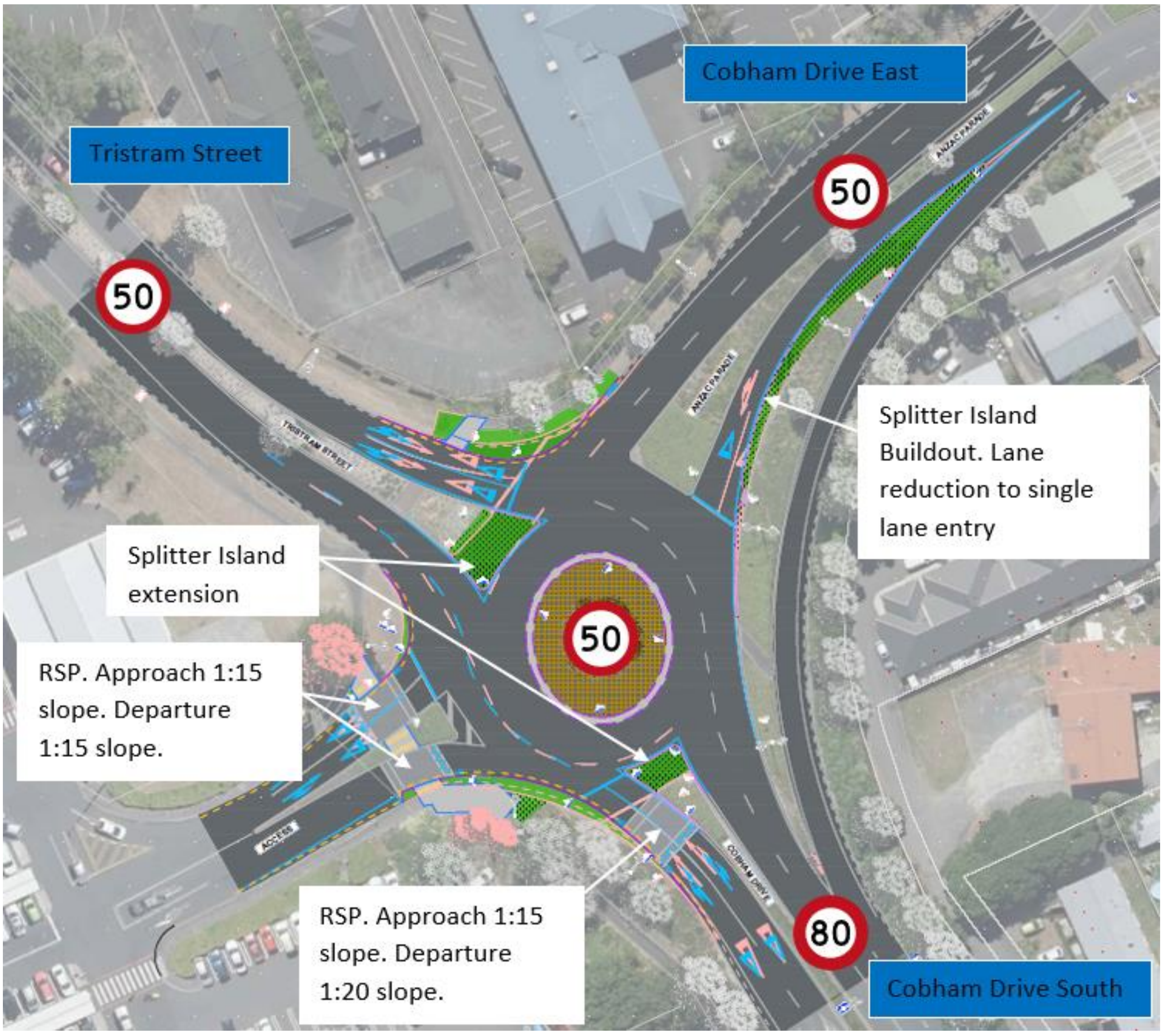
- Tristram Street is a Major Arterial Transport Corridor carrying 22816 vehicles per day (VPD) of which 2% are HCVs northbound and 5% are HCVs southbound.
- Cobham Drive southern leg is a Major Arterial Road carrying 22,400 vpd (ADT) of which 4% are HCVs heading towards the City and 2% heading away.
- Cobham Drive eastern leg is classified as a Minor Arterial Road carrying 19100 vpd (ADT) of which 4% are HCVs.
- PAK'nSAVE is a commercial access road.

12.6.2 Raised Safety Platforms and Key Design Features

Approach-RSPs were added to the Cobham Drive northbound roundabout approach leg with approach and departure ramp slopes of 1:15 and 1:20 respectively. On the PAK'nSAVE leg, a new RSP that spans across the entire carriageway was installed with ramp slopes of 1:15. The RSPs are set back one car length from the new limit lines and have a height of 75mm. Posted speed through the roundabout and the bypass slip lane was dropped to 50km/h as part of this work, see Figure 60.

Other works undertaken at this site were kerb extension works and an extension of the northern and southern splitter islands in order to restrict the roundabout down to a single lane circulating.

Figure 60. Tristram Street and Cobham Drive RSPs General Layout Information



Note. HCC Issue For Construction Drawing. CM Document refference (D-4548800)

12.6.3 Before and After Crash Evidence

RSPs were added to this roundabout in January 2023. Five years before crash data (January 2018 to January 2023) from the NZ Transport Agency CAS database was recovered to analyse the number, severity and type of crashes pre-installation. A search radius of 75m was used for this site and a total of 46 crashes were reported before installation.

After crash data from January 2023 to December 2023 also sourced from CAS showed a total of 2 crashes over this period. Both of these were non-injury type crashes. More details on the crashes are listed in Table 23:

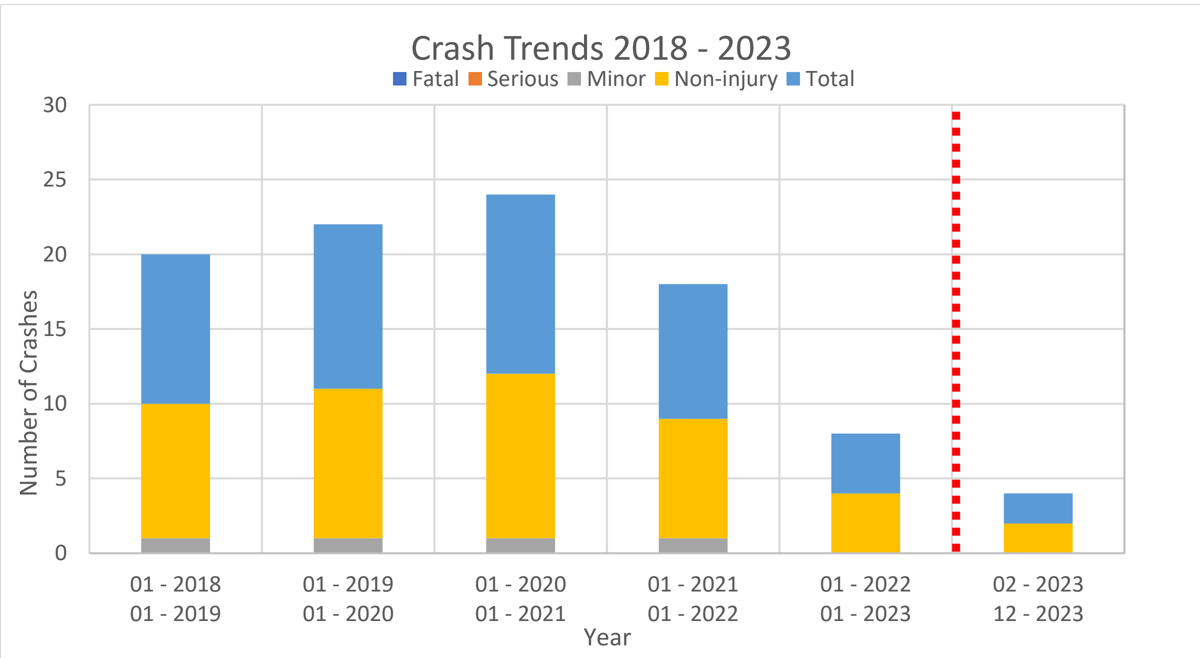
Table 23. Tristram Street and Cobham Drive before and after crash information

	Before			After		
Severity of Crash	**Number of Crash**	**Pedestrian involved**	**Cyclist involved**	**Number of crash**	**Pedestrian involved**	**Cyclist involved**
Fatal	0	0	0	0	0	0
Serious	0	0	0	0	0	0
Minor Injury	4	1	1	0	0	0
Non injury	42	0	0	2	0	0
TOTAL	**46**	**1**	**1**	**2**	**0**	**0**

Note. Data sourced from NZ Transport Agency Crash Database (December 2023)

See Figure 61 for a plot of crash numbers and severity over time at this site:

Figure 61. Before and after crash and severity plot



Note. Data sourced from NZ Transport Agency Crash Database (December 2023). Broken red line shows the time of RSP Installation.

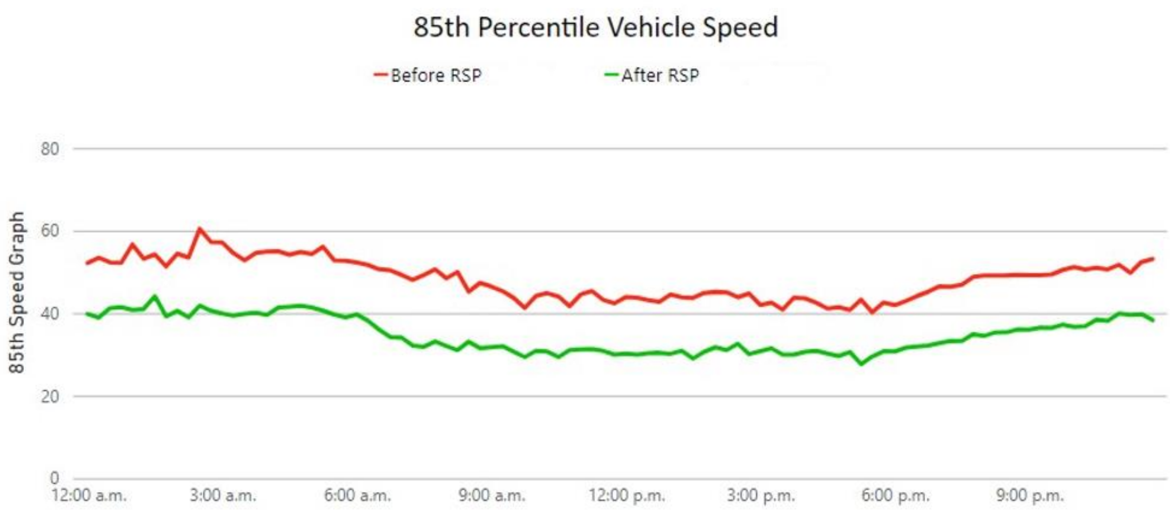
12.6.4 Traffic Speed

Traffic speed data were collected through MetroCount tube over seven days for the Cobham Drive northbound approach. Tubes were left on site for the following period:

1. Before data was surveyed between 17 June 2022 and 25 June 2022.
2. After data was collected between 03 July 2023 and 12 July 2023.

Before and after 85th percentile speed data comparison has shown a 25% reduction in operating speeds on the northbound approach following the RSP (51.60km/h to 38.32km/h). There were no RSPs installed on the southbound direction of this roundabout and the operating speed was seen to increase by 6% to 47.14km/h leaving the roundabout heading south. See Figure 62 for a 24 hour speed distribution.

