Reducing pedestrian delay at traffic signals

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Abbreviations and acronyms

ACC	Accident Compensation Corporation
ARTA	Auckland Regional Transport Authority
BCR	Benefit-cost ratio
CAS	Crash Analysis System
CBD	Central business district
EEM	*Economic evaluation manual*
GPS	Government policy statement on transport
LTNZ	Land Transport NZ
NZTA	NZ Transport Agency
NZTS	New Zealand transport strategy
PEM	*Project evaluation manual*
SCATS®	Sydney Coordinated Adaptive Traffic System

Contents

Executive summary

Little attention has been given in recent years to the delays experienced by pedestrians in urban transport networks. When planning changes to traffic signals or making other network changes, the value of time for pedestrian trips is rarely considered. The traditional approach to road management has been to only focus on improving the carrying capacity relating to vehicles, with an emphasis on maximising the speed and volume of motorised traffic moving around the network. This approach to road management needs to change if we are to make urban areas more pedestrian friendly.

This research paper focuses on identifying means to reduce pedestrian delay. Micro-simulation modelling has shown that reducing pedestrian delay at signalised intersections is possible and beneficial during the middle of the day when pedestrian volumes are highest. Most of the hurdles to achieving reduced delays seem to come down to technology challenges and inefficient road management policy.

The research provides case studies on reducing pedestrian delay in New Zealand's three largest cities (Auckland, Wellington and Christchurch), as well as the findings of pedestrian attitude surveys and a literature review identifying international best practice. These case studies were carried out between 2007 and 2010. The recommendations developed during the course of the research provide both technical and policy mechanisms for improving pedestrian delay in New Zealand's central-city areas.

The problem of pedestrian delay has been compounded by the fact that value of time figures for pedestrians have been lower than those for vehicles, which affects benefit–cost ratios and effectively provides a disincentive to invest in pedestrian issues compared with other modes.

The issue has also been influenced by the way in which traffic signals have been set up and operated. Because the primary stresses on an intersection tend to occur during vehicle (commuter) peaks in the morning and afternoon, intersections tend to be set up and coordinated to allow maximum flow during these peaks.

The result is that during off-peak periods there is often spare capacity that is underutilised. Phasings and timings set up for peaks may not provide the optimum benefits during off-peak times. This is particularly important to pedestrians during lunch-time peaks, when vehicle volumes are low and pedestrian volumes are high. Pedestrians can end up waiting long periods of time as a result of poor signal phasing, rather than due to the demands of other road users being placed on the network.

In order to come up with a fair means of allocating road space, the research looked at 'per-person' delay, which includes the delay of both pedestrians and vehicle occupants (assuming a vehicle occupancy of 1.3). This provides an average delay experienced by people arriving at an intersection, irrespective of their mode of arrival. Changes to the traffic signals can then reallocate space, and be assessed on the impact on 'per-person' delay in order to assess how well the changes allocate road space.

The results of our international literature review, modelling, and pedestrian surveys indicated that there is substantial room for improvement when it comes to reducing pedestrian delay, and that the current system of weighting delay towards vehicles actually increases the overall delays for all road users at intersections.

The research's pedestrian surveys confirmed the findings of international research, including the fact that after about 20–30 seconds of delay, pedestrians' level of frustration grows disproportionately to the actual delay itself, as evidenced by their disproportionate perceptions of delay. This frustration can have implications for traffic safety if pedestrians violate the signals and cross between pedestrian cycles. Observation studies showed that in Auckland and Wellington, pedestrian delays were substantially longer than 30 seconds. Pedestrian attitude surveys found that more than half of respondents, and 75% of Aucklanders, wanted more priority for pedestrians. Two out of three pedestrians stated that they would be willing to walk on a 'solid red man' signal, suggesting a willingness to ignore signals where delays are excessive.

Micro-simulation modelling at three intersections identified that off-peak improvements could be significant for road users, as demonstrated in the following table.

Table Changes to per-person delay at stand-alone intersections

Location	Base delay per person (sec)	Effect of optimisation (sec)	Optimisation + other measures (sec)	Improved per-person delay (sec)
Lake Rd, The Strand (North Shore City)	52	-13	-21	31
Albert St & Customs St (Auckland City)	39	-12	-15	24
Taranaki St & Courtney Place (Wellington City)	36	-10	-14	22

The research resulted in three operational recommendations that could reduce pedestrian delay through relatively simple operational changes, without unfairly disadvantaging other road users:

- reduction of signal cycle times, particularly in off-peak periods when vehicle queuing capacity is less of a factor
- introduction of off-peak signal phasings, to better utilise off-peak capacity (and potentially reduce delays for both pedestrians and vehicles)
- introduction of per-person optimisation, rather than per-vehicle, to allow a fairer distribution of the time available at an intersection for all road users.

In each of the simulated locations, the micro-simulation modelling identified that optimisation decreased pedestrian delay without any substantial increases in vehicle delays during the noon–1:30pm modelled period. However, these improvements require that the intersections operate as a stand-alone intersection outside of vehicle peak periods. This would require a focus on the part of road controlling authorities to improve signalisation by providing funding for signal optimisation, which in turn would benefit both pedestrians and vehicle occupants. Further, greater data collection on pedestrian volumes and destinations would be required in order to effectively consider pedestrian benefits in signalisation improvements.

Abstract

Since 2000, the benefits of walking as a mode of travel have been recognised by the New Zealand government in a raft of policy statements and strategies. However, the Ministry of Transport acknowledges that there are a number of issues to overcome to encourage more walking. This research focuses on one of the key issues: namely, the delay experienced by pedestrians at traffic signals.

Historically, New Zealand's approach to pedestrian delay has been minimal, with pedestrian issues considered primarily from the point of view of safety, rather than level of service or amenity. At traffic signals, pedestrians are often accommodated in a way that causes the least amount of interruption to motorised traffic, and signal cycle times can be long, leading to excessive pedestrian waiting times. This can lead to frustration, causing pedestrians to violate the signals and use their own judgement to cross, resulting in safety risks.

This research, which was carried out between 2007 and 2010 in Auckland, Wellington and Christchurch, used techniques such as pedestrian attitude surveys, micro-simulation modelling and a literature review of international best practice to identify methods of reducing pedestrian delay at signalised intersections in these cities. The recommendations developed during the course of the research provide both technical and policy mechanisms for improving pedestrian delay in New Zealand's central-city areas.

1 Introduction

1.1 Background

Walking is a sustainable mode of travel, and most journeys involve a walking component, whether the main portion of the trip is made by foot, car, or using public transport. The Auckland Regional Transport Authority (ARTA) *Sustainable transport plan 2006–2016* (ARTA 2007) found that around 40% of short journeys (less than 2km) are made entirely on foot and most trips include a walking component as some part of the journey. The Plan also estimated that each year in New Zealand, pedestrians make 2.4 billion road crossings. A key issue in pedestrian journeys is the ability to cross roads safely and efficiently.

The benefits of walking as a mode of travel have been recognised by the New Zealand government in a raft of policy statements and strategies since 2000. Of particular note are the Ministry of Transport publications *Getting there – on foot, by cycle* (2006) and the New Zealand Transport Strategy (NZTS) (2002). The emphasis on walking (and cycling), and on a sustainable multi-modal approach to transport planning, was reinforced with the Government Policy Statement on transport – also known as 'the GPS' (2008) and the updated NZTS 2008. While the specific targets that were in the 2008 version were not included in the 2009 GPS, they do remain in the NZTS, which forms a non-statutory guide for regions seeking to update their regional land transport strategies. A key element of government policy is to reverse the gradual decline in the number of walking trips – this will require engineers, planners and policy makers to promote walking and to reduce the deterrents to walking.

One major deterrent to walking – particularly in built-up areas such as the centre of our major cities, or across busy multi-lane roads – can be delays at crossing locations, whether they are controlled (with traffic signals) or passive (with crossing aids). Poorly designed or poorly operated crossings facilities can act as a deterrent to pedestrians and increase the severance/cleavage caused by busy road corridors. An excessive waiting time can deter people from walking, or lead to unsafe crossing behaviour.

Like cyclists, pedestrians have often been marginalised in road management within New Zealand, with the focus typically being to increase the carrying capacity of the roads and intersections for motor vehicles. The aim has generally been to maximise the speed and throughput volume for vehicular traffic. It can be argued that the level of service for pedestrians has gradually eroded over time because of increasing competition for road space, and a lack of balance in designing roads for all modes of travel. Where pedestrians have been factored into the roading design, such as at traffic signals, they are often accommodated in a way that causes the least amount of interruption to motorised traffic. Traffic signal cycle times can be long and pedestrian waiting times excessive. This is particularly evident in our city centres.

An alternative approach is to consider pedestrians as road users who contribute to increasing the overall carrying capacity of a road corridor through a healthy and completely sustainable transport mode choice. Overseas research suggests that we should be valuing the travel times and crossing delays of pedestrians at least as highly, if not more highly, than that of motor vehicles, particularly in the built-up areas of cities.

This paper reports on research undertaken for Land Transport NZ (LTNZ, now the NZ Transport Agency) on the likely benefits of improving pedestrian travel times and travel reliability, via micro-simulation models, pedestrian questionnaires and observational surveys. The research was carried out between 2007 and 2010.

This research was guided by a steering group made up of the following members:

- Rosie Dempster, formerly of Wellington City Council
- Tim Hughes, NZTA (formerly Land Transport NZ)
- Isy Kennedy, North Shore City Council
- Tim Kirby, Wellington City Council
- Bill Sissons, BasePlus
- Mitch Tse, Auckland City Council.

1.2 Literature review

In order to expand the resources available to New Zealand researchers, an international literature search was undertaken to review research into improved pedestrian travel times, as well as to identify best practice and trial techniques that differ from New Zealand's current practices, and assess how well these approaches might work in New Zealand.

As a starting point, the team reviewed guidelines for signalised intersections from Australia, New Zealand, the UK and the US. The literature review was then expanded to encompass relevant research from a variety of countries.

It is noted that pedestrian environments differ between countries. For instance, the UK and Ireland ban filtered[1] left turns for safety reasons, so turning traffic and pedestrians will not come into direct conflict at a signalised intersection (although left turns are allowed on the red phase for the opposing movement). Although this tends to increase overall cycle times, this is mitigated by the use of traffic islands and 'staggered'[2] crossings. Furthermore, it is not mandatory in the UK for pedestrians to comply with the signals. It is also noted that as North Americans drive on the right-hand side of the road, rather than the left, the lessons learned in North America in regard to left-turning traffic will apply here to right-turning traffic, and vice versa.

1.3 Scope and limitations

This research has focused primarily on signalised pedestrian crossings, with the intention of identifying how operational changes could improve the level of service for pedestrians. The research is not intended to be a best-practice guide, but rather, to identify issues and make possible operational recommendations. Non-signalised crossing types, such as zebra crossings, largely fall outside the research, as there is little opportunity to change their functionality through operational mechanisms.

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1 Filtered turns require the turning vehicle to use gaps in the opposing traffic stream to complete the turning manoeuvre.

2 Staggered intersections consist of opposite approaches of an intersection being displaced by a certain distance; ie the approaches are 'staggered' instead of being geometrically 'opposite' each other.

Although some of the research could apply to mid-block signal-controlled crossings, the focus was on signals located at intersections, which tend to be more complex in their operational requirements and therefore present more opportunity for operational improvement.

The study focused on the ‘level of service’ and delay issues facing pedestrians. The study team initially sought to divorce this from pedestrian safety. This turned out to be impossible in practice, as the primary concern regarding high levels of delay for pedestrians is the safety issues that result from frustrated pedestrians ignoring traffic signals and making their own gap-acceptance judgements. With the exception of accidents involving filtered turns, accidents involving pedestrians at signalised intersections tend to occur when a pedestrian is crossing against a red signal. Pedestrian delay, and the frustration this causes, is therefore intrinsically linked to road safety, as pedestrian delay can lead to decreased compliance with signals and therefore a greater risk of pedestrian injury.

This study has sought to identify realistic and cost-effective measures for pedestrian network management that could be applied, with minimal changes to infrastructure, at existing signal-controlled pedestrian crossings. It would not be cost effective, for instance, to recommend that all intersections be grade separated. Likewise, it would also be unrealistic to suggest any dramatic reform to public culture or legislation.

Finally, the focus of this research was purely to investigate means of reducing pedestrian delay at traffic signals, and was not intended to solve the numerous safety aspects of pedestrian planning. Pedestrian safety was addressed to some extent, but only in terms of its relationship to pedestrian delay.

2 Policy background

Walking is such an integral part of the transportation network that it is largely taken for granted, with pedestrian trips being seen as inevitable rather than as a conscious mode choice. However, walking is an environmentally sustainable mode of travel and is also one of the most common forms of transportation, often comprising part of any trip made. Although the mode share for active transport modes has been in decline in recent years, the concept of mode share itself only considers the main part of the journey. Very few trips in urban areas can be made 'door to door' and as urban environments grow, pedestrian trips are an important means of connecting parking, public transport, commerce, entertainment and employment.

The *Pedestrian planning and design guide* (NZTA 2009) includes a travel survey showing that of the more than 6 billion trips estimated as being undertaken by New Zealand households annually, 1.151 billion trips per year (18.7%) are made by walking. New Zealanders spend 215 million hours per year sharing road space as pedestrians, and make 2.4 billion road crossings on foot.

Walking is a form of transport that has been largely overlooked throughout the highly automobile-focused English-speaking world. However, encouraging a greater number of people to consider walking as part of their daily routine can lead to benefits for public health and in well-pedestrianised cities, can lead to a substantial reduction in the number of vehicle trips made over short distances. Stimulating pedestrian activity, particularly in commercial centres, can also have an added advantage of stimulating economic activities as people live, work and play.

The NZTS 2008 includes several components that are relevant for pedestrian planning. Of these, the most important is the target of increasing walking, cycling and other active modes from 18% of the total trips in urban areas to 30%. 'Key priorities are to strengthen the foundations for effective action; provide supportive environments and systems; influence individual mode choices; and improve safety and security.' We consider that this goal cannot be achieved without greater emphasis on walking as a mode choice. One important way of improving the desirability of pedestrian trips is to reduce delays created by traffic signals. This research has found that it is possible to achieve this without significant capital cost and, in many cases, without adversely affecting other mode choices.

To some degree this will require a shift in thinking, as our attitudes toward pedestrians have largely been shaped by a policy culture throughout the English-speaking world that marginalises pedestrian interests. This evolution of culture was described in *The effectiveness of pedestrian facilities at signal controlled junctions* (Hunt and Al-Neami 1995):

> *In urban areas the junctions that carry the highest traffic flow are usually controlled by traffic signals. In the UK during the 1970s and 1980s highest priority at traffic signal controlled junctions was given to achieving maximum vehicle capacity. This approach was emphasized by urban traffic control (UTC) systems where the needs of pedestrians were not considered explicitly and were secondary to the main objective of improving system performance in relation to vehicles and their occupants.*

This has since changed, with UK policy moving toward a more balanced multi-modal approach.

New Zealand has tended to favour vehicles, with pedestrians often considered only in terms of delay to vehicles and as an impediment to intersection efficiency. Pedestrian travel times and pedestrian capacities have often been marginalised. To some extent this reflects the ease with which data for motorised traffic can be captured (ie through SCATS®) and the limitations of modelled software, which generally factors pedestrians only in terms of delay to traffic. It is more difficult to automate data capture for pedestrians, and also more difficult to model their behaviour. As a result, benefits to vehicles are more tangible and easier to quantify.

The *Pedestrian planning and design guide* (NZTA 2009) notes:

> *Walking is a form of transport, and in this respect is no different to the private car or public transport. For some groups, it is their only means of moving around their community independently. The right to walk is a fundamental element in a considerable body of public policies. Although its contribution to the wider transport network is often underestimated, the importance of walking should not be ignored.*

It is widely considered that if walking was made more attractive, the transport system would become better integrated, because walking is an essential link between the transport network (both public and private) and the destination. Since the passing of the Land Transport Management Act 2003, there has been a gradual shift in policy towards more sustainable and more integrated approaches to transportation in New Zealand. ARTA has developed recommendations for the need for safer crossings, better footpaths, and more pleasant shortcuts and walkways; however, at the time of writing, this had not yet been developed into recommendations regarding pedestrian travel times. The GPS 2008 and the accompanying NZTS 2008 set specific targets for active transport modes, and while the amended GPS 2009 has lost the specific targets, they remain in the NZTS, which forms a non-statutory guide for regions seeking to update their regional land transport strategies. Further, the 2009 GPS did maintain the same level of funding for walking/cycling facilities, and included the following short- to medium-term impacts:

- *Improvements in the provision of infrastructure and services that enhance transport efficiency and lower the cost of transportation through ... better use of existing transport capacity.*
- *Reductions in deaths and serious injuries as a result of road crashes.*
- *More transport choices, particularly for those with limited access to a car, where appropriate.*

Overall, the government policy at the time of this research still tended to favour road building; however, the preservation of the NZTS is a recognition that road building alone will not be a universally effective form of transport investment.

Much of the investment that goes into walking and cycling projects occurs at a local government level, coordinated by regional councils and regional land transport strategies. Local government is also responsible for operating traffic signals and maintaining the (non-state highway) road network. Recent regional land transport strategies, and regional and local government policies, have tended to place increasing emphasis on stimulating active transport modes and integrating modes.

At both central and local government levels, there is a desire to implement improvements without significant additional cost. The most effective means of keeping costs down is to look for increased performance efficiencies and purely operational changes, rather than expensive infrastructure investments. Making the most of existing infrastructure is a cost-effective approach, and a key aim of the GPS 2009. The optimisation of traffic signals is an area that could be given more policy and funding emphasis and achieve results with relatively little cost.

3 The value of time

'Value of time' is essentially the value that policy makers place on efforts to reduce delays. In some cases, this is derived from the values that people place on their own time (referred to as 'willingness to pay'); in other cases it is a value derived by determining values for the public cost or benefit of a project. The value of time is used for project benefit–cost ratios (BCRs) by weighing the financial cost of a project against (among other measures) the benefits gained through travel time savings.

The value of time is therefore fundamentally important to whether or not pedestrian issues will receive funding. A low value of time for pedestrians will result in a correspondingly low emphasis, as the calculated benefits will be lower, making it difficult to justify investment.

Projects in New Zealand are generally funded on a case-by-case basis, with the BCR an important part of capturing funding priority. As there is a limited amount of funding available for transport projects, pedestrian projects compete with other modes. When petitioning for funds, the comparative differences between the value of time for different modes become relevant.

The international literature review showed that in most jurisdictions, the value of time for pedestrians is higher than for vehicle occupants. In some countries the pedestrian value is considered to be two or three times higher than for other mode choices. This effectively represents a policy desire to prioritise pedestrians over vehicles.

In New Zealand, the perceived value of time for pedestrians provided in the *Economic evaluation manual* (EEM) (LTNZ 2008) is considerably lower than that for motorists. The EEM makes a distinction between work-related trips and recreational trips, and puts a higher value upon work-related activities. However, there has been very little work undertaken to determine the value of time for pedestrians in New Zealand. A case could be made for considering the economic implications of excessive pedestrian delays – particularly in central-city areas, where pedestrians are likely to be engaged in commercial activities – in much the same way one would measure the economic costs incurred by delays to motor vehicle traffic. For traffic signals, the value of time figure should also include the safety consequences of pedestrian frustration leading to an increased risk of pedestrian injury.

It should also be noted that a failure to collect pedestrian data for a project means that it is almost impossible to accurately estimate the value of time for pedestrians who are affected (either positively or negatively) by a project. The lack of pedestrian count data for most signalised crossings could be said to contribute to underinvestment in methods to improve pedestrian delays.

The value of time figures for specific modes outlined in the EEM 2008 are more or less the same as those used in 2002. The figures are therefore already somewhat out of date. In addition, the value for time for pedestrians and cyclists on work-related trips (eg commuting to work) has barely changed from the values given in the 1998 Transfund *Project evaluation manual* (PEM), and for non-work trips it has fallen substantially (see table 3.1). This suggests that when inflation is taken into account, a pedestrian's time is valued considerably less now than it was in 1998. This also reinforces the fact that the value of time has not been updated within the current legislative environment, and pre-dates changes to the policy environment from such policy enablers as the Land Transport Management Act 2003 and the NZTS.

Table 3.1 New Zealand travel time values since 1998

Value of time ($/h)	PEM 1998	EEM 2008	% change
Car, motorcycle driver (work)	$21.30	$23.85	+12%
Car, motorcycle driver (non-work)	$7.00	$7.80	+11%
Pedestrian and cyclist (work)	$21.30	$21.70	+2%
Pedestrian and cyclist (non-work)	$10.55	$6.60	-37%

It is also interesting to note that in 1998, the value of time for pedestrians involved in work-related trips was the same as for car drivers, and for non-work related trips, the pedestrian's time was actually valued more highly than that for non-work vehicle drivers, as occurs in numerous other countries.

There are several possible reasons for other countries allocating a higher value of time for pedestrians, such as acknowledging that pedestrians are exposed to the elements and harmful exhaust fumes, or using this factor to promote pedestrian trips for health reasons or as an aid to traffic decongestion.

Since 2002 the value of time for pedestrians in New Zealand has been lower than that for car occupants, and it is unlikely that the issue of pedestrian delay will be adequately resolved while this is the case.

As mentioned previously, the consequences of proposed transportation projects on pedestrians may not be accurately estimated without adequate pedestrian data, including pedestrian value of time. Vehicle volumes at signalised intersections can be readily obtained from SCATS®, but in most urban areas in New Zealand, very little information is collected regarding pedestrian crossing movements and volumes. This information therefore needs to be collected on a case-by-case basis, which increases the costs associated with including pedestrians into BCR calculations. This additional cost increases the likelihood that pedestrians will be ignored in the evaluation of the project or included as an assumed factor, which is likely to result in a bias against pedestrian traffic, as benefits to vehicles will be more tangible.

It should also be noted that while the EEM 2008 updates do not change the overall value of time for pedestrians, the EEM 2008 update did include formulas to work out BCR values for pedestrian-specific projects.

4 Safety and compliance

4.1 Safety

The relationship between pedestrian delay and pedestrian safety is a complex one. Pedestrians who feel they are faced with unreasonable delays will use their own judgement as to when it is safe to cross. However, an increase in delay does not necessarily result in an increase in non-compliance, as high volumes of traffic can act as a deterrent to non-compliance at signalised intersections. Conversely, low pedestrian waiting times do not guarantee universal compliance with traffic signals.

It is therefore difficult to draw a linear relationship between delay and resulting non-compliance. It is also difficult to find an exact correlation between non-compliance and injury, as pedestrians unlawfully crossing the road will use their judgement to determine a safe crossing, and it is only when that judgement is in error that an injury or fatality might occur. Only a small portion of non-compliant activity results in an injury or fatality. However, as traffic volumes increase, any non-compliant behaviour becomes inherently riskier.

4.2 Pedestrian compliance

The *Manual on uniform traffic control devices* (Federal Highway Administration 2009) observes that traffic control signals are often considered a 'panacea' for all traffic problems at intersections; however, simply installing signals does not guarantee a favourable outcome, particularly for low vehicle volumes. Pedestrian signals, if poorly operated, can create unnecessary delay.

Various studies have found that pedestrians are more flexible in their regard for road rules than other mode types. Pedestrians tend to use traffic signals as a guide, but if they become frustrated by long delays, they will likely ignore the signals entirely and cross when they perceive the risk to be acceptable, rather than accept continued delay. Thus, pedestrian signals have a higher non-compliance rate than vehicle traffic signals (and potentially, a much lower enforcement rate). Therefore, it is possible to infer that the primary measure of whether a set of signals is functioning adequately for pedestrian traffic would be the rate of non-compliance. Non-compliance to traffic signals presents a risk to the pedestrian and other road users, and as a result, frustration at pedestrian delay quite quickly translates into a road safety issue. Much of the literature we reviewed considered pedestrian delay entirely from a compliance/safety perspective, rather than as a factor in overall pedestrian travel times.

Ishaque and Noland (2007) found that:

> *... pedestrian non-compliance behaviour is encouraged by signal timings that are not favourable to them. This is the case both when a disproportionately large amount of time is made available to vehicular traffic and when pedestrian volumes are such that they do not fit into the time provided for by the pedestrian phase. Long signal cycles may pose a safety hazard for pedestrians and therefore one of the most effective measures to increase pedestrian safety and compliance is to make traffic signals as good as possible for pedestrians and that is by minimising their waiting times.*

They also reported on several European studies on the topic of pedestrian perception of delay. One two-year study in London found that at controlled crossings, 30–40% of pedestrians felt annoyed when the delay was in the range of 6–22 seconds, but more than 70% felt annoyed when the delay was longer than 26 seconds. Another study on children and adults showed that 30 seconds was the maximum that both children and adults were willing to wait at a signalised intersection, and similar findings in Germany had led to the German *Highway capacity manual* (Institute for Traffic Engineering, Ruhr-University 2000) specifically recommending that signal cycle times longer than 90 seconds should be avoided. Ishaque and Noland found that pedestrian non-compliance was encouraged by timings that were unfavourable to them, and that long cycle times could therefore pose a safety hazard that could be avoided through reducing signalised delays.

