Cyclist delay at traffic signals

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Abstract

Commuting trips by bicycle are generally short. The average one way commuter trip by bicycle in New Zealand is 4.1km long and takes 18.2 minutes. Delay at intersections increases travel time and can be frustrating, particularly in a road network where the primary intersection control is traffic signals. Intersection phase timing is based on the efficient movement of motorised traffic, with no consideration given to the needs of cyclists.

This study has set out to quantify the amount of delay experienced at traffic signals by a cyclist during peak hour traffic. A secondary objective was to determine the most suitable means of collecting the necessary cycle trip data. The literature review identified several previous studies that recognised travel time as a significant factor of bicycle route and mode choice but none that quantified what component of travel time could be attributed to delay.

A total of 80 trips were made in the AM and PM peak hour traffic in Christchurch in 2013. Trip details and time stopped at traffic signals were recorded on each trip using a GPS enabled cycle computer. Two routes were used that included multiple signalised intersections, one which generally followed major arterial roads and the other which generally followed minor arterial roads. As expected, the trips on the major arterial route experienced fewer and shorter delays than the minor arterial trips.

Four different measures have been used to identify delay in this study; average delay per stop, average delay per intersection, average delay per kilometre and average delay as a percentage of total trip time. The average level of delay was identified and compared for the full routes and for the inner and outer city components of both routes.

1. Introduction

Commuting trips by bicycle are generally short. The Ministry of Transport New Zealand Household Travel Survey shows the average one way commuter trip by bicycle in New Zealand is 4.1km long and takes 18.2 minutes (Ministry of Transport, 2013). Intersection delay increases travel time and can be frustrating, particularly in a grid type road network where the primary intersection control is traffic signals. At each stop, additional time is lost in decelerating and then accelerating back to speed; this is exacerbated by the physical exertion required to do so. Intersection design is usually focused on the efficient movement of motorised traffic, with no consideration given to the needs of cyclists.

In a city environment, traffic signals are often coordinated to some extent, and motorists on arterial routes are often able to benefit from a 'green wave' effect, where signal phases along sections of the route are synchronised to enable a motorist travelling at the speed limit to encounter progressive green lights and hence reduce delay. Unfortunately, commuting cyclists generally travel somewhat slower than the speed limit and, subject to the distance between intersections, may reach the next intersection during the green phase but are unlikely to benefit from any 'green wave' effect beyond this.

The Highway Capacity Manual 2010 (HCM 2010) notes that cyclists tend to have about the same tolerance for delay as pedestrians and tend to become impatient when they experience a delay in excess of 30 seconds. Outside of peak hours, waiting at a red signal when there is little or no traffic, and ample time to safely cross the intersection can lead to cyclists running red lights. This situation is a concern for cycle advocate groups who recognise that this behaviour can damage motorists' perception of cyclist behaviour and add stress to the often fragile motorist / cyclist relationship.

1.1 Research Objective

This research project aims to determine the amount of delay experienced by cyclists at signalised intersections during a typical commute to and from work in peak hour traffic. A secondary objective is to determine the most suitable means of collecting the necessary cycle trip data for this and other similar studies.

1.2 Study outline

This study will take the following steps in the attempt to achieve the research objective:

a) a literature review will be undertaken to identify if previous research has quantified cycle delay or considered the impacts of cycle delay on mode or route choice;

b) an investigation will be carried to identify devices that may be suitable to record the study data;

c) suitable devices will be field trialled to assess their relative merits and ability to record and make available usable data. The device to be used in the study will be selected following the field trial;

d) two routes have been selected for the project that travel between the same origins and destinations and both include multiple signalised intersections. The majority of one route travels on major arterial roads and the other route travels on a minor arterial roads for most of its length.

   20 trips will be made on each route in the AM and PM peak hour traffic, with trip details and delay data recorded on each trip;

e) the recorded data will be analysed and the delay experienced at signalised intersections quantified in the most suitable formats;

f) recommendations will be made for areas of extended study.

2. Literature review

Traffic delay is defined in the American Association of State Highway and Transportation Officials (AASHTO) Transportation Glossary 2009 as:

> *The additional travel time experienced by a driver, passenger or pedestrian due to circumstances that impede the desirable movement of traffic. It is measured as the time difference between actual travel time and free-flow travel time.*

This literature review investigates existing research regarding traffic delay as experienced by cyclists and has two component parts. The first part is a review of previous studies that may have identified and possibly quantified delay experienced by cyclists as part of the research. Any available research that has quantified delay, particularly at intersections, will be useful for comparative purposes with the intersection delay recorded as part of this study.

The second part of the literature review investigates existing bicycle travel data recording schemes that have used Global Positioning Systems (GPS) or smartphone applications that have made use of the phone's GPS capability to record bicycle route information. This may help to inform this study to identify the most suitable method of accurately recording cyclist delay at intersections.

2.1 Previous work in the area of assessing cyclist delay

With the exception of environment factors such as gradient (Parkin and Rotheram 2010), or strong winds, the primary cause of traffic delay a commuter cyclist will experience on route to and from work will be at intersections, both unsignalised and signalised. A literature review has been undertaken to identify what previous work has been undertaken in the area of assessing the amount of delay experienced by cyclists as they travel along a route.

The review found very little research that actually identified or quantified the amount of delay a cyclist may expect to encounter on route. The studies that were identified as having given at least some level of consideration to the impact of intersections on cycle travel generally fell into the following categories:

- Bicycle route choice
- Bicycle mode choice
- Bicycle Level of Service (LOS)
- Design or modelling of signalised intersections
- Other studies

These studies generally consider a wide range of other factors or criteria that influence cyclists' decision making. However, the aim of this review is primarily focused on the impact of intersections on delay and the impact on delay of environmental factors, such as gradient, are not included.

2.1.1 Bicycle route choice

Many research articles have been written on route choice analysis and route choice modelling. Most focus on the type of cycle facilities available and safety concern factors such as roadway width, traffic speed and volume and on street parking. The impact of gradients on route choice is also usually surveyed. Travel time is often considered; however it is generally in the context of a desired maximum journey time rather than variations in travel time due to delays on route. The studies noted below identified intersections as a source of delay that could influence route choice but generally differed in their approach to how it was considered.

A bi-objective cyclist route choice model. (Ehrgott et al. 2012)

In a recent Auckland based research into modelling cyclist route choice, the authors noted their modelling approach was based on common observations from previous studies (Aultman-Hall et al. 1997; Howard and Burns 2001; Stinson and Bhat 2003) that travel time appeared to have the most significant influence on the route choice decisions of commuting cyclists. Safety and comfort were also influencing factors (Stinson and Bhat 2003). The route choice model was based on two independent objectives; travel time and suitability. The suitability objective aggregated other factors including safety and comfort.

The travel time objective recognised that delay at signalised intersections makes up a considerable portion of the trip duration. The model estimates the average delay for cyclists at intersections component as follows:

Total signal cycle S_t
Red phase R_t
Cyclist stop rate (approximate) = portion of signal cycle that is red = R_t/S_t
Average delay for stopped cyclist = half red time = $R_t/2$
(allows for cyclists arriving in green phase)
Cyclist stop rate x average delay for stopped cyclist = average delay for all cyclists

$$\text{Average delay} = R_t^2/2S_t$$

The report gives no information as to whether this approach was based on, or has been tested against, recorded data. This simplified approach assumes that cyclist will have to wait for half the red signal phase at every signalised intersection and makes no allowance for time lost by a cyclist in decelerating to a stop and accelerating from a stop back to desired travel speed.

An analysis of bicycle route choice preferences in Texas, US. (Ipek et al. 2009)

As part of bicycle route choice stated preferences research in Texas (Ipek et al. 2009), a literature review considered 32 previous studies dated between 1984 and 2007 that examined the effects of bicycle facility design attributes on bicyclist route preferences. The authors found that few studies had considered the impact of directness or travel time to the destination, although studies that had considered travel time (Hunt and Abraham 2007) (Tilahun et al. 2007) found it to be an important factor in route choice for bicycle commuters.

(Ipek et al. 2009) considered the impact of delay at intersections in a very simplistic manner. Under an attribute category titled *Roadway physical characteristics*, the attribute *Number of stop signs, red lights encountered on the bicycle route* was set at just three levels:

1. 1-2
2. 3-5
3. More than 5

This is a very basic attribute measure, as the number of stop signs and red lights encountered will vary with trip length and intersection density and also trip by trip on the same route. The results found that for bicycle commuters, travel time and motorised traffic volume are the most important attributes in route choice.

Several other studies including (Larsen and El-Geneidy 2011) and (Aultman-Hall et al. 1997) have considered the number of signalised intersection as a route choice factors but have not quantified an amount of delay.

Why do cyclists ride? A route choice model developed with revealed preference GPS data. (Broach et al. 2012)

This revealed preference study was based in Portland, USA and used hand held GPS units clipped to the bicycle to observe the behaviour of 164 cyclists. This study is also noted in more detail in Section 2.2 but is discussed in this section as results included average speed including stops. The study found the average distance for commute trips was 6 km at an average speed (including stops) of 19 km/h.

The report notes:

> *Intersection crossings often delay cyclists, though the presence of a traffic control device (signal or stop sign) has an important bearing on the amount of delay. Depending on the amount of conflicting traffic, signals might be an attractive feature for cyclists trying to travel through or make turns at busy intersections.*

The study also found that:

> *cyclists generally avoided stop signs and traffic signals unless they needed to cross or turn at high traffic streets, in which case traffic signals were valued.*

The study includes a table listing the percentage increase in distance a cyclist will travel to avoid certain features such as gradient or stop signs. The table indicates that to avoid a traffic signal (excluding right turns) a non-commuter will travel 3.6% further and a commuter cyclist will travel 2.1% further.

Delivering effective cycle facilities: modelling bicycle route choice in New Zealand. (Rendall et al. 2012)

As part of this New Zealand based study, intersection delays that were presented as a percentage increase in distance in the Portland study (Broach et al. 2012) were presented as time delays based on an average cyclist speed of 20 km/h.

Using route information data from 400 Christchurch cyclists, the study then used time scaling factors to convert Portland route choice data for comparison with New Zealand. An extract from *Table 9: Portland and New Zealand intersection effective delays* is shown in Table 2-1 below:

Table 2-1: Extract from Table 9 (Rendall et al. 2012)

	Time delay (sec)			
	Portland		New Zealand	
Facility	Commute	Non-commute	Commute	Non-commute
Traffic signal	6.1	10	3.1	5.3

The report notes:

> *The intersection delays noted in Table 9 were presented as percent increase in distance that would be preferable to increasing the number of intersections per mile by one; assuming a cyclist speed of 20 km/h (Austroads 2011) these values are presented as effective time delays in Table 6.*

The delays noted in Table 9 are additional to the average inter-peak traffic signal delay.

Commuter Bicyclist Route Choice: Analysis Using a Stated Preference Survey (Stinson and Bhat 2003)

This stated preference survey considered link and route attributes. One of the route-level factors was *number of red lights (0-5).* As with the use of similar attributes noted above (Ipek et al. 2009), the number of red lights encountered will vary with trip length and intersection density and also trip by trip on the same route. The study found that travel time is the most important route characteristic for bicycle commuters, but also noted that delays caused by red lights is one of the least important attributes in commuter cyclists' evaluation of routes.

Understanding and measuring bicycling behaviour: A focus on travel time and route choice (Dill & Gliebe 2008)

This is another study that analyses the GPS recorded data from 164 adult cyclists in Portland in 2007 and is discussed again in Section 2.2.1. One section of the study looked at trip speeds and found that the average overall speed was 10.8 m/h (17.3 km/h) including times when the bicycle was not moving. Removing times when the GPS recorded zero velocity (eg. when the cyclist was stopped at a traffic light) the average speed was 11.1 mph (17.8 km/h).This information can be used to derive a delay value of 5.7 sec/km.

The report found that reducing waiting time at stop lights and signs was the fourth most important consideration, behind minimising distance, avoiding streets with heavy traffic and availability of cycle lanes.

2.1.2 Bicycle mode choice

As with the route choice studies, most articles on mode choice analysis focus on the type of cycle facilities available and safety concerns. Travel time is usually a factor but again it is generally in the context of a desired maximum journey time rather than variations in travel time due to delays on route. The exception was the study of Dutch municipalities (Rietveld & Daniel, 2004) that quantifies delay in terms of delay in seconds per kilometre.

Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany (Pucher and Buehler 2008)

This article details how the Netherlands, Denmark and Germany have made cycling a safe, convenient and practical way to get around their cities. The following are excerpts from a table of key policies and innovative measures used in Dutch, Danish and German cities to promote safe and convenient cycling:

Intersection modifications and priority traffic signals

- *Advance green lights for cyclists at most intersections*
- *Cyclist short cuts to make right turns before intersections and exemption from red traffic signals at T intersections, thus increasing cyclist speed and safety*
- *Traffic signals are synchronized at cyclist speeds assuring consecutive green lights for cyclists (green wave)*
- *Bollards with flashing lights along bike routes signal cyclists the right speed to reach the next intersection at a green light.*

These measures are all aimed at reducing the delay experienced by cyclists at traffic signals.

Determinants of bicycle use: do municipal policies matter? (Rietveld and Daniel 2004)

This study to determine if municipal policies influenced bicycle use compared bicycle related characteristics of nine Dutch municipalities. One of the characteristics used was 'Delay in seconds per kilometre'. The hindrances that made up the delay were the number of stops or turn offs imposed on cyclists per unit distance; the proportion of time spent walking or biking slowly and the obligation to give priority at crossroads. The data was provided by the Bicyclists' Association.

The level of delay ranges between 50.9 sec/km in Heerlen, described as a hilly area with a population of 98,000 and 0 sec/km in Culemborg, a city with a population of 26,000.

The average delay across the nine Dutch cities was 13.2 sec/km. It is interesting to note that the two cities with the highest delay (both well above the average) also had the lowest bicycle use. Part of Table 4 from the study which tabulates these results is shown in Table 2-2, two additional columns which indicate parking costs and policy efforts are not included.

The study notes that the results confirm that travel time is an important determinant of travel demand and the provision of direct routes and a small number of stops clearly contribute to the attractiveness of the bicycle as a transport mode.

Table 2-2: Delay in Dutch Cities -Extract from (Rietveld & Daniels 2004) Table 4

Cities (and their corresponding provinces): Special features mentioned	**Bicycle use (%)**	**Size in number of inhabitants (x 1000)**	**Delays in seconds per kilometre**
Average value	35.1	84	13.2
Wageningen (Gelderland): City with the highest rate of bicycle use; hosts a university	47.6	34	11.3
Groningen (Groningen): Highest bicycle use rate among the big cities; hosts a university	45.47	176	21.2
Amsterdam (Noord Holland): Biggest city of the Netherlands, which is also the city with the highest parking costs and has two universities	32.73	734	14.3
Rotterdam (Zuid Holland): Second biggest city of the Netherlands	20.92	599	40.5
Heerlen (Limburg): City with the lowest rate of bicycle use; hilly area	13.9	98	50.9
Maastricht (Limburg): City with bicycle-unfriendly slopes	25.72	122	18.2
Heemstede (Noord Holland): City with the highest income per capita	33.76	26	12.6
Schagen (Noord Holland): Smallest municipality in the sample	43.77	17	11.6
Culemborg (Gelderland): City with the least delays	38.19	26	0

Influence of Individual Perceptions and Bicycle Infrastructure on Decision to Bike (Akar and Clifton 2009)

The focus of this study was the opportunities and challenges for cyclists on and around the University of Maryland following a web based survey. The study results indicated that time and cost of travel are important determinants of mode choice and suggest that people are more sensitive to time for non-motorised modes. One of the policies proposed to decrease bicycle travel time was decreasing waiting time at intersections favouring bicyclists.

Transforming Auckland into a bicycle-friendly city: Understanding factors influencing choices of cyclists and potential cyclists (Wang et al. 2012)

As part of this Auckland based study, a comprehensive literature review of 19 international case studies was undertaken, focussing on the factors found to have a significant influence of the decision to cycle as a mode choice. Only two of the factors listed, both identified as deterrents, could possibly be considered to include some component of delay.

Longer travel time was identified in 3 of the 19 studies (Hopkinson & Wardman,1996) (Stinson and Bhat 2003), (Stinson & Bhat, 2004) and *Number of difficult intersections* was identified in just one of the 19 studies (Stinson and Bhat 2003).

The report also included a spatial analysis of a 23.9 km route in which a cyclist is identified as having cycled 3 km longer than the shortest route; however the chosen route had only 30 traffic signals compared to 42 on the shortest route. The report notes *it is quite clear the cyclist is trying to avoid traffic signals, which would have caused delay, traffic noise and air pollution.*

Motivators and deterrents of bicycling: comparing influences on decisions to ride (Winters et al. 2011)

This was a stated preference survey of 1,402 current and potential cyclists in Metro Vancouver that evaluated 73 motivators and deterrents of cycling. One of the items under the factor *Intersections, traffic signals* was *The route has regular traffic signals for all traffic.* This did not feature in the top 10 deterrents and is noted as one of the factors with very little influence on cycling.

2.1.3 Bicycle Level of Service (LOS)

Most bicycle LOS studies such as (Zolnik and Cromley 2007) were found to derive a LOS based primarily on safety perceptions and considered factors such as lane width, provision of cycle lanes, traffic speed and accident records.

Highway Capacity Manual 2010 (Transportation Research Board 2010)

Volume 1 of this manual has a bicycle LOS that is based on bicycle riders' perceptions of LOS. It is based on a *bicycle LOS score* model that incorporates perceived separation from motorised traffic, traffic volumes, cross street width and level of on-street parking. It is interesting to note that delay is not a component of the *bicycle LOS model* however it is a component of the *pedestrian LOS score* model, with pedestrian LOS increasing as delay reduces.

Volume 3 includes the following formula to calculate bicycle delay:

$$d_b = \frac{0.5C(1 - g_b\ )/C)^2}{1 - min\left[\frac{Vbic}{C_b}, 1.0\right]\frac{g_b}{C}}$$

Where d_b = bicycle delay (secs/bicycle)
$Vbic$ = bicycle flow rate (bicycle/hr)
g_b = effective green time for the cycle lane (secs)
C = cycle length (secs)

The HCM 2010 notes that *Bicyclists tend to have about the same tolerance for delay as pedestrians. They tend to become impatient when they experience a delay in excess of 30 sec/cycle. In contrast, they are likely to comply with the signal indication if their delay is less than 10 sec/cycle.*

Intersection level of service for the bicycle thru movement(Landis et al. 2003)

As part of research for the Florida Department of Transportation to develop an intersection LOS for the through movement (Landis et al. 2003), approximately 1000 real-time perceptions of almost 60 cyclists traveling a course through a typical U.S. metropolitan area's signalised intersections were analysed. The course was approximately 27 km long and included 21 intersections, of which 19 were signalised. The participants were asked rate each intersection between A (most safe or comfortable) to F (most unsafe or uncomfortable.

The research found no significant difference in the way those that were delayed at an intersection (for an average of more than 40 seconds) rated the intersection compared with those who rode through without delay. Unfortunately, it is not clear if the 40 sec average delay is across all cyclists or just those that were stopped at intersections.

The report notes that future steps to develop a comprehensive bicycle LOS for Florida 's Department of Transportation will likely include the impacts of delay.

Methodology to Assess Design Features for Pedestrian and Bicyclist Crossings at Signalized Intersections (Steinman and Hines 2004)

This is a methodology to assess the LOS of pedestrians and cyclists crossing signalised intersections in the City of Charlotte, North Carolina.

Near the start of the report, the author makes the following statement:

> *In the authors' opinion, delay is less significant to pedestrians and bicyclists than safety or comfort (whether it's perceived or not). For that reason a different approach was preferred to the HCM. While delay is definitely a crossing factor, crossings that appear unsafe or too imposing result in people shying away from them.*

To obtain the bicycle LOS, the signalised intersection is rated against six intersection features. These focus on safety and comfort and do not include any consideration of delay.

2.1.4 Design or modelling of signalised intersections

A study to examine bicyclist behavior and to develop a micro simulation for mixed traffic at signalized intersections (Raksuntorn 2002)

This research aimed to develop a stochastic micro simulation model that would represent bicycle behaviour at signalised intersections in the US more realistically than existing models. The study is based on analysis of video recordings of cyclist behaviour at a total of 7 signalised intersections in four US cities. Based on this field data, the study examined several characteristics of cyclist movement at an intersection including approach speed and deceleration and acceleration of bicycles approaching and departing the intersection. Models were developed for each characteristic which were then incorporated as sub-models into the micro simulation model.

The study found that cyclists approaching an intersection with a red or amber signal start decelerating approximately 30 m from the stop line. Approach speeds ranged between

7.6 km/h to 35.3 km/h with a mean of 18.3 km/h and a cyclist with a higher average speed applies a higher deceleration rate than one with a lower average speed. The width of an intersection was found to impact on the acceleration rate of cyclists departing an intersection, with a cyclist reaching his/her average speed faster at a narrower (15 m) intersection compared to a wider (30 m) one.

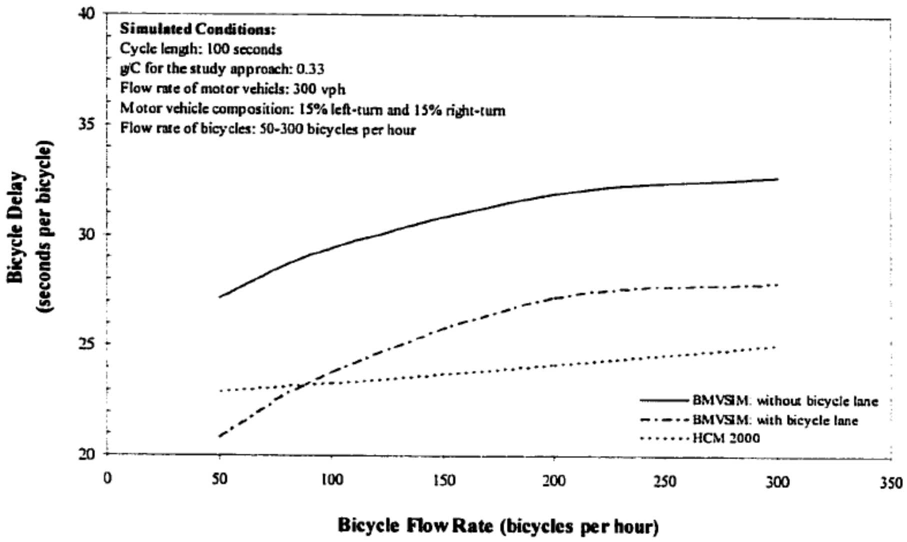


Figure 2-1: Bicycle delay against bicycle flow rate (Raksuntorn 2002)

Figure 2-1 shows Figure 4.16 from the study which plots bicycle delay against bicycle flow rate. Unfortunately this image in poor quality, as it is a copy of a microfilmed version of the study. The graph is based on a signal cycle length of 100 seconds; green time on approach 33%; vehicle flow of 300 vehs/hr and bicycle flow rate of 50 to 300 bikes/hr. The upper(solid) line represents delay from the micro simulation model for an intersection without cycle lanes, the middle (dash dot) line represents delay from the micro simulation model for an intersection with cycle lanes, the lower (dotted) line shows delay estimated by the HCM method which does not make allowance for deceleration and acceleration back to normal travel speed.

Coordinating Traffic Signals for Bicycle Progression (Taylor and Mahmassani 2000)

This study analyses bicycle-automobile mixed traffic progression along signalised streets. Several different phasing concepts are explored to identify their impact. The report notes:

> *In the worst case, an automobile progression scheme could systematically stop a cyclist travelling at a specific speed at every signal, thereby inflicting maximum stops and delay on a cyclist.*

In concluding comments, the report identifies bicycle speed variability as the most important consideration that may impact on the ability of a signal coordination scheme to benefit cyclists.

2.1.5 Other studies

Design speeds and acceleration characteristics of bicycle traffic for use in planning, design and appraisal (Parkin and Rotheram 2010)

In this study based in Leeds, UK, 16 cyclists were provided with GPS units for a week and asked to accrue 100 minutes of data from commuter trips. The study identified a mean speed of 21.6 km/h and a mean acceleration on the flat of 0.231 m/s^2. From a stationary start, at the mean acceleration rate, a cyclist will take 26 seconds to reach the mean speed.

The study also notes that speed studies of cycle traffic are sparse in the literature and that *None of the studies to date offers appropriate and clear guidance on appropriate speed and acceleration characteristics of cycle traffic useful to designers, planners or appraisers.*

As this study made use of GPS technology, it is also discussed Section 2.2.1.

The delaying effect of stops on a cyclist and its implications for planning cycle routes (Graham 1998)

This study notes that some cycle routes have proved unpopular because at several points a cyclist has to stop or slow appreciably and three hypotheses were tested for a cyclist's performance in response to an imposed stop. Trails were carried out on a 2.5 km circuit that featured seven roundabouts. Cyclists were required to make two circuits, one non-stop and one stopping at the roundabouts.

The study concluded that making an adult cyclist stop is approximately equivalent to extending the journey by 50 m.

Using the average speed identified in other studies of 20 km/h, this equates to a delay of 9 seconds per stop.

2.1.6 Discussion

The literature review of previous studies in the area of assessing cycle delay has identified very little research that actually quantifies the amount of delay experienced by cyclists on a commuter trip. There is also conflicting findings of the impact of signalised intersection on bicycle route and mode choice. It may be that respondents of stated preference studies have not actually experience signalised intersections first hand, whereas revealed preference surveys are based on real world cycling data.

One issue that is consistently identified as a significant factor in bicycle route and mode choice is travel time, and this is in the context of the maximum amount of time taken to cycle to a destination. However, none of the bicycle route or mode choice studies noted in this review have identified what component of total travel time is made up of the delay experienced on route or what an acceptable level of delay might be. The acceptable level of delay will clearly vary depending on the type of cycle facility, with a trip on an arterial traffic route likely to experience considerably more delay that an off road path.

2.2 Existing bicycle travel data recording schemes

This part of the literature review has been undertaken to identify existing studies and schemes that have used, or are currently using, GPS or smartphone technology to record bicycle travel data.

Prior to the arrival of small Global Positional System (GPS) devices, the collection of data on cycle routes was limited to manual counts, surveys or recording methods such as video or tube counters and this meant that area wide recording was impractical. Some other cycle data was available from national census information but this was not route specific.

In 1983, the GPS ceased being solely a military system and was made available for public use. By the mid-2000s, technology advances had resulted in the availability of lightweight, unobtrusive and relatively cheap GPS devices that could be used to track and record the movements of an individual cyclist.

The more recent integration of GPS technology enables a smartphone to not only track and record a cyclist's movements, but to send that data to computer. This capability has been recognised by several cities and territorial authorities as an ideal way to gather inexpensive information on cycle numbers and route choice.

2.2.1 Studies that used GPS technology

These are typically studies that pre-date the smartphone boom, and participants were issued with a GPS unit that was either fixed to their person or their bicycle.

Understanding and measuring bicycling behavior: A focus on travel time and route choice (Dill and Gliebe 2008)

This study was carried out in the Portland, Oregon metropolitan area. The study was reviewed and approved by Portland State University's Human Subjects Research Review Committee. The study collected data from a sample of 164 cyclists from March to November 2007. The participants were selected from about 400 who responded to the initial recruitment.

Each participant was provided with a Garmin iQue, personal digital assistant with GPS. The units were specially programmed to collect additional data and had been tested in different weather conditions and in various parts of the city. Participants were required to carry the unit on all bicycle trips for 7 days and were asked to turn the unit on and wait for satellites to be detected before starting their trip. The units were usually mounted to the handlebars using a special bracket or strapped to a bike rack. At the start of each bike trip, the participant was required to enter their trip destination (e.g., work, shopping, exercise) and the weather details. Location points were collected by the GPS units every 3 seconds, which usually provided enough data to recreate the route. The data were downloaded and transformed into lines fitting the regional street network using a set of scripts utilising ArcGIS Network Analyst commands. A total of 1,955 trips were recorded and 177 (8%) were reportedly missed either from equipment malfunction or human error.

Analysis of the recorded data has been the subject of several studies including (Dill & Gliebe, 2008), (Dill 2009) and (Broach et al. 2012).

Route choice of cyclists in Zurich (Menghini et al. 2010)

This study compared chosen cycle routes against non-chosen alternative routes. The choices and routes were extracted from a GPS study which was originally conducted by a private sector company with the aim to explore how often participants pass specific advertising billboards. The chosen routes were identified in a large scale GPS-data set which recorded a representative sample of 2435 residents for an average of 6.99 days in 2004 and tracked 73,493 trips in Zürich.

The street network was compiled from a landscape model of Switzerland, a digital street network of Canton Zurich, the recommended bike routes of Zurich and the built bicycle facilities of Zurich's communal master plan. It merges the relevant characteristics to produce a more detailed network, covering especially the marked bicycle routes and gradients, which were considered crucial in Zürich, which is situated along the valley of the river Limmat and its neighbouring hill sides.

Variables extracted from the GPS data and used in the route choice comparison included route length, average gradient, maximum gradient, percentage of marked bike paths along the route, number of traffic lights and path size.

The study found it is length, which dominates the choices of the Zürich cyclists, but the share of bicycle paths and the gradient has a strong impact on route choice as well, but these were small in comparison with the impact of the length. The study also found that cyclists avoid signal controlled junctions.

An Analysis of Stated and Revealed Preference Cycling Behaviour: A Case Study of the Regional Municipality of Waterloo (Rewa 2012)

Starting in 2010, a year-long study using GPS units to identify cycling movements was conducted in partnership by the University of Waterloo and the Region of Waterloo Ontario. The Regional Municipality of Waterloo is located approximately 110km west of the City of Toronto.

Data were collected from 415 self-selected cyclists, using GPS units to record trip origins, destinations, routes, travel speeds, altitude, and time of travel. Groups of participants were each given the compact GPS loggers/units for a two-week period. The units were calibrated to record longitude, latitude, altitude way-points every 3 seconds or 5 meters. The recorded data were downloaded via USB and stored in an excel database. Recorded points were overlaid onto a map of the Region using a program supplied by the GPS manufacturer and traces were illustrated individually by colour and date. Daily weather conditions were recorded and stored with the data. The GPS units were also equipped with a manual location / time recorder button, which enabled the user to 'flag' perceived hazards on their route. To eliminate incorrect data points, points were evaluated based on both altitude and speed thresholds using Visual Basic code. The final outcome of the study yielded GPS data for approximately 4,800 individual trips.

Together with revealed preference data that was collected using the GPS units, participants were also asked to complete an online survey developed to identify household compositions and characteristics. The GPS trip information and survey data was stored in a comprehensive database developed using Microsoft Access which enabled the study to gain a better understanding of seven key objectives regarding the physical environment and the socio-economic characteristics of regional cyclists including *Who the cyclists are?* and *To where do they travel?*

Design speeds and acceleration characteristics of bicycle traffic for use in planning, design and appraisal (Parkin and Rotheram 2010)

The paper identifies speed and acceleration characteristics from a study of a group of commuter cyclists in Leeds, UK, and provides guidance on speeds and the effect of gradients on cycle traffic for infrastructure designers, planners and appraisers.

A group of regular cycle commuters were provided with handle-bar mountable Garmin TM Edges 305 GPS units. The devices were able to record time-stamped x, y and z coordinates and input from a chest-worn heart rate monitor. Participants were each given the GPS device for a week and asked to accrue 100 minutes of data based on their commuting journeys during summer 2008. A total number of 547 starts were extracted from the data and after elimination of speed, acceleration and gradient outliers, 518 remained for analysis and data was extracted for statistical analysis.

The study found that speeds were consistent across the group of experienced cyclists and that speed is influenced by gradient, with an uphill gradient reducing speed to a larger extent than a downhill gradient increases speed. The mean speed on the flat was 21.6 km/h.

2.2.2 Studies that used Smartphone technology

With the integration of GPS technology, a smartphone has the capability to perform as a tracking device and record the movements of an individual cyclist. This capability has been recognised by several cities and territorial authorities as an ideal way to gather inexpensive information on cycle numbers and route choice.

A GPS-based bicycle route choice model for San Francisco, California (Hood et al. 2011)

To gain a better understanding of the decision-making of cyclists, this study estimated a route choice model for San Francisco using GPS data collected from smartphone users. GPS data of cyclists' routes were collected using CycleTracks, an application for the Apple iPhone and Google Android smartphone platforms that was developed for this study (see Figure 2-2).

Between November 2009, and April 2010, 1,083 users downloaded the application, and 952 submitted at least one trip. The user selected a trip purpose at the start of each trip, and then GPS coordinates were recorded by the phone until the user indicated that the trip was complete. Including all data in and out of the Bay Area, 7,096 traces were collected. The analysis was restricted to the City of San Francisco, and to non-exercise traces, after which 5,178 traces remained.