Figure 62. Before and after Speed changes



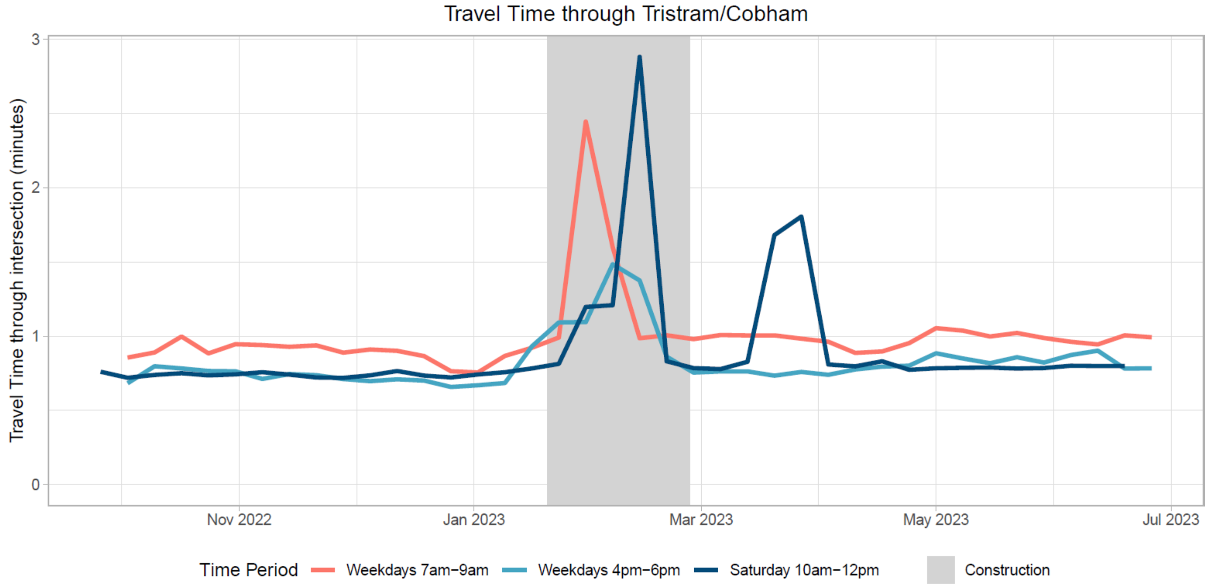
Note. Showing the northbound approach operating speed distribution over a 24 hour period.

12.6.5 Travel Time by Bluetooth Data

Bluetooth data showed only a slight increase in travel time by an extra few seconds through the intersection on the Cobham Drive northbound approach (Normandy Avenue to Tristram Street). This could be partially due to the slowing of speeds over the RSP resulting in safer gaps being created for traffic of other legs to enter the roundabout circulating lane. Based on the finding it can be concluded that the overall travel times through this intersection have remained unchanged.

Traffic travel time delays as would be expected during construction were noted at this intersection as shown by the grey hatching, see Figure 63.

Figure 63. Travel time through Tristram Street and Cobham Drive Roundabout



Note. Source HCC utilising Addinsight Real time Bluetooth data

12.7 Grey Street and TeAroha Street Roundabout

12.7.1 Description and Characteristics of Intersection

The Grey Street and Te Aroha Street intersection is a four-legged single-lane roundabout located in Hamilton East Surburb of Claudelands. The adjoining land on all four corners to this roundabout as per HCC's land use plan is zoned for Businesses, see Figure 64.

Pre-construction the site had informal refuge crossing points on all four of its legs. The Grey Street North southbound approach was used as an informal dual lane entry to the roundabout by drivers during PM peak periods. This rounabout was posted at 50km/h pre- construction of the RSPs

Figure 64. Grey Street and Te Aroha Street Intersection Location (Hamilton, NZ)

Note. Image from HCC GIS City Viewer

The road hierarchy as per the HCC Operative District Plan, traffic volumes and percentage of Heavy Commercial Vehicles (HCVs) as per mobile roads for this site are listed as follows:

- Grey Street is a Minor Arterial Road with the;
  - Southern leg carrying 11,900 vpd (ADT) of which 4% are HCVs and the;
  - Northern leg carrying 12,400 vpd (ADT) of which 4% are HCVs.
- Te Aroha Street east is also a Minor Arterial Transport Corridor carrying 10700 vpd (ADT) with 3% HCVs.
- Te Aroha Street west is a Collector road carrying 5426 vpd (ADT) with 1% HCVs.

12.7.2 Raised Safety Platforms and Key Design Features

RSPs were installed on all approach and departure legs to this roundabout with elevated courtesy crossings. Courtesy crossings are not priority crossings but rely on politeness and courtesy between drivers and active users. These are generally used in slow-speed environments. The RSPs on all legs are positioned quite close to the limit lines and there is no stacking space for a vehicle at the limit line.

All platform approach ramps have a slope of 1:15 for a 30km/h speed profile and departure ramp are also designed and built at 1:15. Platform height is 75mm. All legs of this intersection post-construction were posted at 30km/h compared to 50km/h before construction, see Figure 65.

The project also included some walking and cycling improvement works. There have also been kerb extension works done to narrow the southbound wide lane which in peak times was operating as informal dual lanes in a busy pedestrian area.

Figure 65. Grey Street and Te Aroha Street RSPs General Layout Information

12.7.3 Before and After Crash Evidence

RSPs were installed at this site in August 2019. Five years before crash data (August 2014 to August 2019) from the crash database was retrieved for the analysis of the number, severity, and type of crashes pre-installation. A search radius of 50m was used for this site. This search revealed a total of 27 crashes over this period. After treatment crash data from August 2019 to December 2023 (4-year period) showed a total of 6 crashes. For crash breakdown according to severity type, see table 24.

Table 24. Grey Street and Te Aroha Street before and after crash information

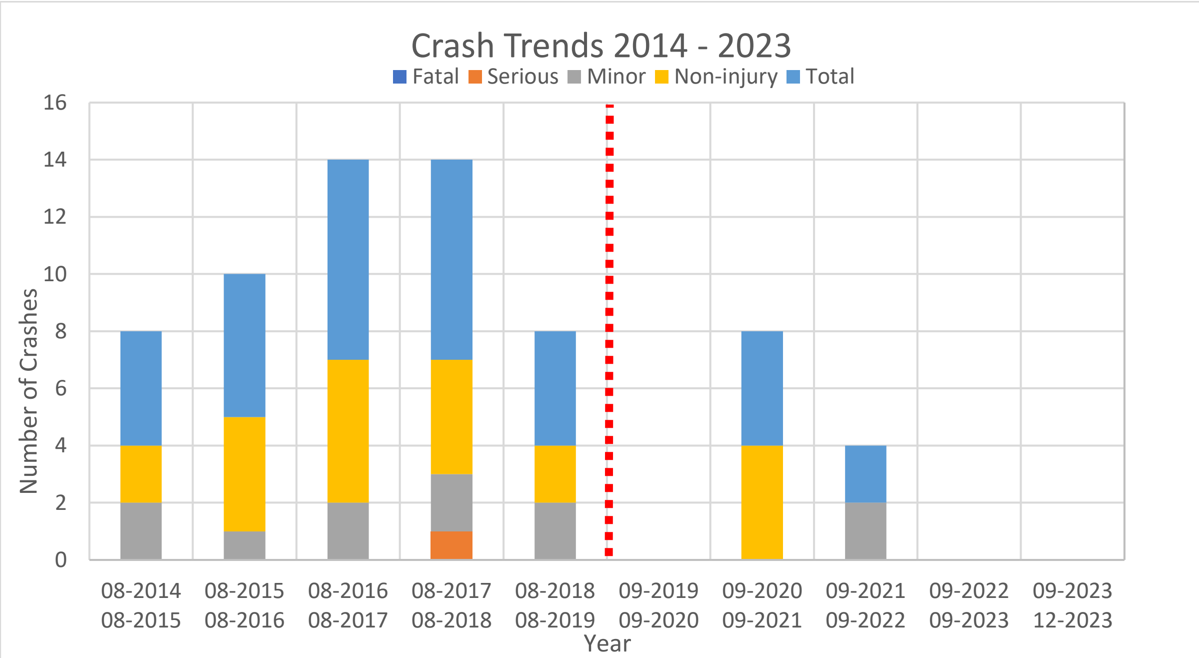
	Before			After		
Severity of Crash	**Number of Crash**	**Pedestrian involved**	**Cyclist involved**	**Number of crash**	**Pedestrian involved**	**Cyclist involved**
Fatal	0	0	0	0	0	0
Serious	1	0	0	0	0	0

Minor Injury	9	5	0	2	1	0
Non injury	17	2	5	4	0	1
TOTAL	**27**	**7**	**5**	**6**	**1**	**1**

Note. data has been sourced from NZ Transport Agency Crash Database (December 2023)

Crash data showed that the number of crashes dropped significantly post construction of the raised safety platyforms. A drop in crashes involving pedestrians and cyclists was also noted. For a plot of total crash numbers and severity types over the investigation period at this site, see Figure 66.

Figure 66. Before and after crash and severity bar graph



Note. Data sourced from NZ Transport Agency Crash Database (December 2023). Broken red line shows the time of RSP Installation.

For further detail about crash data and collision diagram reference should be made to the NZ Transport Agency CAS system.

12.7.4 Traffic Speed

Speed survey data for before and after speeds and volumes at this site was unavailable. Onsite observations from before and after construction were recovered. A desktop study for this site was carried out which revealed the following:

- Grey Street had a wide median which was used as an informal second lane in peak periods heading south.
- Vehicles heading SB on Grey Street were also straightlining the roundabout with high entry speeds in off-peak periods.
- Higher entry speeds and low willingness from drivers to let pedestrians through. Low driver yields to pedestrians wanting to cross the road.
- Pedestrians were seen ducking between vehicles on all legs to get across the road.
- The site had splitter islands on three of the approach legs. Two of which had a pedestrian refuge point.

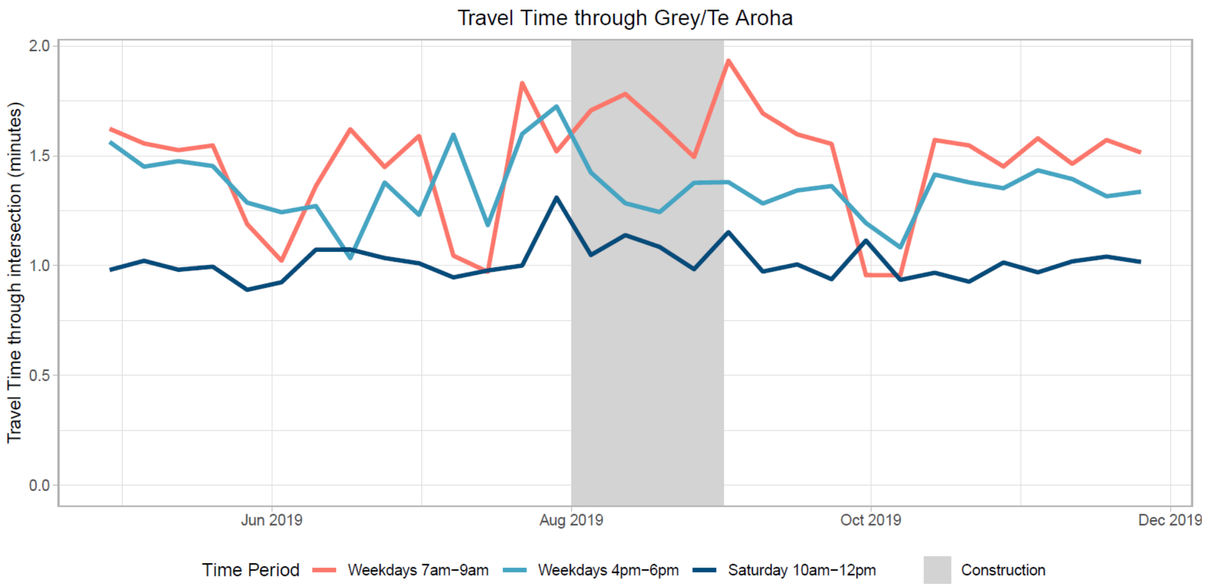
Post Construction observations showed:

- Kerbs were built out on all four corners and RSPs added. Grey Street splitter islands were widened to remove the informal second lane. This created better approach deflection at the roundabout slowing speeds on all approaches.
- Drivers were yielding more to the pedestrians wanting to get across the road creating more safe opportunities for active users to cross the road.
- Traffic looked to be operating better in terms of gaps and improved density but there is no hard data to back this.