A literature review was conducted for the Transport for London publication *Factors influencing pedestrian safety* (Martin 2006). One of the topics he investigated was 'reduction of waiting times for pedestrians'. Martin found that most studies on the subject identified that longer waiting times increased the number of pedestrians who crossed on a red signal, and confirmed the 30-second delay threshold. Martin found that because pedestrians were more likely to become impatient when a 'red man' signal continued to be shown during periods of low vehicle flow, the reduction of unnecessary delay for pedestrians encouraged them to use crossings correctly and reduce risk taking. This is significant in New Zealand, because the intersections observed during the course of our research had cycle times longer than 90 seconds, and average pedestrian delays of more than 30 seconds.

The UK *Traffic advisory leaflet 5/05* (Department for Transport 2005) also raises the issue of signal compliance and reasons for some pedestrians being more willing to take risks:

> *Pedestrian compliance with the Red Man signal is thought to be generally poor. Pedestrians are more likely to disregard the Red Man signal if they consider the distance they have to walk, or the time they have to wait, is unreasonable. (When waiting at a junction in bad weather, a driver may be frustrated but is generally warm and dry. A frustrated, cold and/or wet pedestrian is more likely to take what otherwise they would consider an unacceptable risk).*

Part 7 in the Austroads *Guides to engineering practice – traffic signals* (1994) identifies that drivers and pedestrians will disobey a red signal if delays are abnormally long. The guidelines suggested that a maximum waiting time of 20 seconds would be tolerated in light traffic, and 120 seconds in heavy traffic. This is much longer than the time suggested in literature from other sources, and longer than what was considered acceptable by pedestrians interviewed during this research. As a general rule, signals engineers try to aim for a total cycle of 120 seconds or less, where possible.

Australian research conducted by Daff et al (1991) showed that 24% of pedestrians crossed against a steady 'don't walk' signal, and between 2–15% crossed against a flashing 'don't walk' signal. Of those crossing against the flashing signal, 28% ran for at least part of their crossing.

Heavier traffic flows in more recent times seem to have forced more compliance at intersection signals, though this is likely to be due to perceived safety issues rather than a greater desire to comply with signalised delays. In an effort to improve compliance, some signal operators have introduced countdown timers. These are explored further in section 5.6.5.

The literature reviewed universally found that excessive delay would lead to pedestrian frustration. However, as mentioned earlier, delay might not automatically lead to non-compliance – it depends on traffic volumes and a risk assessment on the part of pedestrians.

A study of a pedestrian sensor technology trial, *Results of VRU-too* (Carsten 1995), found that two of the three trialled sites led to a reduction in pedestrian delay. For the two sites where there was a reduction in pedestrian delay, there was also a reduction in the number of observed pedestrian–vehicle conflicts. For the test site in Leeds, the reduction was 18%. At the test site in Elefinsa, the number of pedestrians waiting more than 30 seconds dropped from 28% to 18%, and the reduction in pedestrian–vehicle conflicts resulting from signal violation dropped by 51%.

The research paper *Pedestrian compliance effects on signal delay* (Virkler 1998) summarised the results of pedestrian modelling research that sought to quantify the benefits of pedestrian non-compliance at traffic signals. Data from 47 crossings was looked at, along with delay and compliance rates. The results showed that observed delay was 31% less than the delay that had been predicted through modelling, because of the following two factors:

- pedestrians changing their walking speed and rushing to cross when they saw a green signal or flashing red signal (resulting in a substantial reduction in delay for them, as it meant avoiding waiting through a full cycle)
- pedestrians avoiding delay by violating the signals.

The research concluded that ‘pedestrians can save significant amounts of delay by using more than just the Walk interval to enter the intersection’. This (unsurprisingly) confirms that pedestrians can benefit from violating signals.

High traffic volumes reduce the risk of non-compliant behaviour, as the perception of risk is greater. Where volumes are low and delays are long (eg outside of vehicle ‘peak’ periods) then pedestrians are more likely to ignore the signals. The dangers associated with this can be aggravated by a number of factors, including:

- the visibility of pedestrians vs other visual distractions (such as oncoming traffic)
- the presence of heavy vehicles, which can have significant blind spots in their field of vision and also are harder to slow down than cars, and may therefore be less able to avoid pedestrians than the pedestrian expects).

It is important, therefore, for road controlling authorities to consider pedestrian delay, and in particular to consider off-peak conditions when setting up signal phasings and timings.

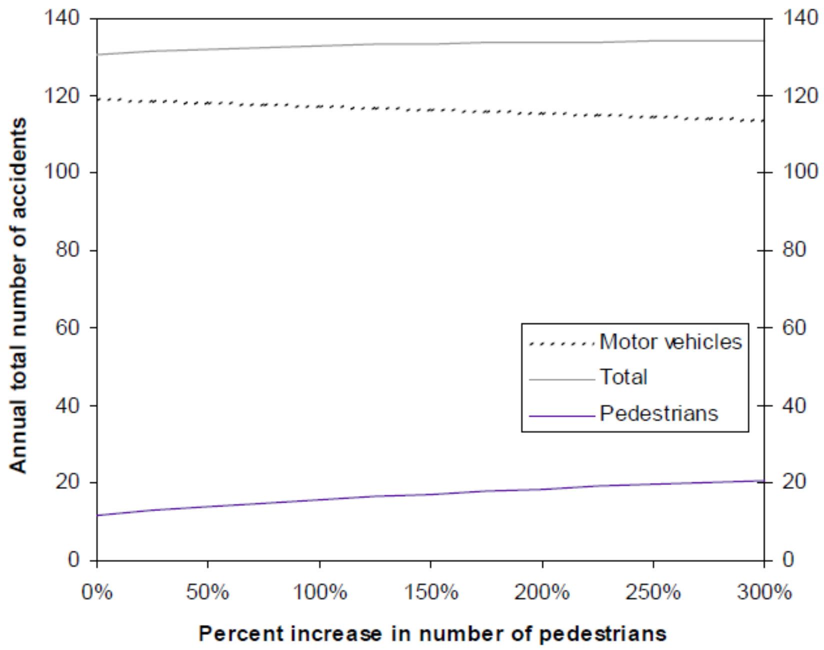
4.3 Pedestrian crash prediction modelling

A substantial amount of work has been undertaken, both in New Zealand and throughout the world, in understanding road safety issues for pedestrians. The most recent pedestrian safety research in New Zealand can be found in *Land Transport NZ report 289: Predicting accident rates for cyclists and pedestrians* (Turner et al 2006). An interesting finding of this research was a comparison between pedestrian and cycling incidents reported to the official Crash Analysis System (CAS) database, and those recorded in the databases of the Accident Compensation Corporation (ACC) and St John Ambulance. This comparison found that there was significant under-reporting of pedestrian and cycling incidents in CAS. This has direct implications for safety research and also for developing day-to-day engineering solutions to safety issues. There is a need to consider this under-reporting while developing crash prediction models.

Turner et al (2006) also found that the people most likely to be injured on New Zealand roads were those aged 10–20 years and the elderly. In the case of those aged 10–20, the number of incidents, although high, matched the percentage of pedestrian trips by this age group. The high rate of incidents could therefore be attributable to the over-representation of this age group as pedestrians, rather than any particular behavioural trait in this age group. People over 80 were the largest group of pedestrian casualties per kilometre travelled. Contributing factors included the likelihood of reduced mobility, and the increased seriousness of their injuries meaning the injury was more likely to be reported.

The crash prediction models developed by Turner et al considered traffic signals and commercial mid-block sites. International research reached similar conclusions on a 'safety in numbers' effect. Essentially, they found that an increase in pedestrians (or cyclists) does not result in a linear increase in crashes. Although there may be more injuries, in absolute terms, an increase in pedestrian numbers appears to lead to an improvement in safety on a per-pedestrian basis. This is demonstrated in figure 4.1 below, which was taken from *Land Transport NZ report 289*. The results of modelling indicated that a 300% increase in pedestrians crossing at signalised intersections could result in a 55% reduction in injuries per pedestrian – ie there is a 'safety in numbers' effect, and as pedestrian volumes increase, the risk per individual pedestrian reduces.

Figure 4.1 Pedestrian and motor vehicle accidents at signalised intersections in Christchurch (LTNZ 2006)



This safety in numbers effect is consistent with other research, such as Jacobsen (2003), who explored several aspects of the safety in numbers effect for walking and cycling. Jacobsen found that cities with a higher walking or cycling mode share had comparatively fewer accidents per kilometre travelled. Jacobsen also found the correlation worked with both increasing and decreasing mode shares, with a reduction in walking or cycling kilometres travelled increasing the per-person/per-km risk. Jacobsen concluded that driver behaviour played a strong part in the likelihood of a pedestrian or cyclist being injured, and that this aspect was influenced by numbers. Presumably this is because a more visible presence of cyclists or pedestrians on the road space leads to greater awareness on the part of motorists of the possible conflicts that may occur.

4.4 New Zealand pedestrian safety statistics

The *Pedestrians crash factsheet* (MoT 2007) contains a number of interesting facts regarding pedestrian road safety, including:

- The total cost of pedestrian injuries and fatalities in 2006 was estimated to be more than $300 million.
- The number of pedestrian fatalities has gradually decreased since 1995; however, the rate of pedestrian hospitalisations has remained relatively consistent.
- The age groups most likely to be injured as pedestrians are children and the elderly, particularly those aged 5–9 and those over 80.
- Ninety percent of pedestrian fatalities occur on urban roads with a speed limit of 70km/h or less.
- An alert driver travelling at 50km/h will take 37 metres to stop.
- An alert driver travelling at 100km/h will take 74 metres to stop – collisions where the speed is higher than 70km/h are invariably fatal.

These facts indicate a genuine need to improve safety between vehicles and pedestrians. If left unregulated by well-timed signalised pedestrian crossings, drivers will be more likely to be travelling faster and to come into conflict with pedestrians, resulting in injuries or fatalities.

Highly urbanised central-city locations are areas where safety and delay issues are the most pronounced. This is demonstrated in ARTA's 2005 *Submission on Queen Street upgrade*, which noted that there were more than 50,000 pedestrians using Auckland's Queen St every day. Pedestrians were involved in 45% of the injuries on Queen St, with 12–15 serious injuries per year. Anecdotal evidence suggests that since the delay at intersections along Queen St have been improved, the number of mid-block crossings by pedestrians has decreased. This suggests that when pedestrians are aware of excessive delays at intersections, this can have a flow-on to safety issues for surrounding mid-block areas.

The research report *Predicting accident rates for cyclists and pedestrians* (Turner et al 2006) included a number of findings relating to pedestrians, including the following extracts:

- *... recent government legislation and policy is promoting an increase in walking within our cities and towns as alternative to the increasing demand for motor vehicle travel. It is known that 46% of motor vehicle driver tours (round trips that begin and end at home) are under 10km in total length and 19% under 4km in length. This highlights the opportunities to increase the mode share of sustainable modes of walking. Concern exists, however, that an increase in [sustainable] modes could lead to a substantial increase in pedestrian fatalities and injuries, particular in larger centres where motorised traffic volumes are high and increasing.*
- *For the whole of New Zealand, from 1993 to 2002 there were 9788 pedestrians reported as injured (serious and minor injuries) and 582 killed.*
- *In 2002, pedestrians accounted for 11% of all fatalities and nearly 8% of all injuries reported on roads in New Zealand. The risk of injury has been steadily falling over the*

last 30 years. However pedestrians are injured disproportionately to distances they travel when compared with all other users.

- *For the above numbers, it should be mentioned that traffic accidents where a vehicle is involved are required to be reported to the police, under Section 22 of the Land Transport Act 1998. This includes accidents on bicycles, skateboards and similar contrivances, even if a motor vehicle is not involved. It also includes injury accidents between cycles and pedestrians. For accidents on a public road that do not involve a vehicle, such as a pedestrian-only injury, no legal requirement exists.*

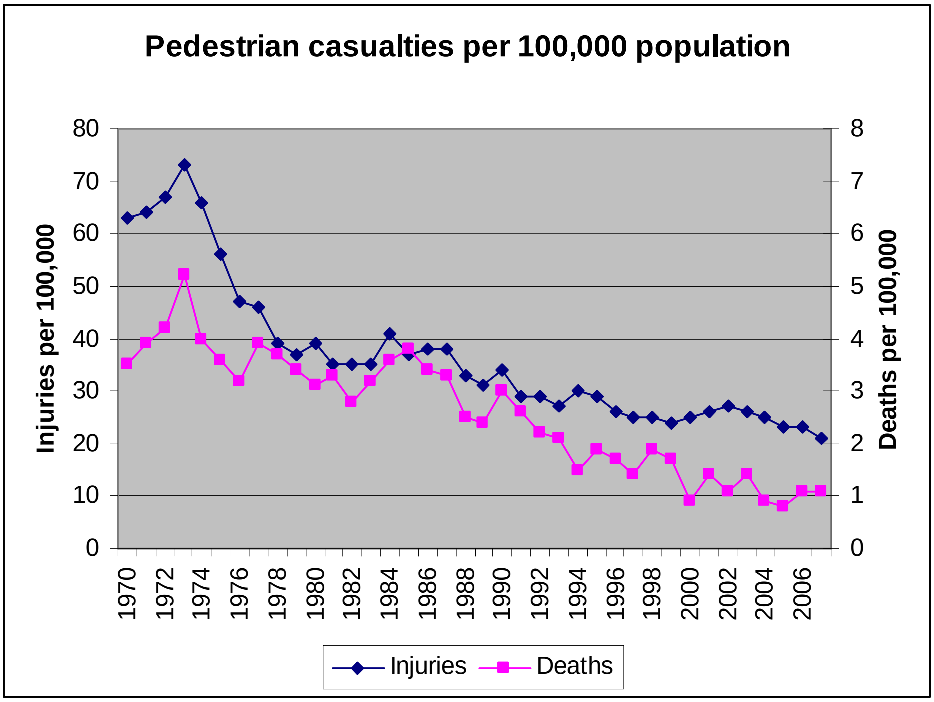
The Ministry of Transport reports on the official road toll each year and publishes road safety information every year in publications such as the *Pedestrians crash factsheet*. Table 4.1 shows official figures for pedestrian fatalities and reported injuries in New Zealand, and was compiled using safety information obtained from the Ministry of Transport webpage (www.transport.govt.nz/).

Table 4.1 New Zealand population and pedestrian casualty statistics (LTSA 2002)

Year	Population	Injured	Killed	Per 100,000 population	
				Injured	Killed
1970	2,852,100	1786	99	62.6	3.5
1975	3,143,700	1760	112	56.0	3.6
1980	3,164,100	1246	98	39.4	3.1
1985	3,311,200	1225	125	37.0	3.8
1990	3,429,100	1161	104	33.9	3.0
1991	3,449,700	1015	88	29.4	2.6
1992	3,485,400	1007	76	28.9	2.2
1993	3,524,800	949	74	26.9	2.1
1994	3,577,200	1063	54	29.7	1.5
1995	3,643,200	1053	71	28.9	1.9
1996	3,717,400	969	63	26.1	1.7
1997	3,761,100	925	54	24.6	1.4
1998	3,790,900	930	71	24.5	1.9
1999	3,810,700	895	63	23.5	1.7
2000	3,830,800	953	35	24.9	0.9
2001	3,850,100	986	52	25.6	1.4
2002	3,939,100	1065	45	27	1.1
2003	4,009,200	1058	58	26	1.4
2004	4,060,900	999	38	25	0.9
2005	4,098,300	943	31	23	0.8
2006	4,139,500	960	44	23	1.1
2007	4,228,300	868	45	21	1.1

As shown in table 4.1, there was a steep drop in the trend for pedestrian deaths and pedestrian injuries in the 1970s, followed by a gradual decline since the 1980s. Figure 4.2 below provides a graphic of this trend since 1970.

Figure 4.2 Pedestrian casualties per 100,000 population



Although a decline in pedestrian casualties may be perceived as positive, it is possible that the decline is because of a corresponding drop in pedestrian numbers. The introductory chapters to the *Pedestrian planning and design guide* (NZTA 2007) note that when population growth is taken into account, the 1990s effectively saw a reduction, by 400,000 trips per day, in trips made solely on foot. One would therefore expect to see a drop in pedestrian casualties, even if there were no other factors involved.

The *Pedestrian planning and design guide* section entitled 'The principles of pedestrian network planning' notes that:

- ninety percent of pedestrian casualties occur while pedestrians are crossing the road
- two-thirds of deaths and 93% of injuries occur in built-up urban areas
- in New Zealand's main urban centres, approximately one-third of road deaths are pedestrians.

The Guide also states that the majority of casualties are on main roads, and that the vast majority of pedestrian casualties occur away from intersections or formal crossings. This suggests that signalised crossings are effective in reducing casualties, and are necessary in urban areas to allow pedestrians to cross roads safely. This is also relevant in terms of delay, in that if a signalised crossing at an intersection causes delays that pedestrians consider unacceptable, they may be encouraged to cross prior to reaching the signals, which involves less delay but may involve a much greater personal risk. Where practical, mid-block crossings could mitigate some of this personal risk.

4.5 Safety design issues

Formal pedestrian crossings are invariably installed with the primary purpose of improving safety, rather than reducing delay. While the focus of this research has been on signalised crossings, there is a definite question as to when signals are an appropriate measure. For example, converting a zebra crossing to a signalised crossing might improve safety, but it might also increase pedestrian delay, as pedestrians lose automatic right-of-way/entitlement to cross, and instead must wait for a signal.

The *Pedestrian planning and design guide* (NZTA 2009) section entitled 'Pedestrian network components' notes the advantages and disadvantages of a number of pedestrian facilities. This section indicates a number of techniques for reducing traffic, traffic calming, and the use of components outside of the roadway. It includes tables that indicate the typical reduction (or increase) in pedestrian crashes when each of the facilities/treatments is installed.

Stops and goes of traffic signals (LTNZ 2006) provides advice on how to improve safety at signalised intersections. Among other findings, the following main factors were found to contribute to crashes involving pedestrians at signalised intersections:

- *Wide intersections intimidate pedestrians.*
- *Drivers are often distracted (from seeing pedestrians) by other vehicles.*
- *Slip lanes are generally safe for pedestrians (but large radii should be avoided).*
- *Simplifying the Give Way rules would help.*

The remedies suggested in this publication include the following:

- *The clearance-time settings need to be based on the actual crossing length and take into account special requirements (eg proximity to a rest home or hospital).*
- *Where arrow displays are present, they should always be used for full or partial pedestrian protection.*
- *If pedestrian protection is deemed warranted but no arrow displays exist, it is acceptable to provide a late start for the parallel vehicle phase (generally about 3 seconds).*
- *Unless full pedestrian protection is used, it is not good practice to provide a crosswalk that right turners from the stem of a T junction have to cross.*
- *Late introduction or reintroduction of a parallel pedestrian phase should only be used if the conflicting vehicle movements (left and right turns) have been terminated or banned (eg crossing the upstream approach of a one-way street).*

The *Pedestrian planning and design guide* (NZTA 2009) notes that heavy vehicles and buses have blind spots at the side and as they turn, the drivers may be unable to see pedestrians who are crossing. Furthermore, these accidents have a higher likelihood of being fatal to the pedestrian.

The Department for Transport (UK) Traffic Advisory Leaflet 5/05, *Pedestrian facilities at signal-controlled junctions* (DfT 2005) explains how complicated or poorly designed intersections can be dangerous for pedestrians. Examples include filtering right turns while allowing pedestrian movements on the exit approach; staggered intersections that lack a crossing pedestrian activation on a centre island; or intersections with multiple vehicle lanes that differ in character. Among other advice, the leaflet recommends that any pedestrian protection arrows that occur during peak periods should extend into off-peak periods as well, to avoid misleading pedestrians who become familiar with the crossing during the peak periods and then have a false sense of security during times when the pedestrian protection is removed. The leaflet also explains that although few pedestrian accidents are solely due to speeding vehicles, reducing vehicle speed at intersections can reduce the severity of accidents when they occur.

5 Signal-controlled pedestrian crossing design

5.1 A comment about jurisdictional differences

It is important to note that there are some fundamental design differences between various traffic jurisdictions. Of these, the most important is that New Zealand, Australia, the UK and Ireland drive on the left-hand side of the road, whereas US and Canadian traffic engineering is for the right-hand side of the road. Therefore texts written in a US context that refer to 'right turns' will be referring to what in New Zealand would be a left turn (ie a short turn). Where possible, this has been altered for the New Zealand context. Some other differences from New Zealand are as follows:

- In American jurisdictions, it is legal to make a right turn (short turn) on a red light. In New Zealand this is only possible where there is a left-turning slip lane[3].
- In the UK and Ireland, filtered turns are not used.
- In the UK it is not considered mandatory for pedestrians to obey red indications.

5.2 Pedestrians

Some interaction between vehicles and pedestrians is inevitable, particularly in urban areas where competition for space becomes more pronounced. Traffic signals are a common means of regulating this interaction and attempting to maintain or improve the safe and efficient use of the road network. Understanding how pedestrians respond to signals is therefore a key factor in their effective operation.

When planning for vehicles, the essential qualities of speed and acceleration are relatively similar across vehicle types, and therefore easy to quantify. For the most part, vehicles will travel at or close to the speed limit, subject only to geometric and environmental constraints. This is because a vehicle's speed is governed not by physical ability, but by safety concerns imposed through regulation and signage. Pedestrian walking speeds, however, are far more closely related to individual physical ability. Behaviour can also be more individualistic and more opportunistic. The primary restrictions for pedestrians do not exist in the form of signage and lane markings, but rather, in individual perceptions of safety.

The 'average' pedestrian is therefore difficult to quantify. Pedestrians vary in size, speed, strength and judgement. Their walking speeds can be affected by their age, gender or physical condition, by the trip and/or route characteristics, and also by environmental characteristics, such as bad weather. *Traffic flow models allowing for pedestrians and cyclists* (Austroads AP-R193/00 2000) discusses the complexities in modelling pedestrian behaviour, and notes that 'Pedestrians vary in their ability to move, read and interpret traffic signs, avoid obstacles, hear approaching vehicles, orientate themselves and to perceive risk'.

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3 Slip lanes at signalised intersections provide a give-way movement for left-turning traffic, allowing it to bypass the signal control while turning into the exit approach.

5.3 Signalised crossings

5.3.1 New Zealand guidelines

In New Zealand, the most suitable resource for designing crossing facilities is the *Pedestrian planning and design guide* (NZTA 2009). The Guide and its supplementary material covers every aspect of pedestrian design, from planning and BCR calculations right down to design, geometry and lighting, as well as access for wheeled and visually impaired pedestrians. Chapter 15 is dedicated to different types of crossings. Figure 5.1 below, is taken from the Guide, and provides a New Zealand approach to pedestrian signalisation of intersections.

Figure 5.1 Benefits and potential problems of signalised intersections (NZTA 2009)

Phasing	Definition	Design issues
Exclusive (dedicated/ Barnes dance)	All vehicles stop and pedestrians can walk in all directions, including across the diagonal.	It is beneficial where there are high pedestrian numbers. It is safer for pedestrians than concurrent phasings. There is greater delay to vehicles. Pedestrian have to wait longer to cross. Those walking on the diagonal have further to travel and may not be able to see the signal heads.
Concurrent (parallel)	Vehicles yield the right of way to pedestrians crossing the road into which they are turning.	Pedestrians normally have a shorter wait. There is less delay to vehicles. Pedestrians may feel intimidated by turning vehicles. A high number of pedestrians can prevent turning vehicles from completing their manoeuvre. Heavy vehicles have blind spots to the side. When turning, drivers may be unable to see pedestrian crossing from alongside.

5.3.2 ‘Red man’ and ‘green man’ signals

According to the international guidelines reviewed, most pedestrian signals have a similar procedure, with a slight variation in symbol/animation on location. Universally, a ‘red man’ or ‘don’t walk’ signal instructs the pedestrian not to attempt to cross the carriageway. A ‘green man’ or ‘walk’ signal indicates to the pedestrian they can begin to cross. A ‘flashing red man’ or ‘don’t walk’ signal indicates that a pedestrian should not to begin to cross, and crossing pedestrians should complete their crossing. It essentially means ‘don't start’. In some countries there are slight variations; for instance, a ‘flashing green man’ signal may be used instead of a ‘flashing red man’. In the UK, the ‘don't start’ phase can be covered by a period where signals are left blank. Figure 5.2 is taken from the *Pedestrian planning and design guide* (NZTA 2009), and provides a New Zealand approach to the meaning of various pedestrian signals.

Figure 5.2 New Zealand pedestrian signal explanations (NZTA 2009)

Symbol		Meaning	Ideal timings	Minimum timings
	Steady red pedestrian figure	Do not step out on to the road. Wait by the kerb.	The green walking pedestrian symbol should be displayed as soon as practicable after the call button is pressed.	The longest average waiting time should be 30 seconds to avoid pedestrians choosing their own gap and trying to cross.
	Green walking pedestrian figure	After checking it is safe to do so, walk across the road.	Provide sufficient time for all waiting pedestrians to enter the crossing. This depends on depth of waiting space occupied and agility of users.	Five seconds (six seconds preferred). At shorter intervals, some pedestrians may start to cross and then turn back.
	Flashing red pedestrian figure	Do not step out on to the road, but finish crossing if already in the road.	A pedestrian who has just entered the roadway and is travelling at the 15th percentile speed (default 15 m/s) on the longest valid crossing route, should be able to reach the opposite kerb before the steady red pedestrian figure appears.	