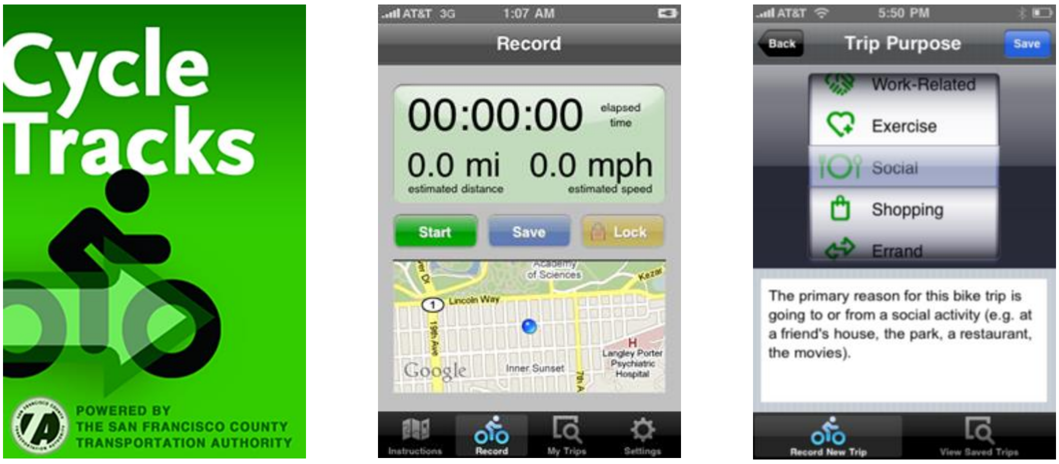


Figure 2-2: CycleTracks screen images

The GPS points were allocated to the street network using a map matching algorithm. After processing, 3,034 bicycle stages from 2,777 traces uploaded by 366 users were successfully matched to the network. Many unusable traces were received and poor signal quality, short duration or the absence of bicycle travel were the primary reasons that traces were discarded. A network model was created by integrating GIS data from multiple sources into the network file maintained by the San Francisco County Transportation Authority.

The study analysed a set of network and environment attributes, including different types of bicycle facility, free flow speed, number of lanes, number of turns and traffic volume.

The route choice model estimated in this study indicated that route length (or travel time) was an important factor in route selection. Cyclists in San Francisco strongly prefer bike lanes to other types of bicycle facility and avoid climbing hills, turning or deviating excessively from the shortest route.

The San Francisco County Transportation Authority website ("Cycletracks in San Francisco", 2012) notes that as of August 2012, 4,365 users have submitted trips and 14% of users have submitted 10 or more trips.

Other cities collecting data with CycleTracks

Following the success of the San Francisco CycleTracks project in 2010, a number of other agencies and municipalities are now using CycleTracks to gather data on the movement of cyclists on their network.

- Austin, Texas – discussed below
- Fort Collins, Colorado – discussed below
- Monterey, California
- Raleigh, North Carolina
- Minneapolis/St. Paul, Minnesota
- Seattle, Washington
- Salt Lake City, Utah

Other cities that have rebranded CycleTracks

Both the application (iPhone and Android versions) and the bike route choice model are open source and available from the San Francisco County Transportation Authority (https://github.com/sfcta). This enables other agencies and researchers across the country to replicate, build on and rebrand CycleTracks. Other US cities that have rebranded CycleTracks include:

- Atlanta, Georgia – rebranded as Cycle Atlanta- discussed below
- Lane County, Oregon rebranded as LaneTracks.
- College Station, Texas – rebranded as AggieTracks.
- Charlottesville, Virginia – rebranded as CVill Bike mAPP (http://www.tjpdc.org/cvillebikemapp/index.asp)

Using Smartphones to Collect Bicycle Travel Data in Texas (Hudson et al. 2012)

For this project, researchers evaluated the smartphone application called CycleTracks, developed by the San Francisco County Transportation Authority (SFCTA), which is available on both iPhones and Android-based smartphones. Austin, Texas, was chosen as the area has a strong cycling culture and several universities including the University of Texas are located there. In a six month period between May 1 and October 31, 2011, a total of 3,615 trips were collected by 317 participants (refer Figure 2-3), but after data cleaning only 3,198 trips remained to be input into the map-matching process. Using algorithms within ArcGIS, researchers were able to match almost 90 percent of the bicycle routes.

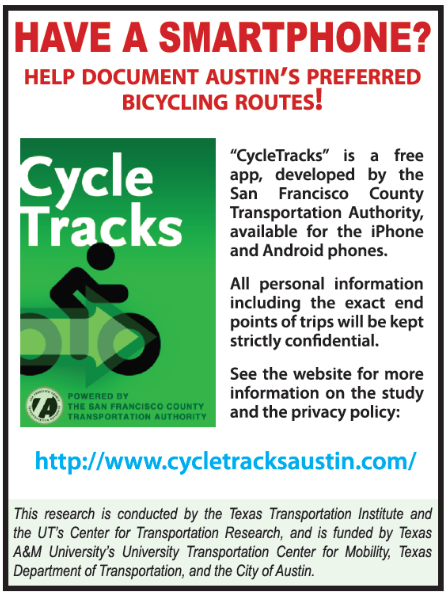


Figure 2-3: Participant recruitment postcard

The CycleTracks application is able to gather information about the cyclist and the purpose of the trip. Participants were asked but not required to enter demographic information and to define the purpose of the bicycle trip. Of the defined trips, 85 percent were for the purpose of transportation as opposed to recreation.

Although this study was not the first to collect and analyse bicycle route information with the CycleTracks smartphone application; it was the first to use ArcGIS software to develop a means to generate routes from the network and analyse the resulting cycling routes. As a result of random and systematic errors contained in the GPS traces collected from the CycleTracks application, the researchers advise that they spent significantly more time than was originally expected on data cleaning, completing the network, and map-matching. Despite this, the report concludes that

> *the potential route data and the wide variety of uses for the data made available through CycleTracks or other smartphone application far surpasses the challenges faced when considering other data collection alternatives.*

CycleAtlanta (www.cycleatlanta.org, 2013)

Cycle Atlanta is a joint project between the City of Atlanta Department of Planning & Community Development, Georgia Institute of Technology, Atlanta Bicycle Coalition and Atlanta Regional Commission.

Cycle Atlanta is a smartphone app for recording bicycle trips based on the CycleTracks app originally developed for the San Francisco Country Transportation Authority. Development of the Cycle Atlanta app is an on-going project being conducted by a team of researchers at Georgia Institute of Technology. The app uses the phone's GPS to record routes in real-time, allowing the City of Atlanta to know which routes cyclists prefer. The app also allows users to report problems along their route such as potholes, obstructed bike lanes, etc.

The smartphone app is a component of the *Cycle Atlanta: Phase 1.0 study*. The goal of the *Cycle Atlanta: Phase 1.0* study is to position the City of Atlanta to secure funding to construct a connected bicycle network within the core of the city, which will be expanded to the rest of the city in the near future.

RiderLog - Bicycle Network Victoria, Australia (www.bicyclenetwork.com.au, 2013)

Bicycle Network Victoria is a charity that promotes community health and The Bicycle Network is the name used by Bicycle Victoria for projects outside Victoria.

In May 2010, Bicycle Network Victoria released a smartphone application for iPhones called RiderLog and in its first year of operation, RiderLog users logged over 250,000km of rides. RiderLog records basic details of cycle trips including elapsed time and average speed (refer Figure 2-4) and anonymously uploads them to the Bicycle Network. The phone can also track riders cumulative distance and time over the week and month, providing a record of their activity.

Cycle trips data is collected from all submissions, however, additional information on gender, age etc. – is only available if the rider agrees to submit that data as well. The GPS traces can be matched to a road network to provide information on where cyclists start and finish trips and allow a greater understanding of the routes chosen by riders. This data gives the Bicycle Network a unique insight into the riding habits of Australian's and is used to inform their approaches to local, state and federal government and road authorities. Australian cities using RiderLog include Freemantle, Melbourne, Brimbank and Port Phillip.

Figure 2-4: RiderLog screen images

Feasibility of using GPS to track bicycle lane positioning (Lindsey et al. 2013)

A recent report investigated the feasibility of using GPS to track bicycle lane positioning. The study compared the accuracy of a smartphone using the CycleTracks app and a high quality external GPS unit. The report field tests found that:

- the GPS traces from the external GPS unit were significantly more accurate than the traces provided by the GPS units in the smartphones;
- route traces from the external GPS unit and the smartphone were affected by the characteristics of the built environment along the route, with accuracy significantly lower in an narrow street with high buildings;
- there is no difference in accuracy between different smartphones.

The report noted:

> *The field tests demonstrated that neither smartphone GPS units or the higher quality external GPS receiver generate data accurate enough to monitor bicyclists' use of bike lanes or other facilities.*

2.2.3 Discussion

The advances in GPS technology have clearly had a revolutionary impact on the quantity and quality of available information on cyclist's route choice. Earlier GPS studies (Dill & Gliebe, 2008) and (Rewa, 2012) provided GPS units to participants and thus the number of participants at any time was limited by the amount of available units. Today's smartphone apps such as CycleTracks and RiderLog utilise the equipment and technology already owned and carried by the cyclists, enabling cities and territorial authorities to gather low cost data on route choice from increasing numbers of cyclists. This allows planners to get a clearer picture of the distribution of cycle trips and provide appropriate infrastructure. However, as noted by (Lindsey et al. 2013), whilst GPS data can be used to identify route choice, it is not currently of sufficient accuracy to identify if a rider chose to use a cycle lane or remain in a traffic lane.

2.3 Impact of the literature review on this study

Whilst several of the previous studies of bicycle route and mode choice have identified travel time as a significant factor, none have quantified what component of travel time could be attributed to delay. The only study found that actual quantified cyclist delay in a meaningful format was a study into the effectiveness of municipal policies (Rietveld and Daniel 2004), which identified a value for delay in seconds/km for nine Dutch cities.

The recent advances in GPS technology integrated into cycle computers and smartphones has made route tracking, speed and trip time data readily available. It would appear however that authorities using data from smartphone apps such as CycleTracks and RiderLog are only recording route data, average speed and elapsed ride time data. If these apps also provide data that identified the amount of time a cyclist was stationary during a trip, then the amount of delay a cyclist could expect on a route could be made available to cyclists, perhaps in the delay in seconds/km format used by (Rietveld and Daniel 2004).

The literature review indicates there has been little previous research that quantifies cyclist delay and this study aims to identify and record the actual amount of delay experienced by a cyclist at intersections during peak hour commuting trips in Christchurch. It is hoped that this can be undertaken by making use of a GPS enabled device such as a smartphone or cycle computer, and the suitability of these devices will be tested during the field trial.

3. Method: Delay measurement

3.1 Possible delay recording devices

This is primarily internet based research into available technology and equipment to identify the most suitable device to record the delay experienced by a cyclist at individual intersections along a route. Section 2.2 of the literature review identified some of the studies and data collection programmes that have used GPS units or smartphone apps to track and map cyclists movements. The typical data outputs of these programs are total trip time and average speed.

As the routes to be surveyed in this study are already set, the route mapping capability is not critical to the research, whereas distance travelled, speed and stationary time are essential. Ideally, the equipment will require a minimum amount of manual operation and be able to download data, possibly remotely, to computer. The technology and equipment being investigated will include, but is not limited to:

- Stopwatches
- video cameras / helmet cameras
- GPS cycle computers
- Smartphone applications

All cost noted are in New Zealand dollars as at 2013. All smartphone apps reviewed featured the current software version at the time of review but the software may since have been updated.

3.1.1 Stopwatches

3.1.1.1 Manual sports watches

There are several high end running / triathlon type sports watches and stopwatches that feature multi lap recording features and some examples are:

- Timex Ironman T5K253 (Figure 3-1)
  Tap screen activated 150 lap memory – approx. $260
- Timex Ironman T5K197 (Figure 3-2)
  Button activated 30 lap memory – approx. $240
- Casio Runner series STR300C-1V (Figure 3-3)
  Button activated 60 lap memory – approx. $80
- Seiko Premium Stopwatch (Figure 3-4)
  300 lap memory – approx. $700

Any of these watches could be used to record the delay using the lap memory feature. The time should be able to be fairly accurately matched against distance along the route to identify the location of any stop, although this may be difficult when several intersections are close together. However, every start and stop of every trip would need to be registered by manual input, either by push button or tap screen, and the lap memory output manually recorded into a spreadsheet to identify the amount of stopped time.

Figure 3-1:Timex T5K253

Figure 3-2: Timex T5K197

Figure 3-3: Casio STR300C

Figure 3-4: Seiko premium stopwatch

It is anticipated that most of the delay recording trips will be made during the winter months when most Christchurch cyclists wear gloves. Any operator error, such as forgetting to record a stop or incorrectly pressing a button would invalidate the entire trip data.

There is also a safety concern that operating the watch at intersections in peak hour traffic will be a distraction, when it would better to have both hands on the handlebars and concentration fully applied to the traffic environment.

3.1.1.2 GPS sports watches

Advances in technology have enabled GPS receivers to be integrated into sports watches. By utilising the GPS, these watches are able to provide the user with speed, distance and altitude information as they run or cycle. Other available features in some models include map display, route tracking. Some GPS watches are able to connect to external sensors such as heart rate monitors using a proprietary wireless sensor network known as ANT, and this system or a USB can be used to transfer data to a computer. Most manufactures have proprietary software that allows users to analyse downloaded data. GPS use drains the battery and watches generally have a relatively short battery life, in the range of 10 to 20 hours. Batteries can usually be recharged by USB.

Some examples of current GPS watches are:

- Garmin Forerunner® 310XT (Figure 3-5) - approx. $425
- NIKE+ SPORTWATCH GPS (Figure 3-6) - approx. $200
- Leikr GPS sports watch (Figure 3-7) – approx. $550
- Timex Global Trainer GPS Watch T5K444 (Figure 3-8) - Approx. $300

For a GPS watch to deliver an advantage over the manual sports watch models, the ability to download the data in a format useful for this research is required. Most GPS watches are able to download data to a website where software designed specifically for that particular brand of watch can display the recorded data in the form of charts, training logs etc.

Figure 3-5: Garmin 310XT

Figure 3-6: Nike GPS Sportswatch

Figure 3-7: Leikr GPS sportswatch

Figure 3-8: Times Global trainer T5K444

A study of GPS equipment review websites (Zahradnik, 2013) and ("GPS running watches", 2013) in April 2013 indicates that the Garmin GPS watches and their Garmin Connect software is the market leader at this time. Some of the Garmin range of GPS watches include an auto pause function, which stops recording if speed falls below a specified speed (refer Figure 3-16) and may be useful if it can accurately detect stopped time. This feature is discussed further in Section 3.2.4.

As a GPS watch would only require manual operation at the start and end of a trip, this would eliminate the potential problems of operating during the winter months wearing gloves and also the safety concern that operating the watch at intersections in peak hour traffic will be a distraction.

3.1.2 Video cameras

As it is clearly not practical to cycle through peak hour traffic and attempt to operate a hand held video camera, the research into the suitability of video recording devices to record delay has been limited to helmet mounted video cameras. Several fully self-contained cameras are available that can be attached to a cycle helmet or handlebars using proprietary mounts.

Some examples of helmet mounted videos cameras:

- Go Pro Hero3 Silver edition (Figure 3-9) - approx. $480
- Drift HD Ghost (Figure 3-10) - approx. $590
- Contour GPS (Figure 3-11) - approx. $650

Figure 3-9: GoPro Hero3

Figure 3-10: Drift HD Ghost

Figure 3-11: Contour GPS

A helmet camera could be used to identify the delay at each intersection as each trip would have the recording time, accurate to one second, viewable on playback. Recordings are stored on a MircoSD memory card, however that largest capacity card provided with a camera can store just 8 minutes of video recording and at least one additional memory card would be required. A 16GB card stores about 2 hours and 32GB card stores about 4 hours recording time. The cards retail for approximately $50 and $80 respectively.

Retrieving the data would be time consuming, as each trip would need to be viewed and the location and duration of each delay manually noted and entered into a spreadsheet. The GPS enabled camera would allow the travelled route to be viewed in Google Maps or similar mapping programme, however the routes in this study are already known and this would have no additional benefit.

As most of the delay recording trips will be made during the winter, the camera would have to be weatherproof. Of the three cameras featured, the Ghost HD is waterproof to a depth of 3 metres, a waterproof case is available for the GoPro Hero and the Contour GPS camera is described as water resistant. Close attention would also need to be paid to battery strength, as the manufacturer’s stated battery life for these cameras is between 2.5 to 3 hours, with a 30 minute reduction on the GPS model when the GPS is activated.

3.1.3 GPS cycle computers

Non GPS enabled cycle computers are able to provide speed and distance information based on wheel revolutions and tyres circumference. A cycle computer with an integrated GPS receiver is able to provide the user not only with speed and distance, but also altitude and route information as they cycle. As with GPS watches, some GPS cycle computers are able to connect to external sensors such as heart rate monitors using a proprietary wireless sensor network known as ANT, and this system or a USB can be used to transfer data to a computer. On some models, data can be saved to MicroSD memory cards. Most manufactures have proprietary software that allows users to analyse downloaded data. Battery life is between 15 to 18 hours and most use rechargeable batteries.

Figure 3-12: Garmin Edge 705

Figure 3-13: Earthmate PN-60

Figure 3-14: Bryton Rider 21E GPS

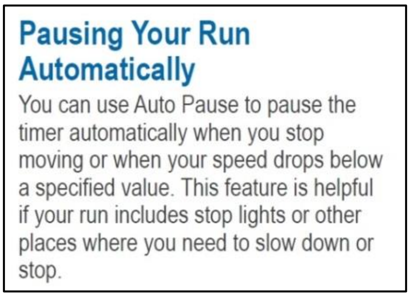
Figure 3-15: Garmin Edge 500

Some examples of GPS cycle computers:

- Garmin Edge 705 (Figure 3-12) - approx. $600
- Earthmate PN-60 (Figure 3-13) - approx. $550
- Bryton Rider 21E GPS (Figure 3-14) - approx. $290
- Garmin Edge 500 (Figure 3-15) - approx. $450

As noted above in the GPS sports watches section, a study of GPS equipment review websites (http://gps.about.com/ and http://www.gearinstitute.com/) in April 2013 indicates that the Garmin Connect software is the market leader at this time.

As they are produced for outdoor use, cycle computers are waterproof and are sold with handlebar mounting brackets as standard or an accessory. These types of unit would be suitable from a practical point of view. However, it is not clear from the authors' research to date if these types of units can record stationary time to an accuracy and in a format that will be of use to this study. Some units offer a timing feature called *Auto Pause*, which will pause the timer automatically if the cyclist stops moving or slows down below a nominated speed. The Garmin description of this feature is shown in Figure 3-16. This feature would appear to be useful for the purpose of this study, but its accuracy and how this data is recorded will need to be field tested.


Pausing Your Run Automatically

You can use Auto Pause to pause the timer automatically when you stop moving or when your speed drops below a specified value. This feature is helpful if your run includes stop lights or other places where you need to slow down or stop.

Figure 3-16: Garmin auto pause function

3.1.4 Smartphone applications

A smartphone application (or app) is a software application designed specifically to run on a smartphone. Apps are widely available for both android and iPhone operating systems and are easily downloaded via the phone operating system at distribution platforms such as the Apple App Store, Google Play or Windows Phone Store. Many apps are available that make use of the smartphones GPS and at the time of writing, there are over 100 "cycle tracking" apps available on the Apple App Store.

Many apps are available, some of which are free to download, that make use of the smartphones' GPS and enable the phone to perform the same functions as a costly GPS cycle computer. As has been noted in Section 2.2.2, smartphone apps such as CycleTracks and RiderLog, which send ride data directly to a nominated server, are being used by local and regional authorities to gather route data.

A study of smartphone cycle apps review websites (Menoni, 2013) and (Arthur, 2012) indicates that the five apps noted in Table 3-1 are among the best available for tracking cycle trips. Each of these apps was able to be downloaded and installed on the authors' iPhone.

Table 3-1: Smartphone apps selected for trial

App name	Features	Data download / export	Cost
MapMyRide Available for iPhone & Android	Time, speed, distance, route, elevation, *Auto Pause*	Sent to MapMyRide website	$2.99
Cyclemeter GPS Available for iPhone & Android	Time, speed, distance, route, elevation, Auto Pause	Email CSV, GPX, TCX files.	$4.99
B.iCycle Available for iPhone	Time, speed, distance, route, elevation, Auto Pause	Sent to 1-2-sports.com website or can emails GPX files.	$9.99
Cycle Tracker Pro Available for iPhone & Android	Time, speed, distance, route, elevation, Auto Pause	Sent to Training Peaks website Or email GPX	$4.19
Garmin Fit Available for iPhone & Android	Time, speed Distance, route Elevation	Sent to Garmin Connect website	$1.29

Note: refer to Section 3.2.3 for descriptions of data export file types.

In order to maximise GPS reception, the smartphone should be mounted on the bike, ideally on the handlebars where it can be easily accessed to start and stop operation but will be exposed to the weather. One disadvantage of using a smartphone for this research is they are not waterproof. Fortunately, there are several proprietary handlebar mounting brackets currently available for smartphones that are integrated with a waterproof case.

A smartphone attached to the handlebars in a waterproof case should be suitable from a practical point of view for this research. However, as with the GPS cycle computers, it is not clear from the authors' research to date if these types of units can record stationary time to an accuracy and in a format that will be of use to this study. As with some GPS cycle computers, some apps also offer the *Auto Pause* timing feature, which would appear to be a useful feature for the purpose of this study, but its accuracy and how this data is recorded and made available to the user will need to be field tested (refer Section 3.2.4.).

Sales and promotional material of the smartphone apps advises that battery use can be reduced when using the GPS by switching off the phones Wi-Fi mode. If selected for field test, the smartphone apps will be tested using an Apple iPhone 5. The Apple website (www.apple.com/nz/iphone/features/) advises that the phones battery life will last for 8 hours of talk time, 8 hours of browsing time or 10 hours of video playback. As such, battery life is not expected to be an issue with total ride times of less than one hour per day and the phone will be charged regularly as part of its routine use.

3.1.5 Selection of data recording equipment

In order to compare the suitability of the different equipment types considered above for this research, they were assessed against six criteria shown in Table 3-2. As some of the criteria are critical to the study and others are operational issues of a more practical nature, a weighting factor between 1 and 5 was applied to each criteria.

Table 3-2: Equipment assessment criteria

Criteria	Weighting
Can the device accurately record multiple stops • This is critical to the study	5
Manual operation only required for trip start & stop • May be difficult during trip with gloves	3
Can the device be easily carried or attached to bicycle • Can it be quickly mounted and removed	3
No battery life issues • Can the device record multiple trips	3
Is the device waterproof • Can the device be damaged by rain	4
Can the trip data be exported in useable format • This is critical to the study	5

Table 3-3 shows a matrix where each device is scored against the criteria to identify the most suitable equipment. The devices that require a trial to assess their ability to accurately record stops were allocated a score of 20% of the weighting.

Table 3-3: Equipment suitability matrix

Device Type	Accurately record multiple stops	Only start & stop operation required	Easily carried or attached	No battery life issues	Water proof	Can export data in useable format	Score
Sports watch	☑ =5	☒ =0	☑ =3	☑ =3	☑ =4	☒ =0	**15**
GPS watch	Requires trial =1	☑ =3	☑ =3	☑ =3	☑ =4	☑ =5	**19**
Camera	☑ =5	☑ =3	☑ =3	☒ =0	☑ =4 With case	☒ =0	**15**
GPS Cycle computer	Requires trial =1	☑ =3	☑ =3	☑ =3	☑ =4	☑ =5	**19**
Smart phone app	Requires trial =1	☑=3	☑ =3	☑ =3	☑ =4 With case	☑ =5	**19**

The suitability matrix indicates that a GPS sports watch, a GPS cycle computer or a smartphone with a GPS tracking app should be the most suitable equipment for this research, with the inability of the sports watch and the camera to export data in a useable format the main reason for their elimination.

3.1.6 Equipment selected for field testing

As the performance of a Garmin GPS watch and a Garmin GPS cycle computer is likely to be comparable, a Garmin Edge 500 GPS cycle computer has been selected for trial over the Garmin GPS watch as a device fixed to the handlebars will be easier to monitor when riding.

The devices selected for the field trial are:

- **A Garmin Edge 500 GPS cycle computer**
- **A smartphone operating the following "cycle tracking" applications:**
    - MapMyRide
    - Cyclemeter GPS
    - B.iCycle
    - Cycle Tracker Pro
    - Garmin Fit

3.2 Field testing

To assess their suitability for use in the study, a Garmin Edge 500 GPS cycle computer and five cycle tracking apps operating on an Apple iPhone 5 smartphone were tested on routes similar in nature and length to the routes to be used in the study. The cycle computer and each app were tested twice, each time on a different route.

During the field trial, the iPhone 5 was secured to the cycle handlebars using a 'Quadlock' proprietary mounting bracket as shown in Figure 3-17. The Garmin unit was fixed to the handlebars using a Garmin proprietary mounting bracket.

Figure 3-17: Smartphone mounted to handlebars

3.2.1 Multi-criteria evaluation framework

It was not clear from the available information on these devices if they are able to record a series of stop / start intervals to an acceptable degree of accuracy. A margin of error of 2 seconds is considered to be an acceptable degree of accuracy for the timing of a stop. The ability for the recorded data to be extracted in a suitable format for this study also needs confirmation.

The performance of the equipment in the field test was assessed against the following criteria in Table 3-4, with a weighting factor applied to each one.

Table 3-4: Field test performance criteria

Criteria	Weighting
Ease of use • Is the device easy and intuitive to operate? • Is on-screen data clear? *Important due to the number of recording required but not critical.*	3
Ability to accuracy record stationary time • Does the device accurately recognise and record stationary time? *Critical to the study.*	5
Availability of recorded data • Can data recorded by the device be readily transferred to a computer? *Important due to the number of recording required.*	4
Usability of recorded data • Is recorded data in a useable format? *Critical to the study.*	5
Overall suitability for this study • What is the overall suitability of the device based on its performance against the other criteria? *The suitability of the device is critical to the study.*	5

3.2.2 Elevation

All of the devices tested were able to record changes in elevation along the route. However, given that the test routes were basically flat and any minor gradients encountered would have minimal effect on speed or delay, the elevation component of the recorded route data was not considered in the field trial data.

3.2.3 Exported data file formats

The devices that were tested were all able export data, either directly to a website or in one of the file formats noted in Table 3-1. A brief description of each file format follows:

GPX format is an xml format designed specifically for saving and exchanging GPS data such as GPS track, waypoint and route data. GPX is based on the XML standard and can be read by programs such as Microsoft Excel.

TCX format is also an xml format that contains GPS waypoints, tracks, routes, etc. and can be read by programs such as Microsoft Excel. TCX format was created by Garmin to include additional data such as heart rate and cadence, with each track point. The format is primarily used by Garmin's fitness oriented GPS devices.

CSV (comma-separated values) format files store tabular data (numbers and text) in plain-text form.

XML (Extensible Markup Language) format defines a set of rules for encoding documents in a format that is both human and machine readable.

3.2.4 Auto pause function

As noted in Sections 3.1.1 & 3.1.3, some GPS devices include a timing feature called Auto Pause, which will pause the timer automatically if the cyclist stops moving or slows down below a nominated speed. This function is available on four of the five smartphone apps and the Garmin Edge 500 GPS cycle computer. Prior to commencing the field testing of the selected equipment, some preliminary trials were carried out to identify the effectiveness of the auto pause feature.

A short, rectangular street circuit was ridden twice using a Garmin Edge 200 GPS cycle computer unit as the recording device. This is a similar unit to the Garmin Edge 500 to be used in the study but without some advanced features such as a heart rate monitor. A stop was made on each of the four sides of the circuit and the length of the stop measured using a wristwatch stopwatch. The first lap was ridden without the *auto pause* function operating, the second lap with *auto pause* on. The ride data was downloaded onto the Garmin Connect website and TCX files, which include time, speed and distance information, were then exported and loaded into an Excel spreadsheet.

Table 3-5 shows a summary comparison of the recorded data. As can be seen, the stopped time recognised in the *auto pause* data is a close match with the hand timed stoppage. When time taken between stopping the bike and operating the stopwatch is taken into consideration, the *auto pause* value is likely to be a more accurate record of the actual stopped time than the hand timed value.

Table 3-5: Auto Pause comparison

GARMIN DATA without AUTO PAUSE					GARMIN DATA with AUTO PAUSE				
Distance (metres)	Speed (m/sec)	Time	Time between points (secs)	Hand timed stop	Distance (metres)	Speed (m/sec)	Time	Time between points (secs)	Hand timed stop
232.3	4.83	2:42:20			217.6	4.54	2:28:04		
296.3	5.58	2:42:32	00:12		279.7	4.78	2:28:17	00:13	
318.0	4.81	2:42:36	00:04		308.0	0.00	2:28:26	00:09	
328.2	2.44	2:43:13	00:37	30 sec	308.0	1.72	2:28:57	00:31	30 sec
359.6	4.89	2:43:20	00:07		345.5	5.27	2:29:05	00:08	
392.8	5.58	2:43:26	00:06		374.5	5.16	2:29:10	00:05	
1137.4	6.75	2:45:55	00:03		1226.8	5.90	2:31:45	00:01	
1164.4	6.65	2:45:59	00:04		1242.9	1.66	2:31:49	00:04	
1225.3	6.38	2:46:08	00:09		1243.9	0.00	2:31:51	00:02	
1277.1	5.18	2:47:23	01:15	60 sec	1243.9	1.77	2:32:53	01:02	60 sec
1338.4	7.00	2:47:32	00:09		1305.0	6.19	2:33:05	00:12	
1401.7	6.80	2:47:41	00:09		1368.1	6.88	2:33:14	00:09	
1824.8	5.12	2:48:43	00:04		1879.7	5.78	2:34:32	00:11	
1889.9	5.19	2:48:55	00:12		1903.0	6.02	2:34:36	00:04	
1912.6	5.80	2:48:59	00:04		1934.1	0.00	2:34:43	00:07	
1975.6	5.62	2:49:47	00:48	30 sec	1934.1	1.41	2:35:17	00:34	30 sec
2039.3	6.01	2:49:57	00:10		1998.3	6.40	2:35:29	00:12	
2069.3	5.98	2:50:02	00:05		2030.1	6.27	2:35:34	00:05	
2254.1	5.76	2:50:33	00:11		2295.2	5.82	2:36:19	00:10	
2318.6	5.60	2:50:44	00:11		2335.4	5.41	2:36:26	00:07	
2328.8	5.23	2:50:46	00:02		2356.2	0.00	2:36:32	00:06	
2390.9	4.55	2:52:05	01:19	60 sec	2356.2	2.55	2:37:35	01:03	60 sec
2452.0	6.07	2:52:16	00:11		2421.9	5.84	2:37:48	00:13	
2464.0	6.08	2:52:18	00:02		2483.4	6.07	2:37:58	00:10	
2525.0	5.74	2:52:28	00:10		2545.0	6.15	2:38:08	00:10	

3.2.5 Testing of Smartphone applications

The performance of each smartphone app was assessed against the criteria noted in Section 3.2.1.

3.2.5.1 MapMyRide app performance assessment

This app was trialed on the following dates with the *auto pause* function activated:

- 27 June 2013 at 3:51pm. Distance 6.7 km.
- 5 July 2013 at 4:07pm. Distance 6.3 km.

<u>Ease of use</u>

This app has an intuitive opening screen with a clear link to a settings page where it is easy to change the units and also turn the *auto pause* function on. This is the only one of the tested apps with a setting that enables the phones' sleep mode to be disabled when the app is running, which prevents the phone turning itself off during the ride. It has a large 'start' button and a large, easily read display showing time, distance and speed (Figure 3-18). A black cross appears on the display to indicate when the *auto pause* function has recognised that the bike is stationary.

Ability to accurately record stationary time

As noted above, a black cross appears on the display to indicate that when the *auto pause* function has recognised that the bike is stationary. Monitoring the screen display whenever a stop was made indicated that this function generally took at least 5 seconds and often as long as 10 seconds, to register that the bike had stopped, engage *auto pause* and stop the timer. A delay of 3 to 5 seconds was consistently observed before the app registered movement and disengaged the *auto pause* function and restarted the timer.