12.7.5 Travel Time by Bluetooth Data

Real-time Bluetooth data shows a slight drop in travel time for the Te Aroha Road westbound approach (River Road to Grey Street), also see Appendix B. Based on the finding it can be concluded that travel times through this intersection have been relatively unaffected even through the RSP spanned across the approach and departure lanes and was marked as curtsey crossings, see Figure 67.

Figure 67. Travel time through Grey Street and Te Aroha Street Roundabout



Note. Source HCC utilising Addinsight Real time Bluetooth data

13. DISCUSSION, LIMITATIONS AND FURTHER RESEARCH

The aim of this project was to investigate the effects of RSPs on travel time and traffic delay at roundabouts in NZ. The results indicate that delay and travel time are not adversely affected by the introduction of RSPs. Microsimulation modelling showed that RSPs improve travel time, and no net change in traffic delays was noted.

Evidence shows that queue lengths increased slightly on approach to the RSP, but this was seen to create better gaps on the circulating lane, resulting in improved flow through the roundabout, providing for a balanced approach, operating a bit like signal ramp metering. Any reduction in LOS is negligible and classed as insignificant through this report.

This paper also found that speeds dropped notably on approach to RSPs, which resulted in a change in driver psychology where drivers yielded more to other users at the roundabout such as pedestrians. Crash data showed a decreasing trend in the number of crashes and their severity following RSP installation across all the sites studied. This improvement in crash severity results from speed reduction at RSPs, which is directly related to kinetic energy in a crash.

Key findings from the project are discussed through the sub-sections below.

13.1 Traffic Delay

Modelling evidence generally shows an increase in delay through the post-construction flow volumes, but when RSP features are modelled to this new base point (above), no firm evidence of a further delay increase is noted. On some approaches, it has even shown a reduction in delay to vehicles exiting the side roads following RSP installation. It was noted that post-construction flow volume change is likely due to population growth and new road commissioning in the study area.

This improvement in vehicle delay is likely due to RSP-induced slower speeds, which is introducing more gaps/opportunities for side road traffic to get into the traffic stream. At slower speeds, mainstream traffic was seen to yield more to traffic approaching from side roads, i.e. RSPs acts in balancing the traffic flows. This behaviour has been confirmed through onsite observation and review of footage from site-mounted temporary cameras.

13.2 Travel Time

Two methods of travel time measurements were undertaken. Method one was through real-time Addinsight Bluetooth data. The second method of investigation was microsimulation traffic modelling at two of the Wairere Drive RSP sites. RSPs at both these sites had a 1:25 (50km/h) approach speed profile and had no pedestrian access across them.

The microsimulation method showed that the largest travel time increase came from post-construction flow volumes. When RSP were run with the post-construction flow volumes, 73 percent (19 of the 26 vehicle routes investigated) of the routes showed a negligible increase in travel time, i.e. under 5 seconds. The remaining seven sites (27% of the routes surveyed) reported a reduction in travel time post-RSP installation, averaging around 25 seconds. This is a strong indication that RSPs, if anything, can improving travel times, and this is potentially due to slower speeds and better gaps resulting in improved density and flow at roundabouts.

Addinsight Bluetooth results also showed a reduction in travel time by 15 to 20 seconds. This compares reasonably well with the microsimulation result of 25 seconds above for the Wairere Drive and Resolution Drive roundabout, given that these studies were run separately on different platforms. The Addinsight travel time was run independently through the RCA.

Comparison was also made with the Wairere Drive and Gordonton Road Roundabout Bluetooth data but given that RSP construction at this roundabout was only completed in December 2023 this roundabout is considered still in the settlement phase following construction. The flow volume data taken for the microsimulation was from mid-February 2023, and it is assumed that this excluded settlement period and factors such as school holidays, remedial works taking place post-construction, and Christmas/New Year holidays. Hence, the microsimulation results are deemed more reliable in comparison to the real-time Bluetooth travel time data in this case.

Four out of the remaining five sites showed negligible change in real time travel time. Thomas Road and Horsham Downs Road roundabout was the only site that showed a significant travel time increase through Bluetooth data. On closure inspection of this site, it is noted that this site is experiencing a gradual traffic growth, which is likely resulting in a gradual increase in travel time, and this problem is unlikely to go away without a major capital works intervention or mode shift. There have also been significant road works in the immediate area with prolonged road closures resulting in re-routing of traffic.

It was also noted that the left turn slip lane on the Thomas Road WB approach was removed as part of the RSP works and priority zebra crossings were added on all four legs of this roundabout. This is likely adding to the delay at this site. It should be noted that this paper does not quantify implications on traffic travel time and delays as a result of raised priority crossing points. Although this is highlighted as an area that warrants further research.

The findings of this paper support outcomes from a past Fortuijn et al. (2005) study from the Netherlands, which looked into a substantial number of RSPs in South Holland that indicated capacity and the ability to negotiate intersections improved through RSPs with a substantial improvement in safety.

13.3 Queue Length

For this discussion, queue lengths less than one car length (5m) are considered as no change. Model results showed no change in queue lengths through post-construction flow volumes at three of the eight approach legs measured across the two test sites. Four approaches came back with a two to four-car increase in queue length. One approach showed a decrease in queues by two car lengths. So generally, 50% of the legs showed some increase in queue lengths.

After this, through the modelling of RSPs and post-construction flow volumes, the model returned five sites with no change in queue length. Two sites showed an increase of two car lengths, and one site showed an increase of eight car lengths. Results show some evidence of an increase in queue lengths on approach to RSP at roundabouts.

This increase in queuing is likely due to vehicles slowing down for the RSP (placed approx. two car lengths back from the limit line). Although some increase in queue length is noted from site observations, it was noted that this helped generate better gaps within the roundabout circulating lane from observations ie, once vehicles are past the RSP, they get more opportunities to get into the mainstream traffic. This is supported by no increased delays at these sites and with LOS not deteriorating, as noted in the traffic delays section above.

This finding is in line with Job & Mbugua (2020), which showed that decreasing speeds does not necessarily increase congestion but can improve flow. This is because as speeds increase, drivers generally leave longer gaps between themselves and the vehicle in front. Thus, at high speed, vehicles are further apart and this does not improve congestion. Reductions in speed as vehicles reach congested conditions result in a smoother flow of traffic. This produces less stop/start traffic movement, with subsequent benefits on the safety and throughput of vehicles.

13.4 Crash Evidence

The effects of RSP on crashes is an area that has been well-researched and documented. Previous literature review has shown that crash likelihood is reduced significantly through the introduction of RSPs. Crash data investigation through this paper at all seven sites supports the past literature findings and concurs with a reduction of both crash numbers and crash severity.

A limitation of this paper was that sites included in this study were relatively new installations of RSPs with only approximately one to two years of after-crash data available. This was still deemed sufficient to show a trend in crashes but having a full five-year data set of after crashes provides for a better data set. One of the sites had four years of after-data set and showed a significant reduction in crash numbers and severity. Based on this, if a full five-year after the data set was available, the evidence on crash number and severity reduction at RSP sites is likely to be even stronger.

International research identified through RSP Safe Systems Case Study by Waka Kotahi NZ Transport Agency has shown RSPs reduce death and serious injuries by about 40% and findings of this paper supports this.

13.5 Speed

Of the seven sites investigated, reliable before and after speed data was available for three sites. Some sites were under post-construction survey process, so they were excluded from this paper. Site observations were undertaken at some of the sites. Data shows a significant reduction in operating speeds following RSP installation in the range of between 23 to 53%. This finding supports previous Austroads (2009) claims that flat-top road humps produce an 85th percentile speed reduction of 24% at the treatment.

Site observations at some of the sites missing speed data has shown a slowing effect on traffic as a result of the RSPs with improved traffic flow and general safety. Drivers were seen to be yielding more to pedestrians and other vehicles, and an environment of courtesy between users was evident.

Social driving is the shifting of priority from vehicles to pedestrians, typically at non-priority crossings, “courtesy crossings”. In these scenarios, there are some user openions that RSPs have caused congestion which they haven’t as it's more a driver psychology change where by at slower speeds drivers yield more to pedestrians resulting in a more balanced approach for all users. Note vehicles still have priority at these types of courtesy crossings.

This behaviour has been confirmed through onsite observation and through data from site-mounted temporary cameras and it can be seen that drivers are stopping for pedestrians at non-priority crossings.

13.6 Limitations

Throughout the course of this paper, time, resources, and funding for this research have been critical limitations. Several other limitations have been identified, and these are discussed more in detail below:

The two Wairere Drive sites, which have undergone the microsimulation process, are both located to the north of Hamilton in an area that is facing steady population growth. The new Waikato expressway, located close to and linking to these sites, was opened to traffic on 14 July 2022. This has resulted in large-scale changes in before and after flow volumes on some legs, resulting in some delays purely as a result of flow changes.

There is a public perception that this delay is a direct result of RSP, which is misleading. This is more likely individual opinions with no factual evidence that back these claims. This delay is more likely attributed to population growth, new roads being commissioned, and a limitation outside the control of this study.

Turning count data availability for use in the model has been a major limitation and setback of this paper. Post-construction data were missing in some cases. This is supported by previous Austroads (2016) research that showed a lack of robust treatment monitoring. Data monitoring and evaluation should be included within the road-controlling project management process so this becomes a key deliverable in the project close-off process. Thought also needs to be given to the type of data collection method to keep parameters and variables constant for effective and more reliable before and after comparisons.

Other intersections in the network potentially have an impact on roundabouts within this study. The modelling approach for this study has excluded other intersections and has based findings on modelling the study roundabouts in isolation. This identifies some warrant for a network model to better understand effects of RSP from a wider network perspective but given external factors such as existing traffic conjestions from non RSP sites this network model is unlikely to yield much benefit.

13.7 Further Reseach

Further research and evaluation with the inclusion of a larger sample size would be the logical next step from this paper to understand if the findings from here relate to the wider NZ and Australian context. This will bring in a better and more homogeneous sample size to help build on the findings of this study further.

In alignment with this, there is some evidence from a further study on the effects of RSP on emergency services, buses, and heavy vehicle. This area is lightly researched and will help understand the effects and develop design changes that suit all users.

Operational effects of RSP through pedestrian priority and non-priority crossings require investigation to understand resultant driver psychology at such crossings.

14. CONCLUSION

This research aimed to identify the effects of RSPs on traffic flow and travel time at roundabouts. Based on a quantitive analysis, it can be concluded that there is a negligible change in delay and a decrease in travel time through the roundabouts surveyed.

The findings of this research show that RSPs create smoother traffic flow and safer and better gap selection, resulting in improved or the same efficiency as before. Some increases in queue lengths resulted on the approach to RSPs and this could relate to driver perception of an increase in congestion.

The methodological approach for this research has proven effective in answering the questions that were set out to be investigated. This research clearly illustrates any adverse LOS change due to RSPs is very minimal and, therefore, classified as insignificant. Therefore any driver perception of an increase in traffic congestion are not supported through this paper.

Bluetooth data and microsimulation modeling both effectively show that RSPs can have an improvement in travel time with a net no change in traffic delays. Sites that showed an increase in travel time were related to population/traffic growth. The research also raises the question of the RSP effects on LOS of raised priority, non-priority crossing points, and other safety improvements at roundabouts.