The UK Department of Transport's Traffic Advisory Leaflet 5/05 explains that the 'red man' and 'green man' displays are easily understood by pedestrians. However, although the solid red and green signals are readily understandable and almost universal in application, the flashing symbol can be misinterpreted. Experience in both New Zealand and overseas indicates that a proportion of people mistakenly interpret the 'flashing red man' signal to mean 'hurry up'. This issue is explored in further detail in section 6.2, along with the results of the pedestrian survey that was conducted as part of this research. We found that while the vast majority of pedestrians in New Zealand accurately understood the traffic signals, it was not uncommon for drivers to honk their horns at pedestrians on a 'flashing red man' signal. Given that the change from a green signal to a 'flashing red man' signal does not change the pedestrian's continued right to cross, or the pedestrian's legal entitlement to right of way, the fact that some drivers honked their horns suggested that understanding of the symbols was not universal.

5.4 Installing signals

Signal phasing and staging must be optimised specifically for each intersection to avoid unnecessary delays to vehicles and pedestrians. Although much of the reviewed literature covered the function of intersections in isolation, several texts made reference to the fact that pedestrians do not randomly arrive at an intersection. Instead, they tend to arrive in cyclical patterns or 'platoons' that result from interaction with adjacent signals, in the same way as vehicle traffic. Therefore, in known pedestrian corridors, pedestrian signal optimisation could benefit from viewing intersections in sequence, rather than in isolation. As with vehicles, this approach would provide the option to improve overall pedestrian travel times and reliability. This will not be suitable in all locations, as pedestrians tend to travel relatively short distances and vary significantly in terms of origin and destinations.

There is some debate, internationally, on the relative benefits of signalised and non-signalised options. The matter is complex. A pedestrian has right of way at a zebra crosswalk and, in theory, suffers little delay as a result. However, a pedestrian does not have right of way at a signalised intersection and must wait until a pedestrian 'walk' phase. Therefore converting a zebra pedestrian crossing into a signalised crossing can increase pedestrian travel times.

The reason for such a change, therefore, is usually either to improve trip reliability for vehicles, or to increase safety for pedestrians. It does not usually improve travel times for pedestrians negotiating busy roads.

A recommended US practice book titled *Design and safety of pedestrian facilities* (Institute of Transportation Engineers 1998), explains:

> *Highly complex, multiphase signals often result in confusion and hazardous situations for pedestrians. Therefore, in cases where such complex phasing is necessary, pedestrian signals and other pedestrian improvements are strongly recommended.*

In New Zealand, the *Pedestrian planning and design guide* (NZTA 2009) recommends that pedestrian signals should be provided across all legs of an intersection, unless there is a sound engineering reason not to do so.

The Austroads *Guide to engineering practice – Part 7* (1994) identifies that the objectives of signal phasing is to improve safety and intersection efficiency. The Guide suggests that these two objectives are in conflict and a compromise needs to be found. Where there are slip lanes, Austroads suggests that pedestrian signals should be provided in cases where conditions are unsafe for pedestrians (eg high vehicle speeds).

Criteria and tools to assist in choosing the most appropriate crossing facilities for New Zealand are available in the supplementary material for the *Pedestrian planning and design guide: guidelines for the selection of pedestrian facilities* (NZTA 2009), as well as in spreadsheets on the NZTA webpage for calculating which type of pedestrian crossing is appropriate. The New Zealand material is intended to provide guidelines rather than mandatory requirements. As well as providing useful direction, they also identify when types of pedestrian crossing facilities are inappropriate. The decision whether or not to use signals is based on several factors, including:

- the volume of pedestrians
- the volume of vehicles
- the number of traffic lanes that pedestrians need to cross
- the speed of traffic
- whether vehicle flow is continuous or interrupted
- proximity to other crossings
- whether or not the primary purpose of the crossing is for specific access for groups such as children or the visually impaired.

The supplementary material also provides guidance on pedestrian level of service and acceptable delays (see table 5.1). The current facilities can be assessed to see if (among other factors) they are providing an appropriate level of service. Note that this is based on average delay, not average cycle times.

Table 5.1 Acceptable levels of service for pedestrians – *Pedestrian planning and design guide* (NZTA 2009)

Average pedestrian delay (sec)	Level of service	Definition	Description	Appropriate situation
<5	A	Excellent	Pedestrians able to cross almost immediately on arrival	Local streets Collector roads
5–10	B	Very good	Most pedestrians able to cross with little delay 95th percentile delay ~40 secs	Local streets Collector roads
10–15	C	Satisfactory	Most able to cross within acceptable period 95th percentile delay ~60secs	Minor arterial Major arterial
15–20	D	Some concern	Some pedestrians must wait longer than desirable for an acceptable gap 95th percentile delay ~80secs	Minor arterial Major arterial
20–40	E	Major concern	Most pedestrians wait longer than desirable for an acceptable gap 95th percentile delay ~80secs	Inappropriate in all situations
>40	F	Unsatisfactory	Almost all pedestrians wait longer than desirable for an acceptable gap 95th percentile delay ~80secs	Inappropriate in all situations

5.5 Signal phasings

Once signals are installed, there are numerous ways in which they can be operated. Differences in timings and phasing can have a significant impact on delays for road users. A number of options exist, including when to add turning arrows or an exclusive pedestrian phase (ie Barnes Dance[4]), and how long the signal phasings should be. Each issue must be addressed on a case-by-case basis.

In 2006 Land Transport NZ published *Stops and goes of traffic signals: a traffic signal auditor's perspective*. This research audited the signals installations of eight territorial local authorities. It identified a number of issues for pedestrians using a signalised crossing, and how they could be treated (see table 5.2).

4 A Barnes Dance is a pedestrian-only phase within the cycle where pedestrians are given a green signal to cross diagonally as well as every other leg of the intersection, while vehicular traffic is stopped.

Table 5.2 Pedestrian phase issues (*Stops and goes of traffic signals* LTNZ 2006)

Issue	Recommendation
Pedestrians need to be able to clear the length of the pedestrian crossing during the clearance period to avoid conflict with crossing traffic.	The clearance-time settings need to be based on the actual crossing length and take into account special requirements (e.g., proximity to a rest home or hospital).
Where the number of pedestrian/vehicle conflicts is high, pedestrian protection using red arrow control should be considered.	Where arrow displays are present, they should always be used for full or partial pedestrian protection. If pedestrian protection is deemed warranted but no arrow display exists, it is acceptable to provide a late start for the parallel vehicle phase (generally about 3 seconds).
Late introduction or reintroduction of a pedestrian phase can catch turning motorists by surprise.	Late introduction or reintroduction of a parallel pedestrian phase should only be used if the conflicting vehicle movements (left and right turns) have been terminated or banned (e.g., crossing the upstream approach of a one-way street).

5.5.1 Clearance times

The *Manual on uniform traffic control devices* (Federal Highway Administration 2009) recommends a 4–7-second ‘walk’ interval for pedestrians. It also notes that when pedestrians see a ‘don’t walk’ signal they will continue to cross the road rather than return to the start point; therefore signal design should take this into account when calculating the ‘don’t walk’ time periods.

Sufficient walk time must be given to allow pedestrians to complete their crossing. This time depends on:

- the number of pedestrians using the crossing
- the space available for queuing pedestrians
- potential conflicts with turning traffic
- the likely presence of pedestrians with reduced mobility.

Walk times of 5–16 seconds are common. To calculate the time, a minimum of 5 seconds is used, and then more time is added if the intersection is near a school, hospital, etc. As with the decision to install signals, the duration of crossing and clearance phases vary from jurisdiction to jurisdiction; however, the proximity of vulnerable or less-confident road users will always have an effect on the engineering decisions that need to be made (eg close to schools, hospitals or nursing homes). This is because the usual gap acceptance and safety issues when designing for able-bodied adults are different for vulnerable road users.

The Austroads Guide (2003) provides more detail on calculating walking and clearance times for intersections of various widths. The formula in equation 5.1 following is for calculating walk time for wide roads (eg those with median sections) in a single pedestrian movement.

$$t_{pw} = L_{pw} / v_{pw}$$
$$\text{subject to } t_{pw} >= 5 \qquad \text{(Equation 5.1)}$$

where

t_{pw} = pedestrian walk time (s)

L_{pw} = pedestrian walking distance (m), determined as the larger of the 'first carriageway width plus median width' measured in each direction

v_{pw} = pedestrian walking speed (m/s).

Likewise, a pedestrian clearance interval is given to allow pedestrians who have begun to cross to finish their crossing safely. This phase is usually 6–20 seconds long and can be calculated from the formula in equation 5.2 below.

(i) Calculate the total clearance time (in seconds) from:

$$t_{pc} = L_{pc} / v_{pc}$$
$$\text{subject to } t_{pc} >= 5 \qquad \text{(Equation 5.2)}$$

where

t_{pc} = pedestrian clearance time (s)
L_{pc} = pedestrian clearance distance (m)
v_{pc} = pedestrian walking speed (m/s).

(ii) Determine the duration of the Clearance 1 and Clearance 2 intervals (t_{c1} and t_{c2}) from:

$$t_{c2} = I$$
$$t_{c1} = t_{pc} - I$$

where

I = intergreen time (s)
t_{pc} = total clearance time (s)

5.5.2 Pedestrian protection

Austroads offers similar advice to the New Zealand guidelines on this topic. Where the number of pedestrian-vehicle conflicts is high, Austroads recommends that a red arrow (or flashing yellow if in Australia) should be displayed to protect pedestrians. If the phase transitions are too complicated, an exclusive pedestrian phase should be provided.

Austroads also offers advice on the reintroduction of a pedestrian phase – ie the late introduction of an exclusive pedestrian phase when there is sufficient time remaining to provide both walk and clearance time. Where a pedestrian phase is added late, or reintroduced, Austroads advises that conflicting vehicle movements should be banned (through red protection arrows), to reduce the potential danger to pedestrians.

In the UK and the Republic of Ireland, filtered turns are banned and pedestrian protection or exclusive phases are required as a matter of course. Although this reduces the theoretical capacity for vehicles, it ensures that pedestrians and vehicles are never expected to coexist in the same place, as long as both are obeying the signals. This is intended to improve the safety of the intersection. Observations of filtered-turn movements suggest that the theoretical benefits of filtered turns may be overstated, particularly where the pedestrian volumes have been underestimated by signal operators. Vehicles are required by law to yield to pedestrians, meaning that where there are high pedestrian volumes, the delays to turning traffic may outweigh the intended benefits of the filtered movement. This is complicated further if the turning lane is also used for through-traffic, and those drivers can become frustrated by having to wait for turning vehicles during a green light. During the course of this research, surveyors frequently observed through-traffic honking their horns at turning vehicles that remained stationary while giving way to pedestrians.

In New Zealand, filtered turns are common. The rules for this are governed by the *Land transport rule 54002 – traffic control devices 2004* (MoT 2004). Filtered turns can occur when motorists are presented with a green traffic signal without any turn protection, but an intersection should never be configured in such a way that a motorist with a green arrow encounters a pedestrian who is crossing legally.

In New Zealand, the pros and cons of filtered versus exclusive signals can be found in table 15.12 of the *Pedestrian planning and design guide* (NZTA 2009) (reproduced in figure 5.3 below).

Figure 5.3 Potential signal phasings and their issues (*Pedestrian planning and design guide*, table 15.12)

Table 15.12 – Potential signal phasings

Phasing	Definition	Design issues
Exclusive (dedicated/ Barnes dance)	All vehicles stop and pedestrians can walk in all directions, including across the diagonal.	It is beneficial where there are high pedestrian numbers. It is safer for pedestrians than concurrent phasings. There is greater delay to vehicles. Pedestrian have to wait longer to cross. Those walking on the diagonal have further to travel and may not be able to see the signal heads.
Concurrent (parallel)	Vehicles yield the right of way to pedestrians crossing the road into which they are turning.	Pedestrians normally have a shorter wait. There is less delay to vehicles. Pedestrians may feel intimidated by turning vehicles. A high number of pedestrians can prevent turning vehicles from completing their manoeuvre. Heavy vehicles have blind spots to the side. When turning, drivers may be unable to see pedestrian crossing from alongside.

The safest form of pedestrian protection is the 'Barnes Dance', or exclusive pedestrian phase, although this is only practical in central business areas, and is only safe if all road users comply with the road rules. If both pedestrians and car drivers comply with the signals, there will be no vehicle movement while pedestrians are crossing. The city of Beverly Hills, California, introduced exclusive pedestrian phases in 1987. A 10-year study found that at 8 of the 10 intersections, the level of service improved. Overall, there was a 66% reduction in pedestrian accidents (Vaziri 1996).

Although pedestrian signals are a means of regulating road users and improving road safety, signalised intersections are only safer if road users comply with the signals.

5.5.3 Cycle times

The *Pedestrian facilities user guide* (US Department of Transportation 2002) suggests that shorter cycle lengths and longer walk times result in better pedestrian compliance, and champions exclusive pedestrian staging and concurrent signals as being efficient solutions from the perspective of pedestrian speed, compliance and safety. The guide stresses that engineers must be willing to reduce vehicle timing; otherwise pedestrians will ignore the crossing signal.

In a literature review of pedestrian issues, *Factors influencing pedestrian safety* (Martin 2006), two studies (Keegan and O'Mahoney 2003, and Catchpole 2003) found that shorter cycle times supported better pedestrian compliance. Martin concluded:

> *... it is highly plausible that a reason for poorer compliance with longer cycle times is that pedestrians become frustrated if they have to wait a long time and when they have to wait a long time to cross a road it increases the probability of acceptable gaps emerging in traffic.*

The international research tends to suggest that when it comes to cycle times, shorter is not only better for reducing delay, but also for improving compliance and safety issues. However, if the cycle times are too short there can be issues with vehicle vs vehicle conflicts (due to issues around adequately clearing vehicles through an intersection) and potentially an increase in vehicles left stranded in the middle of an intersection when the lights change. If vehicles are not cleared from a vehicle queue, the delay for vehicles can be excessive and there is also a risk of queuing traffic backing up through adjacent signalised intersections. These vehicle issues tend to be the primary focus for signal engineers when setting up signal operations.

Note that this is not a universal rule. Introducing additional pedestrian phases (such as a second Barnes Dance crossing phase in periods of high pedestrian volumes) may increase overall cycle times, but could reduce the average delay for pedestrians where they were previously marginalised – therefore the additional time added to the cycle is unlikely to result in additional non-compliance on the part of pedestrians. Thus, decreasing cycle times should be an overall goal as a means of reducing delays for road users; however, this goal should not result in excluding options that will reduce overall delay or safety at an intersection.

It should also be noted that safety of pedestrians at pedestrian facilities depends on the compliance of pedestrians. It is very rare for a pedestrian to be hit by a car that has run a red light. This is especially the case at mid-block crossings. As a result, introducing too much delay for pedestrians will increase the risk of non-compliance, and therefore increase the safety risk.

5.6 Intersection setup

5.6.1 Physical improvements

As well as changing the signal phasing, it is also possible to improve the operation of a signalised intersection by making physical improvements to the intersection. A summary of pedestrian engineering solutions from the *Pedestrian planning and design guide (*NZTA 2009) is shown in tables 5.4 and 5.5.

Figure 5.4 Physical intervention and crash reduction (*Pedestrian planning and design guide* NZTA 2009)

Table 6.3 Physical aids and their typical crash reductions

Measure	Pedestrian crash reduction
Kerb extensions only [79]	36%
Raised median or pedestrian refuge islands [79]	18%
Kerb extensions with raised median islands [79]	32%
Adding kerb extension to existing zebra crossing [145]	44%
Cycle lanes [53]	30%
Roundabouts [79]	48%
Flush medians [79]	30%

Figure 5.5 Formal crossings and their relative crash reductions (*Pedestrian planning and design guide* NZTA 2009)

Table 6.4 – Time separated and priority control measures and their typical crash reductions

Measure	Pedestrian crash reduction
Zebra crossing on a pedestrian platform [145]	80%
Mid-block traffic signals [145]	45%
Zebra crossings with no physical aids [53]	-28%
School patrol crossing [53]	35%
Intersection traffic signals – parallel pedestrian phase [53]	-8%
Intersection traffic signals – exclusive pedestrian phase [53]	29%

5.6.2 Staggered crossings

Different jurisdictions vary in the prevalence of ‘staggered crossings’. A staggered crossing generally involves a pedestrian refuge, traffic island, or ‘pork chop’ island separating two vehicular movements. Although they are widely used in some jurisdictions, they are not common in New Zealand, and most examples here are for mid-block crossings rather than intersections. The advantages of staggered crossings include the following:

- Islands break up the crossing for pedestrians.
- ‘Gap acceptance’ can be simplified, as the vehicle directions can be crossed separately.
- A refuge can provide a greater perception of safety, as it separates pedestrians from vehicles (but conversely, pedestrians stranded on an island may feel intimidated by vehicles).
- Vehicle capacity can be improved, as one vehicle direction can still be operating while the other is held for pedestrians, allowing greater flexibility for coordinating with other vehicle movements.

The disadvantages caused by poor implementation are as follows:

- Staggered crossings require more road space, and thus increase costs.

- Islands can cause complications for emergency-response vehicles, which often like to cross the centreline when travelling through intersections, to avoid queuing traffic.
- Pedestrians can be left 'stranded' in the middle if there is no signal activation provided.
- Mid-block islands are not always designed with the capacity to hold the pedestrian numbers required.

The UK Traffic Advisory Leaflet 5/05 (DfT 2005) suggests that the use of staggered crossings can have capacity advantages for vehicles, which is their primary reason for being recommended. In some circumstances this can also reduce waiting times for pedestrians. The Austroads *Guide to traffic management* (2009) suggests staggered crossings can be useful where there are large walk and clearance times that seriously affect intersection performance, and recommends that they should be offset, to provide a visual indication to pedestrians that the two arms operate separately.

5.6.3 Audible signals

Some of the overseas literature reviewed suggests that audible signals can be of benefit to pedestrians, particularly those with sight problems. However, the *Pedestrian planning and design guide* (NZTA 2009) is one of several texts reviewed that suggests that if they are poorly implemented, audible signals can be confusing or ambiguous regarding the direction of the active crossing. Some solutions are to:

- have the audible signals for different crossing legs spaced as far apart as is practical
- use an audio pulse to help pedestrians find the signal
- use tactile pavers to confirm the direction of travel.

5.6.4 Automated pedestrian detection

Automated detection uses a system (such as infrared or microwave) to detect pedestrians arriving at a crossing. This can be used to:

- call a pedestrian phase when pedestrians arrive, or call a phase early if high pedestrian numbers are detected
- extend a pedestrian phase if pedestrians arrive during the crossing phase.

Such detection systems are able to cancel a pedestrian phase if pedestrians cross prior to the pedestrian phase being called. This means that vehicles will only face delays if pedestrians are crossing during the green phase. If there are no pedestrians, or if pedestrians have already used their judgement to cross between green signals, the pedestrian phase will no longer be called. The primary purpose of pedestrian detection is to reduce delay for vehicles when pedestrian volumes are low.

If implemented correctly, a pedestrian detection system has the potential to reduce pedestrian delays when pedestrian volumes are high, by extending the pedestrian phases; however, this requires an intelligent system to assess the pedestrian demand and extend the green phases accordingly, while still allowing a vehicle phase.

Any automated pedestrian detection system needs to be properly calibrated. Problems can arise if the system detects pedestrians walking past the crossing, or just standing near a crossing location, rather than intending to cross. The system can also fail to achieve desirable results if pedestrians regularly cross outside of the area of detection. Therefore, some guidance must be given to pedestrians regarding the location of the detection area, and care should be taken to place the system on a path that is desirable to pedestrians.

There can also be issues with false cancellation. For example, a pedestrian intending to cross could be outside of the field of detection because of a slow walking speed, or because they are sheltering from the rain. This can mean a pedestrian phase could be cancelled while there are pedestrians still waiting to cross.

In 2001 the US Federal Highway Administration studied such issues in *Evaluation of automated pedestrian detection at signalized intersections FHWA-RD-00-097* (Hughes et al 2001). The study attempted to evaluate whether automatic pedestrian detection improved pedestrian compliance. The research found that the number of pedestrians crossing during the 'don't walk' phase declined significantly at all the test sites that had an automated detection system. The study noted that trials of automated detection systems in the UK, Australia, the Netherlands and Sweden had had varied results. In the US, improved signal compliance was achieved at the three of the four trial locations that had microwave or infrared detectors, with fewer people crossing during a 'don't walk' phase. It was noted that much of this was related to a reduction in pedestrian delay. The findings also noted a reduction in pedestrian–vehicle conflicts.

A similar research project by Carston (1995) evaluated an automated detection system (microwave) trial in three sites within the European Union. He found a decrease in pedestrian–vehicle conflicts in two of the three trial sites, and a reduction in pedestrian delay at all three locations.

5.6.5 Countdown timers

The use of countdown timers is not related to decreasing pedestrian delay, but it is relevant in terms of managing the time available and potentially easing the frustrations of pedestrians and reducing the chances that delay will result in unsafe behaviour.

There are essentially two types of pedestrian timers:

- Some count down the time remaining until a 'walk' phase will occur. These are designed to improve pedestrian compliance by providing information on the remaining delay. However, a countdown timer of this type is unlikely to work if delays are excessive, and may, in fact, encourage risk-taking behaviour.
- Some timers activate during a 'walk' phase and provide a countdown for the time remaining. This is controversial because of the way the timer is usually set up. Generally speaking, the countdown includes the 'don't start' (clearance) phase, of the crossing, and in some cases may not include the green 'walk' portion at all. The issue is therefore one of definitions. The provision of a countdown timer changes the definition of the 'flashing red man' signal from 'don't start' to 'use your own judgement'.

The implementation of countdown timers has been investigated in number of countries. Huang and Zegeer (2000) conducted research into the effect of countdown timers in Florida, where two signalised intersections with pedestrian countdown timers counting down the 'walk' phase were monitored and compared with nearby conventional signalised intersections. The research intended to evaluate the following issues:

- pedestrian compliance/non-compliance with the 'walk' signal
- pedestrians who ran out of time while crossing the street

- pedestrians who started running when the flashing 'don't walk' signal appeared.

The report discovered that pedestrian compliance with the 'walk' signal decreased with the presence of countdown timers (see figure 5.6). The researchers concluded that pedestrians arriving at a flashing 'don't walk' sign with 20 seconds remaining decided to cross rather than wait for the next 'walk' signal.

Figure 5.6 Compliance with 'walk' signal (Huang and Zegeer 2000)

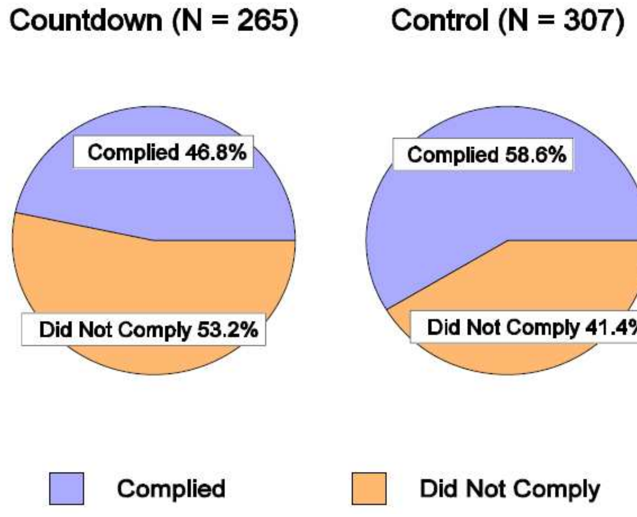
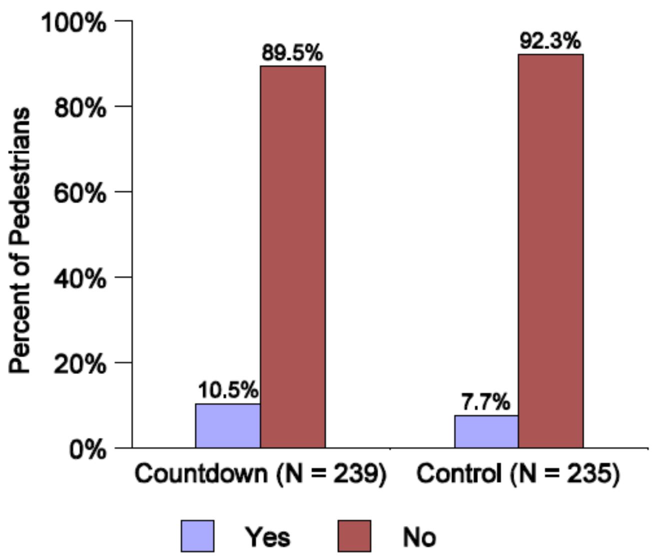


Figure 5.7 shows the difference between the number of pedestrians who ran out of time whilst crossing at a countdown signal, and those crossing at a conventional signalised crossing. The researchers found that when pedestrians saw how much time was remaining to cross, they would walk faster to ensure they were not still on the crossing at the end of the countdown.