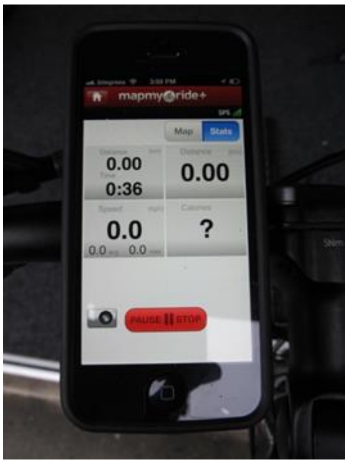


Figure 3-18: MapMyRide screen

Availability of recorded data

Ride duration, distance and average speed data are available on the phone screen, together with a map showing the route. Recorded trip data is automatically sent to the MapMyRide.com website, where an interactive graph shows time, distance & speed data at any selected point along the graph and also indicates the location of the selected point on a map of the route. An example of the interactive graph and map is shown in Figure 3-19.

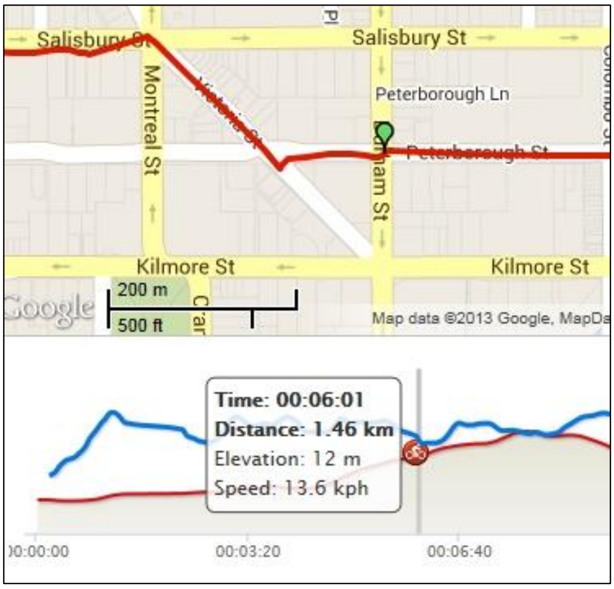


Figure 3-19: MapMyRide website screenshot

Usability of recorded data

A GPX file can be exported from the website and opened in an Excel spreadsheet. The frequency of data points recorded during the trip calculates to an average of one point every 1.8 seconds; however the only trip data exported in the GPX file is the longitude & latitude co-ordinates of the route and the total ride distance. No time, distance or speed data are exported in the GPX file and it is this data that is required to be available in spreadsheet format for this project.

Overall suitability for purpose

The MapMyRide app is not considered as suitable for this study for the following reasons:

- It is not able to identify the stopping and restarting of the bike to the degree of accuracy required to provide meaningful delay data for this study.
- Whilst some time, speed and distance information could be viewed on the website graphical display, this data cannot be exported in a usable format.
- Constant monitoring of the screen to check if a stop has been recognised is an unnecessary distraction and a safety concern in busy traffic.

3.2.5.2 CycleMeter GPS app performance assessment

This app was trialed on the following dates with the *auto pause* function activated:

- 8 July 2013 at 7:56 am. Distance 7.2 km.
- 8 July 2013 at 5:15 pm. Distance 4.8 km.

Ease of use

Opening this app takes you straight to the recording screen, which has a large 'start' button and an easily read display showing ride time, distance, speed and average speed. A small map is also displayed on this screen (Figure 3-20). The settings page is accessed via a small touch button at the bottom of the opening screen where it is easy to change the units and turn the *auto pause* function on.

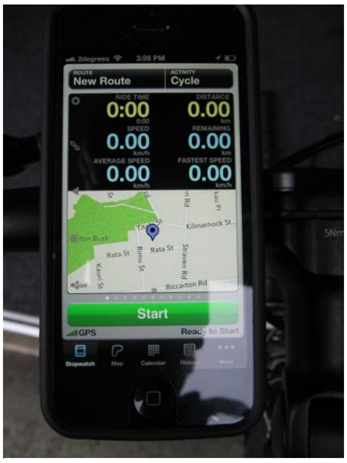


Figure 3-20: CycleMeter screen

Ability to accurately record stationary time

There is no onscreen indication that the auto pause function has identified that movement has stopped and the timer continues to run although the bike is stationary. However, when the bike starts to move again, the duration of the stop identified by the app is deducted from the timer display so that the timer displays the ride time and not the elapsed time. This occurs every time the app detects a stop, with the timer being 'corrected' when restart movement is detected. This makes it very difficult for the user to check how accurately the stop was identified.

To try and verify the accuracy that this app recognises stop / start movements, it was trialed against a Garmin Edge 500 GPS cycle computer on 8 July 2013 over a distance of 4.6 km. The Garmin unit was used as it was shown to accurately identify both stop and restart movements in the *auto pause* test noted in Section 3.2.4. Both devices were fixed to the handlebars with mounting brackets.

A CSV file emailed from the CycleMeter app and a TCX file exported from the Garmin Connect website were entered into a spreadsheet for comparison. The Cyclemeter CSV file was used as the GPX and TCX files could not be successfully imported into Excel. A review of the spreadsheet data indicated that the Garmin unit recorded 69% more points during the ride than the CycleMeter and identified a speed of "0" six times compared to 3 times by the CycleMeter app. A summary is shown in Table 3-6.

Table 3-6: Ride data comparison

Ride data	CycleMeter	Garmin Edge 500
Number of points recorded	123	208
Number of stop detected	3	6
Shortest stop detected	48 secs	4 secs

Availability of recorded data

Distance, average and maximum speed data are available on the phone screen. Also displayed on screen is the ride time and stopped time and this is the only app that identifies stopped time on screen. A map of the route and graphs displaying speed against distance or time are viewable on the smartphone screen.

Usability of recorded data

The app will email the ride data in CSV, GPX, TCX format to a nominated address, however only the CSV format was able to be loaded successfully into Excel. Elapsed time, ride time, stopped time, speed and distance data were available in the spreadsheet although some adjustments to the time data formatting were required before it was usable. Once the data formatting has been amended, the ride data was suitable for use in this study.

Overall suitability for purpose

The CycleMeter app is not considered as suitable for this study for the following reason:

- It is not able to identify the stopping and restarting of the bike to the degree of accuracy required to provide meaningful delay data for this study.
- Constant monitoring of the screen to check if a stop has been recognised is an unnecessary distraction and a safety concern in busy traffic.

3.2.5.3 B.iCycle app performance assessment

This app was trialed with the *auto pause* function activated on the following dates:

- 28 June 2013 at 8:07 am over 7.0 km
- 9 July 2013 at 7:57 am over 7.0 km

Ease of use

This app has intuitive functions although the start button on the touch screen is smaller than other apps. The app can be operated with the screen displaying the timer, speed, the *auto pause* status and a route map (Figure 3-21) or without the route map and with additional distance and speed information displayed. When the app detects that the bike is not moving, the *auto pause* status display indicates "standstill" and the timer is stopped. When restart movement is detected, the "standstill" indicator disappears and the timer is restarted.

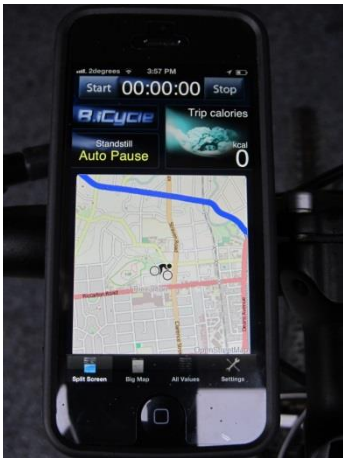


Figure 3-21: B.iCycle screen

Ability to accurately record stationary time

The onscreen *auto pause* display enables the apps ability to accurately identify that the cycle has stopped to be observed during the trial. A delay of 3 to 5 seconds was consistently observed before the app recognised that movement had stopped. During this time, the speed display continued to indicate an ever decreasing speed value. A delay of about 3 seconds was also consistently observed before movement was detected and the timer restarted.

Of particular note was the apps performance during one stop in excess of 20 seconds at a traffic signal. The speed display decreased to 1 km/h and then continued to display this value for the duration of the stop. The *auto pause* function did not register "standstill" and the timer continued to run. The app completely failed to recognise this significant period where the bike was stationary.

Availability of recorded data

Ride time, distance, average and maximum speed data are available on the phone screen. A map of the route is also viewable on screen. The app will send the ride data to the 1-2-sports.com website where it can be accessed following creation of a user account. Alternatively, KML and GPX files can be emailed to a nominated address.

Usability of recorded data

Logging onto the user account at the 1-2-sports.com website provides free access to a basic membership package and enables access to the ride data. However, the website seems to function as a social meeting site and navigating to the ride data is not intuitive. The free basic membership package provides limited features and the only additional information available beyond basic time, speed and total distance is a simple graph showing elevation against distance. No data can be exported from the basic package. Additional features are available via a premium membership package costing 10 Euros per month and this option was not taken up.

Alternatively, the emailed GPX file can be imported in to Excel, however the only trip data contained in the file is latitude, longitude, elevation and time. Whilst distance information could be extracted from the latitude and longitude co-ordinates, it is the speed information that helps identify when stops were registered.

Overall suitability for purpose

The B.iCycle app is not considered as suitable for this study for the following reasons:

- It was not able to identify the stopping and restarting of the bike to the degree of accuracy required to provide meaningful delay data for this study.
- Whilst some time, speed and distance information could be viewed on the website graphical display, insufficient ride data was available in Excel spreadsheet format to be useful for this project.
- Constant monitoring of the screen to check if a stop has been recognised is an unnecessary distraction and a safety concern in busy traffic.

3.2.5.4 Cycle Tracker Pro app performance assessment

This app was trialed with the *auto pause* function activated on the following dates:

- 30 June 2013 at 12:59 pm over 6.5 km
- 12 July 2013 at 8:01 am over 7.2 km

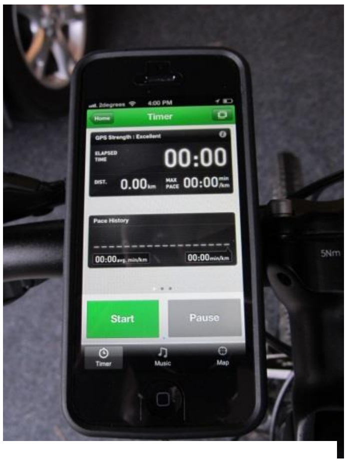


Figure 3-22:Cycle Tracker Pro screen

Ease of use

This app has a large start button and an easy to read display showing time, distance and pace when set in timer mode (Figure 3-22) or a smaller numerical display showing time and distance together with a route map when set to map mode. The settings page is easily accessed and the *auto pause* function easy to locate. On examination of the settings, it was apparent that although this app features an *auto pause* function, the shortest duration pause it can be set to recognise is 30 seconds.

Ability to accurately record stationary time

As noted above, the shortest time this app's auto pause function can be set to recognise is 30 seconds however there is no on screen indication of that the *auto pause* feature has recognised a stop. During the field trial, if the bike was stopped for long enough, then the timer could be observed to stop after approximately 30 seconds. This is clearly not suitable for this project. The timer generally restarted within 2 to 3 seconds of bike movement.

Availability of recorded data

Total trip time, distance, average speed and pace data are available on the phone screen. A map of the route is also viewable on screen. The app sends the ride data to the Trainingpeaks.com website where it can be accessed following creation of a user account. The app will also send an email to a nominated address containing a link to a TrainingPeaks website page that displays the same basic data as that available via the user account.

Usability of recorded data

Logging onto the user account at the Trainingpeaks.com website provides free access to basic ride data such as time, distance, speed and a route map. The user account holds details of all rides recorded on the Cycle Tracker Pro app. The free access provides an interactive graph showing speed against time or distance. The graph can display speed and time or speed and distance data at locations along the route. Although units were set to metric in the website report page, the graph continued to display imperial units, as can be seen in Figure 3-23, which shows a screen shot of the graph with the route map above.

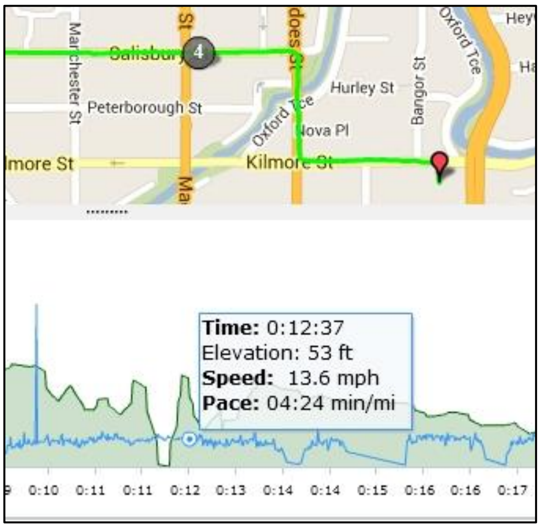


Figure 3-23: TrainingPeaks website screenshot

It is not possible to export data from the user account or the linked page. No data suitable for use in this study could be extracted from this app.

The TrainingPeaks website does offer additional data analysis features via a premium membership package costing US$19.99 per month. This option was not taken up.

Suitability for purpose

The Cycle Tracker Pro app is not considered as suitable for this study for the following reasons:

- It was not able to identify the stopping and restarting of the bike to the degree of accuracy required to provide meaningful delay data for this study.
- Whilst some time, speed and distance information could be viewed on the website graphical display, no ride data that would be useful for this project could be exported.

3.2.5.5 Garmin Fit app performance assessment

This app does not have the *auto pause* function. It was trialed on the following dates:

- 10 July 2013 at 7:59 am over 7.3 km
- 16 July 2013 at 4:50 pm over 6.6 km

Ease of use

This app has a timer screen that only displays elapsed time and distance together with a map of the route (Figure 3-24). The time and distance read outs are easily readable. The *auto pause* feature is not available on this app and there is no on screen indication that the app has detected that the bike is stationary.

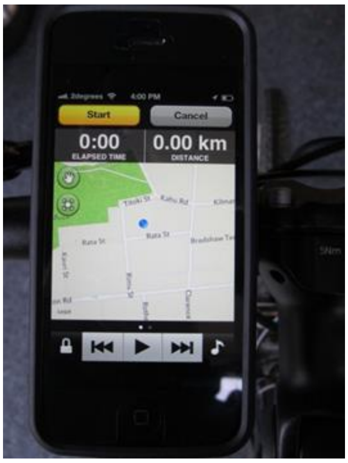


Figure 3-24: Garmin Fit screen

Ability to accurately record stationary time

As this app does not have an *auto pause* feature, to check its ability to identify stop / restart movement, it was trialed alongside a Garmin Edge 500 GPS cycle computer. Both devices were fixed to the handlebars with mounting brackets and the output data of both devices exported from the Garmin Connect website and entered into a spreadsheet for comparison.

Examination of the data revealed an unexpected result, with the Garmin Fit app having recorded data at one second intervals for the duration of the ride. When compared against the Garmin Edge data, the recognition of zero speed and duration of the stoppage were very closely matched. It is interesting to note that, although both data sets are showing the same stop, there is a considerable difference in the recorded distance to that point. One possible reason for this is the accumulated inaccuracy of the distance calculation between the GPS coordinate points, with the addition number of points recorded by the Garmin Fit app leading to an increase in the accumulated inaccuracy. Another possible reason is the inclusion of occasional 'rouge' points in the route data.

As can be seen in Table 3-7, the primary difference in the data sets is that the Garmin Edge cycle computer identifies the stop and does not record any more data until movement is detected again and the timer is restarted, whereas the Garmin Fit app continues to record data every second with the speed recorded as zero.

Table 3-7: Comparison between Garmin Fit & Garmin Edge data

GARMIN FIT APP without AUTO PAUSE					GARMIN EDGE 500 with AUTO PAUSE				
Distance (metres)	Speed (m/sec)	Time	Time between points (secs)	Recorded stop	Distance (metres)	Speed (m/sec)	Time	Time between points (secs)	Recorded stop
5411.6	4.60	20:16:20			5282.8	1.10	20:16:21		
5411.6	0.00	20:16:21	00:01		5282.8	0.00	20:16:22	00:01	
5411.6	0.00	20:16:22	00:01		5282.8	2.04	20:16:36	00:14	14 sec
5411.7	0.00	20:16:23	00:01						
5411.8	0.00	20:16:24	00:01						
5411.8	0.00	20:16:25	00:01						
5412.0	0.00	20:16:26	00:01						
5412.1	0.00	20:16:27	00:01						
5412.1	0.00	20:16:28	00:01						
5412.1	0.00	20:16:29	00:01						
5412.2	0.00	20:16:30	00:01						
5412.3	0.00	20:16:31	00:01						
5412.4	0.00	20:16:32	00:01						
5412.5	0.00	20:16:33	00:01						
5412.5	0.00	20:16:34	00:01						
5417.3	4.79	20:16:35	00:01	14 sec					

This can also be seen in the two following graphs. Figure 3-25 from the Garmin Fit app shows total time on the bottom axis and speed on the horizontal axis. The stops (zero speed) are clearly visible along the bottom of the graph.

Figure 3-25: Garmin Fit graph

Figure 3-26 from the Garmin Edge 500 GPS cycle computer shows elapsed time on the bottom axis and speed on the horizontal axis. The stops (zero speed) are clearly visible along the bottom of the graph but as points, as the timer is stopped until restart movement is detected.

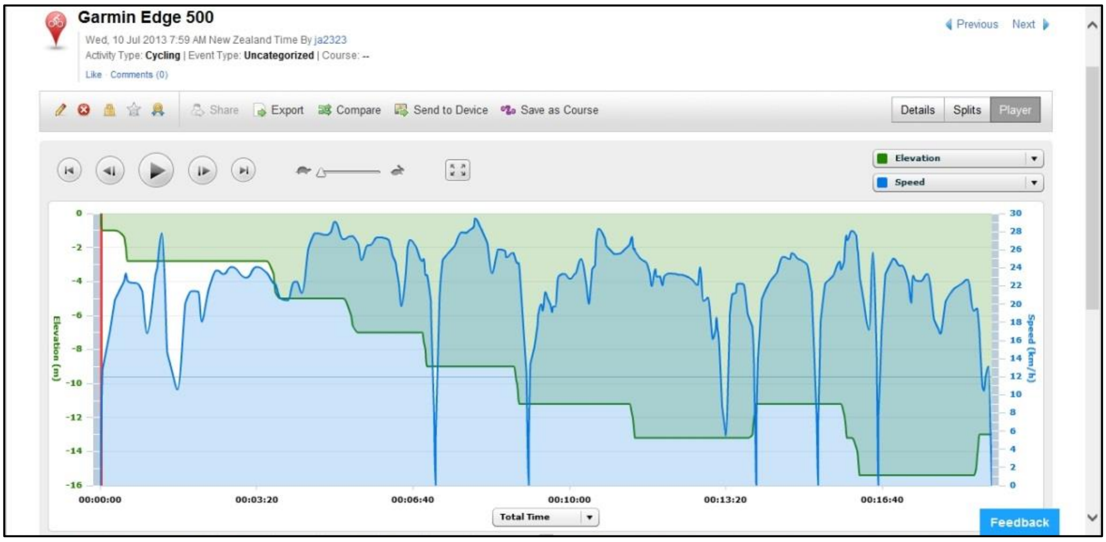


Figure 3-26: Garmin Edge graph

The two graphs appear differently due to the scale difference on the right hand vertical axis, which indicates speed. The Garmin Fit app recorded two rogue speed points of 90 km/h and 60 km/h and this has resulted in the graph showing a speed axis range from 0 to 90 km/h whereas the Garmin Edge 500 unit graph scale has a speed axis range from 0 to 30 km/h.

Availability of recorded data

Total trip time, distance, average speed, a route map and a basic graph showing speed against time are available on the phone screen. Data from the ride is automatically sent to the Garmin Connect website, where it can be accessed via a user account. Data files can be easily renamed if required. GPX or TCX data files are able to be exported for any recorded ride stored on the Garmin Connect website.

Usability of recorded data

Logging onto the user account at the Garmin Connect.com website provides free access to detailed ride data such as time, distance, speed and a route map. The user account holds details of all rides recorded on the Garmin Fit app. The website shows additional time and speed information and interactive graphs showing speed against time or distance. One additional feature available on the Garmin Connect site is the ability to view a map of the route above a graph and watch a marker move along the route and the graph at the same time (refer Figure 3-27). This clearly indicates where stoppages visible on the graph occurred along the route, making it easy to identify which intersection any recorded stop occurred at.

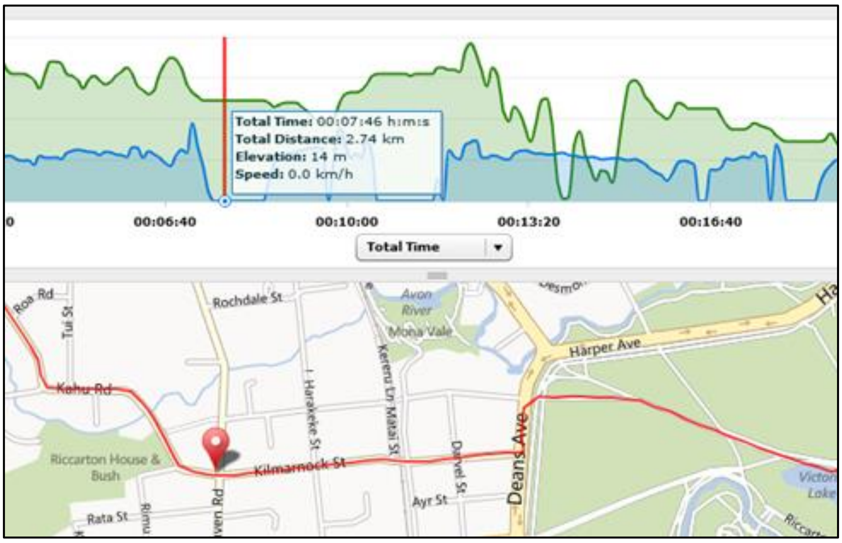


Figure 3-27: Garmin Connect website screenshot

The GPX or TCX data files exported from the Garmin Connect website are able to be opened in Excel spreadsheet format. As noted above, the Garmin Fit app records data points every second, which means a 20 minute ride generates 1200 lines of data, which makes manipulation of the data in the spreadsheet unnecessarily tedious.

Suitability for purpose

The Garmin Fit app is considered as suitable for this study for the following reasons:

- Although this is not confirmed by on screen indication, the app is able to identify the stopping and restarting of the bike to the degree of accuracy required to provide meaningful delay data for this study.
- The Garmin Connect website has excellent on screen graphics that enable accurate identification of the locations of stops along the route.
- Ride data can be imported into an Excel spreadsheet in a format that is useful for aim of this project, although manipulation of approximately 1200 lines of data per trip in the spreadsheet will be time consuming.

3.2.6 Testing of GPS Cycle computer

The GPS cycle computer used in the field trial was a Garmin Edge 500 which was secured to the cycle handlebars using a proprietary mounting bracket (Figure 3-28). The Garmin cycle computer was also used to provide comparative data during the CycleMeter and Garmin Fit smartphone app field tests. The performance of the Garmin Edge 500 unit was assessed against the criteria noted in Section 3.2.1.

Figure 3-28: Garmin Edge mounted to handlebars

3.2.6.1 Garmin Edge 500 performance assessment

This GPS unit was trialed with the *auto pause* function activated on the following dates:

- 10 July 2013 at 5.14 pm over 6.4 km
- 16 July 2013 at 4:50 pm over 6.5 km

<u>Ease of use</u>

The unit has a screen display that is approximately half the size of the iPhone 5 used in the smartphone app trials and unlike the smartphone apps, this unit is not able to display a route map. However, as this trial is being carried out over known routes, the on screen route map is not necessary. The on screen display can be configured in many different combinations of data displayed. For the field trial, it was operated with the timer displayed at the top of the screen and speed, distance, time of day and elapsed time displayed below in smaller size (Figure 3-29). A simple push button on the side of the unit stars and stops the recording, however this unit will not operate until it has located sufficient satellites, and this can take up to a minute. This is noticeably longer than the smartphone apps.

Figure 3-29: Garmin Edge screen

The Garmin Edge 500 includes the auto pause function, which can be set to operate when the bike has stopped or has slowed below a user specified speed. During the field trial, the auto pause feature was turned on and set to operate when the bike was stopped. When the unit detects that the bike has stopped, the message "auto paused" appears on the screen and the unit emits a clearly audible beep. When restart movement is detected, the message “auto resume” appears on screen and the unit emits another clearly audible beep.

Ability to accurately record stationary time

The onscreen *auto pause* messaging, together with the audible beep makes it clear that the unit has identified that movement has stopped or restarted. During the trial, the *auto pause* function consistently engaged and disengaged to an accuracy of 1 to 2 seconds. The slight delay in identifying the stop is balanced by the slight delay in identifying the restart, with the result being an accurate recording of the stop.

Availability of recorded data

Speed, distance, elapsed time data for multiple trips can be stored and viewed on the unit. Trip data for single or multiple trips is easily downloaded via USB cable to the Garmin Connect website.

Usability of recorded data

Once trip data has been downloaded to the Garmin Connect website, the usability is very good and exactly the same as described previously for the Garmin Fit app. As the Garmin Edge unit records about 280 points in a 20 minute trip but still accurately identifies the stopped times, the spreadsheet data is easier to work with.

Suitability for purpose

The Garmin Edge 500 GPS cycle computer is considered as suitable for this study for the following reasons:

- The unit is able to identify the stopping and restarting of the bike to the degree of accuracy required to provide meaningful delay data for this study.
- The onscreen *auto pause* messaging, together with the audible beep makes it clear that the unit has identified that movement has stopped or restarted.
- The Garmin Connect website has excellent on screen graphics that enable accurate identification of the locations of stops along the route.
- Ride data can be imported into an Excel spreadsheet in a format that is useful for aim of this project.
- The audible *auto pause* beep eliminates the need to monitoring the screen to check if a stop / restart has been recognised. This is safety benefit in busy peak hour traffic.

3.2.7 Evaluation of field tested equipment

In Table 3-8, the 5 smartphone apps and the GPS cycle computer have been assigned a score out of 10 based on how well they met the criteria noted in Table 3-4. The scores are then multiplied by the Table 3-4 weighting factors and summed to give score for that device.

Table 3-8: Field testing assessment matrix

Device Type	Ease of use	Ability to accuracy record stationary time	Availability of recorded data	Usability of recorded data	Overall suitability for this study	Total
MapMyRide phone app	7 x 3 (w) = 21	4 x 5 (w) = 20	4 x 4 (w) = 16	0 x 5 (w) = 0	0 x 5 (w) = 0	**57**
Cyclemeter phone app	7 x 3 (w) = 21	1 x 5 (w) = 5	4 x 4 (w) = 16	7 x 5 (w) = 35	3 x 5 (w) = 15	**92**
B.iCycle phone app	8 x 3 (w) = 24	5 x 5 (w) = 25	5 x 4 (w) = 20	0 x 5 (w) = 0	0 x 5 (w) = 0	**69**
Cycle Tracker Pro phone app	4 x 3 (w) = 12	0 x 5 (w) = 0	5 x 4 (w) = 20	0 x 5 (w) = 0	0 x 5 (w) = 0	**32**
Garmin Fit phone app	8 x 3 (w) = 24	8 x 5 (w) = 40	9 x 4 (w) = 36	9 x 5 (w) = 45	9 x 5 (w) = 45	**190**
Garmin Edge 500 GPS Cycle computer	9 x 3 (w) = 27	8 x 5 (w) = 40	9 x 4 (w) = 36	9 x 5 (w) = 45	9 x 5 (w) = 45	**193**

As can clearly be seen in Table 3-8, the Garmin Fit smartphone app and the Garmin Edge 500 GPS cycle computer comprehensively outperformed the other apps. Three of the other four apps were unable to provide the required data in a usable format for this study and were scored zero for overall suitability.

3.2.8 Equipment selected to record delay

Both the Garmin Fit app and the Garmin GPS cycle computer would be suitable for the delay recording component of this project. The performance of both was ranked with the same high score against four of the five criteria. However, the Garmin Edge 500 GPS cycle computer has been selected as the recording device for the study over the Garmin Fit smartphone app for the following two reasons, with the first one considered a significant factor:

1) The Garmin Edge 500 unit emits an audible beep when *auto pause* recognises a stop or restart. This eliminates the need to monitoring the screen in heavy peak hour traffic and is considered a safety benefit.
2) The Garmin Edge 500 unit is waterproof. The Garmin Fit app will require the smartphone to be fitted with a waterproof case which can reduce the sensitivity of the smartphone touchscreen.

3.2.9 Equipment cost

There is a significant difference in cost between the two devices considered most suitable for this study. The Garmin Edge 500 retails for about $450 whilst the Garmin Fit smartphone app can be purchased for just $1.29, although ownership of a smartphone is a prerequisite. The cost of the Garmin Edge 500 was within the budget of this study and it was the preferred option for safety and operational reasons. Other similar studies with a lower budget could consider the Garmin Fit app as a more cost effective solution.

4. Study design

4.1 Introduction

This aims of this research is to quantify the delay experienced by cyclists at signalised intersections during a typical commute to and from work in peak hour traffic. To determine realistic values for the delay, data was recorded on a total of 80 trips in the AM and PM peak hour traffic.

4.2 Methodology

The overall ride duration and time stopped at the signalised intersections along the route were recorded for 20 trips in the AM and PM peak hour weekday traffic on 2 different routes between the same origin and destination. Each trip was recorded using a Garmin Edge 500 GPS cycle computer, which was identified in Section 3.2.8 as the most suitable device to accurately and safely record the data in a readily suitable format. The Garmin GPS unit was mounted to the handlebars the bicycle using a proprietary fixing bracket (Figure 3-28).

The trip time and intersection delay data from the 20 trips on each route was used to identify the average total delay per trip, the average length of each stop, the average delay per intersection along the route and the average delay per kilometre for each route. The relative merits of these different measures of delay are discussed in Section 7.1. Trip data as recorded for each route is detailed in Section 5 and analysed in Section 6. To ensure the intersection delay was accurately recorded, speed was maintained towards a signalised intersection, even if the signal was red, with the brakes then applied firmly close to the limit line if required. No attempt was made to pre-empt a signal change or to slow down and free wheel in the hope a red signal would change before a stop was required.

Trips recorded on the GPS unit were downloaded via USB cable and stored in a password protected account on the Garmin Connect website. Inaccuracies in the GPS positioning information resulted in some discrepancy in the distances recorded by the GPS unit for different trips on the same route. One very useful feature on the Garmin website is the ability to match any point on a speed vs distance graph with the corresponding location on a map of the route (Figure 3-27). This feature allows each stop to be matched with certainty to the intersection where it occurred, even if there are several intersections over a short distance, such as sections of Bealey Avenue.

A TCX file (refer Section 3.2.3) of each trip was exported from the Garmin Connect website and imported as data into an Excel spreadsheet. This generated 53 columns of time, speed and distance data, most of which are not relevant for this study and so only three columns of data containing the appropriate time, speed and distance components of each waypoint were extracted and inserted into another spreadsheet where details of total ride time, total moving time and stationary time were identified for all trips. An example of this initial raw data is shown in Appendix A. The data was then compiled and tabulated for use in the results section of the report.

4.3 The routes

Two routes were selected for the project between the same origins and destinations. Both routes include multiple signalised intersections; however, the character of the two routes is quite different, with Route 1 generally following major arterial roads and Route 2 following minor arterial roads.

In the morning peak, both routes start at the author's home near the western end of Hamilton Avenue in Ilam, close to the University of Canterbury, and both routes finish at the author's workplace at the eastern end of Kilmore Street just prior to Fitzgerald Avenue. In the evening peak the routes reverse, starting at the eastern end of Kilmore Street and finishing at the western end of Hamilton Avenue. As some segments of both routes are one way streets, the AM and PM trips do not follow exactly the same roads in both directions.

Figure 4-1 shows the routes on a street map of Christchurch with a signal lantern icon added to indicate each signalised intersection along the routes. Figure 4-2 shows the routes marked on a map of the Christchurch road hierarchy. As can be seen, Route 1 travels on major arterial roads for almost its entire length and Route 2 generally travels on minor arterial roads. Both routes travel predominantly east – west.

4.3.1 Route 1-AM

Hamilton Avenue to Kilmore Street via Fendalton Road and Bealey Avenue

The majority of this route travels eastwards along major arterial roads with high traffic volumes. Fendalton Road has an AADT of approximately 19,000 vehicles per day (2011) and Bealey Avenue has an AADT of approximately 35,000 vehicles per day (2011). The only sections of the route with marked cycle lanes are the section of Fendalton Road between Clyde Road and Harper Avenue and the section of Kilmore Street between Barbadoes Street and Fitzgerald Avenue. This route passes through 15 signalised intersections, one signalised pedestrian and cycle crossing and one rail crossing that also operates as a signalised pedestrian and cycle crossing. Figure 4-3 & Figure 4-4 show examples of Route 1 outer city and inner city intersections.