Through the findings of this research practitioners and decision makers should consider:

1. To incorporate before and after site monitoring and evaluation into the project life cycle and identify these as key project deliverable. Planning for and appropriate data collection methods should also be incorporated here.

2. Future modelling study to be extended to include priority pedestrian crossings that are placed on the RSPs at roundabouts. This will help better understand the operational implications of raised pedestrian crossings on roundabouts.

3. Building upon the methodologies of this study and extending the research to incorporate a larger RSP sample size across Australia and NZ.

4. Further research on the effects of RSP on emergency services, buses and heavy vehicles.

It should be noted that RSPs are a primary safety intervention tool and are very successful in speed and crash reduction. These can be designed for motorist comfort. RSPs having a negligible effect or a slight improvement in operational efficiency is an added benefit of these devices.

The main aim of this project was to identify and understand RSP implications on delay and travel time at roundabouts. It is concluded that any change in these intersection performance measures through RSPs is insignificant with some slight increase in travel time noted. This study also supports claims from past literature that RSPs are safety improvements measures that reduce vehicle approach speeds, crash number and crash severity outcome.

15. GLOSSARY

(Definition of the glossary terms below have been obtained from Austroads and other sources).

85th Percentile Speed: This is generally used and known as the vehicle's operational speed at a particular point on the road. This is the speed below which 85% of the vehicles travel. This means 15% of the vehicles exceed this threshold. It can also be called the 85th Percentile operational speed.

Annual Average Daily Traffic (AADT): the total number of vehicles on a road (both directions) counted over the whole year divided by 365 days. This flattens out any school holiday and weekend traffic flow variations. It is used to measure long-term trends in travel demand. AADT can be difficult and expensive to collect as it requires real-time data for the whole year. This is expressed as vehicles per day (VPD).

Austroads: is a body funded by Australian and NZTA responsible for providing roading design guidance with a focus on making mobility safer and more reliable for all users.

Average Daily Traffic (ADT): the average number of vehicles travelling on the road during a period shorter than a year but greater than a day. This can be used for a short-span survey period, such as a week-long (seven-day) period. It is a sample taken over the targeted interval to aid in specific operational and short-term planning requirements.

Capacity: The maximum flow rate of a road is its capacity. AGTM03-20_Part_3_ states, "Capacity, as defined in HCM 2016, is the maximum sustainable hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under the prevailing roadway, environmental, traffic and control conditions. The concept applies equally to motorised vehicular traffic and to bicycle and pedestrian traffic."

Courtesy Crossings: Courtesy crossings are generally raised crossings usually made of paving or concrete or asphalt concrete with different coloured surfacing, i.e. MMA. Courtesy crossings are intended to facilitate eye contact between pedestrians and drivers at low speeds, resulting in situations where vehicles are more likely to yield to pedestrians.

Degree of saturation: As per AGTM03-20-Part 3, degrees of saturation range from close to zero for low flows up to 1.0 for saturated flows. Lower saturation results in better traffic levels of service, whereas higher saturation means a poor traffic level of service. Saturation greater than 1.0 indicates an oversaturated condition, which leads to long approach queues. "In practice, the target degrees of saturation of 0.90 for signals, 0.85 for roundabouts and 0.80 for unsignalised intersections are generally agreed to". These are usually called *practical degrees of saturation*.

Delay: the additional travel time experienced by a driver, passenger, or active user while travelling to their destination. It is the difference between ideal travel time and actual travel time. Delay is the time lost by a vehicle occupant due to causes beyond the control of the driver. This can be due to incidents, conditions, road construction and maintenance reasons. Measured in seconds.

Density (k): This is also known as concentration. It is the number of vehicles within a given length of the carriageway at a point in time. This is generally expressed in **veh/km**. For traffic modelling purposes, **veh/m** is commonly used. Density is a descriptor of flow.

Design Speed: is a fixed speed for the design and correlation of geometric features of a carriageway that influence vehicle operation. It is used for the calculation of various geometric design parameters (e.g. sight distance, application of superelevation, horizontal and vertical curve radii).

Flow: is the number of vehicles that can pass a reference point per unit of time and is measured in vehicles per hour. It is the interaction between vehicles, drivers and the road environment. There are two primary types of flow: uninterrupted and interrupted flow.

Gap Acceptance: In many traffic situations, such as pedestrians crossing a road, vehicles overtaking on undivided roads or side-road traffic entering major roads at unsignalised intersections, road users must wait for acceptable time gaps in the traffic stream to which they must give way before they can proceed. The gap time a person waits before taking a gap is gap acceptance and is measured in seconds.

Kinetic Energy: is the energy of an object due to motion. Kinetic energy is directly proportional to the mass of the object and to the square of its velocity: K.E. = 1/2 m v2.

Headway (h): is the time separating passing of a fixed point by two consecutive vehicles in a stream of traffic heading in the same direction. Headway is expressed in seconds per vehicle **(s/veh).** This is worked out by an average of a series of headways in a given stream of traffic.

Heavy Goods Vehicles (HGV): a vehicle that has a gross mass of more than 3.5 tonnes. Also known as Heavy Commercial Vehicles (HCVs).

Interrupted Flow: is where the flow in a stream of traffic is affected by external factors such as intersections and pedestrian crossings.

Issue for construction (IFC) drawings: this is the approved set of drawings that the contractor uses to construct onsite. These go through a stringent check/review and independent safe systems audit process before being issued as final for construction.

Lane Occupancy: is the proportion of time that there is a vehicle present at a specified point in the lane. Lane occupancy is closely related to density and is a dimensionless measure.

Level of Service (LOS): is a qualitative measure for ranking operating conditions or service quality based on service measures such as speed, travel time, delay, density, freedom to manoeuvre, interruptions, comfort, convenience and safety. (Austroads GTM03-20). It is the road users' perceptions of the quality of service. There are six levels of service, A to F, with LOS A representing the best operating condition (i.e. free-flow) and LOS F the worst (i.e. forced or breakdown flow).

Light Goods Vehicles (LGV): A light goods vehicle is defined as a commercial motor vehicle with a total gross weight of 3500kg or less and includes vans and SUVs.

Queue: A stream of slow-moving or stopped traffic. This is where demand exceeds the available capacity. It can be measured in meters and vehicles.

Raised Safety Platform (RSP): A RSP is a flat-topped speed hump. It's not as uncomfortable for drivers/passengers as a traditional judder bar. It's designed to slow vehicle speeds just enough so that when road users make mistakes, drivers have time to react and avoid a crash.

Ramp slope: refers to a consistent slope from the bottom of the ramp (also known as the tow of ramp) at the existing carriageway level to the hingpoint with the RSP flat top surface.

Sight Distance: is the distance measured along the road over which a particular object is visible to the driver e.g. RSPs, pedestrians etc.

RITS: The Regional Infrastructure Technical Specification is a document that sets out how to design and construct transportation, water supply, wastewater, stormwater and landscaping infrastructure in the nine NZ participating councils' areas.

Spacing (s): space between fronts of two consecutive vehicles in a stream of traffic at a given time. This is expressed in metres per vehicle **(m/veh).**

Speed (v): is the distance travelled by vehicle per unit of time. It is generally expressed in metres per second (m/s) or kilometres per hour **(km/h).** Average, mean and median speeds are described below: This is a descriptor of flow.

- **Average Speed:** This is the sum of all given sets of values (speeds) divided by the total number of values.
- **Mean Speed** Is a mathematical term that refers to the average of a set of values.
- **Median Speed:** is the middlemost value of a speed data set once arranged in ascending or descending order.
- **Space Mean Speed:** is the arithmetic mean of speeds of all vehicles in a stream within a specified length of roadway at a point in time.
- **Time Mean Speed:** is the arithmetic mean of speeds of all vehicles passing a fixed point within a specified time interval.

Swedish tables – are a name used for RSPs that have a shallow departure ramp that allows a smooth transition from a tabletop to the adjoining road. The departure ramp slopes sit in the region of 1:40 as opposed to the traditional 1:15 slopes. These are common on bus and heavy vehicle routes.

Sydney Coordinated Adaptive Traffic System (SCATS): is an intelligent real-time traffic management platform that monitors the movement of people and vehicles at traffic signals. It can also be used to remotely optimise signals during peak periods.

Travel Time - Travel time is the time it takes a vehicle to travel between two fixed reference points on the road network.

Uninterrupted flow: flow in a traffic stream that is not delayed by external elements such as intersections and pedestrian crossings. Example: a free-flow motorway situation.

Volume (q): Also known as flow or flow rate. It is the number of vehicles passing a fixed reference point on a road carriageway per unit of time. This is expressed in vehicles per second (veh/s) or vehicles per hour (veh/h) for traffic analysis. It is a descriptor of flow.

Wombat crossings: is a commonly used name for Pedestrian (zebra) Crossings on raised platforms in Australia. The platform sits at the kerb level, which means pedestrians walk at a higher level than the carriageway level. In NZ, these crossings are commonly referred to as Raised zebra crossings.

Zebra Crossing: These are marked priority pedestrian crossings either at grade or incorporated onto the RSP flat top. Traffic legally has to give way to pedestrians at these locations.

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APPENDIX A : TRAFFIC MODELLING SOFTWARE EXAMPLES

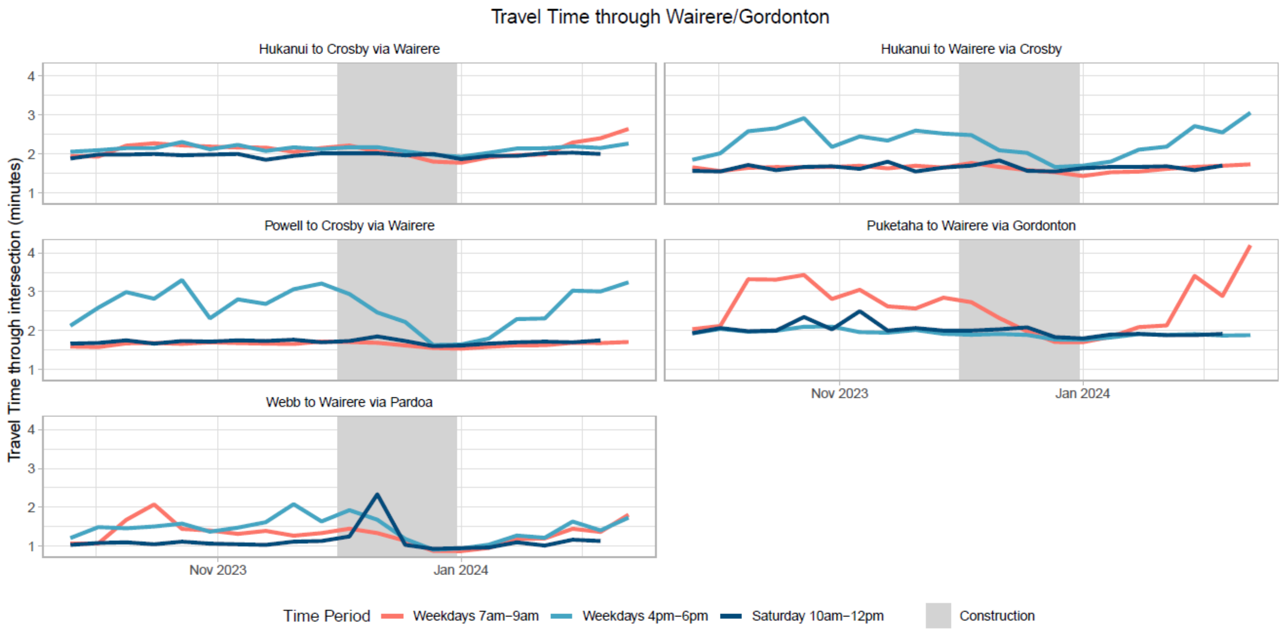
Software examples for each modelling techniques – Sourced from, AGTM03-20 appendix M.