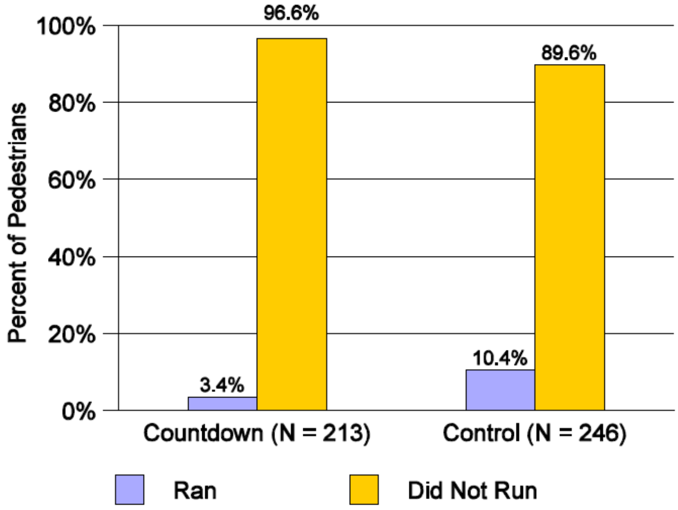
Figure 5.7 Pedestrians running out of time (Huang and Zegeer 2000)



Huang and Zegeer also found that when pedestrians arrived at a crossing with a countdown timer after the start of the 'flashing red man' signal and saw how long they still had to cross, some ran across if they considered they didn't have enough time to safely walk across the crossing, but they could 'run for it'.

However, the number of pedestrians running across the two crossings with countdown timers decreased, as shown in figure 5.8.

Figure 5.8 Pedestrians who run (Huang and Zegeer 2000)



This figure shows that a countdown timer clearly reduces the number of pedestrians who 'run for it', as pedestrians are better informed as to how much time is remaining.

From the research, Huang and Zegeer came to the following conclusions:

- *The countdown signals had both positive and negative effects on pedestrian behaviour at the treatment sites, compared to the matched control sites.*
- *Based on these results and those of other studies, countdown signals are not recommended for use at standard intersections in Florida.*
- *The countdown pedestrian signals should be tested at other signalized intersections.*
- *Instead of pedestrian countdown signals, there may be more effective alternatives to improve pedestrian safety and service at signalized intersections.*

However, these findings go against the prevalent sentiment of the US Department of Transportation, which sees a benefit in installing pedestrian countdown timers across the country. The 2009 *Manual on uniform traffic control devices* (MUTCD) (Federal Highway Administration) requires the installation of pedestrian countdown timers at all new traffic signals and signal upgrades in the US.

The draft text for this legislation that was obtained as part of this research project suggested that these would be installed at all intersections, and not just at mid-block and 'all stop' signals. As with the trial conducted in New Zealand, the countdown timers would be active during the flashing red phase, allowing pedestrians to use their judgement as to whether or not to cross, rather than strictly adhering to the 'don't start' rule. It is important to note that in many locations across the US, right turns are permitted on a red light (the equivalent of a New Zealand left turn). The 2009 MUTCD does not indicate whether any restrictions would be placed on right-turns-on-red when countdown timers were enabled.

The combination of pedestrians crossing where there is a countdown timer as well as vehicles making a filtered right turn increases the risk of an accident in the following two ways:

- Pedestrians may be over-focused on the message displayed on the countdown timer (to ensure they have sufficient time to cross the street), and pay insufficient attention to avoiding turning vehicles.
- In a traditional intersection without countdown timers, the flashing red phase acts as a clearance phase for right-turning vehicles, and few pedestrians enter the crosswalk during this phase. When countdown timers are installed on a 'flashing red man' signal and pedestrians know how much time is left in the flashing red phase, they are more likely to enter the crosswalk during this phase and thus increase the likelihood of conflict between pedestrians and turning vehicles. It should also be noted that in these circumstances, the pedestrians have right of way; however, the increased interaction between pedestrians and vehicles still increases the risk for pedestrians.

The trials undertaken in New Zealand and abroad have reached similar conclusions: pedestrians are *less* likely to still be on the crosswalk when the 'flashing red man' signal becomes solid red, but are *more* likely to try to cross on the 'flashing red man' signal (which means 'don't start') if they judge they have enough time to complete the crossing.

The increase in crossing on a 'flashing red man' signal might be interpreted as non-compliant behaviour, but a 35-second countdown on this signal seems to provide an invitation to cross. Here, it is the road operator confusing the meaning of the 'flashing red man' signal by apparently providing an invitation to cross during a clearance phase, rather than the public misunderstanding the meaning of the signals. That is, having the countdown on the 'flashing red man' signal, when there is clearly sufficient time to begin a crossing manoeuvre, contradicts the intention of the 'flashing red man' signal as a clearance interval.

This could have the wider effect of diluting the meaning of the 'flashing red man' signal and could lead to an increase in non-compliant behaviour in other regions, as people become familiar with crossing during the clearance phase. To avoid this situation, it would be sensible to have the countdown timer on the green phase. This would provide an unambiguous message to pedestrians as to how much time they have left to begin a crossing manoeuvre during the green phase, and the 'flashing red man' signal would maintain its meaning as a clearance phase for those already on the crossing, and a 'don't start' signal for pedestrians who are just approaching the crossing.

Despite differences in implementation, the consensus of the research is that providing the countdown timers for Barnes Dance or mid-block crossings is desirable, so pedestrians can decide whether it is safe to cross.

6 The New Zealand context

In order to understand pedestrian behaviour, perceptions and delays at signalised intersections in New Zealand, a series of surveys were carried out at signalised intersections in Auckland, Wellington and Christchurch. These included:

- interview surveys regarding pedestrian perceptions
- an observational study of pedestrian behaviour
- an observational study of the delays experienced by pedestrians at selected intersections in central-city locations.

6.1 Delays for pedestrians (observational surveys)

Collecting data about pedestrians is considerably more difficult than collecting information on vehicles, which is currently built into the SCATS® system used at signalised intersections in New Zealand. This means that vehicle volumes are easy to obtain, but pedestrian volumes are unknown without manual data collection on a case-by-case basis. Therefore, our research conducted observational studies of pedestrians to determine the average length of time pedestrians waited at the surveyed intersections.

6.1.1 Methodology

The methodology adopted was designed to be simple, cost effective and repeatable. Surveyers randomly selected a person as they approached the intersection (from any angle) and recorded their delay time and crossing time on a stopwatch. After the person had completed the crossing, the next person to arrive at the intersection (from any angle) was the next person observed.

This methodology provides a randomised result weighted by volume of the direction of origin; ie an approach with zero pedestrians arriving would be surveyed zero times, whereas an approach with 50% of the overall total of pedestrians would likely be surveyed around 50% of the time.

Note that this method does not work well for Barnes Dance intersections, where all pedestrians are released simultaneously – this method only captures the delay for the first person arriving at the intersection following the ‘walk’ phase (ie the maximum delay, rather than the average delay). Only two of the 14 intersections surveyed had Barnes Dance crossing: the intersection of Lake Rd, Hurstmere Rd and The Strand (North Shore); and the Hereford St/Colombo St intersection that forms part of the Christchurch corridor model.

The individual intersections and the pedestrian corridors studied in this research were selected by members of the research project’s steering group.

As shown in table 6.1, the survey results for the intersections surveyed showed that the average waiting times were:

- 25 seconds in Christchurch
- 45 seconds in Wellington

- 53 seconds in Auckland.

That is, in relative terms the average waiting time in Auckland was more than double that in Christchurch.

Table 6.1 Pedestrian waiting times: observational studies results

City	Number of intersections surveyed	Observed pedestrians	Average pedestrian waiting time (seconds)
Auckland	5	289	53
Wellington	2	333	45
Christchurch	7	843	25
Combined results	14	1465	41

6.2 Pedestrian attitude surveys

Pedestrian attitude surveys were conducted in Auckland, Wellington and Christchurch. For consistency, all of the surveys were undertaken at the intersections nominated by the steering group, in parallel to the collection of observational data. Each pedestrian was asked 10 simple questions. (The number was kept low in order to improve the response rate.) A total of 811 surveys were completed, with 456 in Auckland, 115 in Wellington, and 244 in Christchurch. The surveys were conducted over the course of two weeks, between the hours of noon and 1:30pm (pedestrian peak times).

The survey form and a more complete analysis of the survey outcomes can be found in the appendix.

6.2.1 Journey times

Pedestrians were asked how long their walk was. Consistent with international findings, 73% of respondents in Christchurch and Auckland reported a journey of 10 minutes or less. (However, Wellington was an exception, with just 45% of walking trips being less than 10 minutes, and almost 35% of trips being longer than 15 minutes.) These results suggest that the delays experienced at intersections could have a significant effect on overall journey times, as each minute of delay within a highly signalised central-city environment generally equates to more than 10% of the overall trip time.

Based on the average delays observed at sample sites, a pedestrian journey in Auckland with four signalised crossings would incur a signal-induced delay total of approximately 3.5 minutes. With most pedestrian journeys being less than 10 minutes, this could potentially limit the distance that is suitable for pedestrian journeys in highly signalised areas.

6.2.2 Pedestrian attitudes to traffic signals

Respondents were asked several questions regarding their attitudes toward traffic signals and their preferred crossing types (eg signalised, zebra, footbridge, pedestrian refuge, underpass, and other). Almost 60% of respondents stated that they preferred signalised intersections. Zebra crossings were the next most-favoured choice, at 23%. Pedestrian refuges were favoured by 5% of respondents, although the term was not widely understood. Interestingly, the two options for grade separation, considered as superior from a safety point of view, rated very poorly with pedestrians – footbridges scored 3% and underpasses 4%. This is likely to be because of the additional walking distance required to use these facilities, and their reputation for personal security issues.

Pedestrians were asked about the meaning of various pedestrian phases. Seventy-one percent of respondents correctly answered that a ‘flashing red man’ signal means ‘don’t start’; 27% answered (incorrectly) that it means ‘hurry up’, and just 4% stated that they didn’t know.

Interestingly, the proportion of Auckland respondents who thought the ‘flashing red man’ signal meant ‘hurry up’ was 33%. This could have been because of the greater competition for time and space in that city, and was consistent with observations of turning motorists on filtered turning movements honking their horns at pedestrians when the ‘flashing red man’ signal appeared. This indicated a misunderstanding on the part of drivers, as the ‘flashing red man’ signal means ‘don’t start’, and pedestrians are still legally entitled to cross and have the right of way. To overcome such misunderstandings about the meaning of the ‘flashing red man’ signal, publicity campaigns have been run in both Wellington and Christchurch.

6.2.3 Perceived vs actual waiting times

Respondents at each intersection were asked how long they felt they had to wait before crossing the road. The average *perceived* delay time was found to be double the *actual* average delay time for the intersection. This is probably because delay is a subjective experience that is difficult to quantify, and pedestrians also tend to not notice short delays. It is also consistent with the level of frustration being higher than the actual quantifiable loss of time.

6.2.4 Perceived vs reasonable waiting times

Having been asked how long they thought a typical waiting time was, the respondents were then asked how long they thought was a reasonable waiting time at each intersection. Given the disparity between the perceived and actual waiting times, we considered it would not be fair to compare the ‘reasonable’ waiting times with ‘actual’ waiting times, as the respondents were basing their answers on how long they thought they were waiting, rather than the actual cycle times of the intersection.

The waiting times considered reasonable by respondents were generally shorter than the perceived waiting times (see table 6.2). Although respondents had difficulty in quantifying the experience of delay, a common response was that delays should be reduced – although the size of this difference varied significantly between cities. By comparing the average perceived waiting time with the perception of a reasonable waiting time, it is possible to gain an understanding of the level of frustration and the desire for improved pedestrian priority.

Table 6.2 Average perceived waiting times and reasonable waiting times

City	Perceived	Reasonable	Difference	% difference
Auckland	123	96	27	28%
Wellington	76	67	9	13%
Christchurch	50	44	6	14%
Combined	83	69	14	20%

The results were particularly significant in Auckland, where the difference between perceived and reasonable times was the highest. In Christchurch, where the *actual* delay was much lower, a greater proportion of respondents considered the perceived delay to be acceptable. This was consistent with the results of our survey, in which 75% of Auckland pedestrians felt that more priority should be given to pedestrians in the central city, compared with fewer than half of Christchurch respondents.

International experience and best-practice guides suggest that pedestrians become frustrated after about 30 seconds of delay, and this is supported by the New Zealand results. An analysis of the responses indicated that somewhere between the 25 seconds of actual delay experienced in Christchurch and the 53 seconds of actual delay experienced in Auckland, there was a critical threshold after which frustration grew and made time seem to stretch disproportionately to the actual additional delay.

6.2.5 Compliance with signals

As detailed in section 4.2, one measure of the frustration caused by crossing signals is the frequency with which they are violated by pedestrians. Compliance is also dependent on traffic volumes, so there is no simple linear relationship between delay and compliance. Pedestrians are more willing to ignore pedestrian signals if the traffic volume is so low that there is minimal perceived risk in violating them. However, international literature suggests that if the signal delays are sufficiently frustrating for pedestrians, their willingness to take risks increases, and the rate at which pedestrians violate the signals intensifies even in highly motorised environments.

When respondents were asked how frequently they crossed on a ‘solid red man’ signal, and on a ‘flashing red man’ signal, the majority admitted to both, and less than a third answered ‘Never’ when asked if they would cross on a ‘solid red man’.

6.2.6 Pedestrian priority

The final question of the survey was ‘Do you think more priority should be given to pedestrians?’ Half of all respondents were in agreement with this, while this figure was almost 75% for respondents in the CBD of Auckland, which had the longest observed delays. This outcome might have been different if the question had been asked outside of a CBD environment. However, within the research study area, this was a clear indication that those affected by delay had negative perceptions of the delay experienced and a desire for more pedestrian priority.

For a more detailed analysis of the pedestrian surveys, see the appendix.

7 Model results

7.1 Pedestrian modelling

A number of different software packages are available to build models that can simulate both vehicle and pedestrian behaviour to test options for reducing delay for pedestrians.

The micro-simulation tools available to model pedestrians are developing rapidly. Software platforms such as Vissim and Aimsun with Legion now allow modellers to include pedestrians with far more ease than previously possible, and it is likely that the development of modelling software will continue as demand for truly multi-modal software increases. For the purposes of this research, the software packages Aimsun and S-Paramics were used to build the intersections and corridors, while Sidra was used for optimisation. These software packages are the preferred models in New Zealand, but are not necessarily the most appropriate tools for pedestrian modelling.

Modelling was undertaken for the time period between noon and 1:30pm, which has high pedestrian volumes but is considered to be 'off-peak' for vehicles – therefore it was the time period in which the most benefits could potentially be gained.

In order to use the versions of Aimsun and S-Paramics that were available to the modelling team, the following steps were taken:

- Car traffic was modelled as usual.
- Vehicle occupancy was assumed to be 1.3 people per vehicle.
- Pedestrians were modelled as a separate vehicle class – essentially 'mini-cars' with their own 'driving lanes' (footpaths).
- To replicate the ability for multiple pedestrians to leave a curb simultaneously (rather than queuing like cars), multiple 'pedestrian lanes' were created at each intersection.
- Pedestrians arriving at an intersection could queue at any queuing lane.
- Each pedestrian queuing lane had signals to indicate to the pedestrians when they could cross.
- Pedestrian speed parameters were amended to replicate pedestrian walking speeds.
- Optimisation was undertaken on a per-person basis rather than a per-vehicle basis.

Safety factors were also considered when modelling different scenarios, using observational assessments by trained micro-simulation modellers. As a result, some scenarios were discarded because of their perceived safety implications.

Survey data was collected for each intersection during the modelled time periods. This included pedestrian volumes and crossing movements, signal-timing information from SCATS®, vehicle-turning movement counts, and observed vehicle queue lengths.

The following intersections and corridors were modelled, as selected by steering group members:

Aimsun models:

- Lake Rd/Hurstmere Rd/The Strand (North Shore City)
- Albert St/Customs St/Fanshawe St (Auckland)
- Vincent St/Mayoral Drive (Auckland).

S-Paramics Models:

- Taranaki St/Courtenay Place intersection (Wellington)
- Jervois Quay (Wellington)
- Manchester St and Hereford St corridors (Christchurch).

The per-person optimisation was conducted using Sidra Intersection 3.2. This optimisation led to cycle times that were suitable during the modelled time period, but might be shorter than required during vehicle peak periods.

The intersections selected by the steering group were, in some cases, linked to other intersections through SCATS® (to aid vehicle flow), meaning that the ability to achieve optimum cycle times in practice could be constrained by adjacent intersections. SCATS® has the ability for signals to 'marry' or 'divorce' when set criteria are met, so the solution to this would be to have intersections linked during vehicle peaks, and optimised to a more pedestrian-friendly independent arrangement during vehicle off-peak periods. The modelled periods at midday tended to have higher pedestrian and lower vehicular volumes than during the peak periods; thus, divorcing a signal from the SCATS® system would have fewer negative impacts and there would be more flexibility around the signal phasing to accommodate pedestrian crossing timing. Further, certain movements (such as right turns that require control during peak periods) could be considered for filtered treatment under lower-flow conditions.

The Aimsun models used a series of parallel 'mini-car lanes' to simulate pedestrians leaving the footpath at the same time, rather than queuing like cars. The purpose of these models was to study the effect of delay at individual intersections and to identify engineering solutions to reduce this delay.

The S-Paramics software was used for two Wellington intersections, and also two pedestrian corridors (Manchester St and Hereford St) in Christchurch, which were used to study the effect of pedestrian 'green waves'[5]. The intersection of Hereford St and Colombo St (Christchurch) was also studied in more detail as a stand-alone intersection.

Pedestrian walking speeds were identified as a potential issue. The modelling software required speeds factored in km/h, as per the following conversions:

- 4km/h = 1.1m/s
- 5km/h = 1.4m/s

5 'Green waves' occur when traffic travelling along a road corridor experiences green signals at successive signalised intersections.

- 6km/h = 1.8m/s.

The literature review was inconclusive in determining a typical average crossing speed to use for pedestrians. Design guides recommended that a minimum pedestrian walking speed of 1.2–1.4m/s be used for estimating clearance times for the 'flashing red man' signal, based on providing clearance for a range of pedestrian walking speeds. For the purposes of modelling, a range of speeds between 1.1m/s and 1.8m/s (4km/h and 6km/h respectively) were used.

All models were validated using standard modelling methodologies as specified in the EEM (LTNZ 2008) and other modelling guidelines.

7.2 Lake Rd/Hurstmere Rd/The Strand (North Shore)

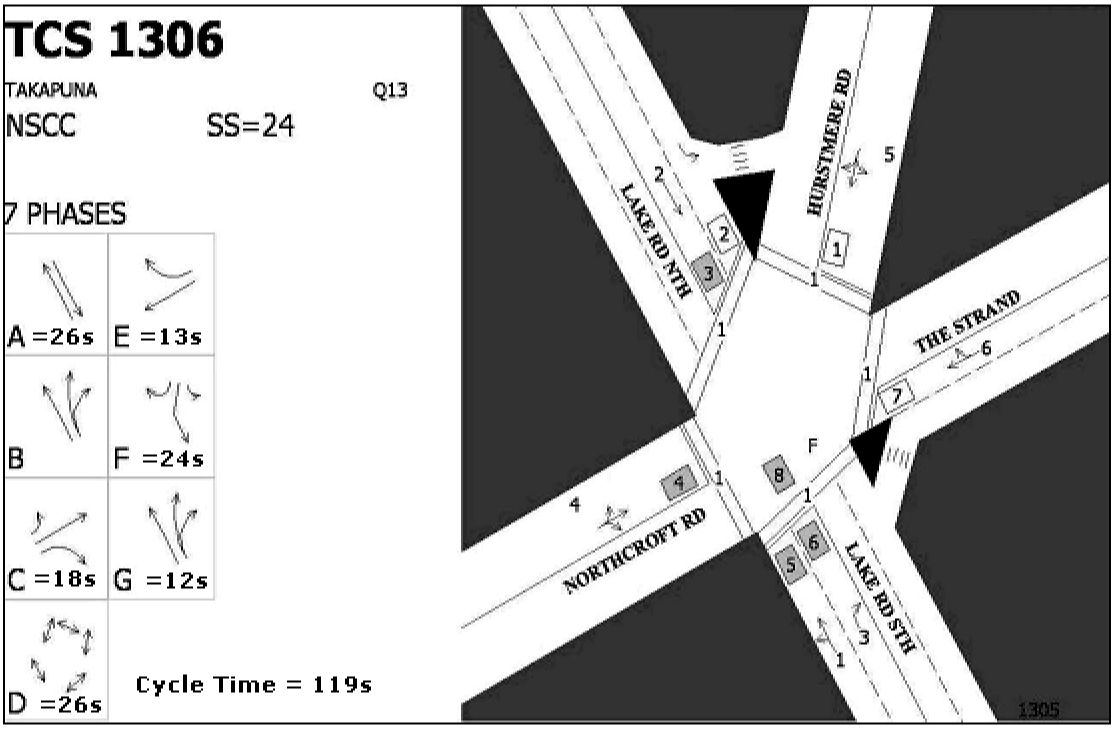
An Aimsun model was developed for the five-legged intersection of Lake Rd, Hurstmere Rd, The Strand, and Northcroft St in Takapuna (North Shore City). At the time of this study, this intersection was a problematic site in the Takapuna central city because of excessive delays for vehicular traffic and pedestrians on all approaches. The modelled period was noon–1.30pm on a weekday.

This intersection is shown in figure 7.1 below. The base model used the existing phase setting according to the SCATS® data provided in figure 7.2. The inter-green time was 5 seconds, including 4 seconds of yellow time and 1 second of all-red time. The total cycle time was 119 seconds, and the final phase was a Barnes Dance for pedestrians on all approaches. The base configuration had a total per-person delay of 52 seconds.

The turning volumes in the Aimsun network were validated against the observed turning volumes. The validation result shows that the GEH Statistic requirement was met by 100% matching the target value. The R-squared value was 85%, and the percentage root-mean-square error (RSME) was 18%, both well within the validation limits recommended in the EEM (LTNZ 2008).

Figure 7.1 Lake Rd/Hurstmere Rd/The Strand intersection (Google)

Figure 7.2 Lake Rd/Hurstmere Rd/The Strand existing signal setting (phase B did not run) (SCATS®)



7.2.1 Option 1: Phasing optimisation in SIDRA

Option 1 optimised the existing intersection signal timings using Sidra Intersection 3.2 on a per-person basis. This resulted in a reduced cycle time of 100 seconds and meant a reduction of 19 seconds to the total cycle times.

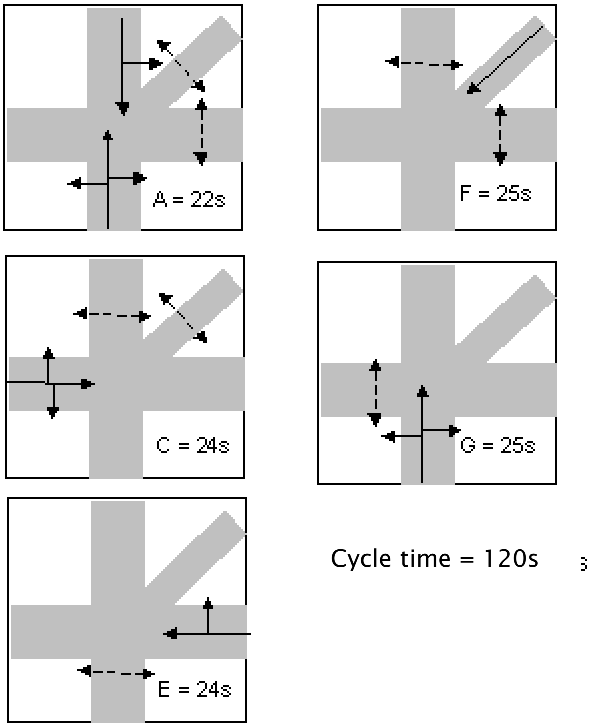
Table 7.1 Option 1 signal setting

Phase	Timing (sec)
A	18
C	11
D	25
E	11
F	18
G	17

7.2.2 Option 2: Remove Barnes Dance

Option 2 eliminated the Barnes Dance and divided up pedestrian movements into the remaining phases so they were crossing in parallel to the corresponding motor vehicle phases (refer to figure 7.3). A late green light for turning traffic gave pedestrians time to enter the intersection ahead of the turning traffic. However, this option was deemed too unsafe and was removed from consideration because of the significant increase in conflicts between pedestrians and vehicles. Additionally, much of the time saved by dropping the Barnes Dance phase was negated by the additional allowance required for including pedestrian movements in the other phases. As well as creating safety concerns for pedestrians, the model indicated that removing the Barnes Dance increased the delay for pedestrians more than options 1 and 3.