It also passes through a signalised pedestrian crossing on Fendalton Road, but in 18 months of cycling this route, the author has never seen it in operation and as such it is not considered to be a potential source of delay and has been ignored.

The direction of travel at all signalised intersections is either through or left, with the following exceptions:

- A right turn is made at the Fendalton / Clyde intersection where the signals allow a short protected right turn followed by a filter turn.
- A hook turn (right) is made at the Bealey / Barbadoes intersection, where access to the right turn lane requires a cyclist to cross three lanes of through traffic (Figure 4-5) and this is avoided for safety reasons in the peak hour traffic.

Figure 4-1: Routes marked on Christchurch street map

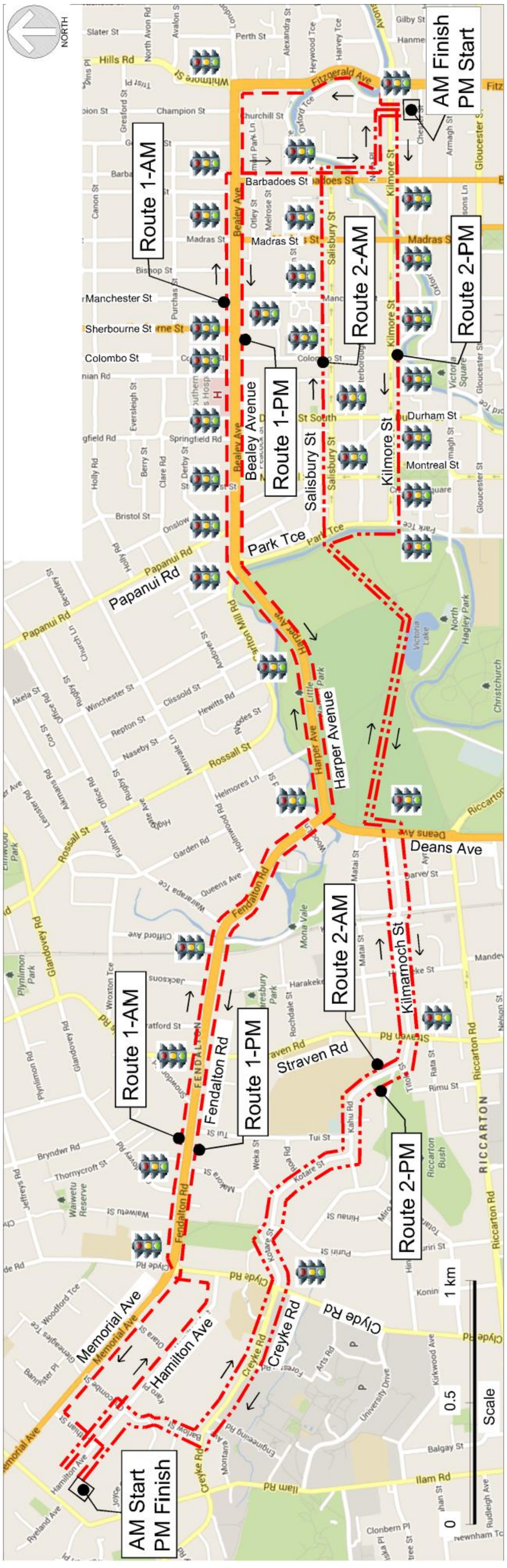


Figure 4-2: Routes marked on road hierarchy map

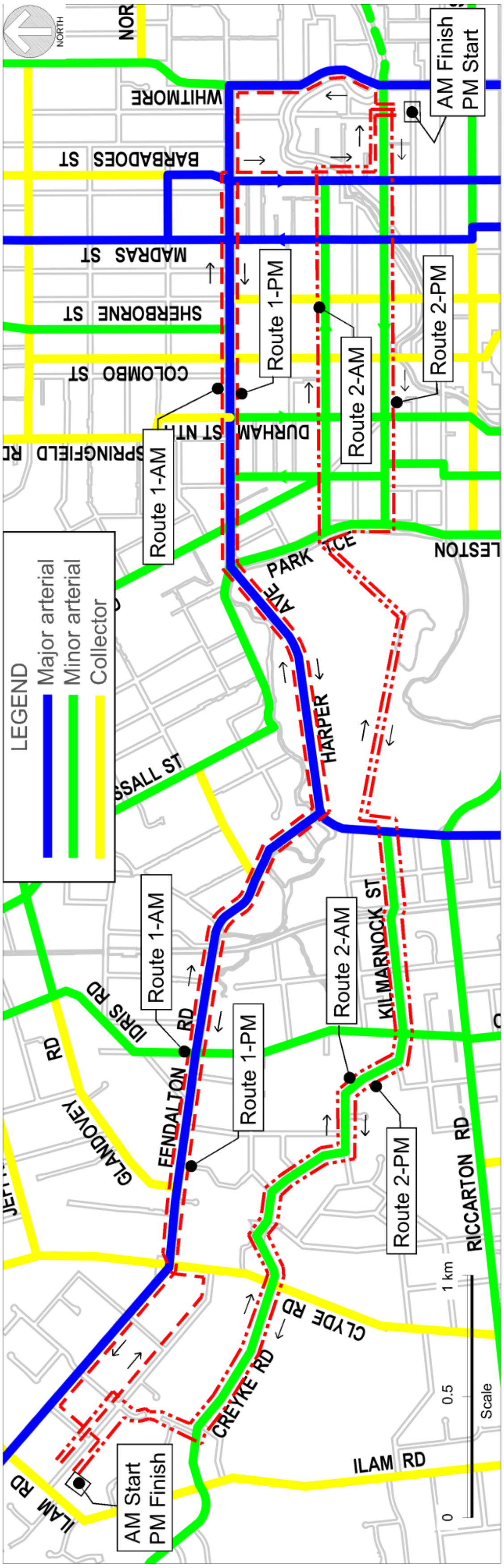


Figure 4-3: Route 1 outer city intersection (Fendalton/Straven) looking west

Figure 4-4: Route 1 inner city intersection (Bealey/Manchester) looking east

Figure 4-5: Bealey / Barbadoes (looking west along Bealey Ave)

4.3.2 Route 1-PM

Kilmore Street to Hamilton Avenue via Bealey Avenue and Fendalton Road

The majority of this route matches the AM route but travel is in the opposite (westerly) direction. This route passes through 15 signalised intersections and one rail crossing that also operates as a signalised pedestrian and cycle crossing. Figure 4-1 shows the route on a Christchurch street map and Figure 4-2 shows the road classifications of the route. Figure 4-3 & Figure 4-4 show examples of Route 1 outer city and inner city intersections.

The changes from the AM route are noted below:

- As Barbadoes Street is a one way street, Fitzgerald Avenue is used between Kilmore Street and Bealey Avenue for the PM route.
- Whilst Fitzgerald / Bealey is a signalised intersection, the route makes a left turn at this intersection using a slip lane with a Give Way control and is not recorded as a signalised intersection.
- On Harper Avenue between Park Terrace and Deans Avenue, there is a shared path available in Hagley Park parallel to Harper Avenue and this is used in preference to Harper Avenue, where a difficult manoeuver is required across a busy left turn lane to access the through lane. This avoids the signalised pedestrian and cycle crossing on Harper Avenue.
- The PM route continues straight ahead at the Fendalton / Clyde intersection and turns left into Lothian Street to access Hamilton Avenue.

There are marked cycle lanes on Fitzgerald Avenue between Kilmore Street and Bealey Avenue and on Fendalton Road from the Harper Avenue intersection to Clyde Road.

4.3.3 Route 2-AM Peak

Hamilton Avenue to Kilmore Street via Kilmarnock Street and Salisbury Street

This route travels westwards and with the exception of the section through Hagley Park, the majority of this route is on minor arterial roads. Kilmarnock Street has an AADT of approximately 10,550 vehicles per day (2011) and Salisbury Avenue has an AADT of approximately 7,000 vehicles per day (2007). This route has marked cycle lanes from Ilam Road to Deans Avenue, and the section of Kilmore Street between Barbadoes Street and Fitzgerald Avenue. This route passes through 10 signalised intersections. The Kilmarnoch / Deans Ave intersection features a separate phase for cyclists entering and exiting Hagley Park. From the park, the route travels along Salisbury Street (one way eastbound) and then turns right into Barbadoes Street (one way southbound), before making a left turn into Kilmore Street. Figure 4-1 shows the route on a Christchurch street map and Figure 4-2 shows the road classifications of the route. Figure 4-6 shows a Route 2 outer city intersection common to both AM & PM trips, Figure 4-7 shows a Route 2-AM inner city intersection.

The direction of travel at all signalised intersections is either through or left, with the following exception:

- A right turn is made at the Salisbury / Barbadoes intersection, which operates as a T intersection.

Figure 4-6: Route 2 outer city intersection (Kilmarnoch/Straven)

Figure 4-7: Route 2-AM inner city intersection (Salisbury/Madras)

4.3.4 Route 2-PM

Kilmore Street to Hamilton Avenue to via Kilmore Street and Kilmarnock Street

As the AM route between Park Terrace and Kilmore Street travels along one way streets, the PM trip returns to Park Terrace via Kilmore Street, which operates as a one way street westbound from Madras Street. Kilmore Street had a pre-quake AADT of approximately 12,000 vehicles per day (2009) but this is currently drastically reduced as a result of major sewer replacement work. From Park Terrace the route enters Hagley Park and then matches the AM route but travelling in the opposite (westerly) direction. This route passes through 11 signalised intersections. Figure 4-1 shows the route on a Christchurch street map and Figure 4-2 shows the road classifications of the route. Figure 4-6 shows a Route 2 outer city intersection common to both AM & PM trips, Figure 4-8 shows a Route 2-PM inner city intersection.

Figure 4-8: Route 2-PM inner city intersection (Kilmore/Barbadoes)

The changes from the AM route are noted below:

- As Salisbury Street and Barbadoes Street are one way, Kilmore Street (one way westbound from Madras Street) is used between Fitzgerald Avenue and Park Terrace.
- The route travels a short distance along Park Terrace before entering Hagley Park.

The direction of travel at all signalised intersections is either through or left, with the following exceptions:

- A right turn is made at the Kilmore Street / Park Terrace T intersection.

4.4 Road works

As a result of the September 2010 and February 2011 earthquakes, there are extensive infrastructure repairs being undertaken in Christchurch during the timeframe of this research. Much of the main sewer network runs along busy roads and traffic patterns are constantly changing in response to lane or road closures at sewer repair work sites. As this project involves recording delay on two different routes, there has been some flexibility in daily route choice to minimise the impacts of road works.

Most of the western and middle sections of both routes have been unaffected by road works, however Bealey Avenue, Salisbury Street and Kilmore Street have all seen significant road works. The worst affected is Kilmore Street, where major sewer replacement work is being carried out. This has resulted in road closures to two different sections of Kilmore Street, the first occurring days before the first delay recording trip was planned along it (Figure 4-9).

Figure 4-9: Kilmore St closed for road works

Traffic lane widths reduced by road cones have resulted in a small number of mid-block delays, where there is insufficient road width to pass queuing vehicles, but this has typically not impacted on the delay recorded at the signalised intersections.

The most significant impact on this project has been on Kilmore Street at the following intersections:

- Kilmore St / Colombo St where the Colombo Street western approach has been closed and the traffic signals are not in operation.
- Kilmore St / Durham St where Kilmore Street is currently only receiving a 12 second green phase from a 2:40 minute cycle.
- Kilmore St / Montreal St where Kilmore Street is currently only receiving a 24 second green phase from a 2:40 minute cycle.

This results in lengthy stops being recorded at these two intersections which do not reflect a typical peak hour delay.

Figure 4-10: Kilmore St reduced to single lane

4.5 Traffic signal phase timing information

The traffic signal timing data used in this report was kindly provided by the Christchurch City Council (CCC) traffic signals operation team. Staff advised that they were unable to readily extract typical operating patterns from the Sydney Coordinated Adaptive Traffic System (SCATS) system but they were able to provide phasing plans and all the signal timing records for every intersection included in this study for a typical week day. This data was imported into an excel spreadsheet and used to identify the average peak hour signal phase timing information used in Sections 5.1.7, 5.2.7, 5.3.7 & 5.4.7. Examples of the information by CCC are attached in Appendix B.

4.5.1 Signal co-ordination

The purpose of this study is to identify the delays experienced by cyclists at traffic signal, and both routes include sections where vehicle progression systems operate.

The CCC staff advised the traffic signals on the Bealey Avenue section of Route 1 are co-ordinated under SCATS control with variable offsets. In the morning peak, the signals are co-ordinated to favour the progression of westbound traffic. This is the opposite direction to Route 1-AM, which travels eastbound along Bealey Avenue, but is still expected to receive some benefit from the co-ordination. In the PM peak the situation will be reversed for Route1-PM trips.

The CCC staff advised the Salisbury Street section of Route 2-AM operates with a fixed offset of 17 seconds from Durham Street intersection to provide a "green wave" as far as the intersection with Madras Street, a major arterial.

Earthquake related issues mean the traffic signals on the Kilmore Street section of Route 2-PM from Manchester Street to Montreal Street are not operating to the normal pattern.

A study in Section 2.1.4 that analysed bicycle-automobile mixed traffic progression along signalised streets (Taylor and Mahmassani, 2000) identified bicycle speed variability as the most important consideration that may impact on the ability of a signal coordination scheme to benefit cyclists and noted that:

> *In the worst case, an automobile progression scheme could systematically stop a cyclist travelling at a specific speed at every signal, thereby inflicting maximum stops and delay on a cyclist*.

The cities of Copenhagen and Odense in Denmark and Amsterdam and Rotterdam in Holland have installed systems with a progressive display of green lights along cycle paths. If a cyclist keeps pace with the green lights beside the path, they will receive a green signal at all intersections along the route.

4.6 Acceleration and deceleration

At each stop, time is lost decelerating to a stop and then accelerating back to desired travel speed. This lost time is additional to the stationary time at the intersection. The following design guides and studies were found that have identified values for acceleration and deceleration rates:

Table 4-1: Acceleration & deceleration rates

Title	Author	Acceleration rate (m/s²)	Deceleration rate (m/s²)
Sign Up for the Bike, Design Manual for a Cycle-friendly Infrastructure	(Ploeger, Botma et al. 1993)	0.8 to 1.2	
Characteristics of Emerging Road Users and Their Safety	(Landis, Petritsch et al. 2004)		-2.33
Guide for the Development of Bicycle Facilities,3rd Edition	(AASHTO 1999)	0.5 to 1	
Contributions to bicycle-automobile mixed-traffic science: behavioral models and engineering applications	(Taylor 1998)	1.16	-2.29
Discharge characteristics of heterogeneous traffic at signalized intersections	(Maini and Khan 2000)	0.5	-0.88
Design speeds and acceleration characteristics of bicycle traffic for use in planning, design and appraisal	(Parkin and Rotheram 2010)	0.231	

A speed of approximately 22 km/h (6.11 m/s) was noted as a consistently achieved, steady commuting speed during the early trip recordings and this speed has been used in the acceleration and deceleration calculations (note: following completion of all the trip recordings, the average commuting speed was found to be 22.5 km/h).

Table 4-2 shows the time taken to accelerating from stationary to 22 km/h and decelerate from 22 km/h to stationary using the acceleration and deceleration rates from Table 4-1. The values for time are derived from the following equation for acceleration:

$$\text{Acceleration (m/s}^{2}\text{)} = \frac{\text{final speed (m/s)} - \text{initial speed (m/s)}}{\text{Time(sec)}}$$

Table 4-2: Acceleration & deceleration rates and times

Acceleration rate (m/s²)	Time (secs)	Deceleration rate (m/s²)	Time (secs)
0.23	26.5	-0.88	6.9
0.5	12.2	-2.29	2.7
0.8	7.6	-2.33	2.6
1.0	6.1		
1.16	5.3		

4.6.1 Field test

Given the wide range of values in Table 4-2, it was considered that field testing would be a more suitable way to identify a realistic value for the time lost decelerating from the mean travel speed to stationary and then accelerating for stationary back to the mean travel speed. During the equipment trial, it was noted that the Garmin Fit smartphone app recorded data at one second intervals and this device was considered to be the most appropriate device for this exercise.

On a quiet street, 15 recordings were made of the time and distance taken to accelerate from stationary to approximately 22 km/h at a steady, but not excessive rate (i.e. remaining seated), consistent with the commuting rate. As noted above, 22 km/h was used as the target speed as this was noted as a consistently achieved, steady commuting speed during the early trip recordings.

Fifteen recordings were also made of the time and distance taken to stop the bicycle by braking at a steady, but not excessive, rate from approximately 22 km/h to stationary. It is noted that the bicycle used in the test is fitted with hydraulic disc brakes which are very efficient.

A summary of the field recordings is shown in Table 4-3. Details of the acceleration and deceleration recordings are included in Appendix C.

Table 4-3: Summary of acceleration & deceleration field tests

	Acceleration			Deceleration		
	Time (secs)	**Distance** (m)	**Rate** (m/sec^2)	**Time** (secs)	**Distance** (m)	**Rate** (m/sec^2)
Minimum	14	86.4	0.33	4	5.7	-0.89
Maximum	20	110	0.42	7	13.4	-1.64
Average	16.9	95.3	0.37	5	9.7	-1.27

Based on the results of the field trial, a value for the amount of time lost for each stop was calculated using the average time and distance values in Table 4-3 and the average moving speed from all recorded trips of 22.5 km/h.

- Average distance of deceleration and acceleration = 9.7 + 95.3 = 105.0m
- Average time of deceleration and acceleration = 5.0 + 16.9 = 21.9 secs

At the average moving speed of 22.5 km/h, the time taken to travel the average deceleration and acceleration distance of 105m is 16.9 seconds.

- Field test average time of deceleration and acceleration = 21.9 secs
- Time taken to travel 105m at 22.5 km/h = 16.9 secs
- Time difference = 21.9 – 16.9 = 5.0 secs

Based on this calculation, each stop at a signalised intersection by a cyclist travelling at 22.5 km/h also results in an additional 5 seconds of delay caused by deceleration and acceleration time losses.

5. Data

The following four different ways have been used to measure the delay recorded at traffic signals in the various tables in this report:

Average delay per stop:
The average recorded stopped time divided by average number of stops.

Average delay per intersection:
The average recorded stopped time divided by the number of intersections on the route.

Average delay per kilometre:
The average recorded stopped time divided the route length.

Average delay as a percentage of total trip time:
The average recorded stopped time divided by the average total trip time.

These measures of delay are discussed in Section 7.1.

5.1 Route 1-AM

Hamilton Avenue to Kilmore Street via Fendalton Road and Bealey Avenue

5.1.1 Trip details

A total of 20 trips were recorded between 17 July 2013 and 24 September 2013 on Route 1 in the AM peak, usually starting from Ilam at close to 8:00am. Details as recorded of each trip are shown in Table 5-1.

Table 5-1 heading definitions:

- Moving time: Total trip time minus stopped time
- Stopped time: Recorded stationary time at intersections
- Average moving speed: Recorded distance divided by moving time
- Wind: Meteorological Service of New Zealand Limited (MetOffice) Christchurch 8:00 am wind speed

Table 5-1: Route 1-AM trip details

Ride No.	Date	Start time	Moving time (min:sec)	Ave speed (km/h)	Stopped time (min:sec)	Total trip time (min:sec)	% of trip stopped	Recorded distance (km)	Wind (knots)
1	17/07/13	7:55 a.m.	18:16	22.5	03:00	21:16	14%	6.86	2SW
2	18/07/13	8:00 a.m.	17:53	23.1	04:04	21:57	19%	7.02	6SE
3	19/07/13	7:55 a.m.	18:01	22.8	03:16	21:17	15%	6.86	13SW
4	22/07/13	7:55 a.m.	18:51	21.7	03:54	22:45	17%	6.82	7NW
5	23/07/13	7:58 a.m.	18:01	23.0	02:41	20:42	13%	6.90	13SW
6	24/07/13	7:59 a.m.	18:25	22.3	02:20	20:45	11%	6.85	2N
7	25/07/13	8:01 a.m.	18:57	21.6	03:30	22:27	16%	6.84	6N
8	26/07/13	8:02 a.m.	18:21	22.5	01:59	20:20	10%	6.87	4SW
9	30/07/13	8:07 a.m.	19:37	20.9	06:03	25:40	24%	6.85	9N
10	31/07/13	7:59 a.m.	18:16	22.5	05:05	23:21	22%	6.86	4NW
11	1/08/13	8:02 a.m.	17:57	22.9	03:00	20:57	14%	6.84	7W
12	2/08/13	7:57 a.m.	17:01	24.2	00:51	17:52	5%	6.88	9SW
13	6/08/13	7:55 a.m.	17:31	23.6	02:19	19:50	12%	6.88	6NW
14	11/09/13	8:06 a.m.	17:51	23.1	02:23	20:14	12%	6.87	26N
15	13/09/13	8:06 a.m.	17:19	23.8	04:18	21:37	20%	6.87	2N
16	16/09/13	8:03 a.m.	17:49	23.4	03:12	21:01	15%	6.94	4N
17	19/09/13	8:01 a.m.	17:36	23.3	01:54	19:30	10%	6.83	4SW
18	20/09/13	8:00 a.m.	16:58	24.4	03:09	20:07	16%	6.90	6NW
19	23/09/13	7:58 a.m.	18:02	22.9	04:40	22:42	21%	6.87	0
20	24/09/13	8:02 a.m.	18:57	21.7	03:40	22:37	16%	6.86	11NE

Impact of the wind on average moving speed

Route 1-AM route travels in a predominantly easterly direction and should benefit from any wind with a westerly component. The average moving speed on the 11 days when the wind had a westerly component was 23.0 km/h and the average moving speed on the 2 days when the wind had an easterly component was 22.4 km/h. The average moving speed for all Route 1-AM trips was 22.8 km/h. As such, the trip times are not considered to have been significantly impacted by the effects of the wind and this is not considered further.

5.1.2 Recorded delay

Table 5-2 shows the amount of stopped time recorded by the Garmin GPS unit at each intersection and also the total time stopped. These are the stationary times as recorded and do not include any allowance for deceleration and acceleration time loss.

Table 5-2: Route 1-AM delay recorded at intersections

Ride No.	Delay Recorded at Intersection (mm:ss)																	Total Delay (mm:ss)
	Fendalton / Clyde	Fendalton / Glandovey	Fendalton / Straven	Fendalton Rail Crossing	Fendalton / Harper	Harper ped crossing	Bealey / Park Tce	Bealey / Papanui	Bealey / Montreal	Bealey / Durham	Bealey / Colombo	Bealey / Sherbourne	Bealey / Manchester	Bealey / Madras	Bealey / Barbadoes	Barbadoes / Salisbury	Barbadoes / Kilmore	
1	00:23			00:12				00:42		00:15					01:03	00:25		03:00
2			00:08				00:50						00:38	00:20	01:46		00:22	04:04
3	00:10		00:30	00:08		00:08		00:41		00:20					01:05		00:14	03:16
4	00:16		00:22		00:34		01:02				00:04	00:17			01:18			03:53
5	00:04	00:05			00:12		00:40			00:04					01:23		00:13	02:41
6			00:34		00:16										01:30			02:20
7	00:20			00:06	00:12		00:54			00:06					01:34	00:18		03:30
8	00:05						00:41								01:06	00:07		01:59
9	00:15	00:33	00:35			00:12	00:07			00:30		00:36	00:11	00:36	02:15		00:13	06:03
10	00:17	00:18	01:08			00:01	00:51			00:29				00:02	01:51	00:08		05:05
11	00:35	00:16	00:25				00:46			00:24				00:11	00:04		00:19	03:00
12		00:10								00:18				00:02	00:12		00:09	00:51
13	00:12				`	00:11				00:05					01:27		00:24	02:19
14	00:09						00:29			00:12					01:33			02:23
15	00:13		00:13		00:08	00:11	00:43			00:24				00:11	01:55	00:20		04:18
16	00:32		00:25								00:09				01:43		00:23	03:12
17		00:12						00:59		00:43								01:54
18		00:51	00:43		00:26	00:10	00:35								00:07		00:17	03:09
19	00:52	00:38	00:26				01:02			00:25					01:11	00:06		04:40
20	01:02	00:07	00:07				00:37			00:19					01:28			03:40
Stops	**15**	**9**	**12**	**3**	**6**	**6**	**13**	**3**	**0**	**14**	**2**	**2**	**2**	**6**	**19**	**6**	**9**	

The average trip and delay details are summarised in Table 5-3 and Table 5-4.

Table 5-3: Route 1-AM average trip summary

Ave start time	**Ave moving time** (min:sec)	**Ave speed** (km/h)	**Ave stopped time** (min:sec)	**Ave total trip time** (min:sec)	**Ave % of trip time stopped**	**Ave recorded distance** (km)
8:00 a.m.	18:05	22.8	03:16	21:21	15%	6.87

Table 5-4: Route 1–AM average delay summary

Number of signalised intersections	**Ave number of stops per trip**	**Ave % of intersections stopped at**	**Ave delay per stop** (mm:ss)	**Ave delay per intersection** (mm:ss)	**Ave delay per km** (mm:ss)
17	6.4	37%	00:31	00:12	00:29

Figure 5-1 shows the percentage of stops recorded in 15 second time bands. 40% of stops were no longer than 15 seconds. The majority of stops in excess of 60 seconds are a result of the Barbadoes Street hook turn where the recorded delay value includes both movements of the turn.

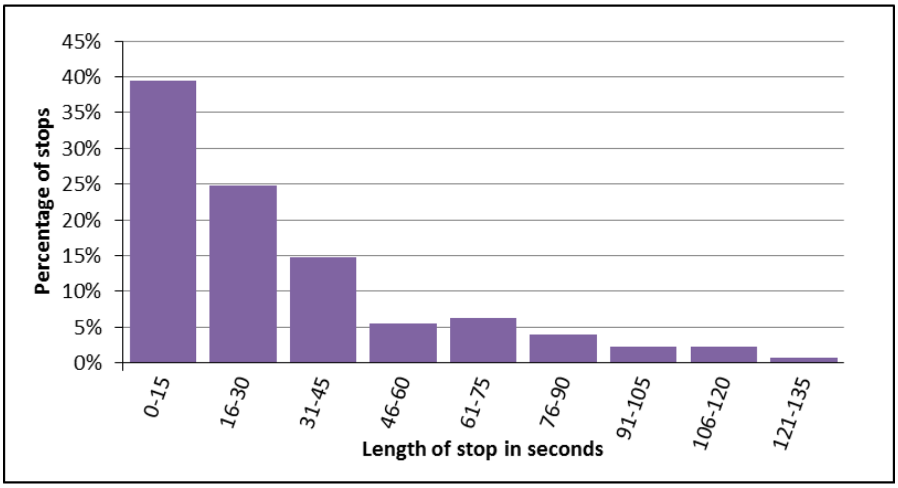


Figure 5-1: Route 1-AM stop length graph

Table 5-5 shows the total percentage of stops below a time limit. As noted above, majority of stops above 60 seconds were recorded at the Barbadoes Street hook turn.

Table 5-5: Route 1-AM stop length breakdown

	Length of stop			
	15 secs or less	30 secs or less	45 secs or less	60 secs or less
Percentage of stops	40%	64%	79%	84%

5.1.3 Inner city and outer city intersections

There is a significant difference in the spacing of intersections between the inner city section and the outer city section of the route. In the first part of the route in the outer city area, there are 7 signalised intersections over a distance of 4.26km at an average spacing of 610m. As the Bealey / Barbadoes intersection was undertaken as a hook turn and therefore subject to two sets of traffic signals to make the turn, the inner city area used in the comparison extends from Bealey/ Harper to Bealey / Barbadoes and includes the delays recorded on Bealey Avenue but not those at the Barbadoes Street leg of the hook turn. As such, the inner city zone has 8 signalised intersections in 1.63 km at an average spacing of 200m apart. The distance from Bealey / Barbadoes to the eastern end of Kilmore Street is not included in the inner city zone distance calculation as this would distort the comparison.

Table 5-6: Route 1-AM intersection spacing vs delay

	Distance (km)	No. of inter-sections	Average distance between inter-sections (km)	Average number of stops	% of inter-sections stopped at	Average delay per inter-section (mm:ss)	Average length of stop (mm:ss)	Average delay per trip (mm:ss)	Average delay per km (mm:ss)
Full route	6.87	17	0.40	6.35	37.4%	00:12	00:31	03:16	00:29
Outer city zone Hamilton Ave to Bealey / Harper	4.26	7	0.61	3.20	45.7%	00:11	00:25	01:20	00:19
Inner city zone Bealey / Harper to Bealey / Barbadoes	1.63	8	0.20	2.15	26.9%	00:06	00:22	00:47	00:29

Table 5-6 shows a comparison of the average delay experienced over the full route against the delay experienced in the inner city and outer city zones. The low stop rate shows the inner city part of this route clearly benefited from the signal co-ordination. The closer spacing of the inner city intersections result in an average delay of 29 secs/km in the inner city zone, 10 secs/km higher than the outer city delay.

Figure 5-2 shows the percentage of stops recorded in each zone in 15 second time bands. The outer city zone recorded a higher percentage of shorter stops but a higher average stop time (Table 5-6) as a result of the stops in the longer time bands.

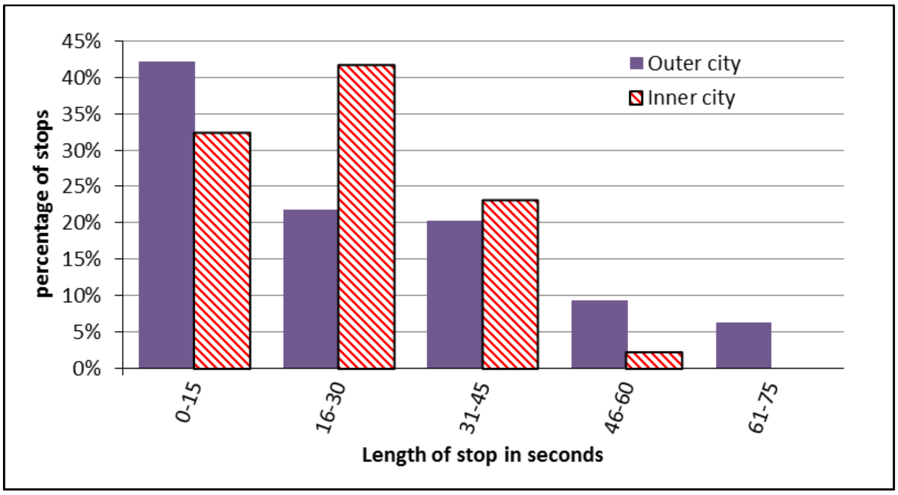


Figure 5-2: Route 1-AM zones stop length graph

Table 5-7 shows the total percentage of stops below a time limit. No inner city stop was greater than 60 seconds.

Table 5-7: Route 1-AM zones stop length breakdown

	Length of stop			
	15 secs or less	**30 secs or less**	**45 secs or less**	**60 secs or less**
Percentage of stops Outer city zone	42%	64%	84%	94%
Percentage of stops Inner city zone	33%	74%	98%	100%

5.1.4 Trip time variability

Table 5-8 heading definitions:

- Moving time: Total trip time minus stopped time
- Average speed: Recorded distance divided by moving time
- Stopped time: Recorded stationary time at intersections

Table 5-8: Route 1-AM summary of trip variability

	Moving time (mm:ss)	**Ave speed** (km/h)	**Stopped time** (mm:ss)	**Total trip time** (mm:ss)	**% of trip stopped**	**Recorded distance** (km)
Minimum	16:58	20.9	00:51	17:52	5%	6.82
Maximum	19:37	24.4	06:03	25:40	24%	7.02
Difference	02:39	3.5	05:12	07:48	19%	0.20
Average	18:05	22.8	03:16	21:21	15%	6.87
Standard deviation	00:39	0.9	01:11	01:37		

As can be seen in Table 5-8, on a route where the average cycle commuting trip time was 21:21 minutes, the variability in time between the shortest and longest trips was almost 8 minutes. Whilst the effects of wind strength and direction will always be a factor in cycle trip time, as noted in Section 5.1.1, the winds experienced during the study do not appear to have had a significant impact and the recorded moving time and speeds were very consistent, with a standard deviation of 39 seconds and 0.9 km/h respectively. The significant factor in the travel time variability was the 5:12 min variability in intersection delay.

Figure 5-3 & Figure 5-4 show the distribution of the recorded delay and trip time.