Technique	Example software	Description – add commentary and update link.
Macroscopic model	EMME	Transport demand modelling software based on 4-step model (http://www.inro.ca/en/index.php, viewed November 2016)
	CUBE	For the modelling of passenger demand, including the 4-step model and activity-based models (http://www.citilabs.com/software/cube/, viewed November 2016)
	TransCAD	Combines GIS and transportation modelling capabilities in a single integrated platform. It can be used for all modes of transportation, at any geographic scale or level of detail. (http://www.caliper.com/tcovu.htm, viewed December 2016)
	CUBE Voyager	For the modelling of passenger demand, including the 4-step model and activity-based models (http://www.citilabs.com/software/cube/, viewed November 2016)
Mesoscopic model	TRANSYT	For the simulation of signalised road network, with traffic signal optimisation (http://mctrans.ce.ufl.edu/featured/transyt-7f/, viewed November 2016)
	SATURN	Macrosimulation combined with assignment and trip matrix estimation (http://www.saturnsoftware.co.uk/, viewed November 2016)
	SYNCHRO	A traffic signal optimisation tool for arterials and networks, using time-space analysis and platoon dispersion models (Sabra, Wallace and Lin 2000)
	LinSig	http://www.jctconsultancy.com/Software/LinSigV3/linsigv3.php#
Hybrid model	CUBE Avenue	Use and works with traditional four-step transportation planning models or with any model type that uses highway assignment (http://www.citilabs.com/citilabs_products/cube-avenue/, viewed December 2016)
	VISUM	Demand model based on the 4-step model with enhanced traffic assignment which incorporates a node delays and time-dynamic assignment and integrated with VISSIM (microsimulation) (http://www.ptvag.com/, viewed November 2016)
	OmniTRANS	Multimodal and multitemporal system, suitable for modelling the interactions between the various means of transport within an urban context. It supports both aggregated and disaggregated methods for modelling the mobility demand (http://www.dat.nl/en/products/omnitrans/, viewed December 2016)
	INRO Dynameq	Multiscale traffic simulation, it provides an advanced vehicle-based traffic simulation and simulation-based dynamic traffic assignment. It is scalable across wide-area urban networks and provides comprehensive vehicle-level detail throughout the model (https://www.inro.ca/en/products/dynameq/, viewed December 2016
	AIMSUN	For the simulation of a multi-modal transport network, it has the capability model hybrid assignments (http://www.aimsun.com/site/, viewed November 2016)
Microsimulation	AIMSUN	For the simulation of a multi-modal transport network (http://www.aimsun.com/site/, viewed November 2016)
	PARAMICS	For the simulation of a multi-modal transport network (http://www.paramics-online.com/, viewed November 2016)

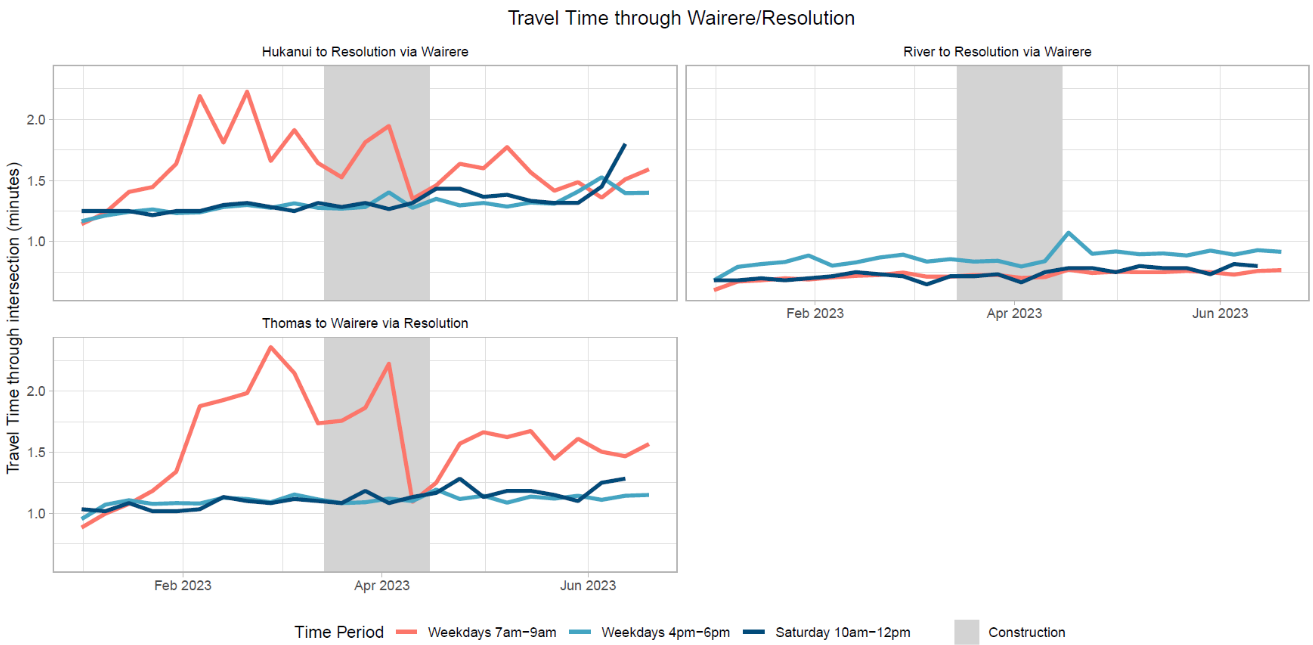
	VISSIM	For the simulation of a multi-modal transport network (http://www.ptvag.com/, viewed November 2016)
	SIDRA TRIP	A single-trip microsimulation model for assessing travel LOS, performance (delay, speed, travel time), operating cost, user cost, fuel consumption, vehicle emissions and noise in real-life road networks (http://www.sidrasolutions.com/, viewed November 2016)
Intersection model	SIDRA Intersection	For the design and analysis of single intersection (signal, roundabout, priority intersections, etc.) (http://www.sidrasolutions.com/, viewed November 2016)
	HCS	A computerised implementation of the Highway Capacity Manual (HCM), and is used to analyse signalised intersections (Sabra, Wallace and Lin 2000) updated to the HCM 2016 (http://mctrans.ce.ufl.edu/mct/index.php/hcs/https://mctrans.ce.ufl.edu/mct/index.php/hcs2010/, viewed September 2017)
	ARCADY	For roundabout analysis and it utilises empirically based models calibrated from British field data (FHWA 2000) (https://trlsoftware.co.uk/) – this UK application is more advanced

APPENDIX B : BLUETOOTH TRAVEL TIME DATA BY APPROACH

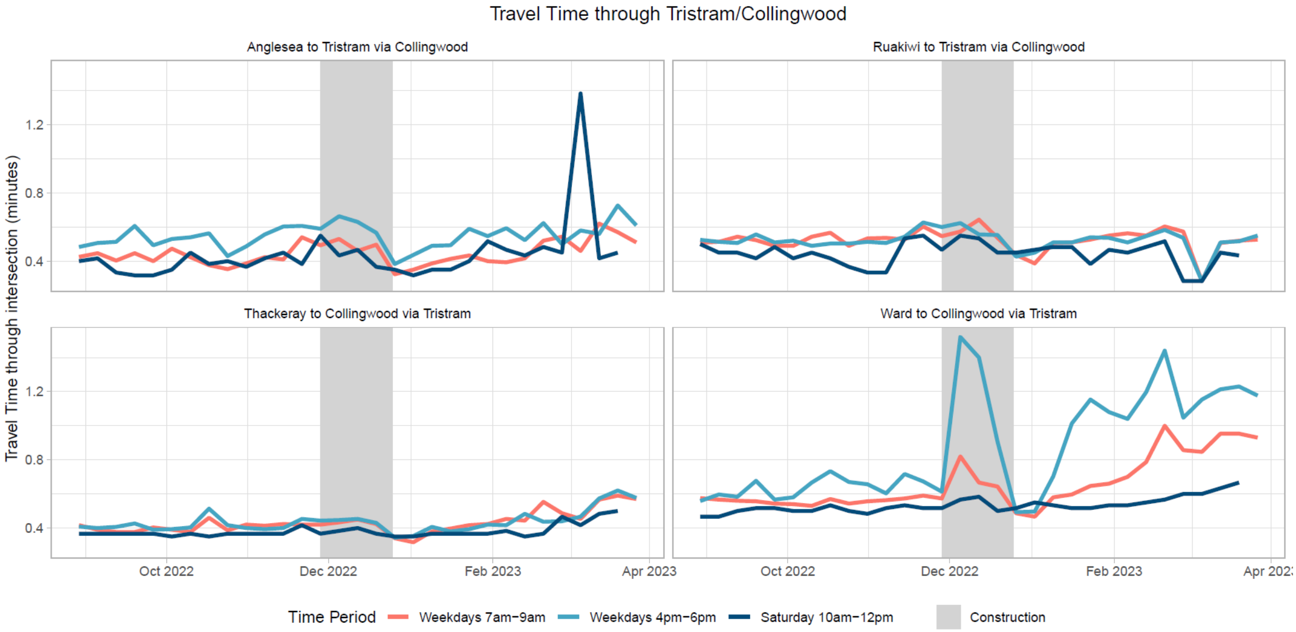
Wairere Drive and Gordonton Road



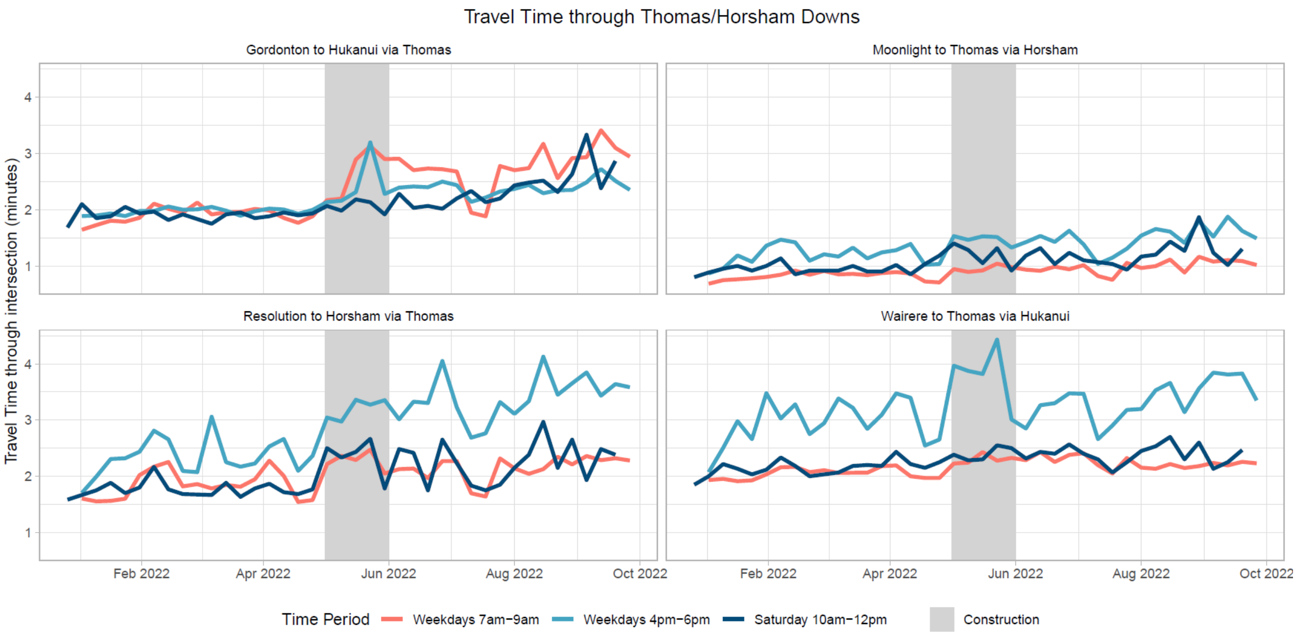
Wairere Drive and Resolution Drive Roundabout