Figure 7.3 Option 2 signal setting (sec)

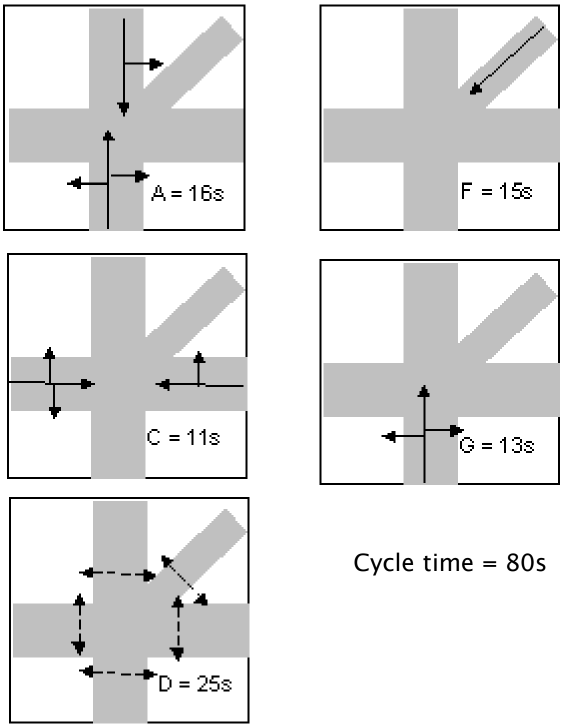


7.2.3 Option 3: Merging phases C and E – Northcroft/The Strand

Option 3, as shown in figure 7.4, combined movements from Northcroft Rd (phase C) and The Strand (phase E) into one phase, having previously operated in a split-phase manner. After optimising the intersection phasing in Sidra, this option reduced the total number of phases to 5 and the total optimised cycle time to 80 seconds.

As the combined phases were only modelled during a time period with comparatively low vehicle volumes, this option would need to be considered in more detail if implemented for the full day. The resulting recommendation might be for the current arrangement during vehicle peaks and the alternative arrangement during the vehicle off peak.

Figure 7.4 Option 3 signal setting (sec)



7.2.4 Model findings: Lake Rd/Hurstmere Rd/The Strand (North Shore)

Table 7.2 shows the result of the user delays at the intersection with each option modelled in Aimsun. It displays the average delay to both pedestrian and vehicular users. The delay per person was obtained by combining delays of both classes (assuming 1.3 person occupancy in vehicles).

Table 7.2 Aimsun NG model result

Model	Average delay (sec)		Delay per person (sec)	Reduction	% reduction
	Veh.	Ped.			
Base	66	54	**52**		
Option 1	48	43	**39**	-13	26%
Option 2	36	45	**34**	-18	34%
Option 3	34	40	**31**	-21	40%

The result of the Sidra optimisation in Option 1 not only reduced pedestrian delay and per-person delay, but also decreased delays for vehicles during the time period modelled. The combined reduction in delays for pedestrians and vehicles resulted in a per-person delay reduction of 13 seconds, or 26% of the original delay.

Option 2 offered further improvement in terms of delay per person, with shorter delay to vehicular users by eliminating the Barnes Dance phase. However, while this reduced the per-person delay, the average delay for pedestrian users was slightly higher than in Option 1, so there was no benefit to pedestrians at all. This option is not recommended – as well as increasing pedestrian delay, it compromised pedestrian safety because of the high pedestrian flows and increased conflicts with turning traffic resulting from the removal of the all-pedestrian phase.

Among the options tested, Option 3 offered the highest reduction of delay per person for all the users. By combining phases C and E and optimising delay per person, it was possible to decrease the average delay for vehicles by 18 seconds and pedestrians by 11 seconds compared with the base model. This result shows that a reduction of 13 seconds per person per cycle could be achieved through optimisation for the time period modelled. The modelling also suggested that combining two of the phases would further reduce delays for both pedestrians and cars, resulting in a total reduction in per-person delay by 21 seconds, or 40% of the total delay. However, before it would be possible to combine two phases, the study would need to extend beyond the modelled period to further assess potential safety issues.

For a full-day study on this intersection, vehicle peak periods would need to be modelled as well. The recommendation could be for the current arrangement during vehicle peaks and the alternative phasing during the vehicle off peak.

7.3 Aimsun Model: Albert St/Customs St/Fanshawe St (Auckland)

An Aimsun model was developed for the four-legged intersection of Albert St/Customs St/Fanshawe St on the north side of the Auckland central city. The modelled period was noon–1.30pm on a weekday. At the time of this research, this intersection had both high vehicle volumes and high pedestrian volumes. The data collected for the modelling showed 1900veh./hr and 2000ped./hr during the noon–1:30pm model period; ie the number of pedestrians and vehicle occupants was very similar. However, the average delay for pedestrians during the modelled period was almost twice that of vehicles.

7.3.1 Base model

The existing intersection is shown in figure 7.5. The base model used the existing phase settings according to the SCATS® data provided in figure 7.6. The inter-green time was 5 seconds, including 4 seconds of amber time and 1 second of all-red time. The total cycle time was 116 seconds. This resulted in an average per-person delay of 39 seconds. In the base model, vehicles had an average delay of about half a minute, and pedestrians had an average delay of nearly a minute.

Figure 7.5 Customs St/Albert St/Fanshawe St intersection (Google)

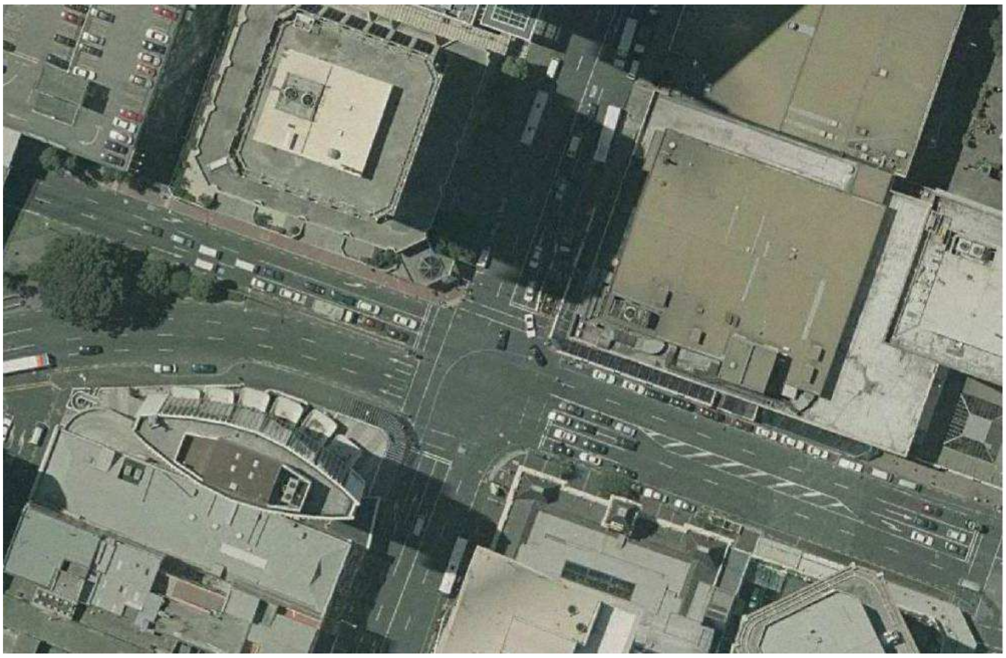
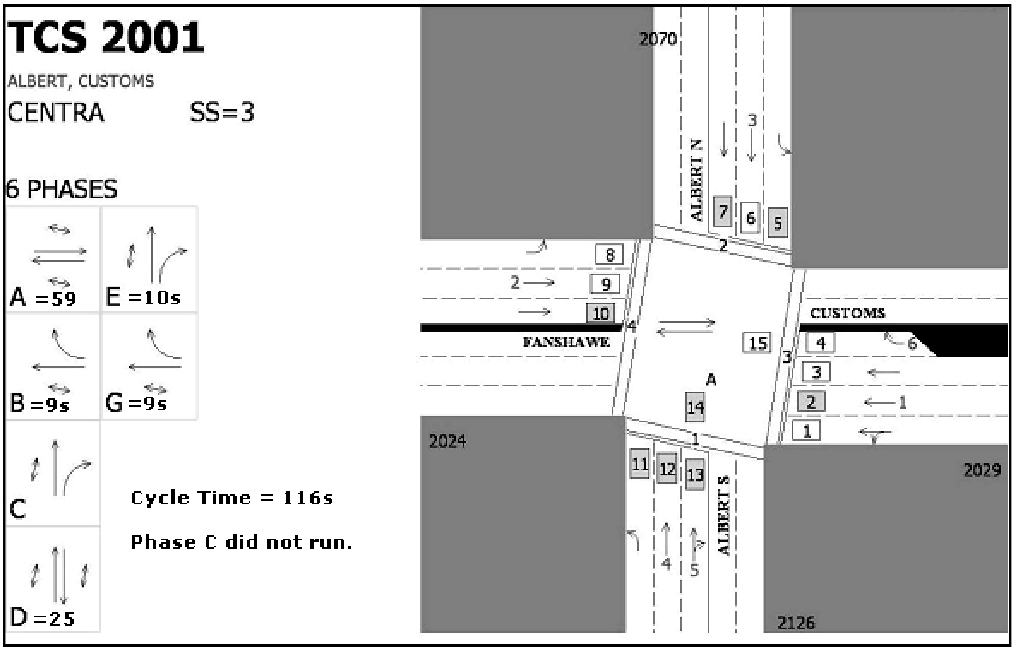


Figure 7.6 Customs St/Albert St/Fanshawe St existing signal setting (SCATS®)



The turning volumes in the Aimsun model were validated against observed turning volumes. The validation results showed that the GEH Statistic requirement was met. The R-squared value was 93%, and the percentage root-mean-square error (RSME) was 19%, both well within the validation limits recommended in the EEM (LTNZ 2008).

7.3.2 Option 1: Phasing optimisation in SIDRA

In Option 1 the existing intersection signal timings were optimised using Sidra. This resulted in a shorter cycle time of 80 seconds. The time per phase is shown in table 7.3.

Table 7.3 Option 1 signal setting

Phase	Timing (sec)
A	22
B	11
D	25
E	11
G	11

7.3.3 Option 2: Merging phases B and G (with phasing-time optimisation in Sidra)

Option 2 attempted to merge similar-movement phases (B and G), to shorten the total cycle time. However Sidra optimisation showed no reduction in total cycle time compared to Option 1. The timing for the new phase G was the same as the total timing for both phases B and G from Option 1. The signal setting for option 2 is shown in table 7.4. Although the total cycle time was the same, there was a slight improvement to average delays for both vehicles and pedestrians because of reductions in lost time within the overall cycle.

Table 7.4 Option 2 signal setting

Phase	Timing (sec)
A	22
D	25
E	11
G	22

7.3.4 Model findings

Table 7.5 shows the impact of amending the different options at the intersection with each option modelled in Aimsun. The delay per person was obtained by averaging the total delays of both classes (assuming 1.3 people in vehicles).

The base model showed that despite there being more pedestrians than vehicles at this location, pedestrians faced much longer delays than vehicles. By optimising the intersection within the modelled time period, the delay for both pedestrians and vehicles was reduced, resulting in savings of 8 seconds per vehicle and 18 seconds per pedestrian. The total per-person delay was reduced by 12 seconds, or 31% for the midday peak period.

Option 2 offered further improvement by merging two phases into one. It resulted in a similar delay reduction to vehicle users, but a further 5-second decrease in the pedestrian average delay, compared with cycle-time optimisation alone (Option 1). By combining two similar phases, it was possible to reduce the per-person delay by 38% from the base model (an average savings of 10 seconds for vehicles and 23 seconds, or 39%, for pedestrians. The normal phasings for this intersection have been set up to aid in conveying vehicles to and from the Auckland motorway. Combining the two phases could work well during the inter-peak period, but it would not be recommended during vehicle peak periods.

Even with the optimisation, the delay for pedestrians was still higher than that for vehicle occupants, though it was substantially improved. After reviewing the effects of adding a Barnes Dance at other locations modelled, it was considered that any further work on this intersection should investigate the idea of adding an exclusive pedestrian Barnes Dance phase.

Table 7.5 Aimsun Customs St model result

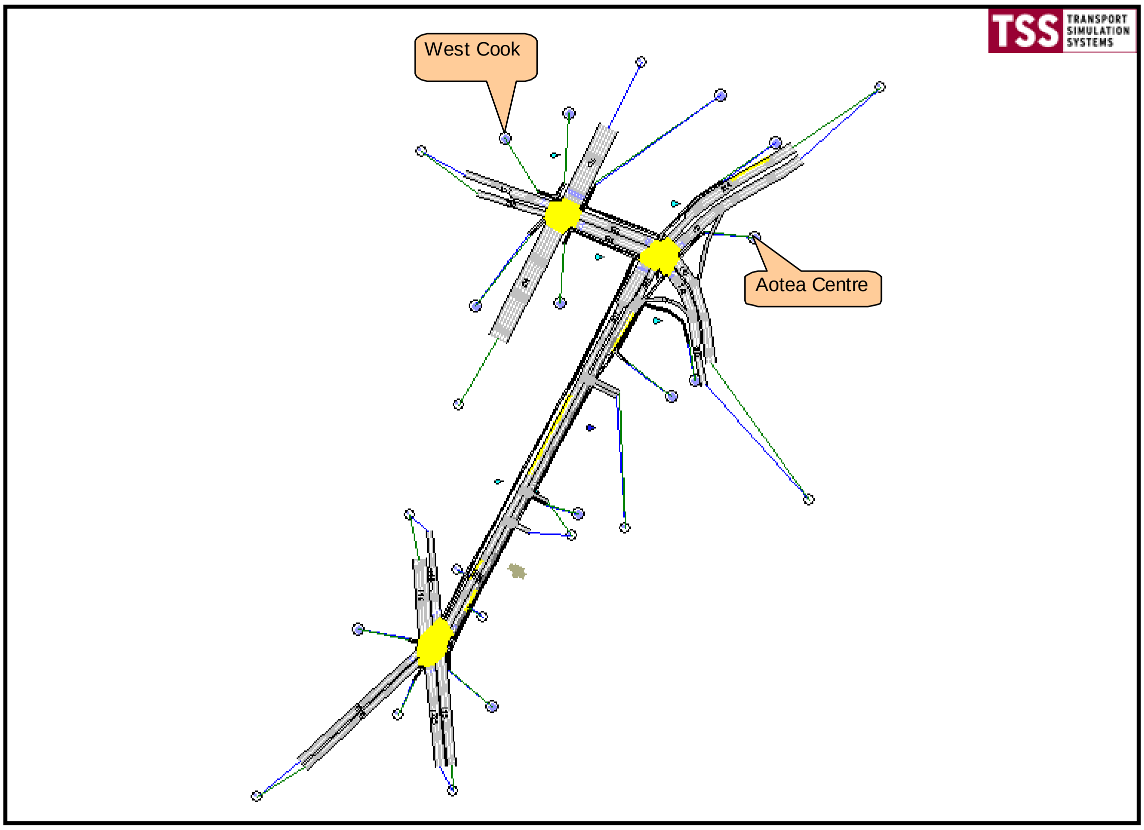
Model	Average delay (sec)		Delay per person (sec)	Reduction	% reduction
	Veh.	Ped.			
Base	31	56	**39**		
Option 1	22	38	**27**	- 12	31%
Option 2	21	34	**24**	- 15	38%

7.4 Aimsun model: Cook St/Hobson St and Vincent St/Mayoral Dr (Auckland)

The Cook St–Vincent St Aimsun model involved linking multiple intersections to test the effect of pedestrian travel between intersections. The goal was to see if pedestrian delay could be improved without adversely affecting vehicular traffic. The model covered three signalised junctions, as shown in figure 7.7. These were:

- Vincent St, Pitt St and Hopetoun St
- Cook St and Hobson St
- Vincent St and Mayoral Drive.

Figure 7.7 Model network

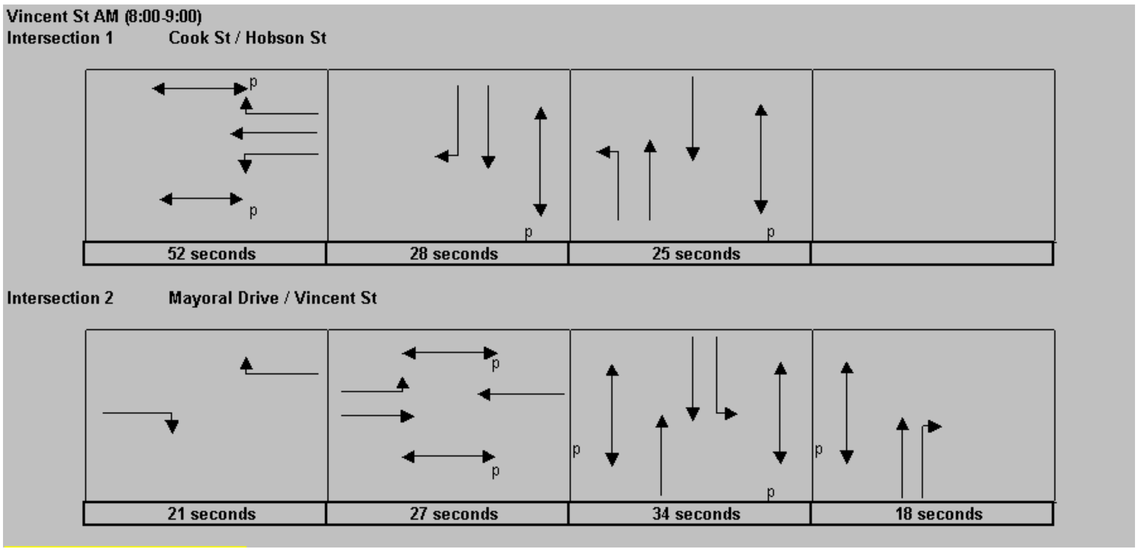


7.4.1 Base model

The base model used the existing phase setting according to the SCATS® data provided (see figure 7.8 for the existing signal setting). The inter-green time was 5 seconds, including 4 seconds of amber time and 1 second of all-red time. The total cycle time was 120 seconds. The model was set up to study pedestrians travelling between intersections, and because of this, only the two closest intersections were required.

The model validation was undertaken for the intersection of Vincent St and Hopetoun St and the intersection of Albert St and Mayoral Drive. The validation result showed that the GEH Statistic requirement was met by 100% matching the target value. The R-squared value was 93%, and the percentage root-mean-square error (RSME) was 19%, both within the validation limits recommended in the EEM (LTNZ 2008).

Figure 7.8 Phase setting in base model

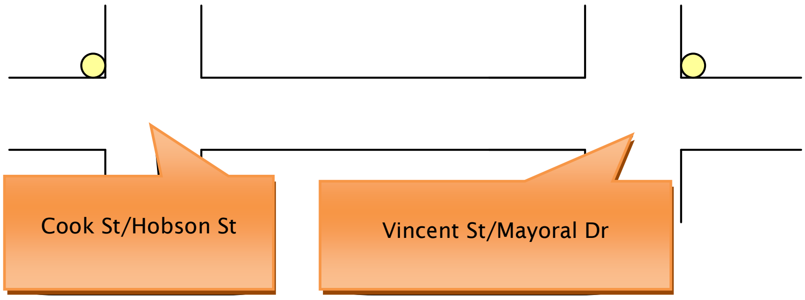


7.4.2 Definition of 'pedestrian journey'

A typical pedestrian journey was selected in order to test the effect of phasings at adjacent intersections on pedestrian delay. The intention of this was to study how the two intersections related to each other, so it could have been possible to use any two intersections.

Figure 7.9 below (not to scale) indicates the pedestrian journey. Yellow circles show the start and end points of the route. The travel time under an assumed free speed of 1.8m/s was also calculated for comparison purposes. It is acknowledged that the pedestrian walking speeds for this model are slightly too fast to be representative of typical walking speeds; however, the findings regarding delay when arriving at an adjacent intersection are still valid, and therefore included here.

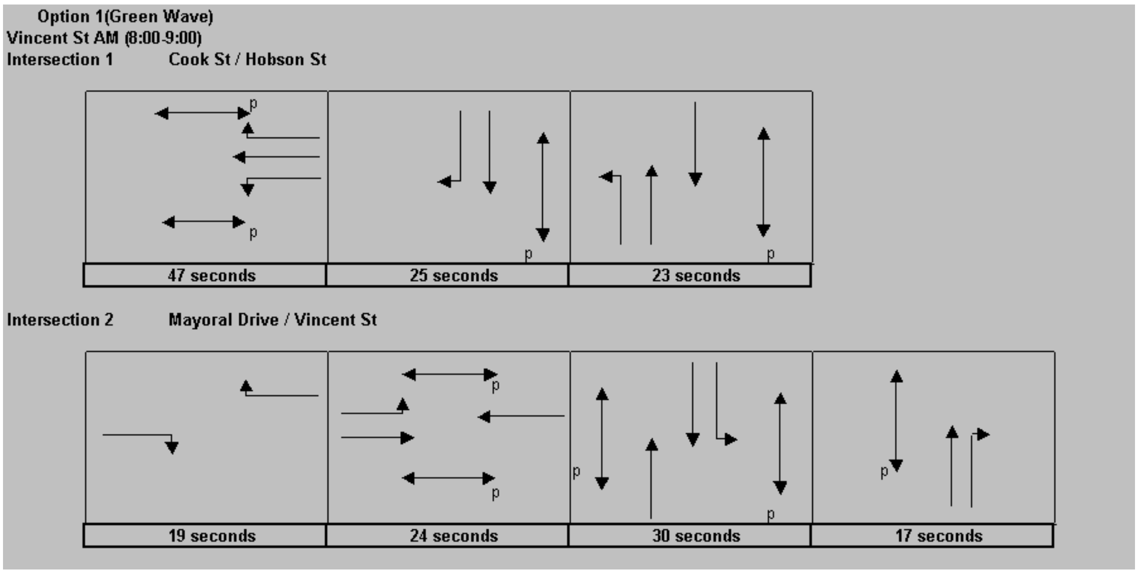
Figure 7.9 Comparison of pedestrian travel time



7.4.3 Option One: Developed alternative

The alternative focused mainly on the pedestrians who crossed both of the intersections along the west-east direction. Therefore, a cycle time of 110 seconds was used to reduce the pedestrian delay. The phase setting, as shown in figure 7.10, was similar to that of the base option, with a cycle time of 110 seconds.

Figure 7.10 Phase setting in developed alternative



7.4.4 Findings of the Aimsun model: Vincent St/Mayoral Drive (Auckland)

The comparison of pedestrian travel times along the east-west (Cook St to Mayoral Drive) route for each option is shown in figure 7.11 and table 7.6. Option 1 decreased the delay for pedestrians by about 5 seconds at the Cook St/Hobson St intersection when compared with the base model. At the intersection of Mayoral Drive and Vincent St, it was possible, through optimisation of the signals, to reduce the average pedestrian delay by 20 seconds. This reduction was achieved without increasing vehicle delay at either intersection. Indeed, a reduction in vehicle delay by an average of 4 seconds was predicted at the Cook St intersection, and slightly less than 1 second at the Vincent St intersection. This was probably the result of the optimisation making better use of available capacity during the noon-1:30pm modelled period.

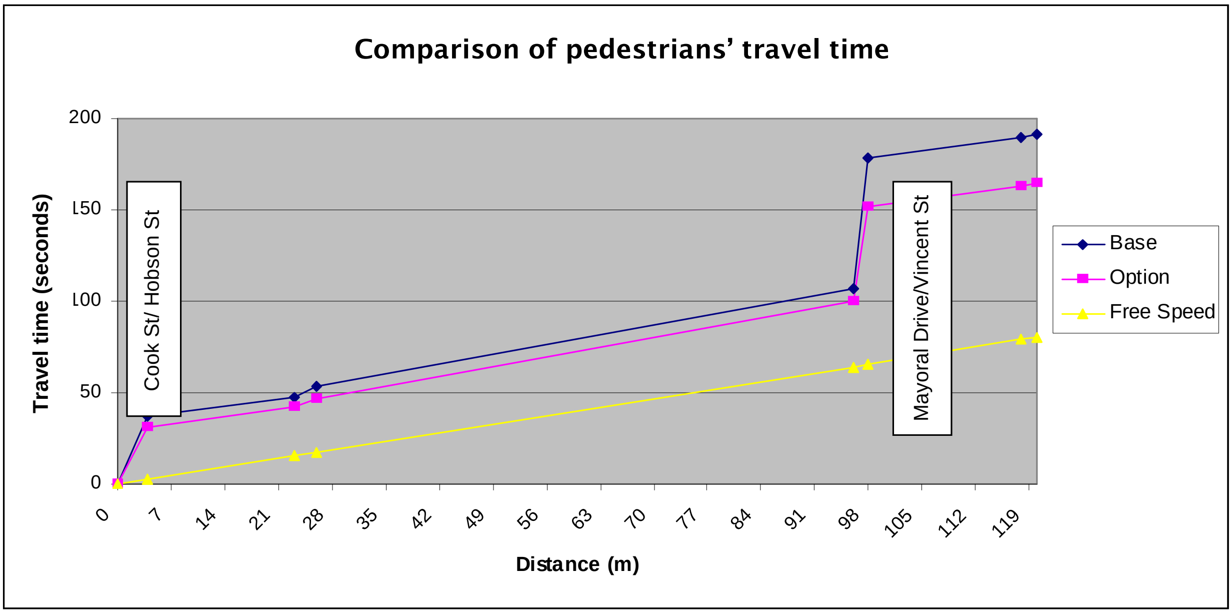
By altering the signal phasings in Option 1, it was possible to reduce pedestrian delays on the east-west direction by an average of 26 seconds, or 14% of the base journey time, without adversely affecting vehicle delay. This savings included a combination of both the signal coordination and decreasing cycle times. This suggests that it would be possible to achieve a significant reduction in pedestrian delay without adversely affecting vehicles during the modelled period. As this would be purely an operational change, it could be achieved at very little cost.