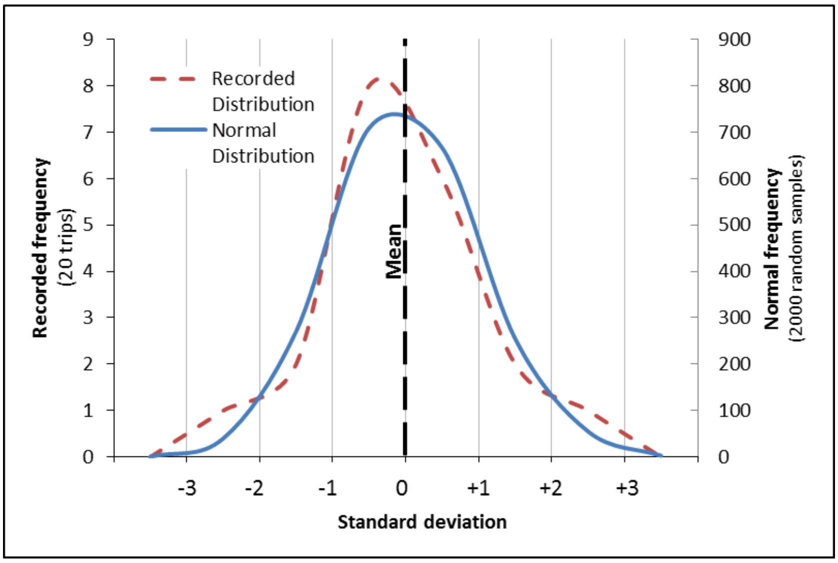


Figure 5-3: Route 1-AM recorded delay distribution

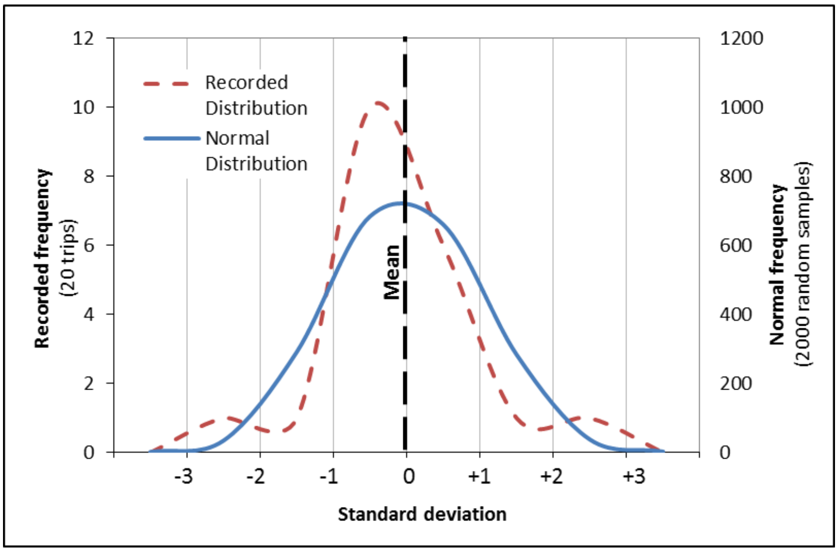


Figure 5-4: Route 1-AM travel time distribution

5.1.5 Acceleration & deceleration time loss

Every time a cyclist is required to stop during a trip, time is lost as a result of decelerating to a stop and accelerating back to the desired travel speed. Clearly, the higher the number of stops on a trip, the more time is lost to deceleration and acceleration. The deceleration and acceleration components of delay are already incorporated into the recorded 'moving time', as this includes slowing to a stop at the limit line and then accelerating back to the desired travel speed time.

Section 4.6.1 identified the additional time lost as a result of deceleration and acceleration as 5 seconds at each intersection stop. The impact of this component is shown in Table 5-9.

Table 5-9: Route 1-AM impact of acceleration & deceleration time loss

Fewest stops on trip		Most stops on trip		Average stops per trip	
No. of Stops	**Decel & accel time loss** (mm:ss)	**No. of Stops**	**Decel & accel time loss** (mm:ss)	**Ave stops**	**Decel & accel time loss** (mm:ss)
3	00:15	11	00:55	6.4	00:32

The average time lost due to deceleration and acceleration on Route 1-PM was 32 seconds per trip.

5.1.6 Unimpeded travel speed comparison

Previous sections of this report have identified the amount of delay experienced at signalised intersections in peak hour traffic. This section compares the average peak hour trip time against the time the trip would take if travelled at an unimpeded travel speed. Route 1-PM and Route 2-AM & PM have lengthy sections of off-road sealed paths in Hagley Park where the unimpeded speed can be identified.

Route 1-AM is the only route where there is no section of off-road travel where an unrestricted travel speed can be readily identified for comparison. To identify an unrestricted speed for this route, the speeds recorded on sections of the route between Fendalton / Straven and Fendalton / Harper and Fendalton / Harper and Bealey / Park Terrace were extracted from the data and averaged. Trips where stops were made at the Fendalton Road rail crossing or the Harper Avenue pedestrian crossing were excluded.

The average speed value is derived by subtracting the total recorded delay from the total trip time to obtain a 'moving' time and then dividing the trip distance by this value. As such, it includes time lost due to acceleration & deceleration, cornering and traffic conditions. The average speed on Route 1–AM was found to be 22.8 km/h (Table 5-3).

Table 5-10 shows a comparison between the unimpeded and route average speeds. The average unimpeded speed on this route was found to be 24.1 km/h. If the entire route were travelled at this speed, the travel time would be 17:06 minutes, which is 4:14 minutes quicker than the average trip time of 21:21. If the route average trip time is compared against the unimpeded speed trip time this equates to a delay of 37 secs/km, compared to the 29 secs/km delay derived from the average results (Table 5-4).

Table 5-10: Route 1-AM unimpeded speed vs route average speed

	Speed (Km/h)	**Total moving time** (mm:ss)	**Total trip time** (mm:ss)	**Delay** (mm:ss)	**Delay per km** (mm:ss)
Unimpeded speed trip	24.1	17:06	17:06	00:00	00:00
Route average trip	22.8	18:05	21:21	04:14	00:37
Difference	1.3	00:59	04:14		

However, whilst it may be possible to maintain the unrestricted speed on a straight section of road unimpeded by traffic, it is not realistic to expect that this speed could be maintained for 6.87km in a peak hour traffic environment with several tight corners, even without the need to stop at intersections.

Table 5-11: Route 1-AM realistic base speed vs route average speed

	Speed (Km/h)	**Total moving time** (mm:ss)	**Total trip time** (mm:ss)	**Delay** (mm:ss)	**Delay per km** (mm:ss)
Realistic base speed trip	23.5	17:33	17:33	00:00	00:00
Route average trip	22.8	18:05	21:21	03:48	00:33
Difference	0.7	00:32	03:48		

A more realistic base travel speed may be obtained by taking the average moving time of 18:05 minutes and subtracting the acceleration and deceleration time loss of 32 seconds (6.4 intersections @ 5 secs/intersection). This gives an average speed of 23.5 km/h and a trip time of 17:33 minutes, 3:48 minutes faster than the average trip time of 21:21. In Table 5-11 the route average trip time is compared against this 'realistic' base speed trip time. This equates to a delay of 33 secs/km, 4 sec/km more than the 29 secs/km delay derived from the average results (Table 5-4).

5.1.7 Comparison of stop rate with signal phase timing

Table 5-12 shows a comparison between the number of stops made at an intersection, the length of available green time and the percentage of the cycle length it represents. This data is indicative only and is based on the average peak hour signal phase timing data as extracted from the information provided by the Christchurch City Council traffic signals team for Thursday 12th September 2013.

Table 5-12: Route 1-AM comparison of stop rate & signal timing

Intersection	No. of times stopped	% of times stopped	Cycle length (mm:ss)	Available green phase (mm:ss)	% of cycle length
Fendalton / Clyde	15	75%	01:58	00:45	38%
Fendalton / Glandovey	9	45%	01:54	01:09	61%
Fendalton / Straven	12	60%	01:29	00:39	44%
Fendalton Rail Crossing	3	15%	Not applicable		
Fendalton / Harper	6	30%	02:07	01:29	70%
Harper Crossing	6	30%	Not applicable		
Bealey / Park Tce	13	65%	01:56	00:49	42%
Bealey / Papanui	3	15%	01:57	00:49	42%
Bealey / Montreal	0	0%	01:57	01:30	77%
Bealey / Durham	14	70%	01:22	00:36	44%
Bealey / Colombo	2	10%	01:56	01:25	73%
Bealey / Sherbourne	2	10%	01:57	00:53	46%
Bealey / Manchester	2	10%	01:57	01:26	74%
Bealey / Madras	6	30%	01:57	01:10	60%
Bealey / Barbadoes	19	95%	Not applicable		
Barbadoes / Salisbury	6	30%	01:20	00:55	69%
Barbadoes / Kilmore	9	45%	01:20	00:57	71%

The Fendalton Road rail and pedestrian crossing and the Harper Avenue pedestrian crossing were not included due to the random nature of their operation. The Bealey / Barbadoes intersection is not included as the right turn was undertaken as a hook turn and was therefore subject to two separate signal phases, one on Bealey Avenue and the other on Barbadoes Street.

The two outliers below the trendline are the Bealey/Papanui and Bealey/Sherbourne intersections, where the stop rates have been impacted by the Bealey Avenue signal co-ordination. The Bealey/ Papanui intersection is preceded by Bealey / Park Terrace which had a stop rate of 65%. As a result of the signal offset and short spacing of 170 m, Table 5-2 shows that any trip stopped at Bealey / Park Terrace was never stopped again at Bealey/Papanui, irrespective of the relatively short available green time. Similarly, the Bealey/Sherbourne stop rate is influenced by Bealey / Durham which had a stop rate of 70%. As a result of the signal offsets and intersection spacing, Table 5-2 shows that only one trip stopped at Bealey / Durham was stopped again at Bealey/Sherbourne. If these two intersections are excluded then an R^2 test gives a result of 0.80, indicating a strong linear relationship.

When only the four intersections in the outer city zone: Fendalton / Clyde, Fendalton / Glandovey, Fendalton / Straven & Fendalton / Harper (circled in red on the graphs) are considered, the best fit line indicates a strong linear relationship, confirmed by an R^2 test result of 0.97.

5.1.8 Inner city zone signal co-ordination

Figure 5-5 shows an indicative diagram based on the average peak hour signal phase timing data extracted from the information provided by the Christchurch City Council traffic signals team for Thursday 12th September 2013. The signal phase time shown is the time until the next phase starts and as such includes the inter-green time. The diagram indicates the progression of a vehicle travelling at 45 km/h, a cyclist travelling at 22km/h and a cyclist travelling at 15 km/h as they through the signalised intersections along Bealey Avenue.

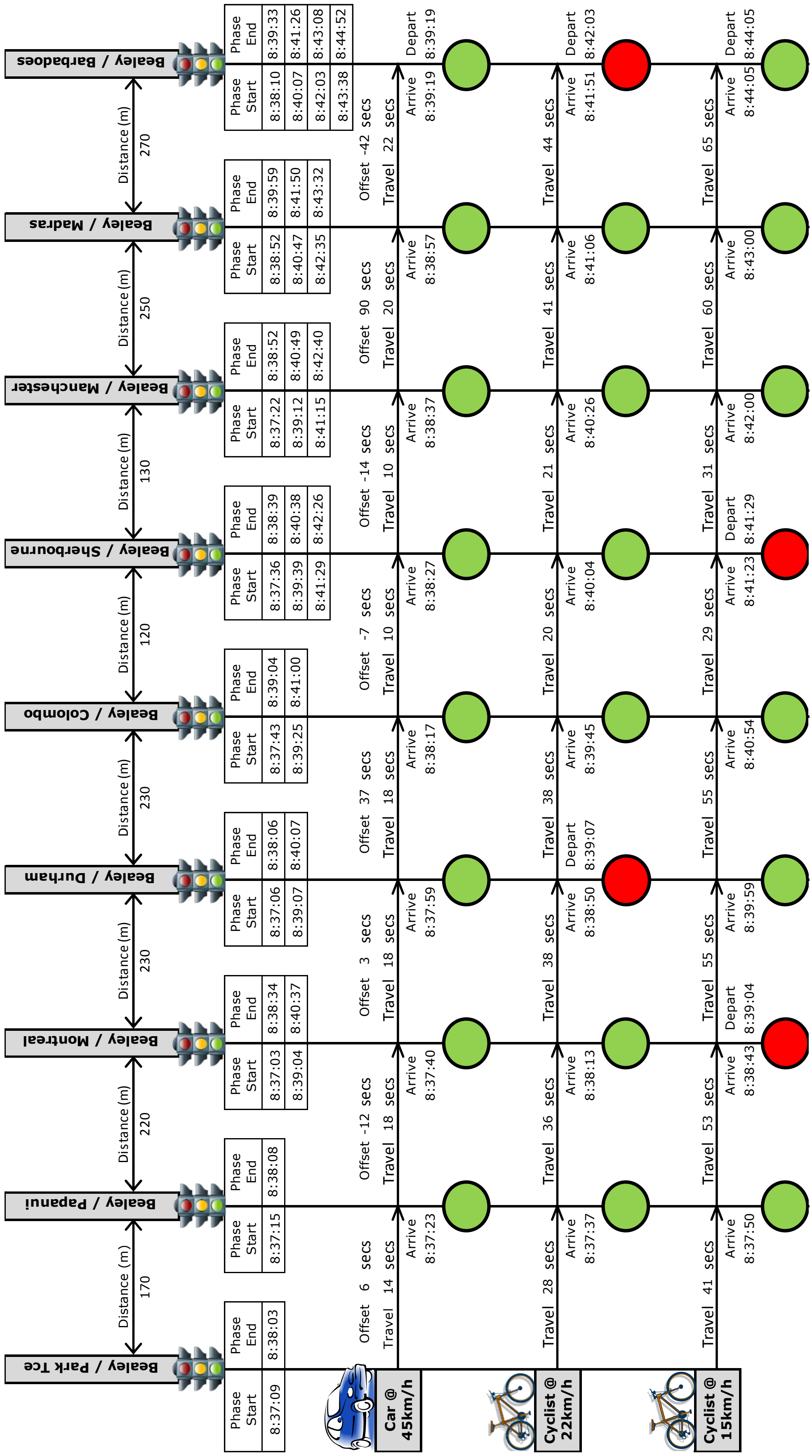
The signal timings used in the diagram are an actual sequence of phases that represented the closest match to the average peak hour phase timings. The diagram is intended as indicative only and is not adjusted to include acceleration and deceleration losses.

The vehicle travelling at 45 km/h and the 22km/h and 15 km/h cyclists all leave the Bealey Ave / Park Terrace intersection at the same time and their travel time, delay and total time are shown in Table 5-13. The car receives a green signal at every intersection and departs from the Bealey / Barbadoes intersection 2:44 minutes ahead of the 22km/h cyclist and 4:46 minutes ahead of the 15 km/h cyclist.

Table 5-13: Route 1-AM Bealey Ave peak travel times

	Travel time (mm:ss)	**Delay** (mm:ss)	**Total time** (mm:ss)	**Slower than car by:** (mm:ss)
Car @ 45 km/h	0:02:10	nil	0:02:10	0:00:00
Cyclist @ 22 km/h	0:04:25	0:00:29	0:04:54	0:02:44
Cyclist @ 15 km/h	0:06:29	0:00:27	0:06:56	0:04:46

Figure 5-5: Route 1-AM Bealey Ave signal co-ordination



5.2 Route 1-PM

Kilmore St to Ilam via Bealey Avenue & Fendalton Rd

5.2.1 Trip details

A total of 20 trips were recorded between 17 July 2013 and 6 September 2013, starting from Kilmore Street usually between 5:00 & 5:45 pm and trip details are shown in Table 5-14.

Table heading definitions as 5.1.1., wind is the Met Office Christchurch 6:00 pm wind speed.

Table 5-14: Route 1-PM trip details

Ride No.	**Date**	**Start time**	**Moving time** (mm:ss)	**Ave moving speed** (km/h)	**Stopped time** (mm:ss)	**Total trip time** (mm:ss)	**% of trip stopped**	**Recorded distance** (km)	**Wind** (knots)
1	17/07/13	5:15 p.m.	18:50	22.0	03:10	22:00	14%	6.92	9W
2	18/07/13	5:48 p.m.	18:53	21.8	01:52	20:45	9%	6.88	7SE
3	19/07/13	5:12 p.m.	18:37	22.3	03:54	22:31	17%	6.90	6SE
4	22/07/13	5:16 p.m.	19:14	21.6	05:18	24:32	22%	6.92	13NE
5	23/07/13	5:16 p.m.	19:24	21.4	03:12	22:36	14%	6.90	9NE
6	24/07/13	5:22 p.m.	18:59	21.7	03:55	22:54	17%	6.87	7W
7	25/07/13	5:19 p.m.	18:44	22.0	04:52	23:36	21%	6.88	11W
8	26/07/13	5:09 p.m.	18:41	22.1	04:08	22:49	18%	6.89	7W
9	30/07/13	5:08 p.m.	18:37	22.2	03:33	22:10	16%	6.90	7NE
10	31/07/13	5:21 p.m.	19:13	21.4	02:52	22:05	13%	6.86	6NE
11	2/08/13	5:44 p.m.	18:32	22.3	02:24	20:56	11%	6.89	7SW
12	6/08/13	5:25 p.m.	18:26	22.3	05:54	24:20	24%	6.86	6W
13	7/08/13	5:16 p.m.	18:09	22.8	04:32	22:41	20%	6.90	17NE
14	13/08/13	5:17 p.m.	17:54	23.1	03:14	21:08	15%	6.88	17NE
15	14/08/13	5:18 p.m.	18:25	22.5	05:16	23:41	22%	6.89	9NW
16	15/08/13	5:33 p.m.	18:50	22.0	04:20	23:10	19%	6.91	13NE
17	19/08/13	5:38 p.m.	18:49	22.0	03:24	22:13	15%	6.90	15E
18	3/09/13	5:18 p.m.	18:18	22.7	03:47	22:05	17%	6.91	6SE
19	5/09/13	5:06 p.m.	18:32	22.4	03:20	21:52	15%	6.92	9SW
20	6/09/13	5:29 p.m.	17:51	23.0	03:48	21:39	18%	6.84	9N

Impact of the wind on average moving speed

Route 1-PM route travels in a predominantly westerly direction and should benefit from any wind with an easterly component. The average moving speed on the 11 days when the wind had an easterly component was 22.1 km/h and the average moving speed on the 8 days when the wind had an easterly component was 22.2 km/h. The average moving speed for all Route 1-PM trips was 22.2 km/h. As such, the trip times are not considered to have been significantly impacted by the effects of the wind and this is not considered further.

5.2.2 Recorded delay

Table 5-15 shows the amount of stopped time recorded at each intersection and also the total stopped time for each trip. These times do not include deceleration and acceleration time loss.

Table 5-15: Route 1-PM delay recorded at intersections

	Delay Recorded at Intersection (mm:ss)															
Ride No.	**Fitzgerald / Kilmore**	**Bealey / Barbadoes**	**Bealey / Madras**	**Bealey / Manchester**	**Bealey / Sherbourne**	**Bealey / Colombo**	**Bealey / Durham**	**Bealey / Montreal**	**Bealey / Papanui**	**Bealey / Park Tce**	**Fendalton / Harper**	**Fendalton Rd Rail Crossing**	**Fendalton / Straven**	**Fendalton / Glandovey**	**Fendalton / Clyde**	**Total Delay** (mm:ss)
1	00:20					00:17	00:18		01:06		00:39				00:30	03:10
2		00:25	00:12						00:14		00:07		00:44		00:10	01:52
3	00:32		00:35	00:46					00:34		00:13		00:51	00:23		03:54
4	00:19	00:52	00:18		00:11		00:32		00:42		01:14	00:19		00:19	00:32	05:18
5	00:28		00:07			00:19			00:41		01:05				00:32	03:12
6	00:35	00:07	00:16		00:14	00:09	00:12		00:49		01:03		00:30			03:55
7	01:10	00:44	00:21			00:07	00:25		00:53		00:23				00:49	04:52
8	00:41		00:32				00:06		00:59		01:03		00:47			04:08
9			00:14			00:19	00:09		00:28		00:53		00:27	00:20	00:43	03:33
10	00:10		00:09				00:08		00:57		00:31		00:51		00:06	02:52
11		00:47							00:42		00:13		00:25		00:17	02:24
12	01:07		00:18		00:22		00:50		01:00		00:21			00:26	01:30	05:54
13		00:56	00:28		00:18	00:10	00:22				01:42		00:36			04:32
14	00:33		00:09		00:15	00:19	00:21				01:09	00:07			00:21	03:14
15	00:34		00:21		00:23		00:39		00:55		01:24	00:24			00:36	05:16
16	00:17		00:25				00:21		00:06		01:08	00:11	00:16	00:35	01:01	04:20
17		00:17	00:22			00:16	00:08		00:55		00:36		00:19		00:31	03:24
18	00:14	00:31	00:14		00:09	00:13	00:09			00:25	00:18	00:12	00:53		00:29	03:47
19	00:37	00:30	00:33		00:14	00:16	00:20		00:50							03:20
20	00:39		00:08				00:21		00:20		01:02	00:12	00:25		00:41	03:48
Stops	**15**	**9**	**18**	**1**	**8**	**10**	**16**	**0**	**17**	**1**	**19**	**6**	**12**	**5**	**15**	

The average trip and delay details are summarised in Table 5-16 and Table 5-17.

Table 5-16: Route 1-PM average trip summary

Ave start time	**Ave moving time** (min:sec)	**Ave speed** (km/h)	**Ave stopped time** (min:sec)	**Ave total trip time** (min:sec)	**Ave % of trip time stopped**	**Ave recorded distance** (km)
5:21 p.m.	18:39	22.2	03:50	22:29	17%	6.89

Table 5-17: Route 1–PM average delay summary

Number of signalised intersections	Ave number of stops per trip	Ave % of intersections stopped at	Ave delay per stop (mm:ss)	Ave delay per intersection (mm:ss)	Ave delay per km (mm:ss)
15	7.6	51%	00:30	00:15	00:33

Figure 5-6 shows the percentage of stops recorded in 15 second time bands. Only 24% of stops were 15 seconds or less.

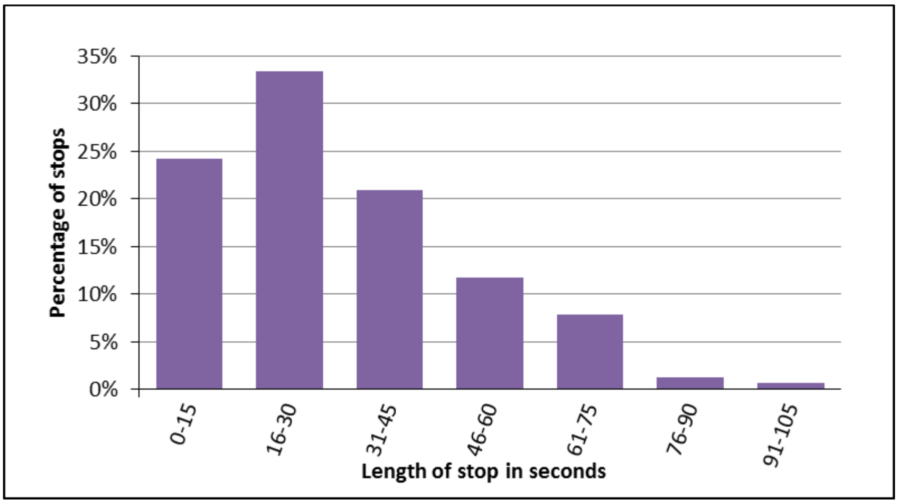


Figure 5-6: Route 1-PM stop length graph

Table 5-18 shows the total percentage of stops below a time limit. 10% of recorded stops were in excess of 60 seconds.

Table 5-18: Route 1-PM stop length breakdown

	Length of stop			
	15 secs or less	30 secs or less	45 secs or less	60 secs or less
Percentage of stops	24%	58%	78%	90%

5.2.3 Inner city and outer city intersections

There is a significant difference in the spacing of intersections between the inner city and outer city sections of the route. The first part of the route travels through the inner city area where there are 10 signalised intersections over a distance of 2.65 km at an average spacing of 270 m, the second part of the route is through the outer city area with 5 intersections over at distance of 3.17 km at an average spacing of 630 m apart. The distance from the final outer city zone intersection (Fendalton / Clyde) to Hamilton Avenue is not included in the outer city zone distance calculation as this would distort the comparison.

Table 5-19 shows a comparison of the average delay experienced over the full route against the delay experienced in the inner city and outer city zones. As with the AM route, the stop rate was higher in the outer city zone but in this case the average stop length was also longer. The inner city stop rate was higher that the AM trip, with the SCATS system dealing with PM peak traffic exiting the central city.

Although the inner city zone has a lower stop rate and shorter stops, when the average delay per kilometre is calculated, the closer spacing of the inner city zone intersections means the inner city delay is 15 secs/ km greater than the outer city area.

Table 5-19: Route 1-PM intersection spacing vs delay

	Distance (km)	**No. of inter-sections**	**Average distance between inter-sections** (km)	**Average number of stops**	**% of inter-sections stopped at**	**Average delay per inter-section** (mm:ss)	**Average length of stop** (mm:ss)	**Average delay per trip** (mm:ss)	**Average delay per Km** (mm:ss)
Full route	6.89	15	0.46	7.60	50.7%	00:15	00:30	03:50	00:33
Outer city zone Bealey / Park Tce to Fendalton / Clyde	3.17	5	0.63	2.85	57.0%	00:21	00:36	01:43	00:33
Inner city zone Kilmore / Fitzgerald to Bealey / Park Tce	2.65	10	0.27	4.75	47.5%	00:13	00:27	02:07	00:48

Figure 5-7 shows the percentage of stops recorded in each zone in 15 second time bands. The outer city zone recording a higher percentage of stops in the higher time bands resulting in a higher average stop time (Table 5-19).

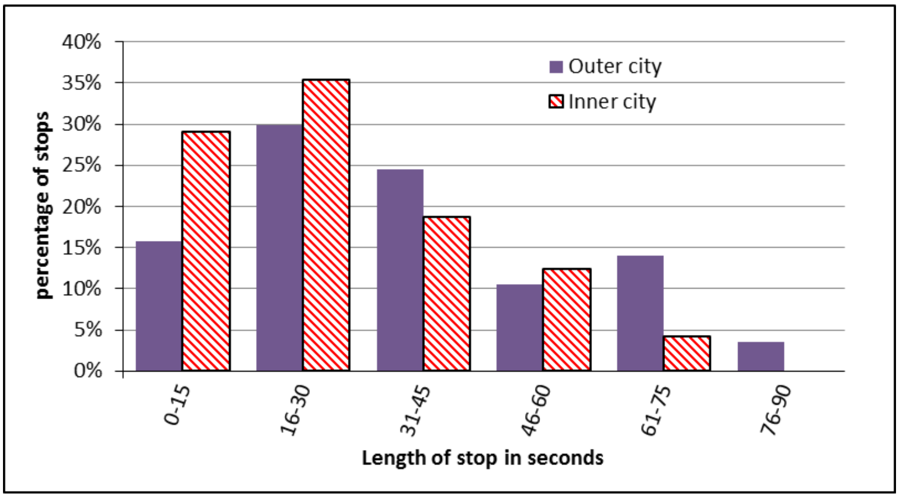


Figure 5-7: Route 1-PM zones stop length graph

Table 5-20 shows the total percentage of stops below a time limit. Only 16% of outer city stops were 15 seconds or less and 30% were in excess of 45 seconds.

Table 5-20: Route 1-PM zones stop length breakdown

	Length of stop			
	15 secs or less	30 secs or less	45 secs or less	60 secs or less
Percentage of stops Outer city zone	16%	46%	70%	81%
Percentage of stops Inner city zone	29%	65%	83%	96%

5.2.4 Trip time variability

Table 5-21 heading definitions as Section 5.1.4.

Table 5-21: Route 1-PM summary of trip variability

	Moving time (mm:ss)	**Ave speed** (km/h)	**Stopped time** (mm:ss)	**Total trip time** (mm:ss)	**% of trip stopped**	**Recorded distance** (km)
Minimum	17:51	21.4	01:52	20:45	9%	6.84
Maximum	19:24	23.1	05:54	24:32	24%	6.92
Difference	01:33	1.7	04:02	03:47	15%	0.08
Average	18:39	22.2	03:50	22:29	17%	6.89
Standard deviation	00:24	0.5	00:58	01:00		

As can be seen in Table 5-21, the PM trip had a variability in intersection delay of 4:02 minutes, just over a minute less than the AM variability of 5:12 minutes, however the variability in total trip time of 3:47 minutes is 4 minutes less than the AM total trip time variability of 7:48 minutes. The total trip time has a standard deviation of 1:00 minute compared with 1:37 minutes for the AM trip.

As noted in Section 5.2.1, the winds experienced during the study do not appear to have had a significant impact. The recorded moving time and speeds were again very consistent, with a standard deviation of 24 seconds and 0.5 km/h respectively.

Figure 5-8 & Figure 5-9 show the distribution of the recorded delay and trip time.

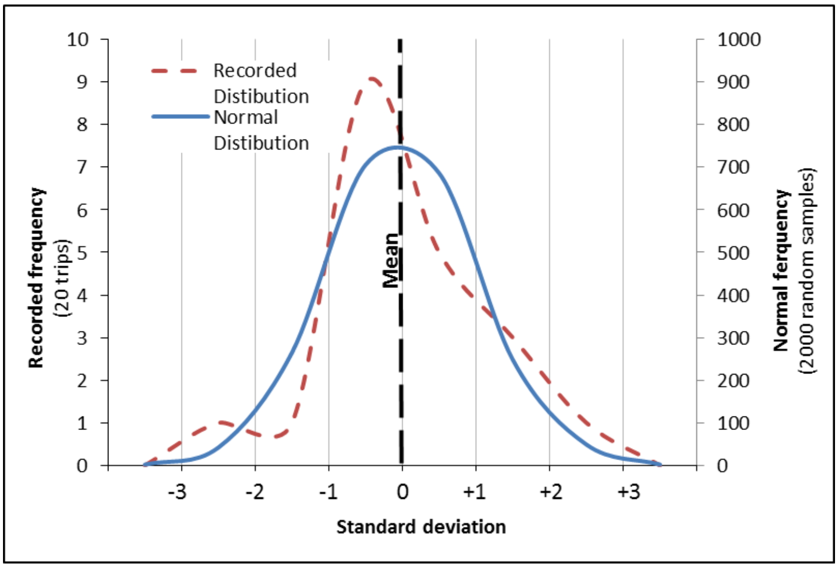


Figure 5-8: Route 1-PM recorded delay distribution

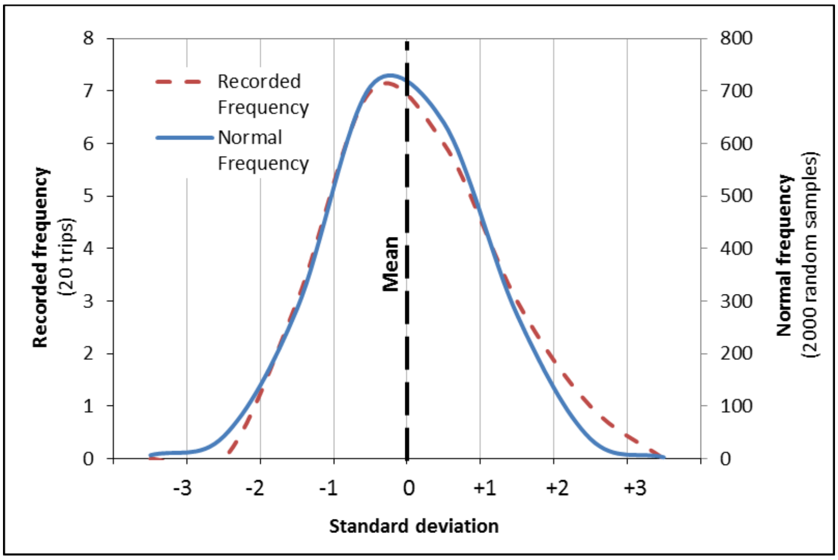


Figure 5-9: Route 1-PM travel time distribution

5.2.5 Acceleration & deceleration time loss

Section 4.6.1 identified the additional time lost as a result of deceleration and acceleration as 5 seconds at each intersection stop. The impact is shown in Table 5-22.

Table 5-22: Route 1-PM impact of acceleration & deceleration time loss

Fewest stops on trip		Most stops on trip		Average stops per trip	
No. of Stops	**Decel & accel time loss** (mm:ss)	**No. of Stops**	**Decel & accel time loss** (mm:ss)	**Ave stops**	**Decel & accel time loss** (mm:ss)
6	00:30	12	01:00	8.6	00:43

The average time lost due to deceleration and acceleration on Route 1-PM was 43 seconds per trip.