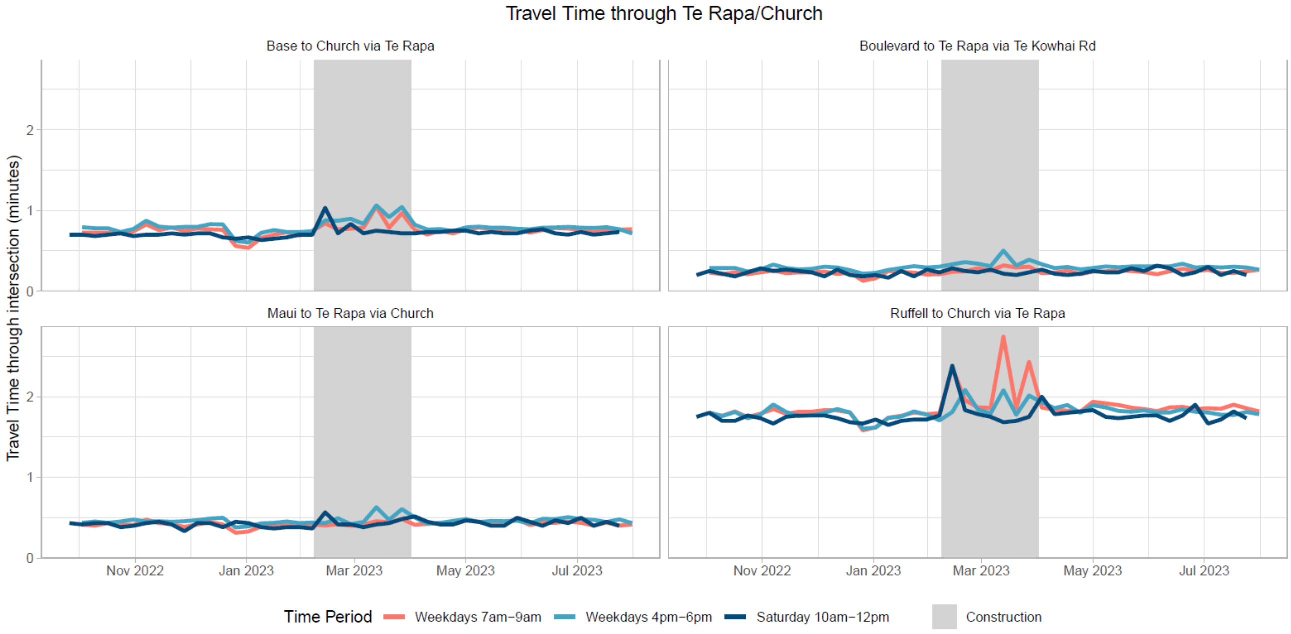
Tristram Street and Collingwood Street roundabout



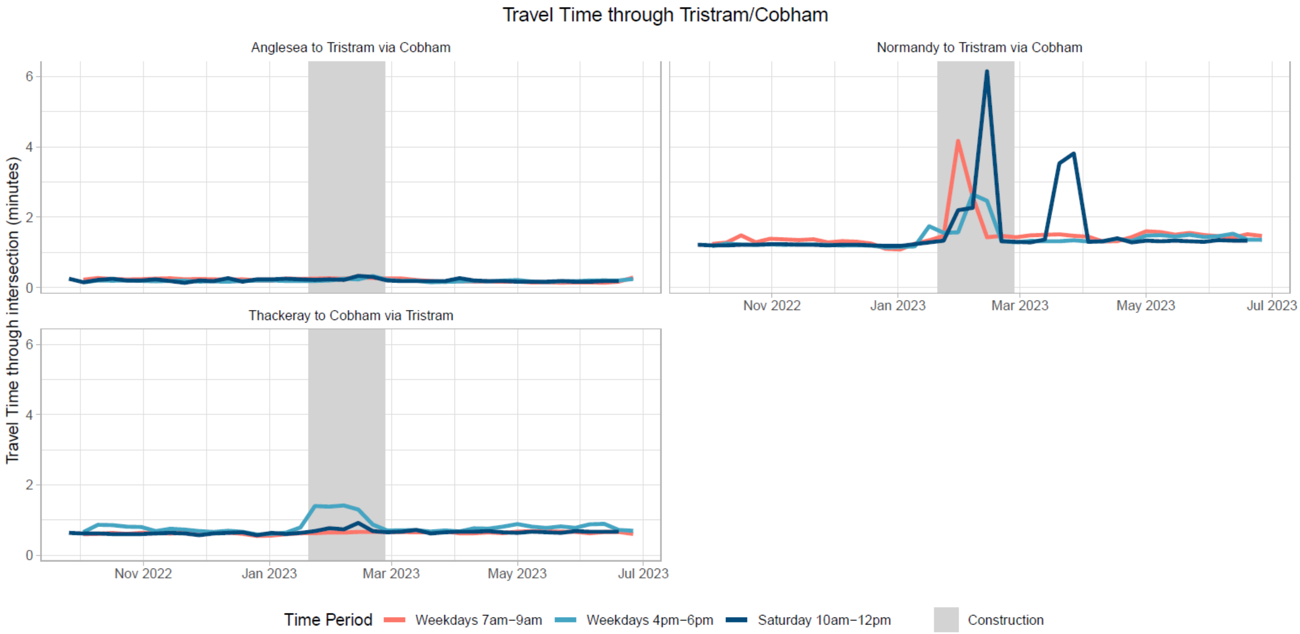
Thomas Road and Horsham Downs Road Roundabout



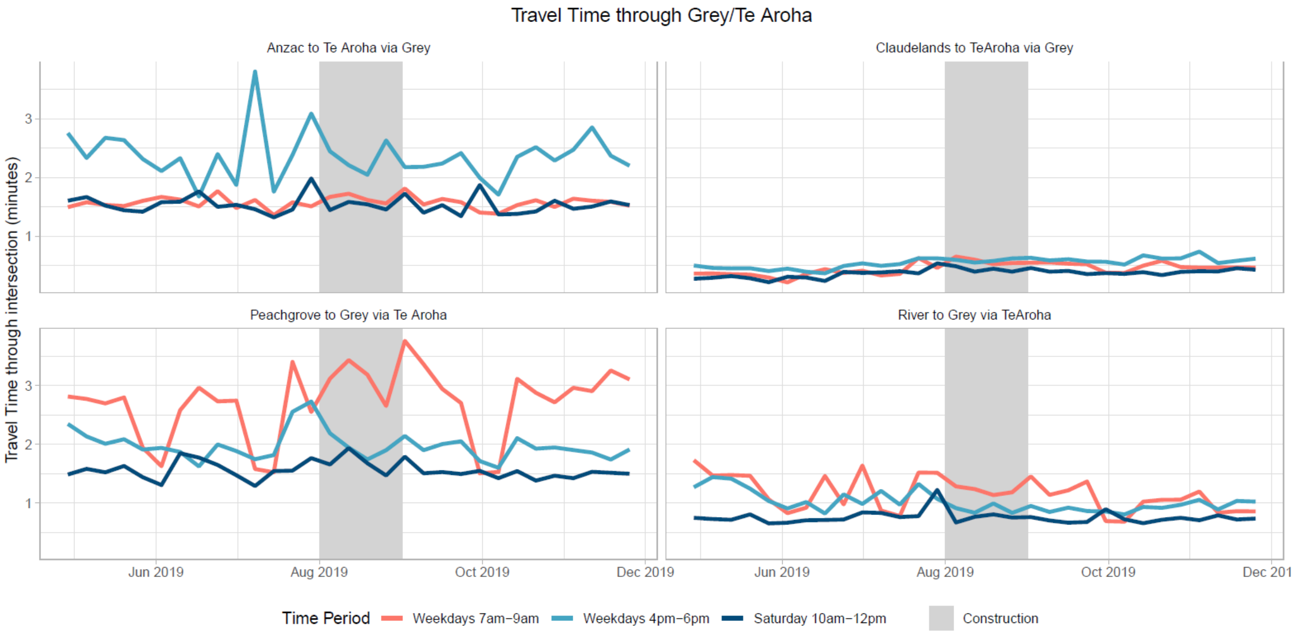
Te Rapa Road and Church Road Roundabout



Tristram Street and Cobham Drive Roundabout



Grey Street and TeAroha Street Roundabout


Travel Time through Grey/Te Aroha
Anzac to Te Aroha via Grey
Claudelands to TeAroha via Grey
Peachgrove to Grey via Te Aroha
River to Grey via TeAroha
Travel Time through intersection (minutes)
Jun 2019
Aug 2019
Oct 2019
Dec 2019
Time Period
Weekdays 7am–9am
Weekdays 4pm–6pm
Saturday 10am–12pm
Construction

APPENDIX C : MICRO SIMULATION OUTPUT RESULTS – WAIRERE/RESOLUTION ROUNDABOUT

Entry Flow Volumes

	BASE- AM	POST - AM		% flow change	BASE - PM	POST PM	% flow change
WAIRERE DRIVE WEST	**1352**	**1218**		**10**	1347	1133	**16**
RESOLUTION DRIVE	**985**	**1088**		**-10**	610	597	**2**
WAIRERE DRIVE EAST	**920**	**919**		**0**	1156	1133	**2**

BASE AM

SIMRUN	TIMEINT	MOVEMENT	QLEN	QLENMAX	VEHS(ALL)	PERS(ALL)	LOS(ALL)	LOSVAL(ALL)	VEHDELAY(ALL)
2	900-4500	1 - 2: Wairere East (WB)@14.2 - 4: Wairere West (WB)@40.4	8	160	868	868	LOS_A	1	10
2	900-4500	1 - 2: Wairere East (WB)@14.2 - 6: Wairere East (EB)@46.1	8	160	5	5	LOS_A	1	9
2	900-4500	1 - 2: Wairere East (WB)@14.2 - 8: Resolution (NB)@37.1	8	160	91	91	LOS_B	2	11
2	900-4500	1 - 5: Wairere West (EB)@456.6 - 4: Wairere West (WB)@40.4	2	53	18	18	LOS_A	1	5
2	900-4500	1 - 5: Wairere West (EB)@456.6 - 6: Wairere East (EB)@46.1	2	53	946	946	LOS_A	1	3
2	900-4500	1 - 5: Wairere West (EB)@456.6 - 8: Resolution (NB)@37.1	2	53	341	341	LOS_A	1	3
2	900-4500	1 - 9: Resolution (SB)@2.4 - 4: Wairere West (WB)@40.4	97	431	702	702	LOS_D	4	31
2	900-4500	1 - 9: Resolution (SB)@2.4 - 6: Wairere East (EB)@46.1	97	431	259	259	LOS_E	5	37
2	900-4500	1 - 9: Resolution (SB)@2.4 - 8: Resolution (NB)@37.1	97	431	15	15	LOS_D	4	31
2	900-4500	1	35.84072	431.482729	3245	3245	LOS_B	2	14

$VEHICLETRAVELTIMEMEASUREMENTEVALUATION:SIMRUN	TIMEINT	VEHICLETRAVELTIMEMEASUREMENT	VEHS(ALL)	TRAVTM(ALL)	DISTTRAV(ALL)
2	900-4500	1: Wairere West to Resolution	342	46	696
2	900-4500	2: Wairere west to Wairere East	945	50	723
2	900-4500	3: Resolution to Wairere East	258	89	643
2	900-4500	4: Resolution to Wairere Drive West	704	93	746
2	900-4500	5: Wairere East to Wairere West	869	57	757
2	900-4500	6: Wairere East to Resolution	92	62	760