In practice, the ability to reduce pedestrian delays between signals would depend on whether the signals were jointly operated in SCATS® ('married') for the purposes of improving vehicle progression between the two intersections. This would need to be assessed on a case-by-case basis. However, SCATS® does allow for signals to be jointly coordinated during vehicle peak periods and operate independently during periods of low vehicle flow.

Table 7.6 Summary of results per road user

	Route journey/cumulative delay			Average intersection delay	
	Ped. travel time (sec)	Delay per ped. (sec)	% delay	Per car	Per ped.
Free speed	80				
Base	192	81	42%	71	81
Alternative	165	55	33%	66	60

Figure 7.11 Comparison of pedestrians' travel time



7.5 Taranaki St/Courtenay Place intersection (Wellington)

The intersection of Taranaki St and Courtenay Place is located in the central business district in Wellington. This intersection consists of four approaching legs: Manners St, Taranaki St, Dixon St and Courtenay Place, as shown in figure 7.12. At the time of this research, Manners St and Dixon St were both part of Wellington's one-way system. This intersection was nominated by members of the steering group because of its complex nature and high pedestrian volumes. An S-Paramics model was developed for this intersection. As with other locations, the modelling period was noon–1:30pm.

Figure 7.12 Taranaki St/Courtenay Place intersection (Google)

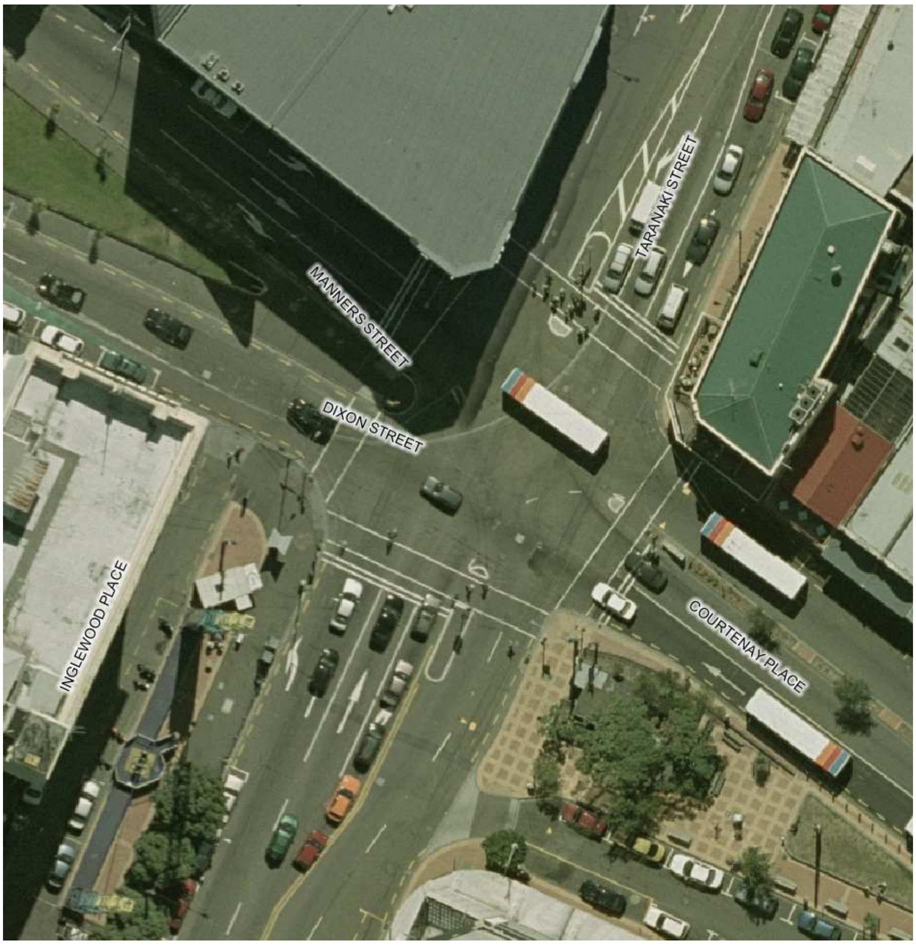
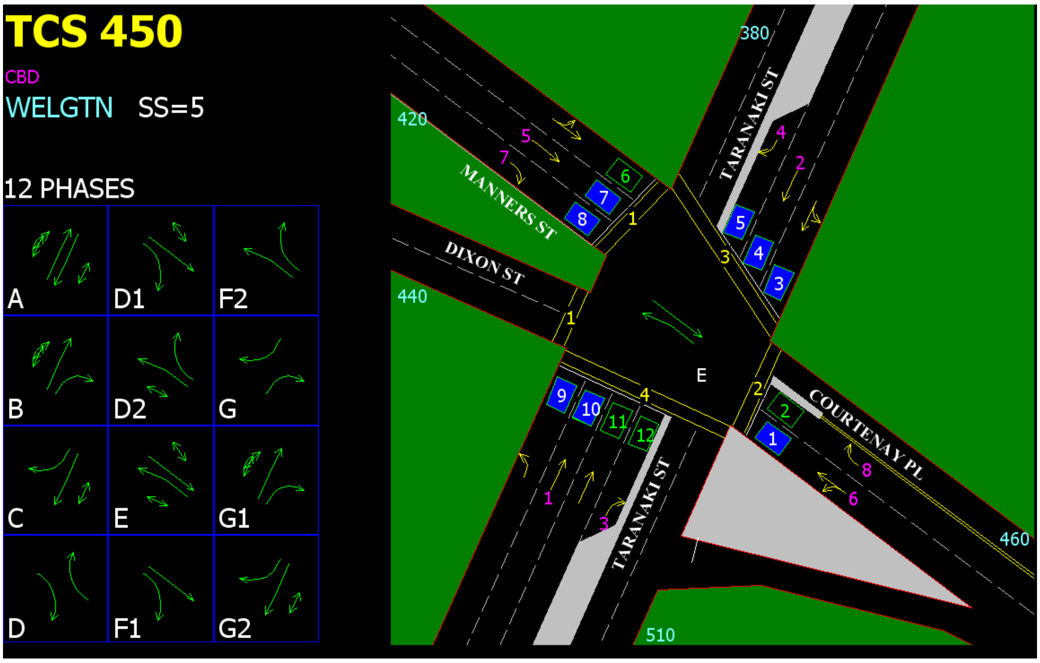


Figure 7.13 Taranaki St/Courtenay Place existing signal setting (SCATS®)



The base model had four phases and a cycle time of approximately 104 seconds during the inter-peak period. Separated right-turning phases were provided for each leg. An average pedestrian walking speed of 5km/h (1.4m/s) was used in both the base and option models. The model provided for a 15% margin of difference in speeds, meaning that some modelled pedestrians walked faster than others.

The base model was validated and checked against EEM guidelines. All the R^2 values were above 0.95, the root-mean-squared error (RMSE) was within 20%, and all the GEH Statistic targets were met.

The following options were modelled:

- Option 1: optimising the traffic signal cycle to minimise the delays
- Option 2: installing an all-stop/Barnes Dance at this intersection, with an optimised signal cycle of 80 seconds.

7.5.1 Option 1: signal optimisation

Option 1 looked at optimising the traffic signal cycle using Sidra. This reduced the cycle time from 104 seconds to 77 seconds. The journey times for pedestrians and vehicles were measured on journey distances selected in the base model and the Option 1 model.

Table 7.7 provides a summary of the benefits of optimisation, including the changes to the average travel time, maximum travel time and average delay for pedestrians for each journey. As can be seen in the table, the average travel time and maximum travel time improved for all pedestrian journeys during the modelled period. As shown in table 7.8, the optimisation also reduced observed vehicle delays.

Table 7.7 Comparison of base model and Option 1 – pedestrian journey time

	Journey length (m)	Free-speed journey time (sec)	Base model			Option 1		
			Max. journey time (sec)	Av. time (sec)	Av. delay (sec)	Max journey time (sec)	Av. time (sec)	Av. delay (sec)
Heading west across Taranaki St (south)	54	39	172	83	**44**	133	69	**30**
Heading east across Taranaki St (south)	54	39	156	79	**40**	134	68	**29**
Heading north across Manners/Dixon Sts	54	38	118	80	**42**	116	66	**28**
Heading south across Manners/Dixon Sts	54	38	174	88	**50**	153	72	**34**
Heading west across Taranaki St (north)	50	36	148	82	**46**	120	70	**34**
Heading east across Taranaki St (north approach)	50	36	144	91	**55**	126	75	**39**
Heading north across Courtney Place	52	37	202	125	**88**	172	82	**45**
Heading south across Courtney Place	52	37	179	84	**47**	121	68	**31**

Table 7.8 Comparison of base model and Option 1 – vehicle journey time

	Journey length (m)	Free-speed journey time (sec)	Base model			Option 1		
			Max. journey time (sec)	Av. time (sec)	Av. delay (sec)	Max. journey time (sec)	Av. time (sec)	Av. delay (sec)
Taranaki St (southbound)	190	14	104	40	**26**	81	36	**22**
Taranaki St (northbound)	161	12	167	40	**28**	94	34	**22**
Courtenay Place to Dixon St	164	12	110	48	**36**	96	37	**25**
Manners St to Courtenay Place	142	10	76	37	**27**	72	29	**19**

7.5.2 Option 2: Sidra optimisation plus Barnes Dance

Option 2 tested the benefit of adding a Barnes Dance for the pedestrian crossing facility at this intersection. A cycle time of 80 seconds was used and each cycle consisted of three phases. The overall cycle was therefore able to be kept relatively short.

In order to account for diagonal crossings, extra crossing movements were included. The average times were derived using the total times for each movement (total crossings multiplied by average delay), meaning that the additional crossings could be factored into the average delays for the new Option 2. However, the actual decrease in times would be greater than shown by the model, as the delay was on a per-crossing basis, and it did not account for people making two separate crossing movements in the base model.

7.5.3 Model findings

Table 7.9 shows that by optimising the signals for the survey period (noon–1:30pm) it was possible to reduce average pedestrian delay at the intersection from 53 seconds per pedestrians to 34 seconds. While still less than ideal, this was a reduction in pedestrian delay of about 37%.

With the Option 2 Barnes Dance, pedestrians experienced less average delay than through optimisation alone. A combination of a reduced cycle time and the addition of a Barnes Dance enabled a reduction in delay for the pedestrians and car occupants, and a reduction in per-person delay of 14 seconds (car occupancy was assumed at 1.3 people per vehicle).

Table 7.9 Summary of result per road user (time in seconds)

	Delay per pedestrian	Change from base model	Delay per car occupant	Change from base model	Delay per person	Change from base model
Base	53		28		36	
Option 1 (optimisation)	34	-19	22	-6	26	-10
Option 2 (Barnes Dance)	24	-29	21	-8	22	-14

As shown in this table, the combination of optimisation and the addition of the Barnes Dance resulted in a significant reduction in pedestrian delay, from the excessively long 53 seconds down to an acceptable 24 seconds. This reduction in delay also reduced the per-person delay to an average of 22 seconds for each person using the intersection.

As an added advantage, the addition of a Barnes Dance would be likely to increase pedestrian safety in this highly pedestrianised area of Wellington.

7.6 S-Paramics model: Jervois Quay (Wellington)

The pedestrian crossing on Jervois Quay is located in central Wellington, connecting the central business area to the Wellington waterfront and a recreation area (including Te Papa Museum), as shown below in figure 7.14. There are two pedestrian signal crossings in this area that operate at the same time. The steering group selected this area because of its high pedestrian volumes and strategic importance for foot traffic. The area essentially operates as a mid-block intersection – although there is a service lane included in the model area, it has very little vehicular traffic.

Figure 7.14 Jervois Quay signalised pedestrian crossings (Google)

The Jervois Quay signals also demonstrate the difficulties in balancing road user needs. The location has roughly three times more vehicles than pedestrians. While this is a busy vehicle corridor, it is also strategically important, as it must be crossed by pedestrians heading to Te Papa Museum or the waterfront.

In the base model, the pedestrian delays were excessive with average delays of 38–41 seconds, whereas average vehicle delays were modest at 4–5 seconds. That is, average pedestrian delays were almost 10 times the delays for vehicles. However, because the vehicle numbers were so much higher than pedestrian numbers, any noticeable increase in delays to vehicles would be likely to increase the per-person delay, which acts as a measure of fair distribution of road space. The challenge was to try to reallocate the cycle times to improve pedestrian delay, without substantially adding to the per-person delay.

As the S-Paramics model is essentially a mid-block model, it was considered more suitable for this location. The two options available were either to:

- decrease both pedestrian ‘walk’ and vehicle phase times to decrease the overall cycle time
- extend the pedestrian ‘walk’ phase but maintain the base cycle length.

The aim was to see which configuration would result in the lowest delays for pedestrians, and which would result in the least impact on vehicle delays.

The base model had a cycle time of 100 seconds during the inter-peak period – 75 seconds allocated for vehicles and 25 seconds for the pedestrian crossing and clearance phase. Pedestrian walking speeds of 5km/h (1.4m/s) were used in both the base and options models. The following options were modelled:

- Option 1: optimise the traffic signal cycle to minimise per-person delay
- Option 2: extend the pedestrian green phase to 35 seconds, calculated within the current cycle time of 100 seconds.

7.6.1 Option 1: Signal optimisation

Option 1 involved optimising the traffic signal cycle to 80 seconds, with a pedestrian phase of 32 seconds. Thus although the cycle times were shorter, vehicles had to wait longer because of the longer pedestrian green phase. Although there was an increase in delay for vehicle occupants, the delay for vehicle occupants after optimisation was still almost half of the average delay experienced by pedestrians. On a per-person basis, Option 1gave vehicle occupants a substantial advantage over pedestrians.

The model used an average walking speed of 1.4m/s. The model also provided for a 15% margin of difference in speeds, meaning that some modelled pedestrians walked faster than others.

Table 7.10 shows that pedestrians experienced reduced journey times crossing Jervois Quay under Option 1. However, vehicle journey times on Jervois Quay (in both directions) were slightly increased from an average of 22 seconds to 28 seconds, as shown in table 7.11.

Table 7.10 Comparison of base model and Option 1 – pedestrian journey time

	Journey length (m)	Free-speed journey time (sec)	Base model			Option 1		
			Max. journey time (sec)	Av. time (sec)	Av. delay (sec)	Max. journey time (sec)	Av. time (sec)	Av. delay (sec)
City to Queens Wharf – northbound	173	124	235	165	**41**	186	147	**23**
Queens Wharf to city – southbound	173	124	219	162	**38**	184	148	**24**

Table 7.11 Comparison of base model and Option 1 – vehicle journey time

	Journey length (m)	Free-speed journey time (sec)	Base model			Option 1		
			Max. journey time (sec)	Av. time (sec)	Av. delay (sec)	Max. journey time (sec)	Av. time (sec)	Av. delay (sec)
City to Queens Wharf – northbound	237	17	47	21	4	55	27	10
Queens Wharf to city – southbound	237	17	50	22	5	57	29	12

7.6.2 Option 2: Increasing the length of the pedestrian phase

Option 2 involved modifying the base model to include longer pedestrian crossing times (35 seconds) within the existing traffic cycle time of 100 seconds.

Tables 7.12 and 7.13 show that in Option 2, increasing the length of the pedestrian phase, with optimisation, meant pedestrians would experience less delay than the base model, while drivers would experience longer delays. However, the benefit for pedestrians was not as great as the Option 1 scenario. The average delay was shorter than that in the base model, but 8 seconds longer than that in Option 1.

Table 7.12 Comparison of base model and Option 2 – pedestrian journey time

	Journey length (m)	Free-speed journey time (sec)	Base model				Option 2			
			Min. journey time (sec)	Max. time (sec)	Av. time (sec)	Av. delay (sec)	Min. journey time (sec)	Max. time (sec)	Av. time (sec)	Av. delay (sec)
City to Queens Wharf – northbound	64	46	40	177	90	**44**	39	121	76	**30**
Queens Wharf to city – southbound	64	46	39	151	83	**37**	39	120	74	**29**

Table 7.13 Comparison of base model and Option 2 – vehicle journey time

	Journey length (m)	Free-speed journey time (sec)	Base model				Option 2			
			Min. journey time (sec)	Max. time (sec)	Av. time (sec)	Av. delay (sec)	Min. journey time (sec)	Max. time (sec)	Av. time (sec)	Av. delay (sec)
City to Queens Wharf – northbound	237	17	15	49	21	**4**	15	59	25	**8**
Queens Wharf to city – southbound	237	17	16	51	22	**5**	16	62	27	**10**

7.6.3 Model findings

Table 7.14 provides a summary of the results of the pedestrian modelling for Jervois Quay.

Table 7.14 Summary of findings for Jervois Quay

	Base model	Option 1	Change from base model	Option 2	Change from base model
Pedestrians – City to Queens Wharf – northbound	41	23	-18	21	-20
Pedestrians – Queens Wharf to city – southbound	38	24	-14	22	-16
Cars – northbound	4	10	+6	14	+10
Cars – southbound	5	12	+7	16	+11
Per-person delay	**11**	**13**	**+2**	**16**	**+5**

The comparison between Option 1 and Option 2 indicated that pedestrian delay could best be improved by reducing the overall cycle times rather than by simply increasing the green phase. However, this led to higher delays for vehicles, largely because the increase in cycle times also included a reallocation of time toward pedestrians in terms of their share of the total cycle. However, this should be noted in the context that the base scenario had pedestrian delays up to 10 times longer than those for vehicles.

In Option 2, the cycle time was longer but the clearance time for pedestrians was extended. The reduction in delay for pedestrians was not as substantial. This was probably because the benefits in Option 2 would be experienced only by those arriving during the extended green phase, whereas a reduction in cycle times would benefit all those arriving outside of the walk phase, as they would have less time to wait until the next cross phase.

The modelling demonstrated that if pedestrians were studied in isolation from vehicles, Option 2 (reduced cycle times) would be the favoured option. This could work in areas where, for instance, pedestrians outnumber vehicle occupants.

In both modelled scenarios, vehicle delay was increased. The base model had delay for pedestrians up to 10 times higher than that for vehicles; however, for the location chosen, there were three times more vehicles than pedestrians, and if vehicle occupancy was taken into consideration, the per-person ratio was even less favourable for pedestrians. An increase in delay to vehicles might not result in a fair distribution of road space at this location.

Both of the options modelled increased per-person delay – less so in Option 1, where the average delay for road users at the intersection went up by 2 seconds. However, the current arrangement has pedestrians waiting 10 times longer than vehicle occupants, and well above the international recommended maximum of 30 seconds. Option 2 reduced pedestrian delay by almost half. There is an equity issue if one mode choice has to wait for excessive periods of time, particularly if this might lead to unsafe behaviour. So although Option 1 adds 2 seconds to the average per-person delay, the significant reduction to pedestrian delay would make this a preferred option, as the delays for vehicles are still minor compared with delays for pedestrians.

It should also be noted that for intersections that are coordinated with adjacent intersections, the preferred option would depend on how the intersection communicates with the adjacent intersection and what sort of time intervals are possible.

For independent intersections where pedestrian numbers are higher than vehicles, the preferred option for reducing pedestrian delay would be to reduce the overall cycle times.

For intersections where cycle times are reliant on coordination with adjacent intersections (a SCATS® master–slave relationship), it may still be possible to decrease delay for motor vehicles and pedestrians by reallocating the time available (ie if significant numbers of pedestrians are marginalised by the current configuration, it might be possible to extend pedestrian green times). However, as long as intersections are in a SCATS® 'master–slave' relationship, the 'slave' has its cycle times determined by the 'master'. This coordination between 'master' and 'slave' means that the 'slave' may have cycle times longer than necessary during the off-peak, which can create longer delays for pedestrians and inefficiencies in moving traffic from other approaches.

A key finding of this research was that a number of intersections are set up for peak loading, and this can lead to inefficiencies during off-peak periods – ie unnecessary delays to both vehicles and pedestrians. To improve the efficiency of intersections, it would be better for intersections to 'divorce' during the off-peak period, or once traffic volumes drop below a defined threshold, so that SCATS® can self-optimise based on flows to each approach. This could reduce cycle times and therefore reduce delay for both pedestrians and vehicles.

7.7 Manchester St and Hereford St corridors (Christchurch)[6]

In order to understand the delays experienced by pedestrians travelling along the length of a road with multiple signalised intersections, an S-Paramics corridor model was developed for two streets in Christchurch – Manchester St and Hereford St. The Manchester St corridor was selected because this route is primarily used for access to adjoining development, rather than as a primary through route, and thus should provide high amenity for active modes such as walking and cycling. The adjacent one-way street system in central Christchurch is promoted as the through-route for traffic wanting to pass through the city.

Manchester St consists of five signalised intersections between Armagh St and Cashel St, evenly spaced about 100m apart. Hereford St consists of three signalised intersections between Oxford Terrace and Manchester St, evenly spaced about 200m apart. A modeller physically walked the route to determine whether the modelled values were realistic.

6 Please note that this research was undertaken before the earthquakes occurred in Christchurch in September 2010 and February 2011. Some descriptions may no longer be accurate in the current conditions.

Figure 7.15 Manchester St and Hereford St corridors, Christchurch

The base model was investigated using two different walking speeds – 1.1m/s and 1.4m/s – to gain an understanding of how a single corridor could offer differing levels of delay for pedestrians with different walking speeds. The cycle times did not change between the two base model options, but the model was populated by pedestrians with these two different walking speeds.

The following options were investigated:

- Option 1 consisted of the base model populated by pedestrians with a walking speed of 1.1m/s.
- Option 2 consisted of the base model populated by pedestrians with a walking speed of 1.4m/s.
- Option 3 provided for a double Barnes Dance at the intersection of Hereford St and Colombo St (the busiest intersection for pedestrians in Christchurch).

7.7.1 Base model

The existing traffic signal cycle obtained from SCATS® data showed an average 77-second cycle at each intersection. The walking speeds were represented with a modelled pedestrian speed of 4km/h (1.1m/s) and compared with the slightly faster speed of 5km/h (1.4m/s). An optimal time was also identified, assuming a 'green-wave' or free-flowing speed for pedestrians.

7.7.2 Base model with pedestrian walking speed of 1.1m/s

Pedestrians with a walking speed of 1.1 m/s were expected to complete the journeys in 440 seconds along Manchester St and 465 seconds along Manchester St. Tables 7.15 and 7.16 show the minimum, maximum and average travel times at a 1.1m/s walking speed, along with the delay and green-wave speed.

Table 7.15 Pedestrian journey times walking at 1.1m/s on Manchester St

	Base model (sec)			Green wave (sec)	Delay occurred (sec)	% delay in average %
	Min.	Max.	Av.			
Armagh St to Cashel St	621	694	638	440	**198**	31
Cashel St to Armagh St	626	676	641	440	**201**	31
Average time	623	685	639	440	**199**	31

Table 7.16 Pedestrian journey time walking at 1.1m/s on Hereford St

	Base model (sec)			Green wave (sec)	Delay occurred (sec)	% delay in average %
	Min.	Max.	Av.			
Oxford Tce to Manchester St	477	637	552	465	**87**	16
Manchester St to Oxford Tce	466	568	504	465	**39**	8
Average time	471	602	528	465	**63**	12

7.7.3 Base model with pedestrian walking speed of 1.4m/s

It was expected that if they had a ‘green man’ signal at every intersection, pedestrians with a walking speed of 1.4m/sec would take 346 seconds to complete the 484-metre journey on Manchester St and 365 seconds to complete the 511-metre journey on Hereford St. Tables 7.17 and 7.18 show the minimum, maximum and average travel times and delay for pedestrians travelling the same route at a 1.4m/s walk speed. Note the signal times are the same as for the 1.1m/s scenario above.

Table 7.17 Pedestrian journey times walking at 1.4m/s on Manchester St

	Base model (sec)			Green wave (sec)	Delay occurred (sec)	% delay in average %
	Min.	Max.	Av.			
Armagh St to Cashel St	422	484	453	346	**107**	24
Cashel St to Armagh St	427	478	450	346	**104**	23
Average time	424	481	452	346	**106**	23

Table 7.18 Pedestrian journey times walking at 1.4m/s on Hereford St

	Base model (sec)			Green wave (sec)	Delay occurred (sec)	% delay in average %
	Min.	Max.	Av.			
Oxford Tce to Manchester St	397	502	444	365	**78**	18
Manchester St to Oxford Tce	414	467	441	365	**76**	17
Average time	406	484	443	365	**77**	17

7.7.4 Pedestrian corridor model – pedestrian speed comparison findings

From the tables above, it can be seen that the current traffic configuration along Manchester St (with signal cycles times of approximately 77 seconds at each intersection) results in a cumulative delay of 199 seconds for pedestrians travelling at 1.1m/s, but only 106 seconds for pedestrians travelling at 1.4m/s.