5.2.6 Unimpeded travel speed comparison

The terms 'unimpeded travel speed' and 'realistic base travel speed' are defined in Section 5.1.6.

The average speed on Route 1–PM, which includes time lost due to acceleration & deceleration, cornering and traffic conditions, was found to be 22.2 km/h (Table 5-16). The unimpeded speed for this route is averaged from speeds recorded on the section of Route 1-PM that travelled on an off-road sealed path through Hagley Park. The unimpeded travel speed was found to be 23.2 km/h.

If the entire route were travelled at this speed, the travel time would be 17:51 minutes, which is 4:39 minutes quicker than the average trip time of 22:29. If the route average trip time is compared against the unimpeded speed trip time this equates to a delay of 40 secs/km, compared to the 33 secs/km delay derived from the average results (Table 5-17). The comparison is shown in Table 5-23.

Table 5-23: Route 1-PM unimpeded speed vs route average speed

	Speed (Km/h)	**Total moving time** (mm:ss)	**Total trip time** (mm:ss)	**Delay** (mm:ss)	**Delay per km** (mm:ss)
Unimpeded speed trip	23.2	17:51	17:51	00:00	00:00
Route average trip	22.2	18:39	22:29	04:39	00:40
Difference	1.0	00:48	04:39		

The realistic base travel speed gives an average speed of 23.1 km/h, just 0.1 km/h slower than the unimpeded speed. This speed gives a trip time of 17:56 seconds, 4:33 minutes faster than the average trip time of 21:21. If the route average trip time is compared against this 'realistic' base speed trip time (Table 5-24), this equates to a delay of 40 secs/km, the same as the unimpeded speed.

Table 5-24: Route 1-PM realistic base speed vs route average speed

	Speed (Km/h)	**Total moving time** (mm:ss)	**Total trip time** (mm:ss)	**Delay** (mm:ss)	**Delay per km** (mm:ss)
Realistic base speed trip	23.1	17:56	17:56	00:00	00:00
Route average trip	22.2	18:39	22:29	04:33	00:40
Difference	0.9	00:43	04:33		

5.2.7 Comparison of stop rate with signal phase timing

Table 5-25 shows a comparison between the number of stops made at an intersection with the length of available green time and the percentage of the cycle length it represents. This data is indicative only and is based on the average peak hour signal phase timing data is extracted from the information provided by the Christchurch City Council traffic signals team for Thursday 12th September 2013. The Fendalton Road rail crossing was not included due to the random nature of its operation.

Table 5-25: Route 1-PM comparison of stops and signal timing

Intersection	No. of times stopped	% of times stopped	Cycle length (mm:ss)	Available green phase (mm:ss)	% of cycle length
Fitzgerald / Kilmore	15	75%	01:52	00:42	37%
Bealey / Barbadoes	9	45%	02:03	00:54	44%
Bealey / Madras	18	90%	01:58	01:10	59%
Bealey / Manchester	1	5%	01:54	01:29	77%
Bealey / Sherbourne	8	40%	01:58	01:32	78%
Bealey / Colombo	10	50%	01:58	01:29	76%
Bealey / Durham	16	80%	01:58	00:59	50%
Bealey / Montreal	0	0%	01:58	01:20	68%
Bealey / Papanui	17	85%	01:57	00:50	43%
Bealey / Park Tce	1	5%	01:58	01:13	62%
Fendalton / Harper	19	95%	01:46	00:25	23%
Fendalton Rd rail crossing	6	30%	Not applicable		
Fendalton / Straven	12	60%	01:26	00:37	43%
Fendalton / Glandovey	5	25%	01:48	01:18	73%
Fendalton / Clyde	15	75%	01:49	00:40	37%

Figure 5-10 shows the percentage of stops plotted against the percentage of the cycle length the green time represents. The trend line indicates some relationship when all the points are considered and an R^2 test gives a result of 0.50.

The outlier above the trendline is the Bealey/Madras intersection. Madras Street is a major arterial one way street but there is no clear reason why this result is an outlier. If this intersection is excluded, the R^2 test result increases to 0.61.

When only the four intersections in the outer city zone (Fendalton/Harper, Fendalton/ Straven, Fendalton/Glandovey & Fendalton/Clyde – circled in red on the graphs) are considered, the best fit line indicates a very strong linear relationship, confirmed by an R^2 test result of 0.98.

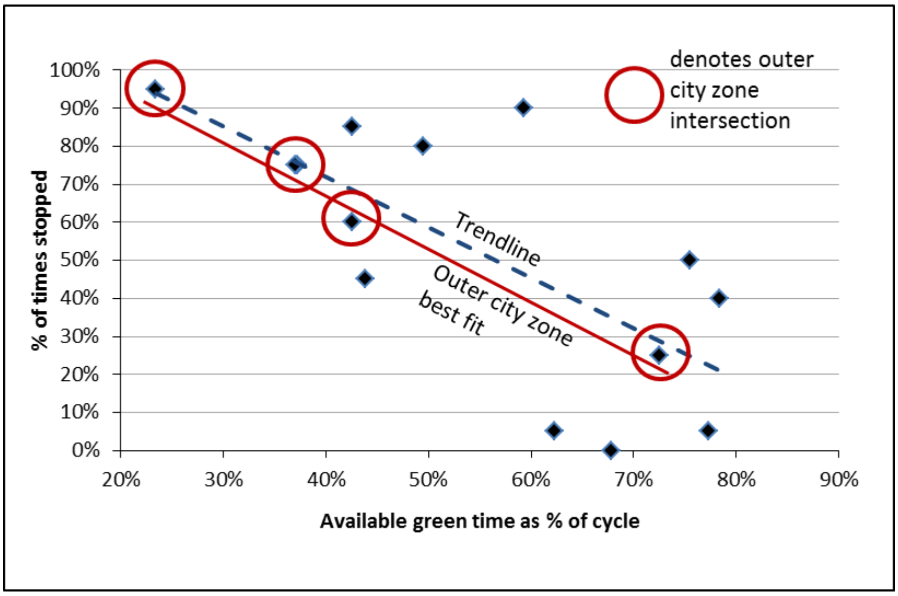


Figure 5-10: Route 1-PM number of stops vs percentage of cycle time

5.2.8 Route 1-PM inner city zone signal co-ordination

The diagram shown in Figure 5-11 is based on the average peak hour signal phase timing data extracted from the information provided by the Christchurch City Council traffic signals team for Thursday 12th September 2013. The diagram indicates the progression of a vehicle travelling at 45 km/h, a cyclist travelling at 22km/h and a cyclist travelling at 15 km/h as they travel through the signalised intersections along Bealey Avenue.

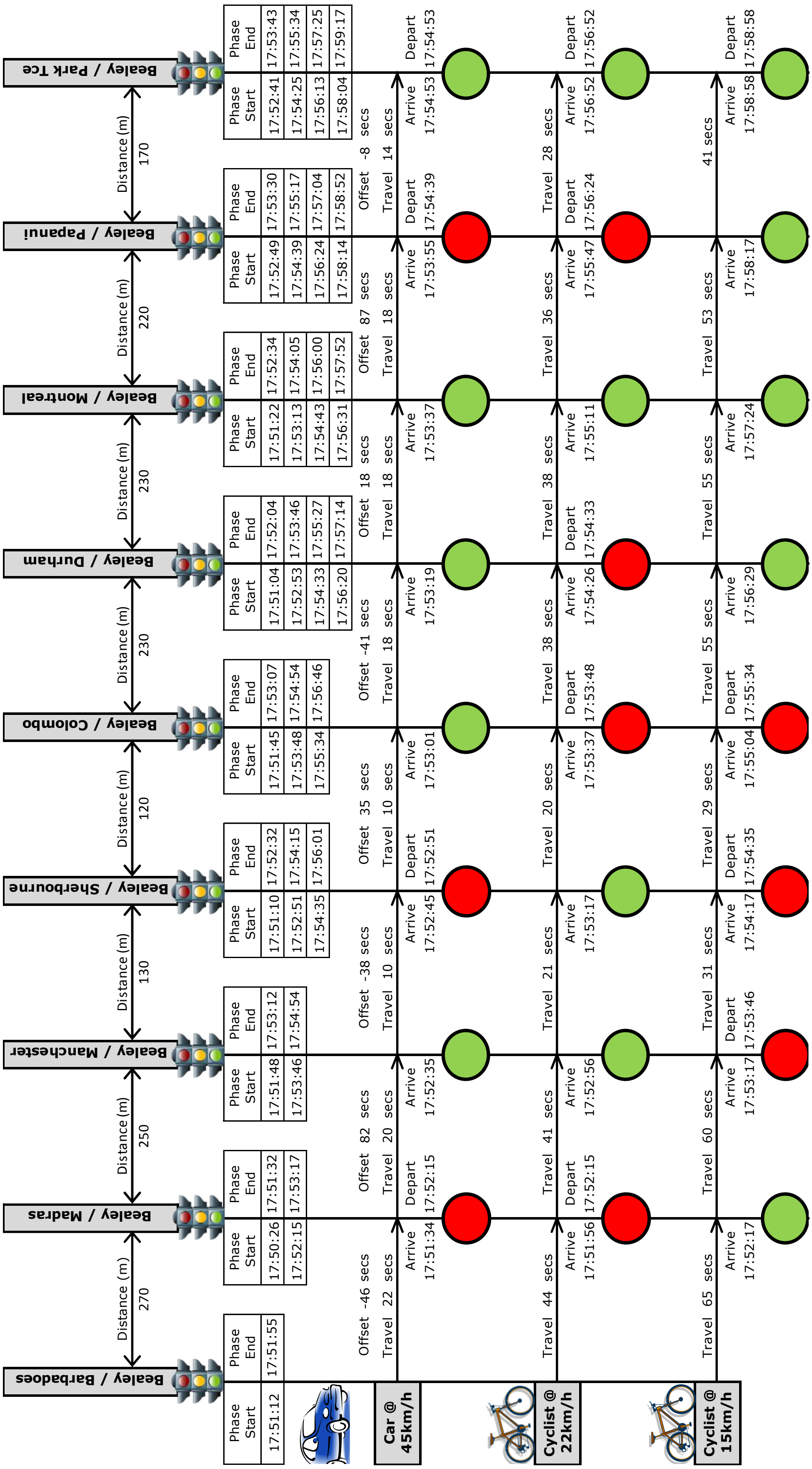
The signal phase time shown is until the next phase starts and as such includes the inter-green time. The signal timings used in the diagram are the actual sequence of phases that represented the closest match to the average peak hour phase timings. The diagram is indicative and is not adjusted to include acceleration and deceleration losses.

Table 5-26 shows a comparison of the relative travel times and delay. Having all started at the same time, the vehicle departs from the Bealey / Harper intersection 1:59 minutes ahead of the 22km/h cyclist and 4:05 minutes ahead of the 15 km/h cyclist.

Table 5-26: Route 1-PM Bealey Ave travel times

	Travel time (mm:ss)	**Delay** (mm:ss)	**Total time** (mm:ss)	**Slower than car by:** (mm:ss)
Car @ 45 km/h	0:03:41	nil	0:03:41	0:00:00
Cyclist @ 22 km/h	0:04:25	0:01:15	0:05:40	0:01:59
Cyclist @ 15 km/h	0:06:29	0:01:17	0:07:46	0:04:05

Figure 5-11: Route 1-PM Bealey Ave signal co-ordination



5.3 Route 2-AM

Hamilton Avenue to Kilmore Street via Kilmarnock Street and Salisbury Street

5.3.1 Trip details

A total of 20 trips were recorded between 7 August 2013 and 9 September 2013, starting from Hamilton Avenue at close to 8:00am and trip details are shown in Table 5-27.

Table heading definitions as 5.1.1., wind is the Met Office Christchurch 8:00 am wind speed.

Table 5-27: Route 2-AM trip details

Ride No.	Date	Start time	Moving time (min:sec)	Ave moving speed (km/h)	Stopped time (min:sec)	Total trip time (min:sec)	% of trip stopped	Recorded distance (km)	Wind (knots)
1	7/08/13	8:02 a.m.	19:36	21.5	01:31	21:07	7%	7.03	9NE
2	8/08/13	7:59 a.m.	18:38	22.7	01:54	20:32	9%	7.05	4NE
3	12/08/13	7:55 a.m.	18:29	22.9	02:52	21:21	13%	7.05	6W
4	13/08/13	7:59 a.m.	18:42	22.6	03:41	22:23	16%	7.04	2NE
5	14/08/13	7:56 a.m.	18:13	23.2	03:00	21:13	14%	7.04	6SW
6	15/08/13	7:56 a.m.	18:42	22.5	02:47	21:29	13%	7.02	2NE
7	19/08/13	7:59 a.m.	20:08	21.0	01:56	22:04	9%	7.05	20E
8	20/08/13	7:54 a.m.	20:24	20.8	03:39	24:03	15%	7.06	26E
9	22/08/13	7:57 a.m.	19:09	22.1	04:09	23:18	18%	7.04	15NE
10	23/08/13	8:04 a.m.	18:15	23.3	04:11	22:26	19%	7.07	13N
11	26/08/13	7:55 a.m.	17:39	24.0	02:52	20:31	14%	7.05	19SW
12	27/08/13	7:55 a.m.	18:31	22.9	02:52	21:23	13%	7.07	4SE
13	28/08/13	8:05 a.m.	18:10	23.3	02:15	20:25	11%	7.07	2N
14	29/08/13	8:04 a.m.	19:01	22.2	02:14	21:15	11%	7.03	11W
15	30/08/13	8:05 a.m.	18:32	22.6	02:53	21:25	13%	7.00	13SW
16	2/09/13	8:03 a.m.	18:27	22.8	03:59	22:26	18%	7.01	2NW
17	3/09/13	7:59 a.m.	18:26	22.9	03:32	21:58	16%	7.02	6N
18	5/09/13	8:05 a.m.	18:24	23.0	03:15	21:39	15%	7.06	19SW
19	6/09/13	8:00 a.m.	19:17	21.8	03:20	22:37	15%	7.02	4NE
20	9/09/13	8:05 a.m.	18:44	22.5	02:52	21:36	13%	7.03	9W

Impact of the wind on average moving speed

Route 2-AM route travels in a predominantly easterly direction and should benefit from any wind with a westerly component. The average moving speed on the 8 days when the wind had a westerly component was 22.9 km/h and the average moving speed on the 9 days when the wind had an easterly component was 22.0 km/h. The average moving speed for all Route 2-AM trips was 22.5 km/h. This is a slightly larger difference than the other three routes but is not considered to impacted trip times any more than fluctuations in the cyclists' daily energy level and is not considered further.

5.3.2 Recorded delay

Table 5-28 shows the amount of stopped time recorded by the Garmin GPS unit at each intersection and the total delay for the trip. These are the stationary times as recorded and do not include any allowance for deceleration and acceleration time loss.

Table 5-28: Route 2-AM delay recorded at intersections

	Delay Recorded at Intersection (mm:ss)										
Ride No.	**Creyke / Clyde**	**Kilmarnoch / Straven**	**Kilmarnoch / Deans**	**Salisbury / Montreal**	**Salisbury / Durham**	**Salisbury / Colombo**	**Salisbury / Manchester**	**Salisbury / Madras**	**Salisbury / Barbadoes**	**Barbadoes / Kilmore**	**Total Delay** (mm:ss)
1	00:30			00:11		00:40		00:10			01:31
2			00:13	00:15		00:41			00:45		01:54
3		00:33	00:48	00:07		00:38			00:46		02:52
4		01:40		00:40		00:40		00:41			03:41
5		00:37	00:26	00:29		00:43			00:45		03:00
6			00:32	00:54		00:43	00:13	00:25			02:47
7	00:33	00:07			00:48		00:28				01:56
8	00:31	01:10	00:04	00:47		00:32		00:35			03:39
9		01:16	01:18	00:18		00:39		00:38			04:09
10	00:22	01:27	00:11	00:50		00:42		00:39			04:11
11	00:09	00:14	00:57			00:39			00:48	00:05	02:52
12	00:21	00:10		00:52		00:46		00:43			02:52
13		00:48			00:45		00:42				02:15
14	00:16	00:25		00:06		00:45		00:42			02:14
15			00:50	00:38		00:43		00:42			02:53
16		00:16	01:10	00:54		00:44			00:45	00:10	03:59
17		00:29	00:48	00:46	00:51		00:38				03:32
18		00:53	00:43	00:16		00:43		00:40			03:15
19	00:37	00:41	00:05	00:42		00:35		00:37		00:03	03:20
20	00:39	01:03				00:32		00:38			02:52
Stops	**9**	**16**	**13**	**16**	**3**	**17**	**4**	**12**	**5**	**3**	

The average trip and delay details are summarised in Table 5-29 and Table 5-30.

Table 5-29: Route 2-AM average trip summary

Ave start time	**Ave moving time** (min:sec)	**Ave speed** (km/h)	**Ave stopped time** (min:sec)	**Ave total trip time** (min:sec)	**Ave % of trip time stopped**	**Ave recorded distance** (km)
7:59 a.m.	18:46	22.5	02:59	21:46	14%	7.04

Table 5-30: Route 2–AM average delay summary

Number of signalised intersections	Ave number of stops per trip	Ave % of intersections stopped at	Ave delay per stop (mm:ss)	Ave delay per intersection (mm:ss)	Ave delay per km (mm:ss)
10	4.90	49%	00:37	00:18	00:25

Figure 5-12 shows the percentage of stops recorded in 15 second time bands. The majority (45%) of stops were in the 31 to 45 second band.

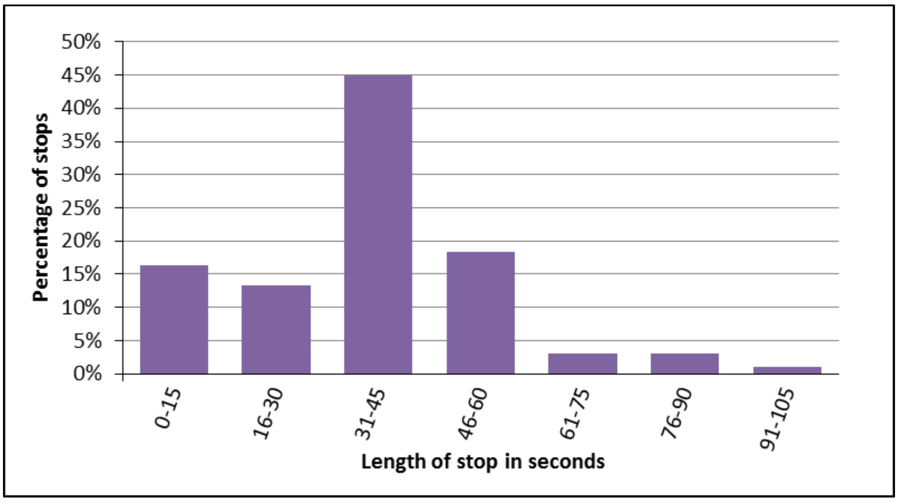


Figure 5-12: Route 2-AM stop length graph

Table 5-31 shows the total percentage of stops below a time limit. 70% of stops were in excess of 30 seconds.

Table 5-31: Route 2-AM stop length breakdown

	Length of stop			
	15 secs or less	30 secs or less	45 secs or less	60 secs or less
Percentage of stops	16%	30%	74%	93%

5.3.3 Inner city and outer city intersections

As with Route 1, there is a significant difference in the spacing of intersections between the inner city area and the outer city area. In the first part of the route in the outer city area, there are 4 signalised intersections over a distance of 5.25 km at an average spacing of 1.31 km. The remaining 6 signalised intersection in the inner city area cover at distance of 1.48 km at an average spacing of 250m apart.

Table 5-32: Route 2-AM intersection spacing vs delay

	Distance (km)	No. of inter-sections	Average distance between inter-sections (km)	Average number of stops	% of inter-sections stopped at	Average delay per inter-section (mm:ss)	Average length of stop (mm:ss)	Average delay per trip (mm:ss)	Average delay per Km (mm:ss)
Full route	7.04	10	0.70	4.90	49.0%	00:18	00:37	02:59	00:25
Outer city zone Hamilton Ave to Salisbury / Montreal	5.25	4	1.31	2.70	67.5%	00:24	00:36	01:38	00:19
Inner city zone Salisbury / Montreal to Barbadoes /Kilmore	1.48	6	0.25	2.20	36.7%	00:14	00:37	01:21	00:55

Table 5-32 shows a comparison of the average delay experienced over the full route against the delay experienced in the inner city and outer city zones. The stop rate was much higher in the outer city zone but the average stop length in each zone was very similar. The close spacing of the inner city intersections results in a much higher average delay per kilometre.

Figure 5-13 shows the percentage of stops recorded in each zone in 15 second time bands. 70% of the inner city zone stops were between 30 to 45 seconds.

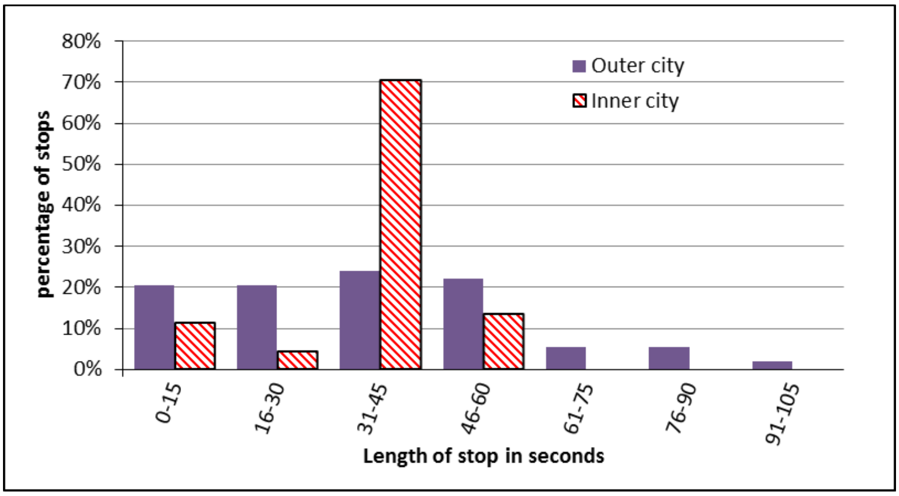


Figure 5-13: Route 2-AM zones stop length graph

Table 5-33 shows the total percentage of stops below a time limit. Only 16% of inner city stops were 30 seconds or less but none were longer than 60 seconds.

Table 5-33: Route 2-AM zones stop length breakdown

	Length of stop			
	15 secs or less	**30 secs or less**	**45 secs or less**	**60 secs or less**
Percentage of stops Outer city zone	20%	41%	65%	87%
Percentage of stops Inner city zone	11%	16%	86%	100%

5.3.4 Trip time variability

The Route 2-AM trip had the smallest variability in stopped time and total trip time of all four routes. The stopped time variation was 2:40 minutes with a standard deviation of 44 seconds. As noted in Section 5.3.1, this route had the largest variation in average moving speed when the wind direction experienced on during the study was taken into consideration, however this does not appear to have had a significant impact. The recorded moving time and speeds were again very consistent, with a standard deviation of 39 seconds and 0.8 km/h respectively.

Table 5-34 heading definitions as Section 5.1.4.

Table 5-34: Route 2-AM summary of trip variability

	Moving time (mm:ss)	**Ave speed** (km/h)	**Stopped time** (mm:ss)	**Total trip time** (mm:ss)	**% of trip stopped**	**Recorded distance** (km)
Minimum	17:39	20.8	01:31	20:25	7%	7.00
Maximum	20:24	24.0	04:11	24:03	19%	7.07
Difference	02:45	3.2	02:40	03:38	11%	0.07
Average	18:46	22.5	02:59	21:46	14%	7.04
Standard deviation	00:39	0.8	00:44	00:54		

Figure 5-14 & Figure 5-15 show the distribution of the recorded delay and trip time.

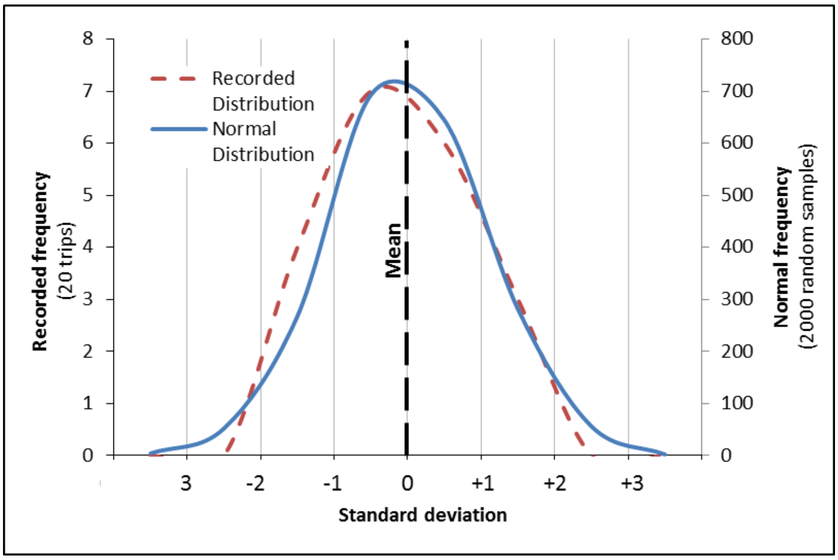


Figure 5-14: Route 2-AM Recorded delay distribution

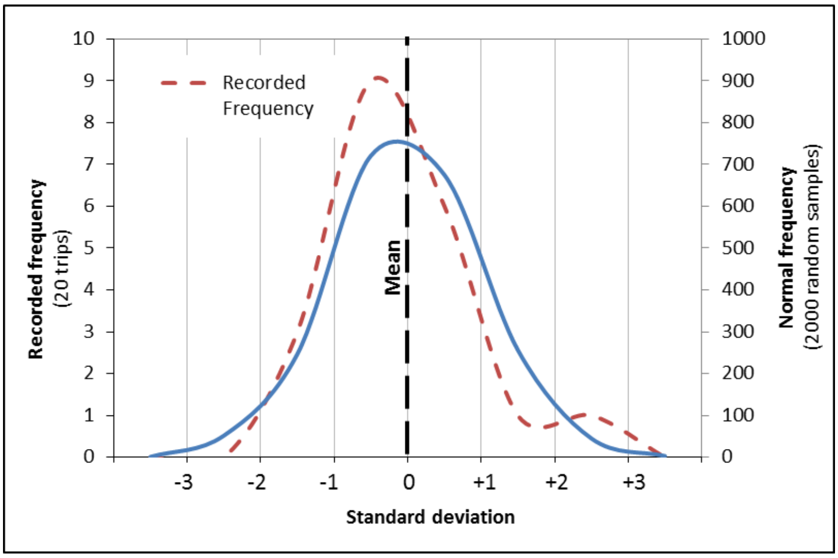


Figure 5-15: Route 2-AM Travel time distribution

5.3.5 Acceleration & deceleration time loss

Section 4.6.1 identified the additional time lost as a result of deceleration and acceleration as 5 seconds at each intersection stop. The impact on Route 2-AM trips is shown in Table 5-35.

Table 5-35: Route 2-AM impact of acceleration & deceleration time loss

Fewest stops on trip		Most stops on trip		Average stops per trip	
No. of Stops	**Decel & accel time loss** (mm:ss)	**No. of Stops**	**Decel & accel time loss** (mm:ss)	**Ave stops**	**Decel & accel time loss** (mm:ss)
3	00:15	7	00:35	4.9	00:25

The average number of stops on this route was 4.9 out of the 10 intersection. The average time lost due to deceleration and acceleration on Route 2-AM was 25 seconds per trip.

5.3.6 Unimpeded travel speed comparison

The terms 'unimpeded travel speed' and 'realistic base travel speed' are defined in Section 5.1.6.

The unimpeded speed on this route is averaged from the speeds recorded on the section of Route 2-AM that travelled on a sealed path through Hagley Park and calculates to 24.0 km/h. In Table 5-36, the average speed on Route 1–PM of 22.5 km/h (Table 5-29) is compared to the unimpeded speed.

If the entire route were travelled at the unimpeded speed, the travel time would be 17:37 minutes, which is 4:09 minutes quicker than the average trip time of 21:46. If the route average trip time is compared against the unimpeded speed trip time this equates to a delay of 35 secs/km, compared to the 25 secs/km delay derived from the average Route 2-AM results (Table 5-30).

Table 5-36: Route 2-AM unimpeded speed vs route average speed

	Speed (Km/h)	**Total moving time** (mm:ss)	**Total trip time** (mm:ss)	**Delay** (mm:ss)	**Delay per km** (mm:ss)
Unimpeded speed trip	24.0	17:37	17:37	00:00	00:00
Route average trip	22.5	18:46	21:46	04:09	00:35
Difference	1.5	01:09	04:09		

Table 5-37 compares the average route speed of 22.5 km/h to the realistic base speed. The realistic base travel speed calculates to 23.0 km/h, 1.0 km/h slower than the unimpeded speed. This speed gives a trip time of 18:21 seconds, 3:24 minutes faster than the average trip time of 21:46. This equates to a delay of 30 secs/km, 5 sec/km more than the 29 secs/km delay derived from the average route results.

Table 5-37: Route 2-AM realistic base speed vs route average speed

	Speed (Km/h)	**Total moving time** (mm:ss)	**Total trip time** (mm:ss)	**Delay** (mm:ss)	**Delay per km** (mm:ss)
Realistic base speed trip	23.0	18:21	18:21	00:00	00:00
Route average trip	22.5	18:46	21:46	03:24	00:30
Difference	0.5	00:25	03:24		

5.3.7 Comparison of stop rate with signal phase timing

Table 5-38 shows a comparison between the number of stops made at an intersection with the length of available green time and the percentage of the cycle length it represents. This data is indicative only and is based on the average peak hour signal phase timing data is extracted from the information provided by the Christchurch City Council traffic signals team for Thursday 12th September 2013.

Table 5-38: Route 2-AM comparison of stops and signal timing

Intersection	No. of times stopped	% of times stopped	Cycle length (mm:ss)	Available green phase (mm:ss)	% of cycle length
Creyke / Clyde	9	45%	01:15	00:34	45%
Kilmarnoch / Straven	16	80%	02:08	00:41	32%
Kilmarnoch / Deans	13	65%	02:07	00:14	11%
Salisbury / Montreal	16	80%	01:21	00:20	24%
Salisbury / Durham	3	15%	01:20	00:33	41%
Salisbury / Colombo	17	85%	01:20	00:35	44%
Salisbury / Manchester	4	20%	01:20	00:37	46%
Salisbury / Madras	12	60%	01:20	00:38	47%
Salisbury / Barbadoes	5	25%	01:20	00:25	31%
Barbadoes / Kilmore	3	15%	01:20	00:57	71%

Figure 5-16 shows the percentage of stops plotted against the percentage of the cycle length the green time represents. The trend line indicates no clear relationship when all the points are considered and an R^2 test gives a result of 0.26 and is not influenced by clear outliers.

No linear relationship is apparent when only the four intersections in the outer city zone (Creyke/Clyde, Kilmarnoch/Straven, Kilmarnoch/Deans & Salisbury /Montreal – circled in red on the graphs) are considered, confirmed by an R^2 test result of 0.24.

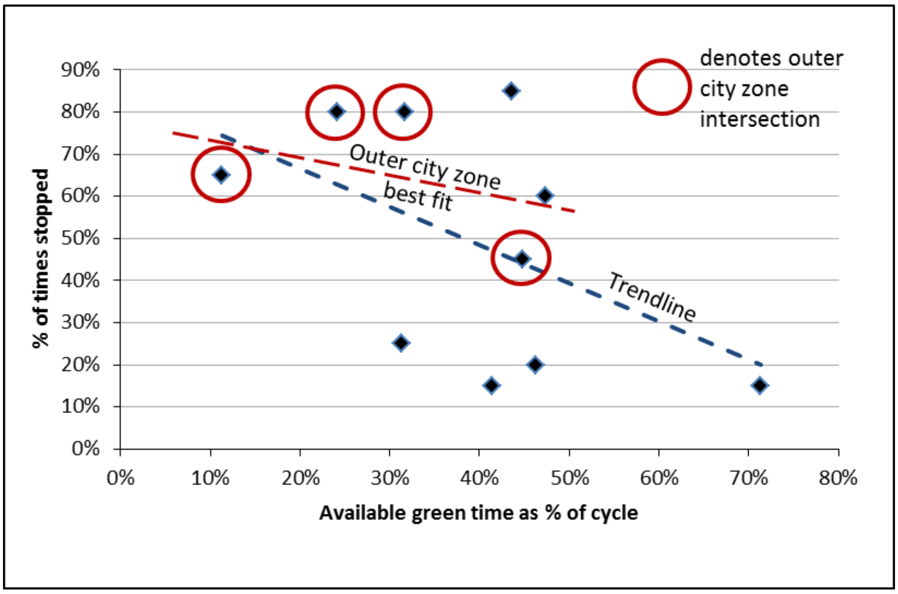


Figure 5-16: Route 2-AM number of stops vs percentage green time

5.3.8 Inner city zone signal co-ordination

The diagram shown in Figure 5-17 is based on the average peak hour signal phase timing data extracted from the information provided by the Christchurch City Council traffic signals team for Thursday 12th September 2013. The diagram indicates the progression of a vehicle travelling at 45 km/h, a cyclist travelling at 22km/h and a cyclist travelling at 15 km/h as they travel through the signalised intersections along Salisbury Avenue in the AM peak. Figure 5-17 shows the car being stopped at Salisbury / Durham and Salisbury / Manchester however these stops are for just 2 seconds and 1 second respectively.