POST AM - without RSP RSA

SIMRUN	TIMEINT	MOVEMENT	QLEN	QLENMAX	VEHS(ALL)	PERS(ALL)	LOS(ALL)	LOSVAL(ALL)	VEHDELAY(ALL)
1	900-4500	1 - 2: Wairere East (WB)@14.2 - 4: Wairere West (WB)@40.4	9	171	797	797	LOS_A	1	9
1	900-4500	1 - 2: Wairere East (WB)@14.2 - 6: Wairere East (EB)@46.1	9	171	12	12	LOS_A	1	8
1	900-4500	1 - 2: Wairere East (WB)@14.2 - 8: Resolution (NB)@37.1	9	171	152	152	LOS_B	2	12
1	900-4500	1 - 5: Wairere West (EB)@456.6 - 4: Wairere West (WB)@40.4	2	53	15	15	LOS_A	1	6
1	900-4500	1 - 5: Wairere West (EB)@456.6 - 6: Wairere East (EB)@46.1	2	53	865	865	LOS_A	1	4
1	900-4500	1 - 5: Wairere West (EB)@456.6 - 8: Resolution (NB)@37.1	2	53	309	309	LOS_A	1	3
1	900-4500	1 - 9: Resolution (SB)@2.4 - 4: Wairere West (WB)@40.4	181	455	676	676	LOS_D	4	30
1	900-4500	1 - 9: Resolution (SB)@2.4 - 6: Wairere East (EB)@46.1	181	455	386	386	LOS_D	4	34
1	900-4500	1 - 9: Resolution (SB)@2.4 - 8: Resolution (NB)@37.1	181	455	14	14	LOS_D	4	27
1	900-4500	1	64	455	3226	3226	LOS_B	2	15

$VEHICLETRAVELTIMEMEASUREMENTEVALUATION:SIMRUN	TIMEINT	VEHICLETRAVELTIMEMEASUREMENT	VEHS(ALL)	TRAVTM(ALL)	DISTTRAV(ALL)
1	900-4500	1: Wairere West to Resolution	310	46	696
1	900-4500	2: Wairere west to Wairere East	865	50	723
1	900-4500	3: Resolution to Wairere East	386	104	643

1	900-4500	4: Resolution to Wairere Drive West	670	108	746
1	900-4500	5: Wairere East to Wairere West	802	56	757
1	900-4500	6: Wairere East to Resolution	153	62	760

POST AM - with RSP RSA

SIMRUN	TIMEINT	MOVEMENT	QLEN	QLENMAX	VEHS(ALL)	PERS(ALL)	LOS(ALL)	LOSVAL(ALL)	VEHDELAY(ALL)
5	900-4500	1 - 2: Wairere East (WB)@14.2 - 4: Wairere West (WB)@40.4	11	212	800	800	LOS_B	2	10
5	900-4500	1 - 2: Wairere East (WB)@14.2 - 6: Wairere East (EB)@46.1	11	212	12	12	LOS_B	2	13
5	900-4500	1 - 2: Wairere East (WB)@14.2 - 8: Resolution (NB)@37.1	11	212	152	152	LOS_B	2	12
5	900-4500	1 - 5: Wairere West (EB)@456.6 - 4: Wairere West (WB)@40.4	2	52	15	15	LOS_A	1	4
5	900-4500	1 - 5: Wairere West (EB)@456.6 - 6: Wairere East (EB)@46.1	2	52	866	866	LOS_A	1	3
5	900-4500	1 - 5: Wairere West (EB)@456.6 - 8: Resolution (NB)@37.1	2	52	309	309	LOS_A	1	3
5	900-4500	1 - 9: Resolution (SB)@2.4 - 4: Wairere West (WB)@40.4	93	456	674	674	LOS_C	3	23
5	900-4500	1 - 9: Resolution (SB)@2.4 - 6: Wairere East (EB)@46.1	93	456	384	384	LOS_D	4	28
5	900-4500	1 - 9: Resolution (SB)@2.4 - 8: Resolution (NB)@37.1	93	456	14	14	LOS_C	3	16
5	900-4500	1	35.52394	456	3226	3226	LOS_B	2	13

$VEHICLETRAVELTIMEMEASUREMENTEVALUATION:SIMRUN	TIMEINT	VEHICLETRAVELTIME MEASUREMENT	VEHS(ALL)	TRAVTM(ALL)	DISTTRAV(ALL)
5	900-4500	1: Wairere West to Resolution	310	47	696
5	900-4500	2: Wairere west to Wairere East	866	51	723
5	900-4500	3: Resolution to Wairere East	385	82	643
5	900-4500	4: Resolution to Wairere Drive West	670	85	746
5	900-4500	5: Wairere East to Wairere West	802	58	757
5	900-4500	6: Wairere East to Resolution	152	63	760

APPENDIX D : MICRO SIMULATION OUTPUT RESULTS – WAIRERE/GORDONTON ROUNDABOUT

Volumes	BASE- AM	POST - AM	% flow	BASE - PM	POST PM	% flow change
WAI WEST	870	871	**0**	698	690	**1**
Gordonton	731	986	**-35**	545	608	**-12**
Pardoa	510	510	**0**	644	744	**-16**
Wai South	701	691	**1.4**	896	844	**6**
Crosby	108	122	**-13**	83	133	**-60**

BASE AM

$VEHICLEINPUT:N(	NAME	LINK	VOLUME(1)	VEHCOMP(1)			
1		10: Crosby Road	108	1: Car, LGV, HGV (50 km/h)		10: Crosby Road	**122**
2		14: Wairere West	870	1: Car, LGV, HGV (50 km/h)		14: Wairere West	**871**
3		16: Gordonton Road	731	1: Car, LGV, HGV (50 km/h)		16: Gordonton Road	**986**
4		18: Pardoa BLVD	510	1: Car, LGV, HGV (50 km/h)		18: Pardoa BLVD	**510**
5		2: Wairere South (NB)	701	1: Car, LGV, HGV (50 km/h)		2: Wairere South (NB)	**691**

SIMRUN	TIMEINT	MOVEMENT	QLEN	QLENMAX	VEHS(ALL)	PERS(ALL)	LOS(ALL)	LOSVAL(ALL)	VEHDELAY(ALL)
8	900-4500	1 - 2: Wairere South (NB)@437.6 - 6: Wairere West (WB)@51.8	1.720002	37	389	389	LOS_A	1	3
8	900-4500	1 - 2: Wairere South (NB)@437.6 - 7: Gordonton (NB)@60.6	1.720002	37	196	196	LOS_A	1	4
8	900-4500	1 - 2: Wairere South (NB)@437.6 - 8: Pardoa (EB)@54.8	1.720002	37	66	66	LOS_A	1	5
8	900-4500	1 - 2: Wairere South (NB)@437.6 - 9: Crosby (WB)@27.8	1.720002	37	26	26	LOS_A	1	3
8	900-4500	1 - 2: Wairere South (NB)@437.6 - 11: Wairere South (SB)@78.2	1.720002	37	5	5	LOS_A	1	8
8	900-4500	1 - 3: Pardoa (WB)@47.7 - 6: Wairere West (WB)@51.8	409.125947	510	174	174	LOS_F	6	295
8	900-4500	1 - 3: Pardoa (WB)@47.7 - 7:	409.125947	510	30	30	LOS_F	6	318
8	900-4500	1 - 3: Pardoa (WB)@47.7 - 8: Pardoa	409.125947	510	4	4	LOS_F	6	312
8	900-4500	1 - 3: Pardoa (WB)@47.7 - 9: Crosby	409.125947	510	50	50	LOS_F	6	154
8	900-4500	1 - 3: Pardoa (WB)@47.7 - 11: Wairere South (SB)@78.2	409.125947	510	90	90	LOS_F	6	126
8	900-4500	1 - 4: Gordonton (SB)@21.1 - 6: Wairere West (WB)@51.8	448.535799	506	81	81	LOS_F	6	126
8	900-4500	1 - 4: Gordonton (SB)@21.1 - 7: Gordonton (NB)@60.6	448.535799	506	4	4	LOS_F	6	131
8	900-4500	1 - 4: Gordonton (SB)@21.1 - 8: Pardoa	448.535799	506	65	65	LOS_F	6	132
8	900-4500	1 - 4: Gordonton (SB)@21.1 - 9: Crosby	448.535799	506	84	84	LOS_F	6	129
8	900-4500	1 - 4: Gordonton (SB)@21.1 - 11: Wairere South (SB)@78.2	448.535799	506	451	451	LOS_F	6	124
8	900-4500	1 - 5: Wairere West (EB)@25.2 - 6: Wairere West (WB)@51.8	4.521792	98	9	9	LOS_A	1	6
8	900-4500	1 - 5: Wairere West (EB)@25.2 - 7: Gordonton (NB)@60.6	4.521792	98	68	68	LOS_A	1	3
8	900-4500	1 - 5: Wairere West (EB)@25.2 - 8: Pardoa (EB)@54.8	4.521792	98	237	237	LOS_A	1	3
8	900-4500	1 - 5: Wairere West (EB)@25.2 - 9: Crosby (WB)@27.8	4.521792	98	12	12	LOS_A	1	9
8	900-4500	1 - 5: Wairere West (EB)@25.2 - 11: Wairere South (SB)@78.2	4.521792	98	520	520	LOS_A	1	7
8	900-4500	1 - 10: Crosby Road@204.8 - 6: Wairere West (WB)@51.8	0.891463	24	8	8	LOS_A	1	5
8	900-4500	1 - 10: Crosby Road@204.8 - 7: Gordonton (NB)@60.6	0.891463	24	19	19	LOS_B	2	11
8	900-4500	1 - 10: Crosby Road@204.8 - 8: Pardoa	0.891463	24	42	42	LOS_C	3	15
8	900-4500	1 - 10: Crosby Road@204.8 - 9: Crosby	0.891463	24	1	1	LOS_D	4	26
8	900-4500	1 - 10: Crosby Road@204.8 - 11: Wairere South (SB)@78.2	0.891463	24	37	37	LOS_B	2	14
8	900-4500	1	144.281077	510	2668	2668	LOS_F	6	66

	SIMRUN	TIMEINT	VEHICLETRAVELTIMEMEASUREMENT	VEHS(ALL)	TRAVTM(ALL)	DISTTRAV(ALL)
1	8	900-4500	1: Crosby to Wairere West	8	41	448
2	8	900-4500	2: Crosby to Gordonton	19	48	450
3	8	900-4500	3: Crosby to Pardoa	42	64	573
4	8	900-4500	4: Crosby to Wairere	38	66	589
5	8	900-4500	5: Wairere West to	67	44	684
6	8	900-4500	6: Wairere West to	236	56	804
7	8	900-4500	7: Wairere West to	519	63	824
8	8	900-4500	8: Wairere West to	12	66	822
9	8	900-4500	9: Gordonton to Pardoa	65	333	755
10	8	900-4500	10: Gordonton to	452	327	774
11	8	900-4500	11: Gordonton to	84	337	772
12	8	900-4500	12: Gordonton to	81	343	849
13	8	900-4500	13: Pardoa to Wairere	89	466	728
14	8	900-4500	14: Pardoa to Crosby	50	529	734
15	8	900-4500	15: Pardoa to Wairere West	175	610	803
16	8	900-4500	16: Pardoa to Gordonton	31	602	797
17	8	900-4500	17: Wairere South to	26	49	694
18	8	900-4500	18: Wairere South to	389	54	774
19	8	900-4500	19: Wairere South to	196	57	774
20	8	900-4500	20: Wairere South to	67	69	906

	$VISION	POST AM - without RSP RSA				
$VEHICLEINPUT:N	NAME	LINK	**VOLUME(1)**	VEHCOMP(1)		
1		10: Crosby Road	**122**	1: Car, LGV, HGV (50 km/h)	, LGV, HGV (50 km/h)	
2		14: Wairere West	**871**	1: Car, LGV, HGV (50 km/h)	, LGV, HGV (50 km/h)	
3		16: Gordonton Road	**986**	1: Car, LGV, HGV (50 km/h)	, LGV, HGV (50 km/h)	
4		18: Pardoa BLVD	**510**	1: Car, LGV, HGV (50 km/h)	, LGV, HGV (50 km/h)	
5		2: Wairere South (NB)	**691**	1: Car, LGV, HGV (50 km/h)	, LGV, HGV (50 km/h)	