It is interesting to note, therefore, that pedestrians travelling at the slower speed not only take longer to complete the route because of their slower speed, but also incur a penalty of another 93 seconds in additional intersection delays.

Based on observation of the models and also of real intersections, it is thought that the reason for this is relatively straightforward – a pedestrian arriving slightly early at an intersection has to wait only a short length of time before the 'walk' phase is activated; a pedestrian arriving late at an intersection has to wait for the entire cycle before the beginning of the next crossing phase.

The implications of this are two-fold:

- Firstly, when engineering a green wave it is preferable to underestimate the speed of pedestrians rather than overestimate it. If the speed is overestimated, more people may arrive just after the 'walk' phase ends, and so the average per-person delay may actually be increased rather than reduced.
- Secondly, this reinforces the conclusion identified previously – that it is better to reduce pedestrian delay by reducing cycle times, rather than by extending the 'walk' phase. This is because extending the 'walk' phase only benefits those arriving at the crossing during that phase, whereas reducing the cycle times benefits those arriving outside the 'walk' phase, which is a longer proportion of the overall cycle.

It would be impossible to eliminate pedestrian delay entirely, as the variation in walking speeds can be significant. To improve pedestrian speeds, it may therefore be simpler to look at improving the delay at intersections within pedestrian areas, rather than going through the onerous task of assuming an average walking speed and trying to engineer SCATS® with fixed times to coordinate signals to match it. This would also improve the delays for pedestrians who are walking just a portion of the corridor. (Note that it is unlikely that the majority of pedestrians would be walking from one end of the corridor to the other.)

Further investigation found that the addition of a double-cycle Barnes Dance on the Hereford St/Colombo St intersection would reduce average delays for pedestrians at both walking speeds. However, a double-cycle Barnes Dance could have a negative impact on vehicular delay, and should only be applied selectively in highly pedestrianised areas.

7.8 Modelling summary

Table 7.19 shows the base per-person delay for each stand-alone intersection modelled, as well as the improvements to per-person delay that were considered possible during the modelled period of noon–1:30pm.

Table 7.19 Changes to per-person delay at stand-alone intersections

Location	Base delay per person (sec)	Effect of optimisation (sec)	Optimisation + other measures (sec)	Improved per-person delay (sec)
Lake Rd, The Strand (North Shore City)	52	-13	-21	31
Albert St & Customs St (Auckland City)	39	-12	-15	24
Taranaki St & Courtney Place (Wellington City)	36	-10	-14	22

As can be seen in table 7.19, significant improvements were possible at the surveyed intersections, with signal optimisation and other measures not only providing a fairer distribution of road space, but also bringing the average delays down to levels that pedestrians are likely to find more acceptable. As previously mentioned, the ability to implement these changes would depend on whether or not the signals were permitted to operate independently during the modelled time period.

8 Conclusions

8.1 General observations

The results of our international literature review, modelling, and pedestrian surveys, indicate that there is substantial room for improvement when it comes to reducing pedestrian delay, and that the current system of weighting delay towards vehicles actually increases the overall delay for all road users at intersections.

This research's pedestrian surveys confirmed the finding of International research, that after about 20–30 seconds of delay, pedestrians' level of frustration grows disproportionately to the actual delay itself, as evidenced by their disproportionate perceptions of delay. This frustration has implications for traffic safety if pedestrians violate the signals and crossed between pedestrian cycles.

Thus, we found that improvements to delays for pedestrians at signalised crossings are necessary, from both a delay and a safety perspective.

8.2 Safety vs efficiency

There is often an inherent trade-off between efficiency and safety. If all road users obey the road rules, the safest intersections are those where pedestrians are provided complete protection (ie exclusive crossing movements), either through a Barnes Dance or through red-arrow signals for vehicles and an absence of filtered turns. However, if delays are perceived to be too long (ie greater than 30 seconds), pedestrians are likely to violate the signals and use their own judgement to cross. Thus, an apparently safe design option may not lead to a safe outcome, as it may increase non-compliant (risk-taking) behaviour.

As a result, both safety and efficiency need to be considered when operating signalised crossings, and even where there are comparatively low pedestrian volumes, excessive pedestrian delays should be avoided.

8.3 Off-peak periods

The research also confirmed that it is possible to reduce pedestrian delay without causing undue delay for vehicular traffic. This is particularly true during vehicle off-peak periods, where the spare capacity means that the additional delay to vehicles might be small or non-existent.

When intersections are coordinated in a SCATS® 'master–slave' relationship, the 'slave' has its cycle times determined by the 'master'. This may improve coordination between 'master' and 'slave', but it also means that the 'slave' may have cycle times longer than necessary during the off-peak, which creates longer delays for pedestrians and also can be inefficient in moving traffic from other approaches. To improve the efficiency, it is better for intersections to 'divorce' during off-peak periods, or once traffic volumes drop below a defined threshold, so that SCATS® can self-optimise based on flows to each approach. This is likely to reduce cycle times and therefore reduce delay for both pedestrians and vehicles.

The results of our modelling indicated that optimising signals would have a significant benefit for pedestrians. The modelled period was noon–1:30pm; ie traditionally busy pedestrian periods. Almost all of the sites studied showed improvements to pedestrian times without adversely affecting delays for vehicles. While it is true that the results might have been different during traditional vehicle peaks, this does indicate that during off-peak periods there is room to improve pedestrian delay without negatively affecting vehicles.

The beneficial effects of phase profiles and/or fixed timings that are designed to cater for vehicle peak loading may be wasted, or even counter-productive, during off-peak periods. By creating separate off-peak settings, it would be possible to reduce delays for both pedestrians and vehicles, and thus improve the through-put of these intersections at relatively little cost.

8.4 A fairer (per-person) allocation of time

When engineering signal design, the overall function of the intersection for all users should be considered, not just the vehicle volumes. Our modelling identified that the delays caused to pedestrians accounted for a significant amount of the per-person delay generated by a signalised intersection, as pedestrians frequently faced longer delays than vehicles. In some of the high-pedestrian areas modelled, the delay for pedestrians was more than double that for vehicles.

Some pedestrian delay is inevitable; however, the delays measured in Auckland were significantly higher than those recommended internationally. Eliminating delay altogether would be impossible, but allocating pedestrian time based on a total road-user delay would not discriminate against pedestrian trips as a mode choice. Simply including pedestrians in designs to optimise for all road users (rather than just for vehicles) could greatly reduce the delay for pedestrians and improve the overall per-person delay at an intersection.

8.5 Operational interventions

The research resulted in four key findings with relation to operational changes such as cycle times and coordination.

8.5.1 Progression and offset

To improve pedestrian speeds along a corridor, it may be possible to improve pedestrian progression between intersections through a similar approach to that used for vehicular traffic; ie determine suitable off-set times based on average pedestrian speeds, and extend the ‘walk’ phase at intersections to accommodate the ‘wave’ of pedestrians. However, for this to be successful the intersections would need to be close together – a greater distance between intersections means that pedestrians’ arrival times vary because of individuals’ different walking speeds. There is also a danger that by attempting to coordinate the intersections, the total delay might increase if the number of people arriving just after a pedestrian ‘walk’ phase increases (thus increasing the number of people who have to wait through an entire cycle). It is therefore better to underestimate pedestrian speeds, so that those arriving just before a ‘walk’ phase have a much shorter wait than those arriving just afterwards.

8.5.2 Extending green times

The modelling showed that it is preferable to reduce cycle times rather than to extend green times, particularly for mid-block crossings. Extending a green phase can be logical for cars, where there is a need to clear queues that may exceed the capacity of the intersection if unchecked. However, in the case of pedestrians, the queues are cleared almost instantly. The benefits of extending the 'walk' phase are experienced only by those arriving during the extended 'walk' phase, whereas a reduction in cycle times benefits all those arriving outside of the 'walk' phase, as they have less time to wait until the next one.

8.5.3 Decreasing cycle times/reducing 'green wastage'

The modelling results also suggest that to improve pedestrian delay, it might be simpler to look at decreasing cycle times, even where intersections are adjacent, as this caters to pedestrians arriving from any location, not just those from the adjacent intersection. This can mean changing the priority of an intersection, or reducing 'green wastage' (ie where no one is moving, as the traffic has already cleared). One example of how this can be achieved is by improving off-peak efficiency, such as having signals 'divorce' when vehicle volumes drop below an established threshold.

8.5.4 Increasing pedestrian 'walk' times or signal cycle times

The research found that it is desirable to determine whether pedestrians are receiving a fair share of the existing cycle times at intersections by comparing the delays for pedestrians and for vehicle occupants, along with their comparative volumes.

In some cases it will not be possible to improve the existing use of cycle time in order to provide more pedestrian time. For example, if pedestrians are being marginalised at an intersection (ie pedestrian volumes are disproportionate with the amount of cycle time given to them), decreasing their delay may actually require an increase in cycle times (ie by adding more time for pedestrians, without reducing the clearance time for vehicles).

8.6 Intersection optimisation and policy

The literature review identified that every pedestrian is different (eg elderly pedestrians require a longer 'walk' phase than other pedestrian groups) and the results of our modelling suggested it is better to engineer a pedestrian green wave to be slightly slower, rather than slightly faster, than the average pedestrian speed. This is because if a pedestrian arrives too soon for a 'walk' phase, they wait only a short time until it begins; if they arrive too late for a 'walk' phase, they have to wait an entire cycle before the next one begins. Thus, the way a green wave is engineered can have a significant impact on total delay for pedestrians.

As there are many different pedestrian environments to cater for, and many different types of intersections, there is no one-size-fits-all recommendation that can be made for intersections. Intersections should be engineered with regard to their observed characteristics and their place within the wider network. Improvements for the different types of pedestrians should be tailored to suit the specific needs of the intersection, and incorporated into the intersection design and operation. The simplest way of reducing delay for pedestrians is to include this factor in any signal optimisation. Optimisation based on total delay for road users, rather than just delay for vehicles, leads to a fairer and more efficient use of the intersection.

This research identified that an improvement in pedestrian travel times would require a change of policy focus. The literature review showed that the value of time for pedestrians in this country is low, by world standards, but it would be hard to argue that New Zealand pedestrians contribute any less to the economy than those in other countries. As long as pedestrians are disadvantaged through the central governments' value-of-time policy, there will be little incentive for local government agencies to reduce pedestrian delay, as the economic gain will be considered marginal. It is therefore appropriate to consider revisiting the EEM's (LTNZ 2008) value of time for pedestrians, as it has not been updated for a number of years. A review could be undertaken to determine whether New Zealand's approach is consistent with international best practice, as well as whether the current value is still appropriate, given the NZTS objective of increasing active modes to 30% of total mode share in urban areas.

At a local government/operational level, standard practice for optimising traffic signals does not yet involve including a requirement to consider pedestrians; pedestrian-volume counts are not common or required. As a result, the effects of signal phasings on pedestrians are often not considered, and the economic costs or benefits of pedestrian delay are unknown. Another way of looking at this is to consider that if pedestrians are not included, the value of time for pedestrians defaults to zero – their true economic value is overlooked and the true efficiency of an intersection may be unknown.

Thus the issue of pedestrian delay moves beyond a purely technical issue, as improving the status quo will rely on a policy focus that is genuinely multi-modal in its strategic approach and in its implementation at local government level.

9 Recommendations

9.1 Technical implementation

The most important observation to come out of this research is that it is possible to reduce pedestrian delay through relatively simple operational changes, without unfairly disadvantaging other road users. The following three operational recommendations could be used to achieve this:

- reduction of signal cycle times, particularly in off-peak periods when vehicle queuing capacity is less of a factor
- introduction of off-peak signal phasings, to better utilise off-peak capacity (and potentially reduce delays for both pedestrians and vehicles)
- introduction of per-person optimisation, rather than per-vehicle, to allow a fairer distribution of the time available at an intersection for all road users.

In order to achieve this, pedestrian counts should be undertaken for any intersection modelling project. This would require additional surveyors, but ultimately it would result in very little additional cost if the data was collected at the same time as surveys for vehicle-turning movements and vehicle queue lengths.

For existing SCATS® users, there are a number of other ways to decrease pedestrian delay at intersections. The following is a list of SCATS®-based signal options that can be used to influence pedestrian movements at signalised intersections:

- extended ‘walk’ phases
- automatic demand for the ‘walk’ cycle
- staggered crossing/use of pedestrian refuges
- double cycle
- allow gaps in vehicle traffic to terminate the vehicle phase, so that the signal moves through its phases faster and serves pedestrian demands sooner
- ‘call ahead’ – ie signals at a series of intersections are linked to generate auto-demand at adjacent intersections
- early introduction of the pedestrian phase at an intersection (also known as ‘leading pedestrian interval’)
- overlap of ‘walk’ and ‘walk clearance’ cycles
- use of a scramble/Barnes Dance phase where there is a high volume of pedestrians
- use of a double Barnes Dance arrangement where there is a very high number of pedestrians relative to the number of vehicles – this would provide the protection of an exclusive pedestrian phase, but without the pedestrian delay that sometimes accompanies a single Barnes Dance.

The usefulness or appropriateness of each option will vary on a case-by-case basis, and will depend on a number of factors such as physical layout, road geometry, vehicle volumes, pedestrian volumes and destinations, freight volumes, bus priority, and the proportion of potentially vulnerable pedestrians.

Optimising signals to include per-person delay rather than per-vehicle delay, would improve travel times for pedestrians, recognising their contribution to the transport network, without providing any mode-specific favouritism.

At an operational level, the most appropriate simulation tools should be used; eg software packages such as Vissim, which includes pedestrian modelling features, and ARTIS, which can be used to study the effect of changes to SCATS® signal operation prior to their implementation in the field.

9.2 Policy development

The research identified that New Zealand value of time figures for pedestrians have not been updated for some time, and may be inconsistent with international best practice. At a central government level, it is recommended that the current EEM value of time for pedestrians be revisited to determine whether the current EEM approach is:

- consistent with the changes to New Zealand legislation over the past seven years
- consistent with the NZTS objective of increasing active modes to 30% of total mode share in urban areas.

At a local and regional government level, it is recommended that policy be developed to consider multi-modal outcomes while assessing the performance of intersections and traffic corridors. This can be achieved by:

- providing resources to optimise signals regularly (eg every three years) to improve the efficiency of signals at moving all road users (including pedestrians)
- including optimisation of both peak and off-peak signals, recognising that peak loading and off-peak conditions have different requirements – this would not only reduce pedestrian delay by making better use of spare capacity, but would also likely reduce vehicle delays caused by 'green wastage'
- including pedestrians in all modelling, optimisation and cost–benefit calculations of central-city areas.

To be effective, these requirements would need to apply to network consultants and other consultant contracts. Failure to provide this requirement would mean that the true economic outcomes of optimisation would remain unknown.

9.3 Areas for future research

A number of areas of research could build upon the findings of this research, to improve issues around pedestrian safety and delay. Examples include the following:

- development of a best-practice guide for reducing pedestrian delay, including a requirement to consider pedestrians when optimising signals or making operational changes
- a re-evaluation of the EEM value of time for pedestrians, in light of international best practice

- a study of pedestrian delay during peak periods (morning and afternoon)
- pedestrian micro-simulation best practice – an analysis of the available micro-simulation tools, using the same data inputs (controlled data), to identify the most suitable package for New Zealand
- further investigation into the safety implications of filtered-turning movements, adjusted for both pedestrian volumes and traffic volumes (ideally including before and after studies)
- a controlled test on a specific intersection(s) to identify the relationship between delay and compliance
- examination of the change to accident rates and delay after the provision of such features as cycle lanes and pedestrian refuges
- research into the actual walking speeds of New Zealand citizens, possibly in conjunction with research into the value of time of pedestrians – because walking speeds and value of time may differ from place to place, this would need to canvas a variety of locations, perhaps separating out the walking speeds for urban, suburban, and semirural environments, for use in modelling
- further research into pedestrian-countdown mechanisms and their effects on compliance, safety, delay and user satisfaction
- further research into the reporting gap between CAS and databases held by ACC and St John Ambulance, with a view to identifying opportunities for improving CAS reporting.

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Appendix

A1 Pedestrian attitude survey

Pedestrian Attitude Survey

Time:

Site Location:

Trip Specific Questions

Q.1 Where are you going to? *(Determine whether commuters have different behaviour to shoppers or tourists)*

Work	☐	**Education**	☐	**Shopping**	☐	**Food/Meal**	☐
Entertainment	☐	**Public Transport**	☐	**Other**	________		

Q.2 How long is your current walk? *(Only take the walking time required for the whole journey that involves travelling on vehicles???)*

< 5 minutes	☐	***5-10 minutes***	☐	***10-15 minutes***	☐	***> 15 minutes***	☐

Q.3 How long do you feel you generally have to wait before crossing at a signalised intersection? *(Perceptions of wait times)*

< 15 seconds	☐	**15-30 seconds**	☐	**30-45 seconds**	☐	**45-60 seconds**	☐
> 1 minute	☐	**> 2 minutes**	☐	**> 3 minutes**	☐		

Q.4 What do you think the reasonable waiting time should be to cross this road / intersection?

< 15 seconds	☐	**15-30 seconds**	☐	**30-45 seconds**	☐	**45-60 seconds**	☐
> 1 minute	☐	**> 2 minutes**	☐	**> 3 minutes**	☐		

General Questions

Q.5 How often do you start crossing when you see a Solid red man at traffic signals? *(Determine pedestrian willingness to risk / obey traffic signals)*

Never	☐	**Occasionally** *<50%*	☐	**Usually** *>50%*	☐	**Always**	☐

Q.6 How often do you start crossing when you see a Flashing red man at traffic signals? *(Determine pedestrian willingness to risk / obey traffic signals)*

Never	☐	**Occasionally** *<50%*	☐	**Usually** *>50%*	☐	**Always**	☐

Q.7 How often do you cross the road if there is no formal crossings? *(Determine the willingness to cross mid-block where no formal crossing exist)*

Never	☐	**Occasionally** *<50%*	☐	**Usually** *>50%*	☐	**Always**	☐

Q.8 Do you think more priority should be given to pedestrians in CBD areas, even if it means increasing traffic delays?

Yes	☐	**No**	☐	**Unsure**	☐

Q.9 What pedestrian facilities do you prefer?

Signalised	☐	**Zebra**	☐	**Foot Bridge**	☐	**Ped Refuge / Staggered crossing**	☐
Underpass	☐	**Other**					

Q.10 What does a Flashing Red signal mean?

Don't Start	☐	**Hurry Up**	☐	**Don't Know**	☐

Your comments will help us improve the quality of travel around the country. Thank you for your time taking this survey.

A2 Analysis of pedestrian attitude survey

To understand the issues for pedestrians in a New Zealand context, data was collected at a variety of sites in Auckland, Wellington and Christchurch. This included surveying a random sample of pedestrians in order to learn more about the following issues:

- trip purpose
- trip length
- perceived length of wait
- opinions regarding a 'reasonable' length of wait
- preferred crossing type
- willingness to walk in spite of red signals, flashing red signals, or to make an informal crossing
- desire for further improvements for pedestrians
- the level of understanding of the meaning of signals.

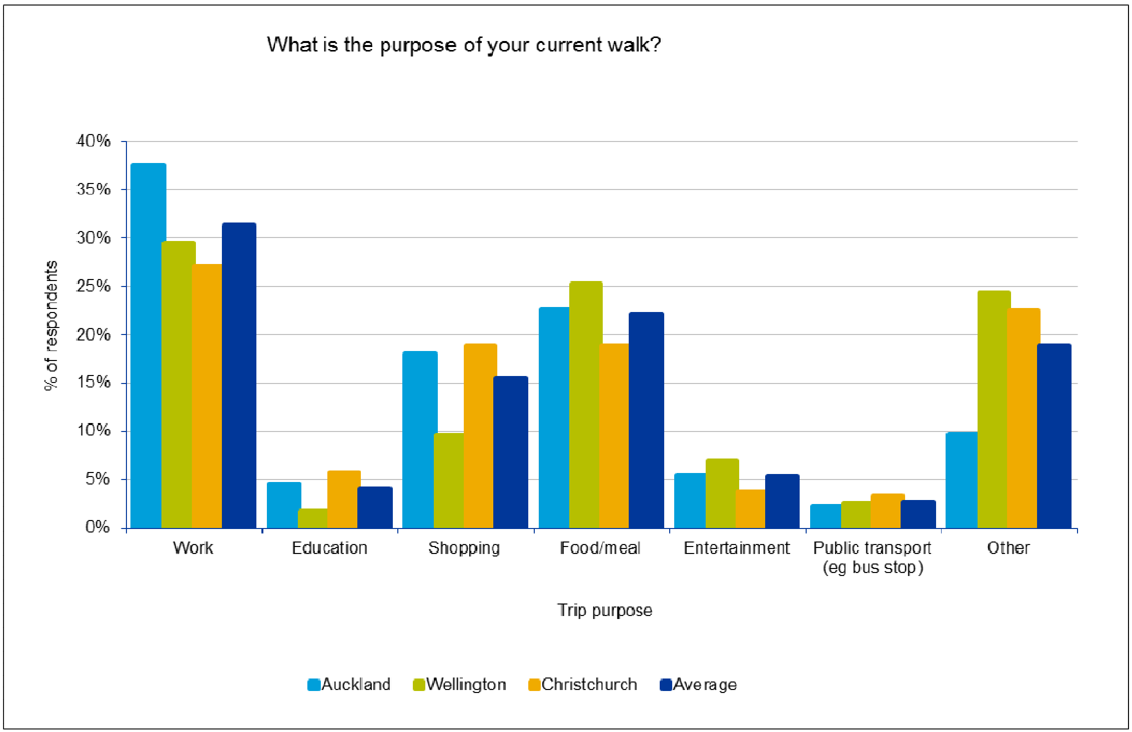
The next sections describe the results of the 811 pedestrian surveys undertaken in Auckland, Wellington and Christchurch. This data was compared between cities, and also compared against the observations of pedestrian behaviour that occurred at the same time. The surveys were kept as short and simple as possible, to make it more likely that pedestrians would agree to be questioned.

These surveys provided information for urban central-city areas – asking the same questions in a suburban setting would probably have had different results. Note also that some of these results are skewed because of the timing of the surveys (ie noon–1:30pm on a weekday).

A2.1 Purpose of the walking trip

Pedestrians were asked to state the purpose of their walking trip. The two most common answers were 'work' and 'food/meal', with the third-highest option being 'shopping'. This is unsurprising considering the time of day, but it does suggest that rather than milling about aimlessly, pedestrians are as much a part of the economy as other transport mode shares. See figure A1 for a chart of these results.

Figure A1 Chart of survey results for walking purpose



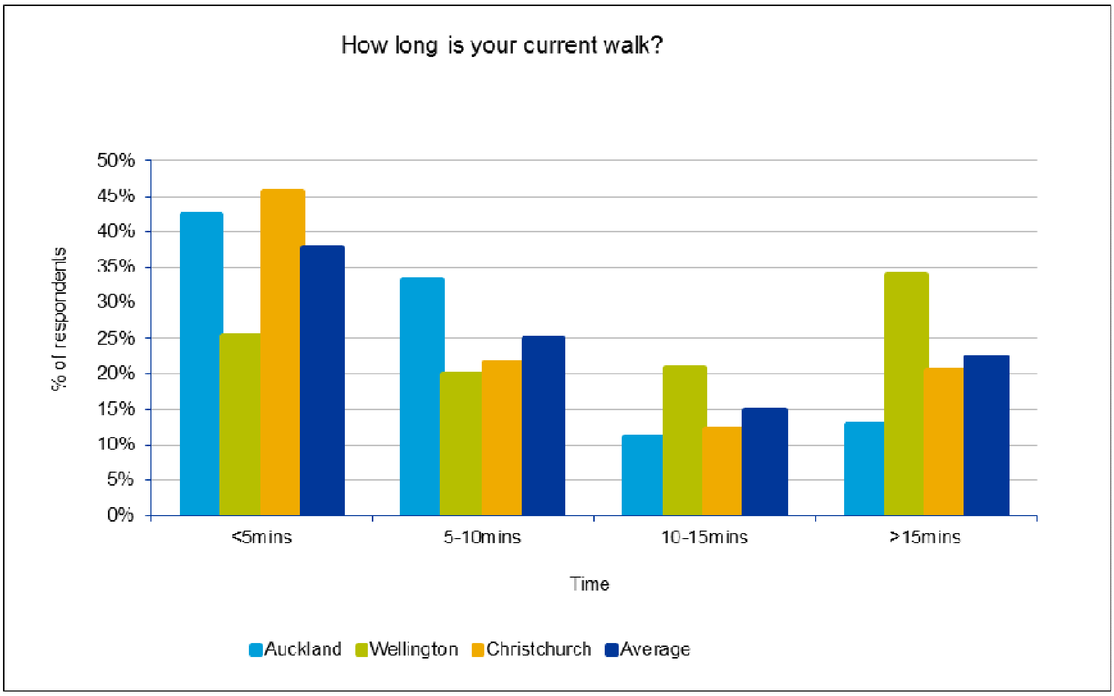
A2.2 Length of the walking trip

A number of the international sources studied in the literature review suggested that most pedestrian trips are of less than 10 minutes in origin. This is relevant, as 1 minute of delay at an intersection would therefore represent a 10% increase (or variation) in the total trip time.