The signal phase time shown is to the start of the next phase and as such includes the inter-green time. The signal timings used in the diagram are the actual sequence of phases that represented the closest match to the average peak hour phase timings. The diagram is indicative and is not adjusted to include acceleration and deceleration losses.

Table 5-39 shows a comparison of travel times and delay for the car and the two cyclists. Having all started at the Salisbury / Montreal intersection at the same time, the vehicle departs from the Salisbury / Barbadoes intersection 2:48 minutes ahead of the 22km/h cyclist and 4:32 minutes ahead of the 15 km/h cyclist.

Figure 5-17: Route 2-AM Salisbury Ave signal co-ordination

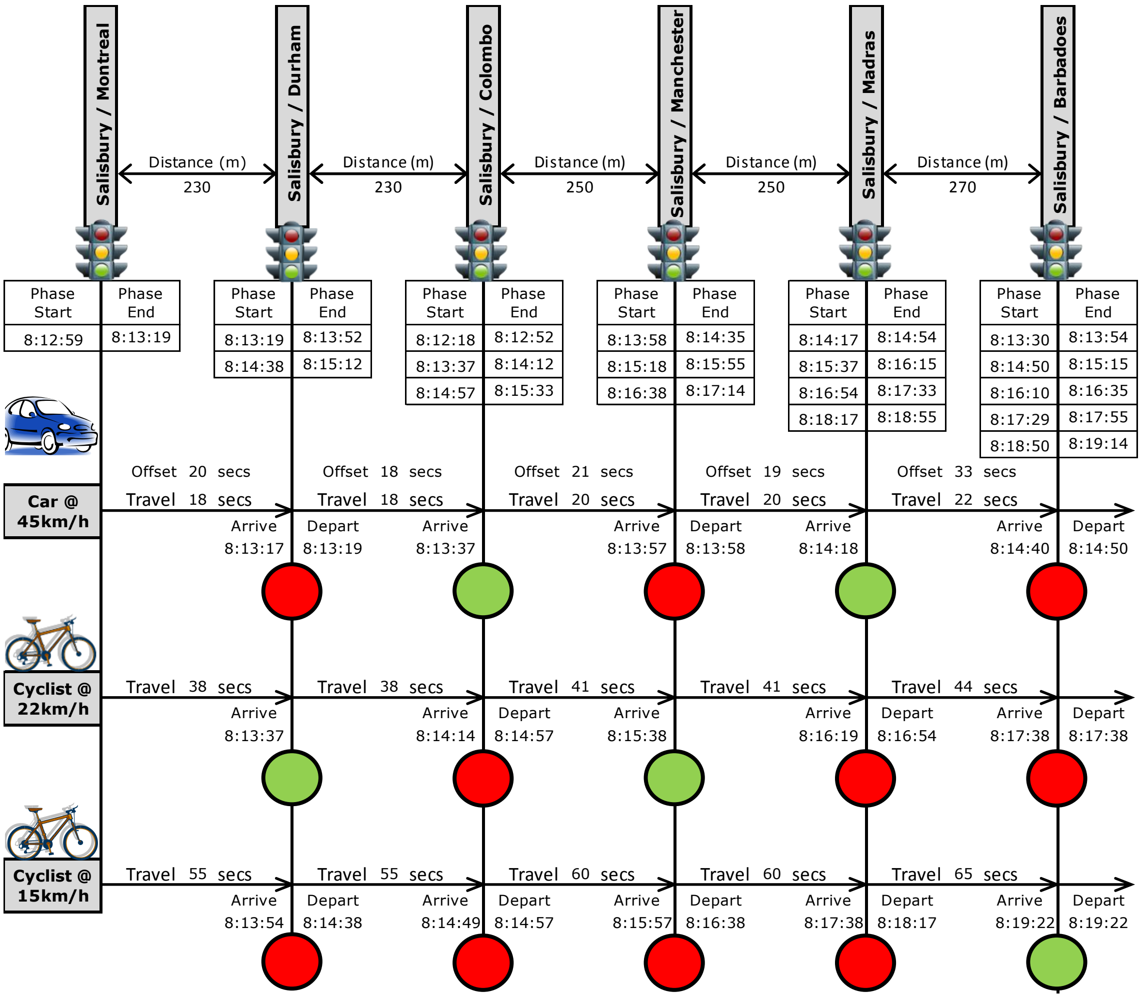


Table 5-39: Route 2-AM Salisbury Ave travel times

	Travel time (mm:ss)	**Delay** (mm:ss)	**Total time** (mm:ss)	**Slower than car by:** (mm:ss)
Car @ 45 km/h	0:01:49	0:00:02	0:01:51	0:00:00
Cyclist @ 22 km/h	0:03:21	0:01:18	0:04:39	0:02:48
Cyclist @ 15 km/h	0:04:11	0:02:11	0:06:23	0:04:32

5.4 Route 2-PM

Kilmore Street to Hamilton Avenue via Kilmore Street and Kilmarnock Street

As noted in Section 4.4, the flexibility in daily route choice when recording trips generally enabled the impacts of earthquake infrastructure repair road works on this study to be minimised. Unfortunately this was not the case on the section of Kilmore Street between Manchester Street and Montreal Street.

As a result of road closures on Colombo Street, the Kilmore / Colombo signalised intersection was not in operation and both Kilmore / Durham and Kilmore / Montreal signalised intersections were operating with a double phase for Durham Street and Montreal Street traffic. The data from Manchester Street up to and including the Montreal Street intersection is summarised in Table 5-40.

Table 5-40: Route 2-PM average Kilmore St trip time between Manchester & Montreal St

	Stopped time (mm:ss)	**Total trip time** (mm:ss)	**% of trip stopped**	**Recorded distance** (m)
Average	02:48	04:54	56%	687

The stopped time of 2:48 minutes is for just two signalised intersections and equates to 56% of the trip time on this 687 m section of the route. If this is compared with a combined average stopped time of 3:33 minutes for the other 3 full distance routes, which equates to 16% of the average trip time, then it is clear that the recorded data for the section of Kilmore Street between Manchester Street and Montreal Street does not represent the normal operation on this part of the route.

The recorded data from the remaining sections of Route 2-PM is considered to be representative of normal route operation and is included in the study. The following Route2-PM data is presented both as recorded for the full route and with the section of Kilmore Street from Manchester Street to Montreal Street intersection excluded. Route 2-PM data with the section of Kilmore Street from Manchester Street to Montreal Street intersection excluded is identified in the following text and tables as “Route 2-PM abridged”.

Only the Route 2-PM abridged data has been used to represent Route 2-PM in the Section 6.

5.4.1 Trip details

A total of 20 trips were recorded between 22 August 2013 and 8 October 2013, usually starting from Kilmore St between 5:00 & 5:30pm and details are shown in Table heading definitions as 5.1.1., wind is the Met Office Christchurch 6:00 pm wind speed.

Table 5-41.

Table heading definitions as 5.1.1., wind is the Met Office Christchurch 6:00 pm wind speed.

Table 5-41: Route 2-PM trip details as recorded

Ride No.	Date	Start time	Moving time (mm:ss)	Ave moving speed (km/h)	Stopped time (mm:ss)	Total trip time (mm:ss)	% of trip stopped	Recorded distance (km)	Wind (knots)
1	22/08/13	5:42 p.m.	19:10	21.8	06:29	25:39	25%	6.95	9NE
2	23/08/13	5:31 p.m.	19:57	19.2	07:06	27:03	26%	7.01	6E
3	26/08/13	5:09 p.m.	19:04	22.1	06:47	25:51	26%	7.02	7SE
4	28/08/13	5:09 p.m.	18:42	21.0	03:51	22:33	17%	6.99	11NE
5	9/09/13	5:29 p.m.	17:59	23.3	05:37	23:36	24%	6.99	7SW
6	10/09/13	5:18 p.m.	19:39	21.3	06:38	26:17	25%	6.98	20NE
7	11/09/13	5:13 p.m.	19:29	21.5	07:08	26:37	27%	6.89	13N
8	13/09/13	5:27 p.m.	18:48	22.2	05:49	24:37	24%	6.97	9N
9	16/09/13	5:12 p.m.	18:07	23.1	07:25	25:32	29%	6.98	9S
10	18/09/13	5:12 p.m.	18:07	23.2	04:39	22:46	20%	7.01	9E
11	19/09/13	5:10 p.m.	18:37	22.4	07:46	26:23	29%	6.96	22NE
12	20/09/13	5:19 p.m.	18:30	22.7	06:20	24:50	26%	7.00	13NE
13	23/09/13	5:11 p.m.	19:26	21.5	03:17	22:43	14%	6.98	15E
14	24/09/13	5:16 p.m.	18:47	22.4	03:48	22:35	17%	7.03	13E
15	25/09/13	5:11 p.m.	20:27	20.6	06:54	27:21	25%	7.01	15SW
16	26/09/13	5:16 p.m.	19:14	21.6	05:01	24:15	21%	6.94	15S
17	1/10/13	5:17 p.m.	17:45	23.6	06:16	24:01	26%	6.99	11NE
18	2/10/13	5:14 p.m.	19:56	21.0	07:04	27:00	26%	6.97	15NE
19	7/10/13	5:08 p.m.	18:28	22.7	06:18	24:46	25%	6.98	20E
20	8/10/13	5:11 p.m.	19:37	21.3	07:30	27:07	28%	6.97	19S

Impact of the wind direction

Route 2-PM route travels in a predominantly westerly direction and should benefit from any wind with an easterly component. The average moving speed on the 13 days when the wind had an easterly component was 21.9 km/h and the average moving speed on the 2 days when the wind had a westerly component was 21.9 km/h. The average moving speed for all Route 2-PM trips was 21.9 km/h. As such, the trip times are not considered to have been significantly impacted by the effects of the wind and this is not considered further.

Table 5-42 shows the Route 2-PM abridged data.

Table 5-42: Route 2-PM abridged trip data

Ride No.	Moving time (mm:ss)	Ave moving speed (km/h)	Stopped time (mm:ss)	Total trip time (mm:ss)	% of trip stopped	Recorded distance (km)
1	16:59	22.2	04:16	21:15	20%	6.27
2	17:53	21.2	03:35	21:28	17%	6.33
3	17:04	22.3	03:11	20:15	16%	6.34
4	16:41	22.6	01:35	18:16	9%	6.30
5	16:02	23.6	04:36	20:38	22%	6.30
6	17:23	21.7	04:23	21:46	20%	6.30
7	17:13	21.6	03:31	20:44	17%	6.20
8	16:31	22.8	03:31	20:02	18%	6.28
9	15:42	24.0	05:14	20:56	25%	6.29
10	16:09	23.4	01:50	17:59	10%	6.31
11	16:33	22.8	04:13	20:46	20%	6.28
12	16:28	23.0	02:47	19:15	14%	6.32
13	17:25	21.7	01:01	18:26	6%	6.30
14	16:44	22.7	01:31	18:15	8%	6.34
15	18:19	20.7	03:27	21:46	16%	6.33
16	17:01	22.0	02:56	19:57	15%	6.25
17	15:53	23.8	03:52	19:45	20%	6.30
18	17:47	21.2	03:36	21:23	17%	6.28
19	16:32	22.9	02:37	19:09	14%	6.30
20	17:34	21.5	03:55	21:29	18%	6.29

The average trip details for the full Route 2-PM and the abridged data are summarised in Table 5-43 and Table 5-44.

Table 5-43: Route 2-PM average trip summary

Ave start time	Ave moving time (min:sec)	Ave speed (km/h)	Ave stopped time (min:sec)	Ave total trip time (min:sec)	Ave % of trip time stopped	Ave recorded distance (km)
5:16 p.m.	18:59	21.9	06:05	25:05	24%	6.98

Table 5-44: Route 2-PM abridged average trip summary

Ave start time	Ave moving time (min:sec)	Ave speed (km/h)	Ave stopped time (min:sec)	Ave total trip time (min:sec)	Ave % of trip time stopped	Ave recorded distance (km)
5:16 p.m.	16:54	22.4	03:17	20:11	16%	6.29

5.4.2 Recorded delay

Table 5-45 shows the amount of stopped time recorded at each intersection and also the total stopped time for each Route 2-PM trip. These times do not include deceleration and acceleration time loss.

Table 5-45: Route 2-PM delay recorded at intersections

	Delay Recorded at Intersection (mm:ss)										
Ride No.	**Kilmore / Barbadoes**	**Kilmore / Madras**	**Kilmore / Manchester**	**Kilmore / Colombo**	**Kilmore / Durham**	**Kilmore / Montreal**	**Kilmore / Park Terrace**	**Kilmarnoch / Deans**	**Kilmarnoch / Straven**	**Creyke / Clyde**	**Total Delay** (mm:ss)
1	01:04	00:43	00:13		00:10	02:03	00:16	01:13	00:35	00:12	06:29
2	00:20	00:39	00:18		01:32	01:59	00:46	00:50	00:05	00:37	07:06
3	00:28	00:23	00:18		01:40	01:56	00:29	00:23	01:07	00:03	06:47
4		00:35	00:16		00:16	02:00		00:44			03:51
5		00:47	00:18		00:22	00:39	00:15	02:13	00:53	00:10	05:37
6	00:29	00:42	00:16		00:19	01:56	00:20	00:57	01:36	00:03	06:38
7	00:03	00:40	00:17		01:42	01:55	00:10	01:29	00:21	00:31	07:08
8	00:32	00:44	00:19		00:23	01:55	00:44	00:36	00:05	00:31	05:49
9	00:41	00:45	00:21		01:36	00:35	00:02	01:47	01:38		07:25
10	00:38	00:46			02:06	00:43	00:08	00:18			04:39
11	00:24	00:44	00:21		01:34	01:59	00:34	01:44	00:26		07:46
12		00:40	00:17		01:37	01:56	00:08	01:01		00:41	06:20
13		00:34	00:18		00:18	01:58	00:06			00:03	03:17
14		00:39	00:15		00:18	01:59			00:03	00:34	03:48
15	00:53	00:44	00:15		01:31	01:56		01:03		00:32	06:54
16	00:01	00:39	00:15		00:11	01:54		01:14	00:47		05:01
17	00:42	00:44	00:21		01:43	00:41		01:45	00:20		06:16
18	00:59	00:42	00:16		01:31	01:57	00:18	00:58		00:23	07:04
19	00:12	00:45	00:19		01:39	02:02		00:08	00:31	00:42	06:18
20	00:54	00:39	00:20		01:32	02:03		00:58	00:54	00:10	07:30
Stops	**15**	**20**	**19**	**0**	**20**	**20**	**13**	**18**	**14**	**14**	

The average delay details for the full Route 2-PM and Route 2-PM abridged data are summarised in Table 5-46 and Table 5-47.

Table 5-46: Route 2-PM average delay summary

Number of signalised intersections	**Ave number of stops per trip**	**Ave % of intersections stopped at**	**Ave delay per stop** (min:sec)	**Ave delay per intersection** (min:sec)	**Ave delay per km** (min:sec)
9	7.65	85%	00:48	00:41	00:52

Table 5-47: Route 2-PM abridged average delay summary

Number of signalised intersections	**Ave number of stops per trip**	**Ave % of intersections stopped at**	**Ave delay per stop** (min:sec)	**Ave delay per intersection** (min:sec)	**Ave delay per km** (min:sec)
7	5.65	81%	00:35	00:28	00:31

Whilst the percentage of intersections stopped at is still high, Table 5-47 shows a significant reduction in the average delay values.

Figure 5-18 shows the percentage of stops recorded in 15 second time bands. The high number of stops in excess of 90 seconds is a result of Kilmore / Durham and Kilmore / Montreal signalised intersections operating with a double phase against Kilmore Street.

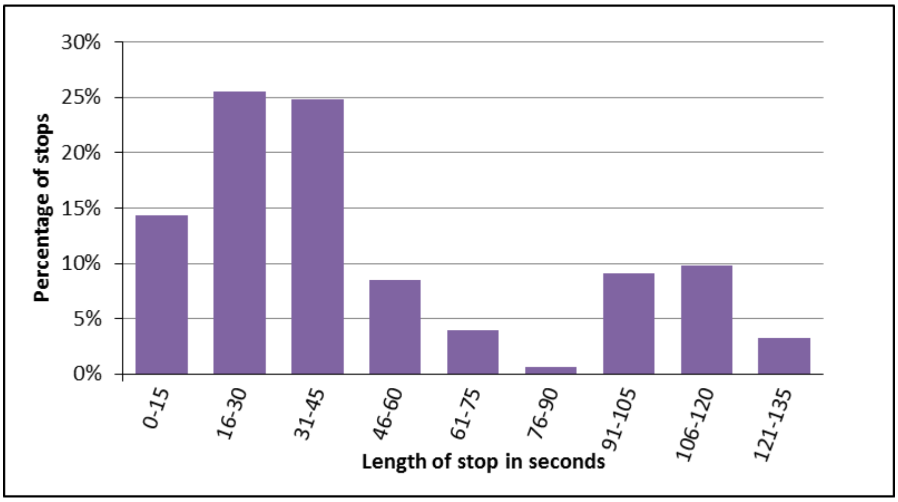


Figure 5-18: Route2-PM stop length graph

Table 5-48 shows the total percentage of stops below a time limit. Over a quarter (27%) of all stops were in excess of 60 seconds.

Table 5-48: Route 2-PM stop length breakdown

	Length of stop			
	15 secs or less	**30 secs or less**	**45 secs or less**	**60 secs or less**
Percentage of stops	14%	40%	65%	73%

5.4.3 Intersection density

There is a significant difference in the spacing of intersections between the inner city area and the outer city area. The first part of this route is in the inner city area and travels through 6 operating signalised intersections (Kilmore/Colombo not included) over a distance of 3.93 km at an average spacing of 280 m. The remaining 3 signalised intersections are in the outer city area over at distance of 3.93 km at an average spacing of 1.7 km apart.

Table 5-49 shows the average delay in the inner and outer city zones. The inner city zone values are not considered to be representative of normal operation of this part of the route as both Kilmore / Durham and Kilmore / Montreal signalised intersections were operating with a double phase against Kilmore Street traffic.

Table 5-49: Route 2-PM inner & outer city zones delay

	Distance (km)	No. of inter-sections	Average distance between inter-sections (km)	Average number of stops	% of inter-sections stopped at	Average delay per inter-section (mm:ss)	Average length of stop (mm:ss)	Average delay per trip (mm:ss)	Average delay per Km (mm:ss)
Route 2-PM	6.98	9	0.78	7.65	85.0%	00:41	00:48	06:05	00:52
Outer city zone Kilmore / Park Tce to Creyke / Clyde	3.93	3	1.31	2.30	76.7%	00:34	00:44	01:42	00:26
Inner city zone Kilmore/ Barbadoes to Kilmore /Park Tce	1.7	6	0.28	5.35	89.2%	00:44	00:49	04:23	02:35

Table 5-49 shows this route had a very high stop rate in both the outer city zone. The impacts of double phasing against Kilmore Street at both Kilmore / Durham and Kilmore / Montreal resulted in an excessive inner city average delay of 2:35 min/km.

Table 5-50 shows the total percentage of stops below a time limit. Over 25% of stops recorded in both zones were in excess of 60 seconds.

Table 5-50: Route 2-PM zones stop length breakdown

	Length of stop			
	15 secs or less	**30 secs or less**	**45 secs or less**	**60 secs or less**
Percentage of stops Outer city zone	22%	35%	59%	74%
Percentage of stops Inner city zone	11%	42%	67%	73%

Table 5-51 shows Route 2-PM abridged delay. The inner city zone abridged values have the data from the section of Kilmore Street between Manchester Street and Montreal Street removed. This reduces the number of intersections included in the analysis to just four; however the results are considered to better represent the normal operation of this section of the route.

Table 5-51: Route 2-PM abridged inner & outer city zone delay

	Distance (km)	No. of inter-sections	Average distance between inter-sections (km)	Average number of stops	% of inter-sections stopped at	Average delay per inter-section (mm:ss)	Average length of stop (mm:ss)	Average delay per trip (mm:ss)	Average delay per Km (mm:ss)
Route 2-PM abridged	6.29	7	0.90	5.65	80.7%	00:28	00:35	03:17	00:31
Outer city zone Kilmore / Park Tce to Creyke / Clyde	3.93	3	1.31	2.30	76.7%	00:34	00:44	01:42	00:26
Inner city zone abridged	1.02	4	0.26	3.35	83.8%	00:24	00:28	01:35	01:33

Figure 5-19 shows the percentage of stops recorded in each zone in 15 second time bands without the impacts of double phasing against Kilmore Street at both Kilmore / Durham and Kilmore / Montreal. The longer outer city stops were generally recorded at the Kilmarnoch / Deans intersection.

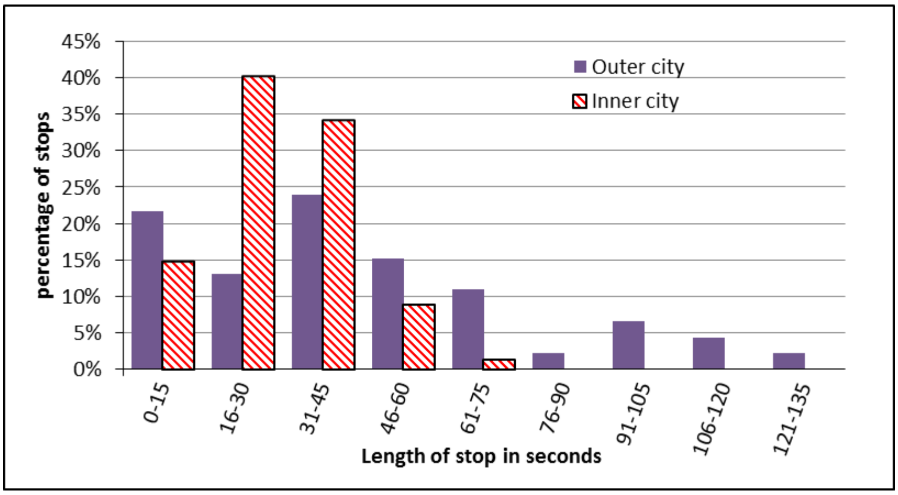


Figure 5-19: Route 2-PM abridged zone stop length graph

Table 5-50 shows the total percentage of stops below a time limit. In the inner city, only 15% of stops were 15 seconds or less but 90% were 45 seconds or less.

Table 5-52: Route 2-PM abridged zone stop length breakdown

	Length of stop			
	15 secs or less	30 secs or less	45 secs or less	60 secs or less
Percentage of stops Outer city zone	22%	35%	59%	74%
Percentage of stops Inner city zone	15%	55%	90%	99%

5.4.4 Trip time variability

Table 5-53 and Table 5-54 heading definitions as Section 5.1.4.

As noted in Section 5.4.1, the winds experienced on the route during the study do not appear to have had a significant impact.

Table 5-53: Route 2-PM summary of trip variability

	Moving time (mm:ss)	**Ave speed** (km/h)	**Stopped time** (mm:ss)	**Total trip time** (mm:ss)	**% of trip stopped**	**Recorded distance** (km)
Minimum	17:45	19.2	03:17	22:33	14%	6.89
Maximum	20:27	23.6	07:46	27:21	29%	7.03
Difference	02:42	4.4	04:29	04:48	15%	0.14
Average	18:59	21.9	06:05	25:05	24%	6.98
Standard deviation	00:43	1.1	01:17	01:36		

Table 5-54: Route 2-PM abridged summary of trip variability

	Moving time (mm:ss)	**Ave speed** (km/h)	**Stopped time** (mm:ss)	**Total trip time** (mm:ss)	**% of trip stopped**	**Recorded distance** (km)
Minimum	15:42	20.7	01:01	17:59	6%	6.20
Maximum	18:19	24.0	05:14	21:46	25%	6.34
Difference	02:37	3.3	04:13	03:47	19%	0.14
Average	16:54	22.4	03:17	20:11	16%	6.29
Standard deviation	00:41	0.9	01:05	01:13		

As expected with the excessive delays experienced at Kilmore/Durham and Kilmore/Montreal intersections, Table 5-53 shows that this route has the longest average stop time and longest average trip time, even though there are only 9 signalised intersections compared to 17 & 15 for Routes 1-AM & 1-PM respectively.

When the data for the section of Kilmore Street between Manchester and Montreal Street is removed (Table 5-54), the results are similar to the other three routes. The moving time and speeds were again very consistent, with a standard deviation of 41 seconds and 0.9 km/h respectively.

Figure 5-20 & Figure 5-22 show the distribution of the recorded delay for the full route and the abridged route respectively. The distribution is positively skewed in both cases.

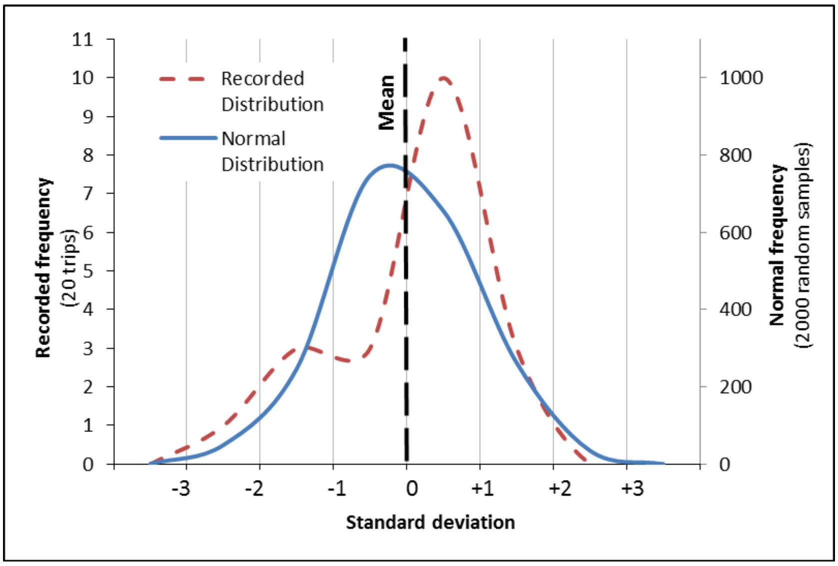


Figure 5-20: Route 2-PM stopped time distribution

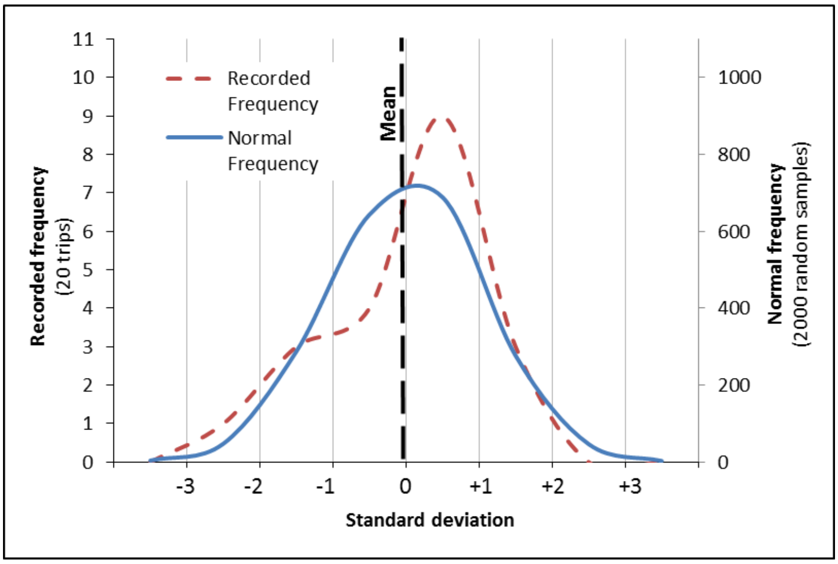


Figure 5-21: Route 2-PM abridged stopped time distribution

Figure 5-20 & Figure 5-22 show the distribution of the recorded delay for the full route and the abridged route respectively. Given the small sample size of 20 trips, the recorded distribution is reasonably similar to the normal distribution.

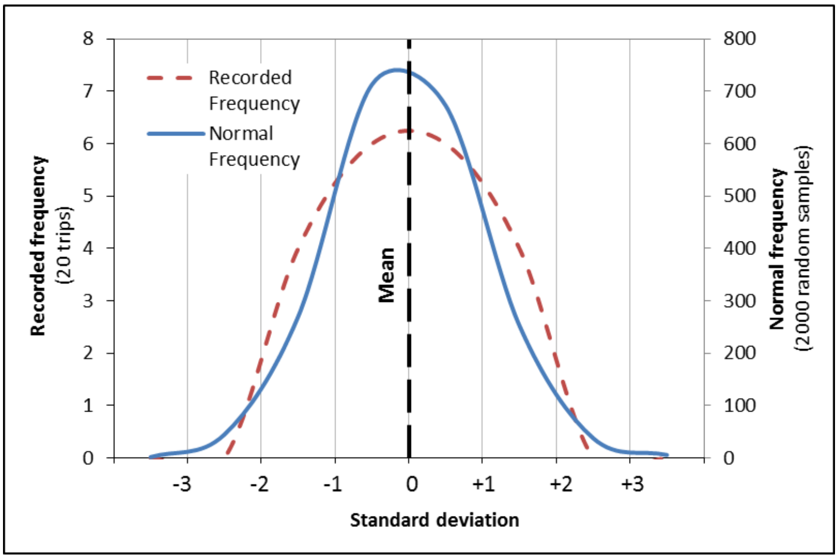


Figure 5-22: Route 2-PM trip time distribution

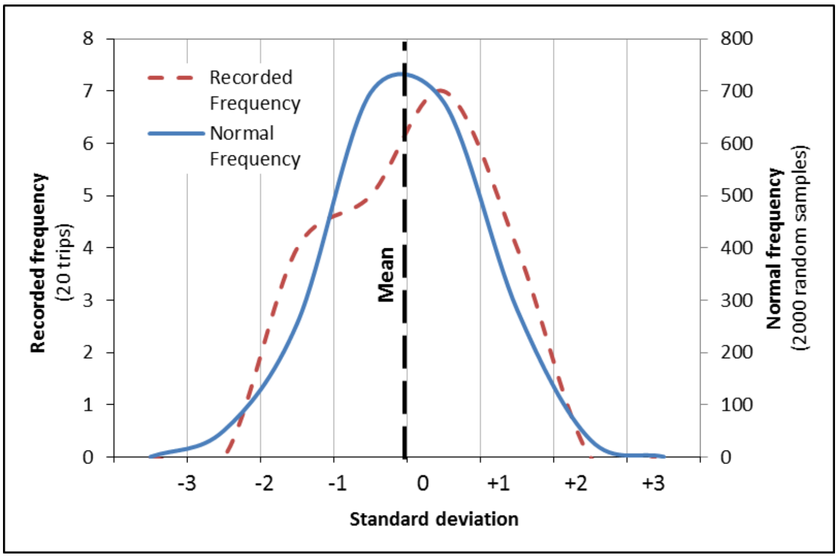


Figure 5-23: Route 2-PM abridged trip time distribution

5.4.5 Acceleration & deceleration time loss

Section 4.6.1 identified the additional time lost as a result of deceleration and acceleration as 5 seconds at each intersection stop. The impact on Route 2-PM is shown in Table 5-55.

Table 5-55: Route 2-PM impact of acceleration & deceleration time loss

Fewest stops on trip		Most stops on trip		Average stops per trip	
No. of Stops	**Decel & accel time loss** (mm:ss)	**No. of Stops**	**Decel & accel time loss** (mm:ss)	**Ave stops**	**Decel & accel time loss** (mm:ss)
6	00:30	9	00:45	7.7	00:39

With an average of 7.7 stops from the 9 intersections, the average time lost due to deceleration and acceleration on Route 2-PM was 39 seconds per trip.