SIMRUN						PERS(ALL)	LOS(ALL)	LOSVAL(ALL)	VEHDELAY(ALL)
1	900-4500	1 - 2: Wairere South (NB)@437.6 - 6: Wairere West (WB)@51.8	2	41.330786	323	323	LOS_A	1	2
1	900-4500	1 - 2: Wairere South (NB)@437.6 - 7: Gordonton (NB)@60.6	2	41.330786	236	236	LOS_A	1	4
1	900-4500	1 - 2: Wairere South (NB)@437.6 - 8: Pardoa (EB)@54.8	2	41.330786	71	71	LOS_A	1	4
1	900-4500	1 - 2: Wairere South (NB)@437.6 - 9: Crosby (WB)@27.8	2	41.330786	38	38	LOS_A	1	3
1	900-4500	1 - 2: Wairere South (NB)@437.6 - 11: Wairere South (SB)@78.2	2	41.330786	6	6	LOS_A	1	6
1	900-4500	1 - 3: Pardoa (WB)@47.7 - 6: Wairere West (WB)@51.8	474	499.770017	150	150	LOS_F	6	362
1	900-4500	1 - 3: Pardoa (WB)@47.7 - 7:	474	499.770017	28	28	LOS_F	6	361
1	900-4500	1 - 3: Pardoa (WB)@47.7 - 8: Pardoa	474	499.770017	4	4	LOS_F	6	272
1	900-4500	1 - 3: Pardoa (WB)@47.7 - 9: Crosby	474	499.770017	68	68	LOS_F	6	160
1	900-4500	1 - 3: Pardoa (WB)@47.7 - 11: Wairere South (SB)@78.2	474	499.770017	59	59	LOS_F	6	167

1	900-4500	1 - 4: Gordonton (SB)@21.1 - 6: Wairere West (WB)@51.8	469	516.418327	85	85	LOS_F	6	149
1	900-4500	1 - 4: Gordonton (SB)@21.1 - 7: Gordonton (NB)@60.6	469	516.418327	8	8	LOS_F	6	153
1	900-4500	1 - 4: Gordonton (SB)@21.1 - 8: Pardoa	469	516.418327	45	45	LOS_F	6	139
1	900-4500	1 - 4: Gordonton (SB)@21.1 - 9: Crosby	469	516.418327	73	73	LOS_F	6	132
1	900-4500	1 - 4: Gordonton (SB)@21.1 - 11: Wairere South (SB)@78.2	469	516.418327	426	426	LOS_F	6	135
1	900-4500	1 - 5: Wairere West (EB)@25.2 - 6: Wairere West (WB)@51.8	10	110.483801	9	9	LOS_A	1	5
1	900-4500	1 - 5: Wairere West (EB)@25.2 - 7: Gordonton (NB)@60.6	10	110.483801	59	59	LOS_A	1	3
1	900-4500	1 - 5: Wairere West (EB)@25.2 - 8: Pardoa (EB)@54.8	10	110.483801	180	180	LOS_A	1	4
1	900-4500	1 - 5: Wairere West (EB)@25.2 - 9: Crosby (WB)@27.8	10	110.483801	22	22	LOS_C	3	15
1	900-4500	1 - 5: Wairere West (EB)@25.2 - 11: Wairere South (SB)@78.2	10	110.483801	578	578	LOS_B	2	11
1	900-4500	1 - 10: Crosby Road@204.8 - 6: Wairere West (WB)@51.8	1	24.565641	10	10	LOS_A	1	4
1	900-4500	1 - 10: Crosby Road@204.8 - 7: Gordonton (NB)@60.6	1	24.565641	20	20	LOS_B	2	13
1	900-4500	1 - 10: Crosby Road@204.8 - 8: Pardoa	1	24.565641	57	57	LOS_B	2	12
1	900-4500	1 - 10: Crosby Road@204.8 - 9: Crosby	1	24.565641	1	1	LOS_A	1	1
1	900-4500	1 - 10: Crosby Road@204.8 - 11: Wairere South (SB)@78.2	1	24.565641	33	33	LOS_B	2	12
1	900-4500	1	159.495206	516.418327	2589	2589	LOS_F	6	71

SIMRUN	TIMEINT	VEHICLETRAVELTIMEMEASUREMENT	VEHS(ALL)	TRAVTM(ALL)	DISTTRAV(ALL)
1	900-4500	1: Crosby to Wairere West	10	40	448
1	900-4500	2: Crosby to Gordonton	20	50	450
1	900-4500	3: Crosby to Pardoa	57	62	573
1	900-4500	4: Crosby to Wairere South	32	64	589
1	900-4500	5: Wairere West to Gordonton	59	43	684
1	900-4500	6: Wairere West to Pardoa	180	57	804
1	900-4500	7: Wairere West to Wairere South	576	67	824
1	900-4500	8: Wairere West to Crosby	22	72	822
1	900-4500	9: Gordonton to Pardoa	45	369	755
1	900-4500	10: Gordonton to Wairere South	426	385	774
1	900-4500	11: Gordonton to Crosby	74	375	772
1	900-4500	12: Gordonton to Wairere West	85	382	849
1	900-4500	13: Pardoa to Wairere South	59	642	728
1	900-4500	14: Pardoa to Crosby	70	588	734
1	900-4500	15: Pardoa to Wairere West	150	788	803
1	900-4500	16: Pardoa to Gordonton	28	786	797
1	900-4500	17: Wairere South to Crosby	38	48	694
1	900-4500	18: Wairere South to Wairere West	323	54	774
1	900-4500	19: Wairere South to Gordonton	235	56	774
1	900-4500	20: Wairere South to Pardoa	72	68	906

$VISION **POST AM - with RSP RSA**

$VEHICLEINPUT:N(	NAME	LINK	VOLUME(1)	VEHCOMP(1)
1		10	122	1
2		14	871	1
3		16	986	1
4		18	510	1
5		2	691	1

SIMRUN	TIMEINT	MOVEMENT	QLEN	QLENMAX	VEHS(ALL)	PERS(ALL)	LOS(ALL)	LOSVAL(ALL)	VEHDELAY(ALL)
1	900-4500	1 - 2: Wairere South (NB)@437.6 - 6: Wairere West (WB)@51.8	2	50.371229	323	323	LOS_A	1	3
1	900-4500	1 - 2: Wairere South (NB)@437.6 - 7: Gordonton (NB)@60.6	2	50.371229	236	236	LOS_A	1	4
1	900-4500	1 - 2: Wairere South (NB)@437.6 - 8: Pardoa (EB)@54.8	2	50.371229	71	71	LOS_A	1	5
1	900-4500	1 - 2: Wairere South (NB)@437.6 - 9: Crosby (WB)@27.8	2	50.371229	38	38	LOS_A	1	3
1	900-4500	1 - 2: Wairere South (NB)@437.6 - 11: Wairere South (SB)@78.2	2	50.371229	6	6	LOS_A	1	5
1	900-4500	1 - 3: Pardoa (WB)@47.7 - 6: Wairere West (WB)@51.8	467	510.252783	154	154	LOS_F	6	353
1	900-4500	1 - 3: Pardoa (WB)@47.7 - 7:	467	510.252783	29	29	LOS_F	6	354
1	900-4500	1 - 3: Pardoa (WB)@47.7 - 8: Pardoa	467	510.252783	4	4	LOS_F	6	237
1	900-4500	1 - 3: Pardoa (WB)@47.7 - 9: Crosby	467	510.252783	71	71	LOS_F	6	140
1	900-4500	1 - 3: Pardoa (WB)@47.7 - 11: Wairere South (SB)@78.2	467	510.252783	62	62	LOS_F	6	151

1	900-4500	1 - 4: Gordonton (SB)@21.1 - 6: Wairere West (WB)@51.8	471	516.493455	86	86	LOS_F	6	152
1	900-4500	1 - 4: Gordonton (SB)@21.1 - 7: Gordonton (NB)@60.6	471	516.493455	8	8	LOS_F	6	162
1	900-4500	1 - 4: Gordonton (SB)@21.1 - 8: Pardoa	471	516.493455	44	44	LOS_F	6	122
1	900-4500	1 - 4: Gordonton (SB)@21.1 - 9: Crosby	471	516.493455	73	73	LOS_F	6	137
1	900-4500	1 - 4: Gordonton (SB)@21.1 - 11: Wairere South (SB)@78.2	471	516.493455	427	427	LOS_F	6	137
1	900-4500	1 - 5: Wairere West (EB)@25.2 - 6: Wairere West (WB)@51.8	9	115.628524	9	9	LOS_A	1	6
1	900-4500	1 - 5: Wairere West (EB)@25.2 - 7: Gordonton (NB)@60.6	9	115.628524	59	59	LOS_A	1	3
1	900-4500	1 - 5: Wairere West (EB)@25.2 - 8: Pardoa (EB)@54.8	9	115.628524	180	180	LOS_A	1	4
1	900-4500	1 - 5: Wairere West (EB)@25.2 - 9: Crosby (WB)@27.8	9	115.628524	22	22	LOS_B	2	15
1	900-4500	1 - 5: Wairere West (EB)@25.2 - 11: Wairere South (SB)@78.2	9	115.628524	577	577	LOS_B	2	10
1	900-4500	1 - 10: Crosby Road@204.8 - 6: Wairere West (WB)@51.8	1	19.71358	10	10	LOS_A	1	4
1	900-4500	1 - 10: Crosby Road@204.8 - 7: Gordonton (NB)@60.6	1	19.71358	20	20	LOS_A	1	8
1	900-4500	1 - 10: Crosby Road@204.8 - 8: Pardoa	1	19.71358	57	57	LOS_B	2	10
1	900-4500	1 - 10: Crosby Road@204.8 - 9: Crosby	1	19.71358	1	1	LOS_B	2	12
1	900-4500	1 - 10: Crosby Road@204.8 - 11: Wairere South (SB)@78.2	1	19.71358	32	32	LOS_B	2	13
1	900-4500	1	158.505805	516.493455	2599	2599	LOS_F	6	70

SIMRUN	TIMEINT	VEHICLETRAVELTIMEMEASUREMENT	VEHS(ALL)	TRAVTM(ALL)	DISTTRAV(ALL)
1	900-4500	1: Crosby to Wairere West	10	40	448
1	900-4500	2: Crosby to Gordonton	20	46	450
1	900-4500	3: Crosby to Pardoa	57	60	573
1	900-4500	4: Crosby to Wairere South	31	64	589
1	900-4500	5: Wairere West to Gordonton	59	45	684
1	900-4500	6: Wairere West to Pardoa	181	56	804
1	900-4500	7: Wairere West to Wairere South	577	66	824
1	900-4500	8: Wairere West to Crosby	22	72	822
1	900-4500	9: Gordonton to Pardoa	44	361	755
1	900-4500	10: Gordonton to Wairere South	428	387	774
1	900-4500	11: Gordonton to Crosby	73	379	772
1	900-4500	12: Gordonton to Wairere West	86	387	849
1	900-4500	13: Pardoa to Wairere South	62	604	728
1	900-4500	14: Pardoa to Crosby	72	570	734
1	900-4500	15: Pardoa to Wairere West	153	751	803
1	900-4500	16: Pardoa to Gordonton	29	756	797
1	900-4500	17: Wairere South to Crosby	38	49	694
1	900-4500	18: Wairere South to Wairere West	323	55	774
1	900-4500	19: Wairere South to Gordonton	235	58	774
1	900-4500	20: Wairere South to Pardoa	72	71	906