Of the surveys collected in New Zealand, more than 50% were for trip durations of 10 minutes or less. However, there was a noticeable difference between the New Zealand cities. Trips tended to be shorter for respondents in Auckland, longer in Christchurch, and longer still in Wellington, where the most common answer was >15 minutes. To some degree, this may reflect a reaction to the pedestrian environment, with Aucklanders being less willing to become pedestrians, except for very short journeys. This correlates with later questions, which showed that Aucklanders perceived the longest waiting times of the three cities, and 75% of those respondents felt that pedestrians deserved more priority.

In all cities there was a gradual decline in the percentage of respondents walking (see figure A2). The walking time for the greatest number was 5 minutes, although the spike for a walking time of 15 minutes suggests that 'typical' journeys were short, but many pedestrian journeys were longer than 'typical'.

Figure A2 Chart of survey results for walking time



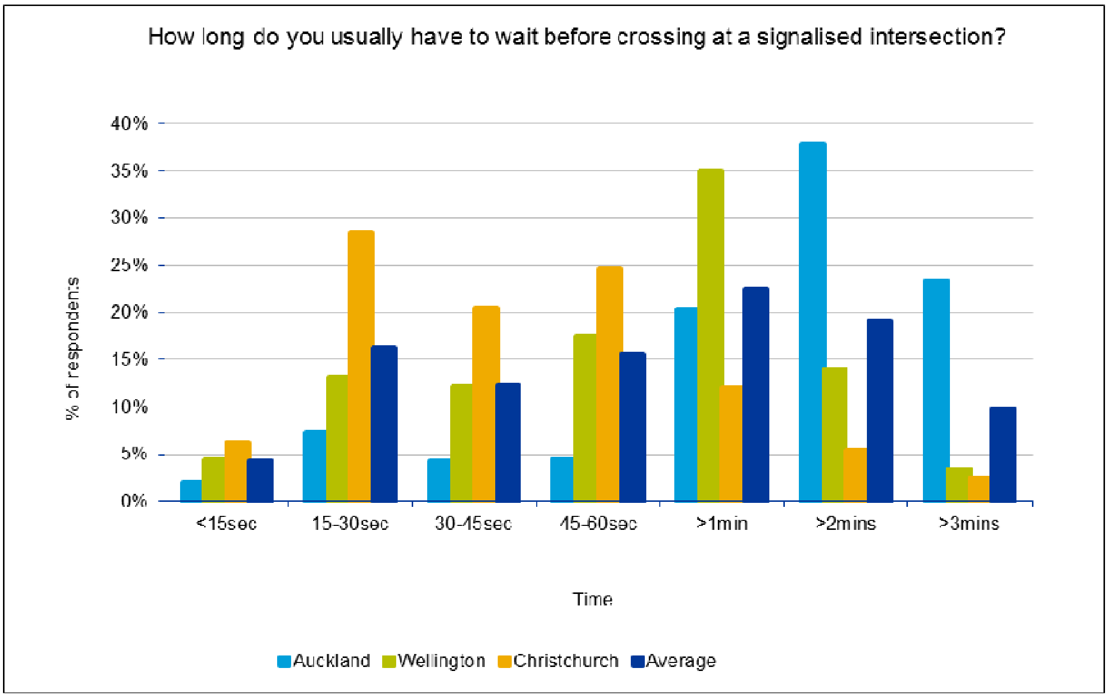
A2.3 Perceived waiting time

Pedestrians were asked how long they believed their waiting time to be. Since delay is a subjective experience, this was not intended to be an exact measure of their waiting time. Rather, the perception of delay was collected as a benchmark to compare with the next question, on what was considered reasonable. It was also collected in order to compare the cities.

The shortest 'perceived waiting times' were in Christchurch. This result matched the observed waiting times, which were also found to be shortest in Christchurch. Likewise, Auckland had both the longest perceived waiting times and the longest actual waiting times. In all three cities, the answers were distributed across a bell curve. It was difficult to establish whether this was a variation in pedestrians' perceptions or a variation in their actual experience.

The average perceived waiting time was longest in Auckland (>2min) followed by Wellington (>1min) and Christchurch (45–60sec). The questionnaire was limited by the number of answers available. The answers indicated delays that were longer than we expected. Should this survey be repeated, it is recommended that a consistent time interval of 30 seconds be used. See figure A3 for a chart of these results

Figure A3 Chart of survey results for perceived waiting time



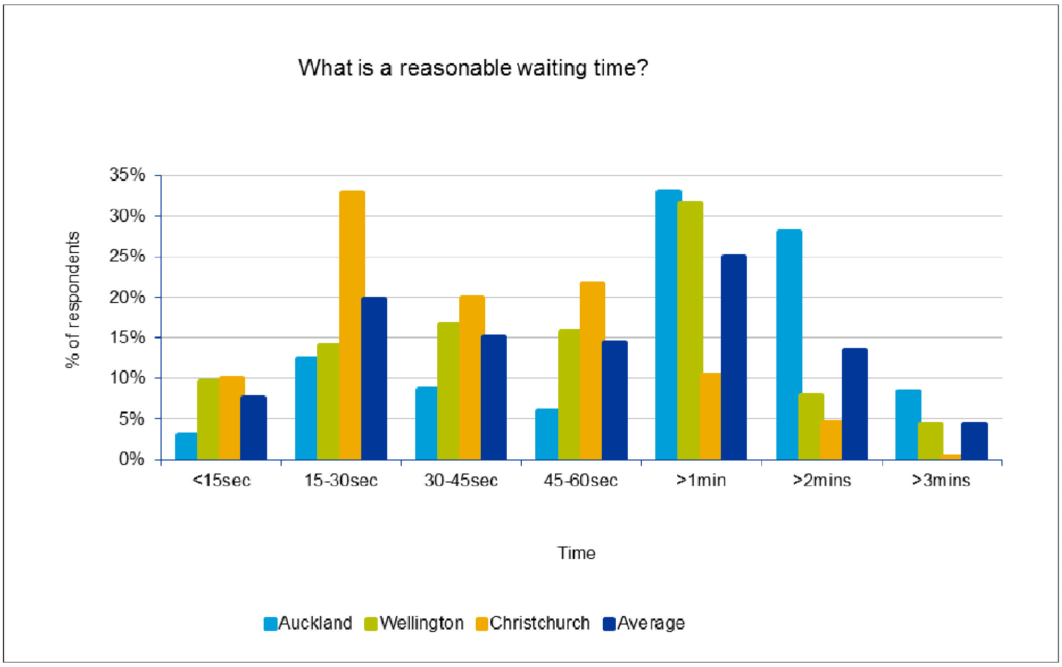
A2.4 Reasonable waiting time

Pedestrians were asked how long they considered was 'reasonable' for waiting times. These results were then compared with the previous question on how long pedestrians felt was a 'typical' waiting time. The results were also compared to the actual waiting times observed at the surveyed intersections.

The lowest reasonable waiting time was found in Christchurch (15–30sec), while it was higher (between 1 and 2 minutes) in Auckland and Wellington. There was more variation in reasonable waiting times in Christchurch and Wellington than in Auckland.

Interestingly, pedestrians in Christchurch, who had the shortest actual waiting times, also had the shortest perceptions of reasonable waiting times, whereas pedestrians in Auckland, who had the longest observed waiting times, also had expectations of much longer reasonable waiting times. This indicated an acknowledgement by Auckland pedestrians that delay is inevitable as competition for road space increases. See figure A4 for a chart of these results.

Figure A4 Chart of survey results for reasonable waiting time



A2.5 Comparison of 'perceived' and 'reasonable' waiting times

The results of the survey questions were analysed to compare the difference between pedestrians' 'perceived' and 'reasonable' waiting times in each city, as compared with the actual observed median waiting times.

In all cities, the perceived waiting times were longer than the actual waiting times. This was consistent with the concept of delay being a subjective experience that is difficult to quantify.

The literature review identified that delays above 30 seconds lead to excessive frustration, and as a result of that frustration, a perception of delay that is disproportionate to the actual delay experienced. Christchurch was the only city with an average waiting time below 30 seconds, and also the only city where the reasonable waiting time matched the perceived waiting time.

In both Auckland and Wellington, the perceived waiting times were greater than the time considered reasonable by recipients. In Auckland, the perceived waiting times were substantially higher than the observed average waiting time, suggesting that frustration with delay played a factor in the calculation of the delay time. See figures A5–A7 for charts comparing perceived, reasonable and actual waiting times in Auckland, Wellington and Christchurch respectively. Figure A8 provides a national comparison, while table A1 below gives the median value for each centre.

Table A1 Comparison of perceived, reasonable and actual waiting times

Median waiting time (seconds)	Auckland	Wellington	Christchurch
Perceived	150	91	38
Reasonable	90	45	38
Actual	49	42	28

Figure A5 Comparison of perceived, reasonable and actual waiting times – Auckland

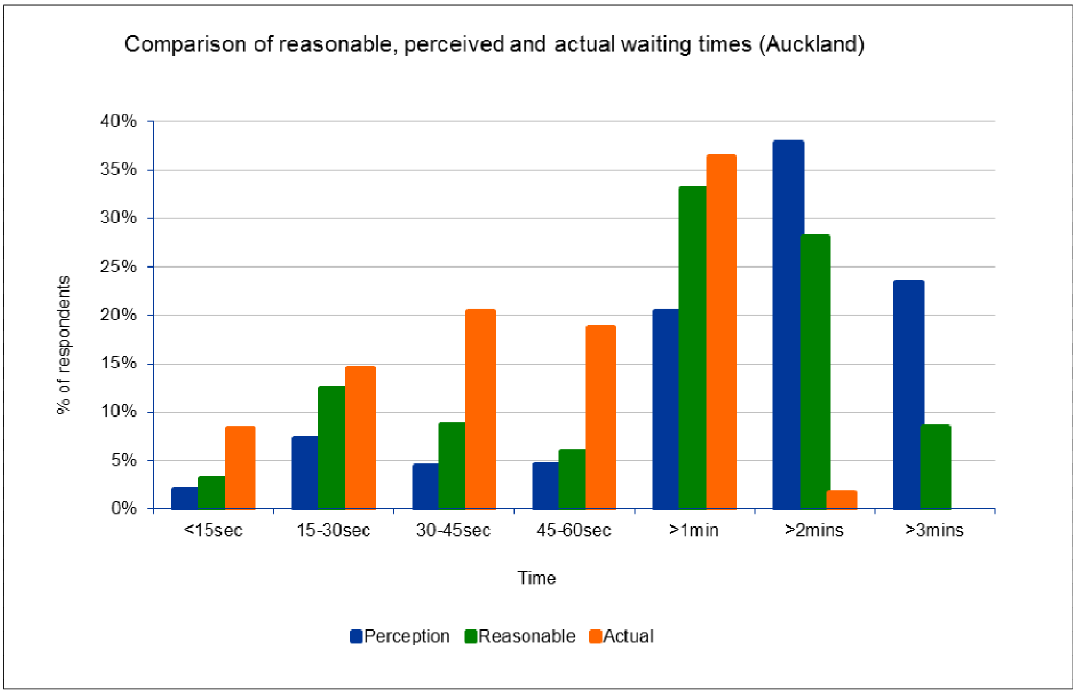


Figure A6 Comparison of perceived, reasonable and actual waiting times – Wellington

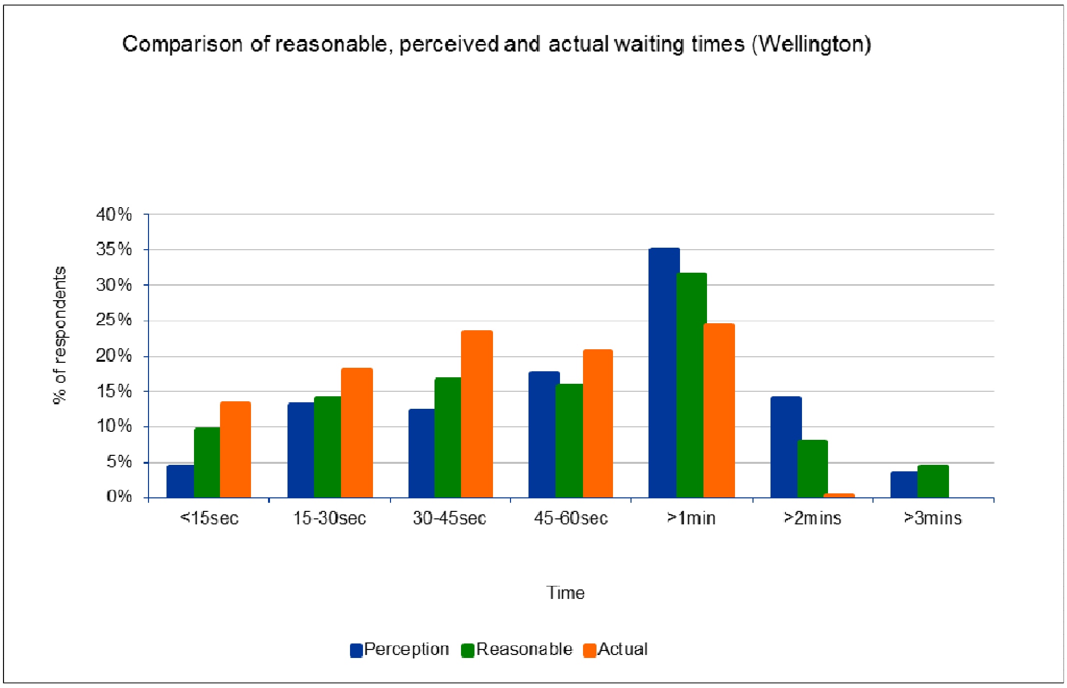


Figure A7 Comparison of perceived, reasonable and actual waiting times – Christchurch

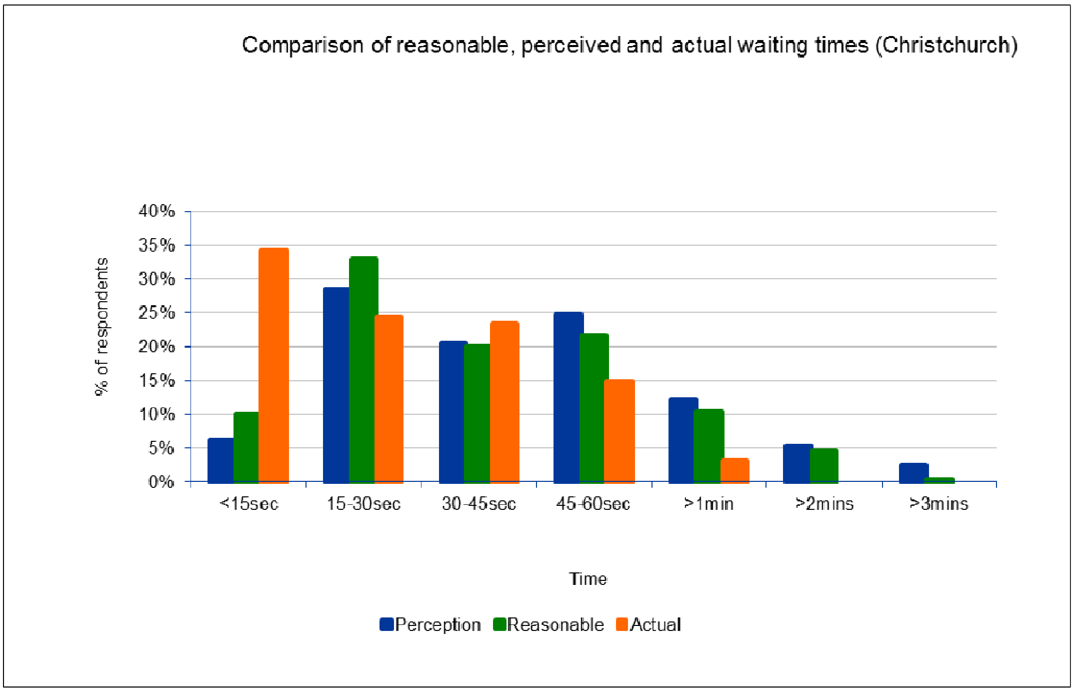
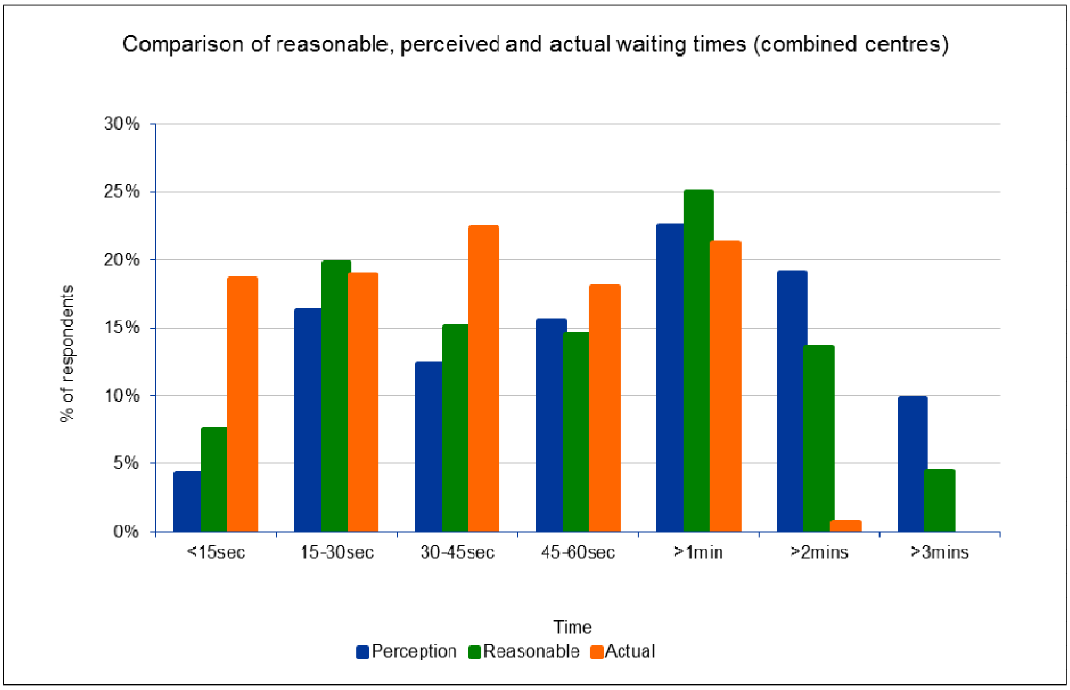


Figure A8 Combined comparison of perceived, reasonable and actual waiting times



A2.6 Compliance with the 'solid red man' signal

Pedestrians were asked if they would cross on a 'solid red man' signal. Interestingly, the most common response in Auckland was 'never', even though that city had the longest delays for pedestrians. This indicated that safety is a factor in non-compliance, as Auckland also had the highest traffic volumes.

See figures A9 and 10 for charts of these results.

Figure A9 Chart of compliance with a 'solid red man' signal

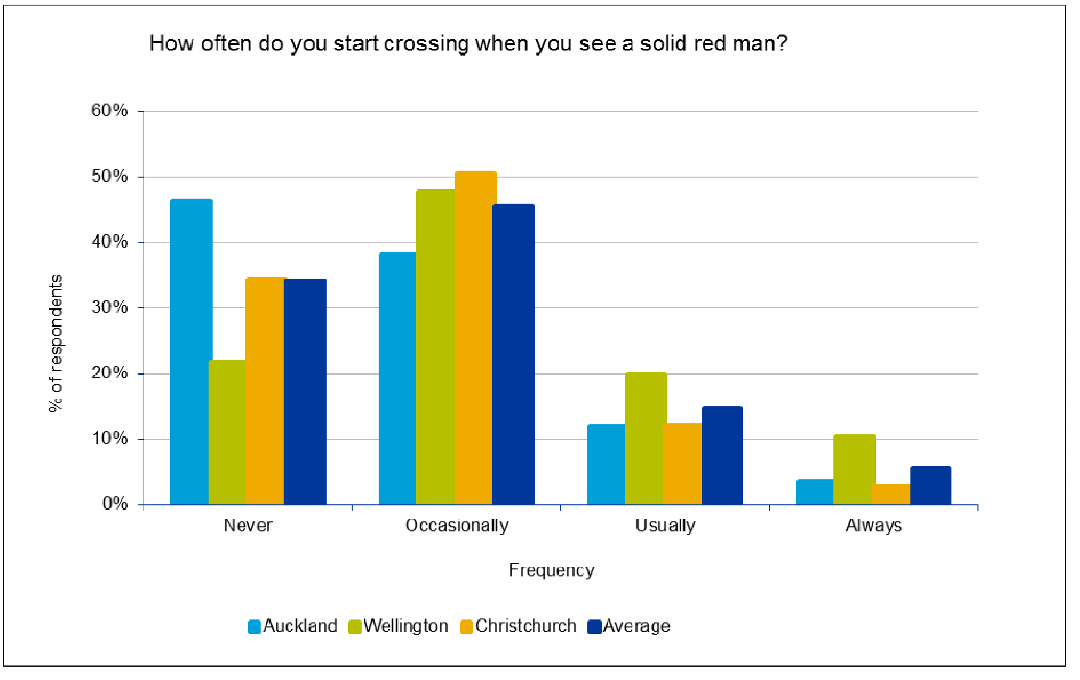
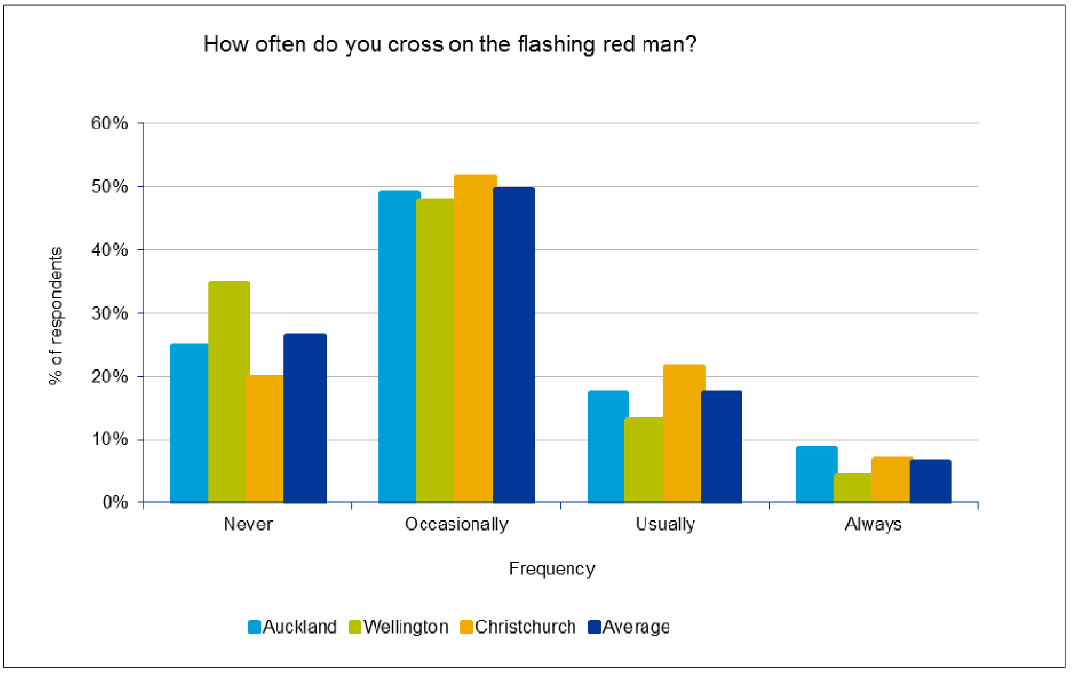


Figure A10 Chart of compliance with a 'flashing red man' signal



Across the country, 75% of recipients admitted that they would cross on a ‘solid red man’ signal, with the most common answer being ‘occasionally’. Worryingly, almost a third of Wellingtonians answered ‘usually’ or ‘always’ when asked about crossing on a ‘solid red man’ signal. This was supported by anecdotal evidence from Wellington City Council, which suggested that compliance rate was low in the city. There may be a number of factors influencing this. As pedestrian non-compliance generally results from pedestrians perceiving ‘acceptable’ gaps in traffic, it is possible to speculate that this situation could potentially be improved through operational changes to reduce pedestrian delays, and timing ‘cross’ phases to match any gaps in traffic (typically caused by vehicles ‘platooning’ from adjacent intersections).

As can be seen from figures A9 and 10, there is a significant public willingness to ignore both the ‘flashing red man’ signal and the ‘solid red man’ signal. This reinforces the need to keep delays caused by for traffic signals within socially acceptable levels to retain their usefulness in regulating traffic and improving safety.