5.4.6 Unimpeded travel speed comparison

The terms 'unimpeded travel speed' and 'realistic base travel speed' are defined in Section 5.1.6.

The unimpeded speed on this route is averaged from the speeds recorded on the section of Route 2-AM that travelled on a sealed path through Hagley Park and calculates to 23.6 km/h. In Table 5-56, the average speed on Route 2–PM of 21.9 km/h (Table 5-44) is compared to the unimpeded speed.

If the entire route were travelled at this speed, the travel time would be 17:45 minutes, which is 7:19 minutes quicker than the average trip time of 25:05. If the route average trip time is compared against the unimpeded speed trip time, this equates to a delay of 62 secs/km, 10 sec/km more than the 52 secs/km delay derived from the average results (Table 5-46).

Table 5-56: Route 2-PM unimpeded speed vs route average speed

	Speed (Km/h)	**Total moving time** (mm:ss)	**Total trip time** (mm:ss)	**Delay** (mm:ss)	**Delay per km** (mm:ss)
Unimpeded speed trip	23.6	17:45	17:45	00:00	00:00
Route average trip	21.9	18:59	25:05	07:19	01:02
Difference	1.7	01:14	07:19		

Table 5-57 compares the average route speed of 21.9 km/h to the realistic base speed. The realistic base travel speed calculates to 22.8 km/h, 0.8 km/h slower than the unimpeded speed. This speed gives a trip time of 18:20 seconds, 6:44 minutes faster than the average trip time of 25:05. This equates to a delay of 59 secs/km, 7 sec/km more than the 52 secs/km delay derived from the average route results.

Table 5-57: Realistic base speed vs route average speed

	Speed (Km/h)	**Total moving time** (mm:ss)	**Total trip time** (mm:ss)	**Delay** (mm:ss)	**Delay per km** (mm:ss)
Realistic base speed trip	22.8	18:20	18:20	00:00	00:00
Route average trip	21.9	18:59	25:05	06:44	00:59
Difference	0.9	00:39	06:44		

5.4.7 Comparison of stop rate with signal phase timing

Table 5-58 shows a comparison between the number of stops made at an intersection with the length of available green time and the percentage of the cycle length it represents. This data is indicative only and is based on the average peak hour signal phase timing data is extracted from the information provided by the Christchurch City Council traffic signals team for Thursday 12th September 2013.

The impacts of earthquake infrastructure repair road works on the section of Kilmore Street between Manchester Street and Park Terrace means data recorded in this stretch of road does not represent the normal operation of this part of the route (refer Section 5.4.)

Table 5-58: Route 2-PM comparison of stops and signal timing

Intersection	No. of times stopped	% of times stopped	Cycle length (mm:ss)	Available green phase (mm:ss)	% of cycle length
Kilmore / Barbadoes	15	75%	01:20	00:15	18%
Kilmore / Madras	20	100%	01:20	00:24	30%
Kilmore / Manchester	19	95%	00:40	00:16	40%
Kilmore / Colombo		Not applicable - signals not operational			
Kilmore / Durham	20	100%	02:41	00:12	8%
Kilmore / Montreal	20	100%	02:40	00:24	15%
Kilmore / Park Terrace	13	65%	01:25	00:15	18%
Kilmarnoch / Deans	18	90%	01:49	00:15	13%
Kilmarnoch / Straven	14	70%	02:06	00:43	34%
Creyke / Clyde	14	70%	01:48	00:49	46%

Table 5-58 shows the relatively short green phase and low percentage of cycle length that this route receives and this is reflected in the high stop rates. This is a result of several factors:

- The route crossing three major arterials; Barbadoes Street, Madras Street and Deans Avenue
- Although Straven Road is a minor arterial, it receives a significantly higher percentage of the cycle than Kilmarnoch Street, also a minor arterial.
- Double phasing against Kilmore Street at Durham and Montreal Streets as a result of earthquake infrastructure repair road works.

Creyke/Clyde, the only intersection with almost equally phase distribution, also had a higher than expected stop rate (70%) but this is considered to be a result of the random nature of the stops and the small sample size of 20. It is likely to trend closer to 50% if more trips were recorded.

Figure 5-24 shows the percentage of stops plotted against the percentage of the cycle length the green time represents. The trend line indicates no clear relationship when all the points are considered and an R^2 test gives a result of 0.09.

The lowest point below the trendline is Kilmore/Park Terrace intersection and could be considered an outlier but there is no clear reason for this. If this intersection is excluded, the R^2 test result increases to 0.22.

When only the three intersections in the outer city zone (Kilmarnoch/Deans, Kilmarnoch/Straven & Creyke /Clyde – circled in red on the graphs) are considered, the best fit line indicates a strong linear relationship, confirmed by an R^2 test result of 0.87 although this is obtained from a small sample size of three intersections.

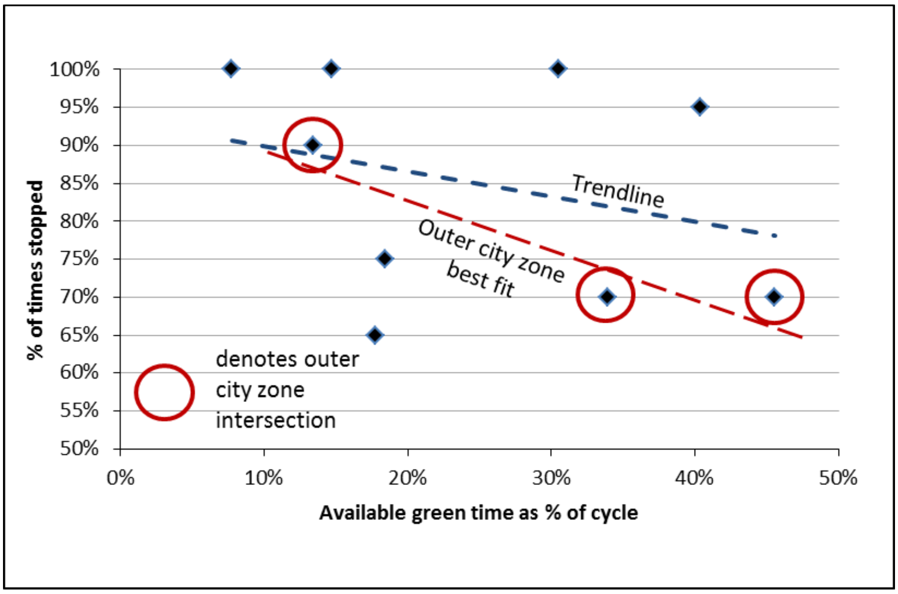


Figure 5-24: Route 2-PM number of stops vs percentage green time

5.4.8 Inner city zone signal co-ordination

As noted in Section 5.4, this section of Route 2-PM was significantly disrupted by infrastructure recovery road works and only the first three intersections of the route were operating to a normal fixed offset co-ordination pattern. As such, no progression diagram is included for this route.

6. Analysis and results

This section summarises the average results from the data recorded on all of the routes and compares the delays experienced on Route 1, which generally follows major arterial roads and Route 2, which generally follows minor arterial roads. The routes are detailed in Section 4.3.

As discussed in Sections 4.4 and 5.4, the impacts of earthquake infrastructure repair road works have fortunately been minimal, with the exception of part of the inner city section of Route 2-PM. To enable the remaining Route 2-PM data to be used in this study, the recorded data for the section of Kilmore Street between Manchester and Montreal Streets has been isolated and removed from the full route data. The amended Route 2-PM data is identified in Section 5.4 as 'Route 2-PM abridged' and is considered to be more representative of the normal operation of this route. The 'Route 2-PM abridged' values are used to represent Route 2-PM in this section.

6.1 All routes comparison

Table 6-1 compares the average speed and delay data of all four routes. The average moving time, average stopped time and average trip time for each route are not included in the following tables as variations in route distance and numbers of intersections make these values incomparable

Table 6-1: All routes speed & delay averages

	Number of signalised intersections	Ave speed (km/h)	Ave % of intersections stopped at	Ave % of trip time stopped	Ave delay per stop (mm:ss)	Ave delay per intersection (mm:ss)	Ave delay per km (mm:ss)
Route 1-AM	17	22.8	37%	15%	00:31	00:12	00:29
Route 1-PM	15	22.2	51%	17%	00:30	00:15	00:33
Route 2-AM	10	22.5	49%	14%	00:37	00:18	00:25
Route 2-PM abridged	7	22.4	81%	16%	00:35	00:28	00:31
Average of all routes		22.5	54%	15%	00:33	00:18	00:30
Route 1 average		22.5	44%	16%	00:31	00:13	00:31
Route 2 average		22.5	65%	15%	00:36	00:23	00:28

Table 6-1 demonstrates the consistency of the average speed across all four routes and the similarity in the amount of time stopped when considered as a percentage of the trip time.

The route averages show a lower level of delay for a cyclist travelling on Route 1, generally following major arterial roads, with a lower percentage of stops and shorter stops, however, the fewer number of intersections on Route 2 result in less delay per kilometre on this route.

If Route 2 featured 16 signalised intersections (the Route 1 average), using the Route 2 percentage stop rate and a time per stop values, the average delay per kilometre would increase to 54 seconds. This is 23 seconds slower per kilometre than the Route 1 value and a more realistic comparison between the two routes if they featured the same number of intersections.

Figure 6-1 shows the percentage of stops recorded on all the routes in 15 second time bands. There is surprising consistency across the first three time bands at 25%, 26% & 26% respectively.

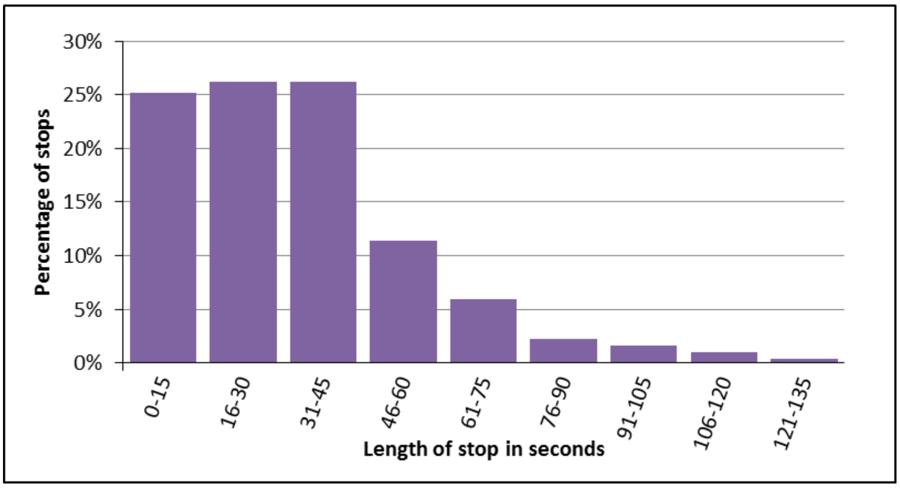


Figure 6-1: All routes stop length graph

Table 6-2 shows the total percentage of stops below a time limit. 77% of all stops were 45 seconds or less, however, 11% of all recorded stops were in excess of 60 seconds.

Table 6-2: All routes stop length breakdown

	Length of stop			
	15 secs or less	30 secs or less	45 secs or less	60 secs or less
All routes Percentage of stops	25%	51%	77%	89%

Note: Figure 6-1 & Table 6-2 are based on the Route 2-PM abridged data.

Figure 6-2 shows the percentage of stops recorded on Routes 1 & 2 in 15 second time bands. Route 1 has a much higher percentage of shorter stops. The majority (37%) of Route 2 stops were between 30 & 45 seconds.

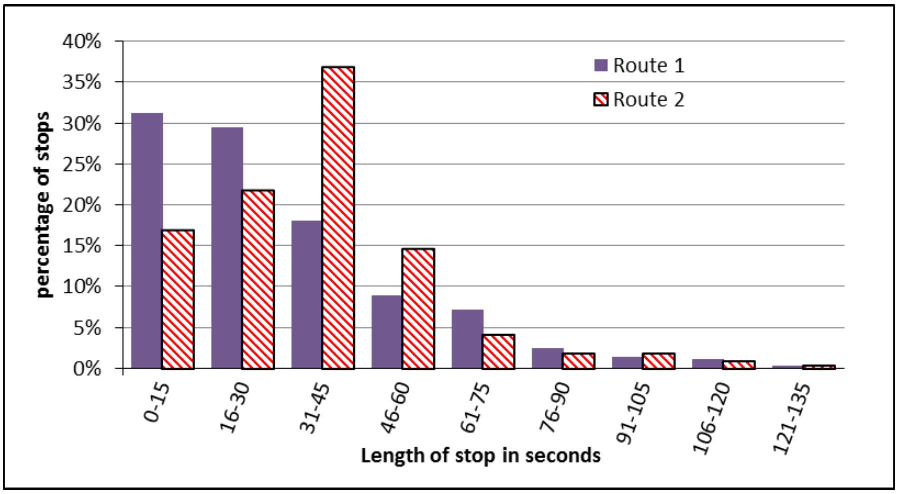


Figure 6-2: Route 1 & 2 stop length graph

Table 6-3 shows the total percentage of stops below a time limit. Although Route 1 clearly experienced a higher percentage of shorter stops, the percentage of stops of 45 seconds or less are very similar.

Table 6-3: Route 1 & 2 stop length breakdown

	Length of stop			
	15 secs or less	**30 secs or less**	**45 secs or less**	**60 secs or less**
Percentage of stops Route 1	31%	61%	79%	88%
Percentage of stops Route 2	17%	39%	76%	91%

6.2 Outer city zone delay

As previously noted, there is a significant difference in the spacing of intersections between the inner city section and the outer city section of the route. Table 6-4 compares the delays recorded on the outer city sections of Routes 1 & 2.

The Route 1 outer city intersections had a lower average stop rate, and shorter average stop length, however the closer spacing between intersections resulted in a slightly higher average delay per kilometre.

Table 6-4: Comparison of Route 1 & 2 outer city zones

	Distance (km)	No. of inter-sections	Average distance between inter-sections (km)	% of inter-sections stopped at	Average delay per inter-section (mm:ss)	Average length of stop (mm:ss)	Average delay per km (mm:ss)
Route 1-AM Outer city zone	4.26	7	0.61	45.7%	00:11	00:25	00:19
Route 1-PM Outer city zone	3.17	5	0.63	57.0%	00:21	00:36	00:33
Route 1 Outer city zone Average			0.62	51.4%	00:16	00:31	00:26
Route 2-AM Outer city zone	5.25	4	1.31	67.5%	00:24	00:36	00:19
Route 2-PM Abridged Outer city zone	3.93	3	1.31	76.7%	00:34	00:44	00:26
Route 2 Outer city zone Average			1.31	72.1%	00:29	00:40	00:22

Figure 6-3 shows the percentage of stops recorded in the Route 1 & 2outer city zones in 15 second time bands. As would be expected on the major arterial route, Route 1 had a higher percentage of shorter stops.

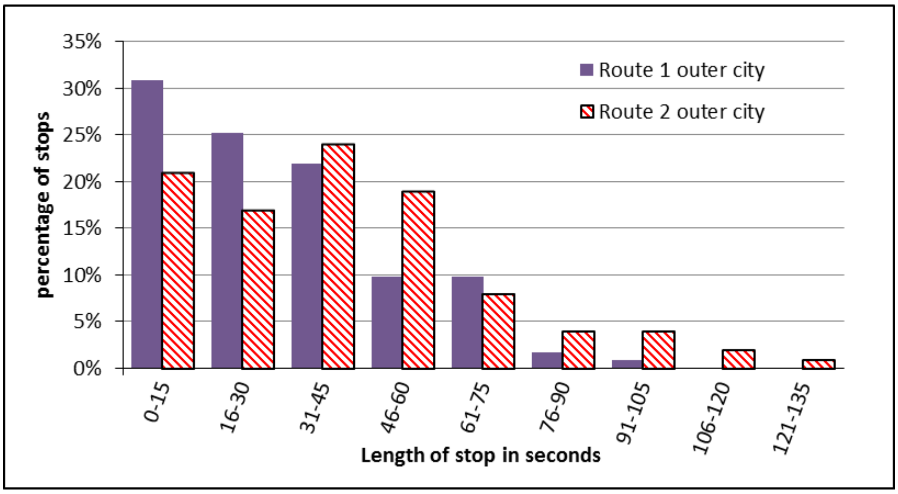


Figure 6-3: Route 1 & 2 outer city zone stop length graph

Table 6-5 shows the total percentage of Route 1 & 2 outer city zone stops below a time limit. Route 1 has the higher percentage in all four categories, indicating the stops were shorter on Route 1. 19% of Route 2 outer city zone stops exceeded 60 seconds.

Table 6-5: Route 1 & 2 outer city zone stop length breakdown

	Length of stop			
	15 secs or less	30 secs or less	45 secs or less	60 secs or less
Percentage of stops Route 1 Outer city zone	31%	56%	78%	88%
Percentage of stops Route 2 outer city zone	21%	38%	62%	81%

6.3 Inner city zone delay

Table 6-6 compares the delays recorded on the inner city sections of Routes 1 & 2. The Route 1-AM data excludes the hook turn as noted is Section 5.1.3 and the Route 2-PM data is abridged as noted in Section 5.4.

The inner city intersections on Route 1, the major arterial route, had a much lower average stop rate, shorter average delay per intersection and shorter average stop length. As the spacing between intersections was similar on both routes, Route 1 also had a much lower average delay per kilometre.

Table 6-6: Comparison of Routes 1 & 2 inner city zones

	Distance (km)	**No. of inter-sections**	**Average distance between inter-sections** (km)	**% of inter-sections stopped at**	**Average delay per inter-section** (mm:ss)	**Average length of stop** (mm:ss)	**Average delay per km** (mm:ss)
Route 1-AM Inner city zone (No hook turn)	1.63	8	0.20	26.9%	00:06	00:22	00:29
Route 1-PM Inner city zone	2.65	10	0.27	47.5%	00:13	00:27	00:48
Route 1 Inner city zone Average			0.23	37.2%	00:09	00:24	00:38
Route 2-AM Inner city zone	1.48	6	0.25	36.7%	00:14	00:37	00:55
Route 2-PM Abridged Inner city zone	1.02	4	0.26	83.8%	00:24	00:28	01:33
Route 2 Inner city zone Average			0.25	60.2%	00:19	00:33	01:14

Figure 6-4 shows the percentage of stops recorded in the Route 1 & 2inner city zones in 15 second time bands. As would be expected on the major arterial route, Route 1 had a higher percentage of shorter stops.

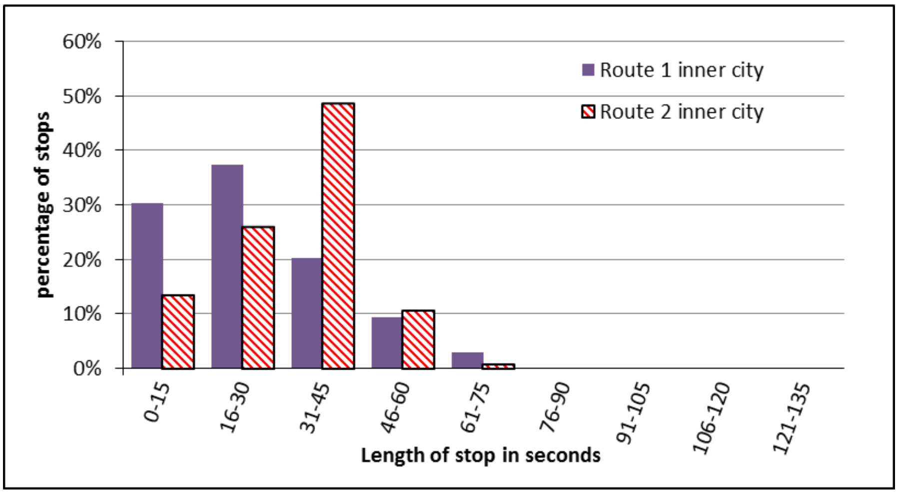


Figure 6-4: Route 1 & 2 inner city zone stop length graph

Table 6-7 shows the total percentage of Route 1 & 2 inner city zone stops below a time limit. Route 1 has much higher percentages in the first two categories, with the two routes very similar on the last two categories. Very few trips in the inner city zones exceeded 60 seconds.

Table 6-7: Route 1 & 2 inner city zone stop length breakdown

	Length of stop			
	15 secs or less	**30 secs or less**	**45 secs or less**	**60 secs or less**
Percentage of stops Route 1 Inner city zone	30%	68%	88%	97%
Percentage of stops Route 2 Inner city zone	14%	40%	88%	99%

6.4 Average stop rates

The primary reason for the difference in the delay experienced between Route 1 and Route 2 can be seen in Table 6-8 & Table 6-9, which show the average stop rates and signal phase details summarised from Table 5-12, Table 5-25, Table 5-38 & Table 5-58.

Table 6-8: Route 1 average stop rates & signal phase details

	Ave % of times stopped	**Ave cycle length** (mm:ss)	**Ave available green phase** (mm:ss)	**Ave % of cycle length**
Route 1-AM	37%	01:48	01:02	58%
Route 1-PM	51%	01:53	01:03	55%
Route 1 average	**44%**	**01:50**	**01:02**	**56%**

Table 6-9: Route 2 average stop rates & signal phase details

	Ave % of times stopped	Ave cycle length (mm:ss)	Ave available green phase (mm:ss)	Ave % of cycle length
Route 2-AM	49%	01:29	00:33	39%
Route 2-PM abridged	81%	01:30	00:25	29%
Route 2 average	**65%**	**01:29**	**00:29**	**34%**

Route 2, which generally follows minor arterial roads, typically receives a much shorter green phase, both in real time and as a percentage of the cycle length. This is reflected by the higher percentage stop rate and longer average stopped time.

In Table 6-10 to Table 6-13, the stop rates and signal phase details are further broken down into the inner and outer city zones of each route.

Table 6-10: Route 1 Outer city zone average stop rates & signal phase details

	Ave % of times stopped	Ave cycle length (mm:ss)	Ave available green phase (mm:ss)	Ave % of cycle length
Route 1-AM Outer city zone	46%	01:53	00:58	51%
Route 1-PM Outer city zone	57%	01:42	00:45	44%
Route 1 average	**51%**	**01:47**	**00:52**	**48%**

Table 6-11: Route 1 Inner city zone average stop rates & signal phase details

	Ave % of times stopped	Ave cycle length (mm:ss)	Ave available green phase (mm:ss)	Ave % of cycle length
Route 1-AM Inner city zone	32%	01:45	01:05	62%
Route 1-PM Inner city zone	48%	01:57	01:10	59%
Route 1 average	**40%**	**01:51**	**01:07**	**61%**

Table 6-12: Route 2 Outer city zone average stop rates & signal phase details

	Ave % of times stopped	Ave cycle length (mm:ss)	Ave available green phase (mm:ss)	Ave % of cycle length
Route 2-AM Outer city zone	68%	01:43	00:27	28%
Route 2-PM Outer city zone	77%	01:54	00:36	31%
Route 2 average	**72%**	**01:49**	**00:31**	**29%**

Table 6-13: Route 2 Inner city zone average stop rates & signal phase details

	Ave % of times stopped	Ave cycle length (mm:ss)	Ave available green phase (mm:ss)	Ave % of cycle length
Route 2-AM Inner city zone	37%	01:20	00:37	47%
Route 2-PM Abridged Inner city zone	84%	01:11	00:18	27%
Route 2 average	**60%**	**01:16**	**00:28**	**37%**

It can be seen that Route 1, with generally follows major arterial roads, benefits from much longer available green phase, both in time and as a percentage of the phase cycle length and this is reflected in the percentage stop rate. This is consistent in both inner and outer city zones.

6.5 Trip time variability

Table 6-14 compares the variability in stopped time and total trip time across the four routes. The average total stopped time and average total trip times for each route are not averaged due to differences in the route length.

Table 6-14: All routes stopped time & trip time variability summary

	Ave total stopped time (mm:ss)	Stopped time variability as % of ave total trip time	Stopped time standard deviation (mm:ss)	Ave total trip time (mm:ss)	Trip time variability as % of ave total trip time	Total trip time standard deviation (mm:ss)
Route 1-AM	03:16	24%	01:11	21:21	37%	01:37
Route 1-PM	03:50	18%	00:58	22:29	17%	01:00
Route 2-AM	02:59	12%	00:44	21:46	17%	00:54
Route 2-PM abridged	03:17	21%	01:05	20:11	19%	01:13
Average of all routes		**19%**	**01:00**		**22%**	**01:11**

When considered as a percentage of trip time, Route 2-AM has the lowest variability in stopped time at 12% and it is interesting that this is not reflected in the total trip variability percentage.

When considered as a percentage of trip time, the variability in trip time of Route1-PM and Route 2-AM & PM was very similar at between 17% & 19%. The exception is Route1-AM where the trip time variability was 37% of the average total trip time.

Route 1-AM had the highest number of intersections and although the Bealey Avenue signal co-ordination is set to benefit AM peak traffic travelling in the opposite (easterly) direction, the westbound traffic obviously also benefits from the extended phase times and on some days a westbound cyclist does too. From the total of 17 signalised intersections, the least number of stops on this route was 3, which was recorded twice, but the minimum trip time was recorded on a trip with 5 short stops. The maximum trip time was from the trip that also recorded the highest number of stops at 11.

Table 6-15 and Table 6-16 show the stopped and trip time variability recorded on Routes 1 and 2 respectively.

Table 6-15: Route 1 stopped time & trip time variability

	Ave total stopped time (mm:ss)	Stopped time variability as % of ave total trip time	Stopped time standard deviation (mm:ss)	Ave total trip time (mm:ss)	Trip time variability as % of ave total trip time	Total trip time standard deviation (mm:ss)
Route 1-AM	03:16	24%	01:11	21:21	37%	01:37
Route 1-PM	03:50	18%	00:58	22:29	17%	01:00
Route 1 average		**21%**	**01:05**		**27%**	**01:19**

Table 6-16: Route 2 stopped time & trip time variability

	Ave total stopped time (mm:ss)	Stopped time variability as % of ave total trip time	Stopped time standard deviation (mm:ss)	Ave total trip time (mm:ss)	Trip time variability as % of ave total trip time	Total trip time standard deviation (mm:ss)
Route 2-AM	02:59	12%	00:44	21:46	17%	00:54
Route 2-PM abridged	03:17	21%	01:05	20:11	19%	01:13
Route 2 average		**17%**	**00:55**		**18%**	**01:04**

With the higher number of intersections, Route 1 would be expected to have greater variability in both stopped and trip time and this is the case when the two route averages are compared. However, when the individual routes are considered, Route 2-PM abridged had a high stopped time variability even without the impacts of the Kilmore / Durham and Kilmore / Montreal intersections. This is a result of this Route crossing three major arterials (Barbadoes, Madras and Deans Ave) and the Straven Road minor arterial which also receives a significantly longer phase.

7. Discussion

7.1 Measures of delay

Four different ways have been used to measure the delay recorded at traffic signals in the various tables in this report:

Average delay per stop: is the average recorded total stopped time on a trip divided by average number of stops and indicates how long a cyclist can expect to wait each time they are stopped at a red signal.

This gives an indication of the general road hierarchy of the route, as this study has found that the higher priority route experienced shorter stops. On its own, this measure is of limited use unless accompanied by an average stop rate percentage.

Average delay per intersection: is the average recorded total stopped time divided by the number of intersections on the route and is used to calculate the average delay per kilometre.

This is a useful measure that varies subject to the route priority. It enables the average delay for any route with a number of signalised intersections to be to easily identified. Different values can be applied to suit differing intersection priorities and spacing along a route.

Average delay per kilometre: is the average stopped time on a route divided by the route length and can be used to compare delay on different routes.

This is a useful 'broad brush' value to identify expected delay on a route. However, this study has found intersection spacing has a significant impact on delay per kilometre and this should be considered when applying this measure of delay to a route where intersection spacing is not consistent.

Average delay as a percentage of total trip time: is the average recorded stopped time on a route divided by the average total trip time and indicates what percentage of trip time is made up of delay at traffic signals.

This measure is an easily understood way to compare the level of expected delay on different routes and is likely to be a useful route selection tool for cyclists.

Of these four measures, the most useful measure is considered to be the average delay per intersection. With known values for the average delay per intersection, expected delay for routes of varying hierarchal composition, number and spacing of intersections and route length can be compared. Delay per kilometre can be derived for any route where the average delay per intersection in known.

The average delay per kilometre and average delay as a percentage of total trip time are both easily understood measures than could be useful route information on cycle network maps, perhaps with the routes coloured to indicate different ranges of expected delay.

7.2 Acceptable levels of delay

The Highway Capacity Manual 2010 (Transportation Research Board 2010) notes that cyclists tend to have about the same tolerance for delay as pedestrians. They can become impatient when they experience a delay in excess of 30 seconds. The findings of this report indicate that the average stop at an intersection in peak hour traffic is 33 seconds, with 49% of all stops in excess of 30 seconds.

A signalised intersection provides a means for a vulnerable road user such as a cyclist to safely cross a busy peak hour traffic flow and it is reasonable to expect some level of delay as a result. What level of delay is considered to be an acceptable price for a safe crossing will vary from cyclist to cyclist.

This study has quantified the delays experienced by cyclists at traffic signals and this may be a useful starting point for further research with the aim of identifying acceptable levels of delay, and if the acceptable level varies on routes of differing hierarchy. It may be that shorter delays should be targeted on primary cycle network routes and lower hierarchy routes, as these are often preferred by cyclists. Road controlling authorities could be encouraged to work towards achieving these acceptable delay levels at traffic signals, particularly on the more popular cycle routes. The concept of acceptable limits in the levels of delay could then promoted to the general cycling public, possibly with the help of cycle advocate groups, with the aim of discouraging red light running.

Removing unnecessary delays by allowing cyclists to turn left on a red signal and continue through the head of a T intersection, particularly where cycle lanes are marked, would also eliminate these common red light offences.

7.3 Limitation of this study

7.3.1 The September 2010 and February 2011 earthquakes

As noted in Section 4.4, extensive infrastructure repairs resulting from of the September 2010 and February 2011 earthquakes have been ongoing in Christchurch during the timeframe of this research. Christchurch City traffic patterns are constantly changing in response to lane or road closures at sewer repair work sites. Some flexibility in daily study route choice has minimised the impacts of road works during the data recording trips for this study but traffic volume and route choice do not match pre-quake patterns.

Significant changes proposed to the inner city road network mean that the routes used in this study will not be able to be used for additional research to verify or to build on the findings.

7.3.2 Cycle travel speed

The results of this study are based on the trip time and delay recordings of a single cyclist travelling at an average speed of 22.5 km/h. Other cyclists travelling at different speeds will experience different stop rates and stopped time subject to the timing of their arrival each signalised intersection. This was demonstrated in Figure 5-5, Figure 5-11 & Figure 5-17.

However, the average speed of 22.5 km/h is similar to average speed values from studies found in the literature section of this report; 17.8 km/h (Dill & Gliebe, 2008), 18.3 km/h (Raksuntorn 2002) and 21.6 km/h (Parkin and Rotheram 2010). It is therefore hoped that these results will be applicable to a wide band of cycle commuters.

7.3.3 Road environment and climate

The routes used in this study were primarily major and minor arterials roads, as the intersections along routes of these classifications are often signalised. Although this study did consider inner and outer city zones, the possible impacts of changes in land use were not considered. The majority of trip recordings were undertaken during New Zealand's winter and spring seasons and no consideration has been given to the possibility of seasonal variation on the recorded delay.

7.3.4 Smartphone app updates

The smartphone apps reviewed in this study were all running the current software version at the start of the review. However, these apps are updated regularly and may now include features and functionality not available at the time of the review. This may mean an app excluded from consideration for this study, may now better meet the criteria and be suitable for future similar studies.

8. Conclusions

8.1 Delay at traffic signals

Many of the reports in the literature review identified delay as a significant component of cyclists mode and route choice, however only one study (Rietveld and Daniel 2004) quantified delay, using seconds per kilometre as the measure.

This study has recorded the actual delays experienced during peak hour traffic on two different routes, one which generally followed major arterial roads and one which generally followed minor arterial roads. Values have been identified for the average delay likely to be experienced at signalised intersections on each route.

When the distribution of recorded trip delay and trip time were compared to a normal distribution, all were found to be a reasonably good match allowing for the relatively small sample size of 20 trips.

Field testing found that deceleration and acceleration for a cyclist travelling at 22 km/h added an additional delay of 5 seconds per stop, but this value is based on a cyclist maintaining their speed until close to the intersection limit line and then braking if necessary. In reality, cyclists will tend to slow down and cruise up to a red signal in the hope it will change before they have to stop. The acceleration and deceleration time loses will be a component of almost any cycle trip and will vary with cycle speed. As such, additional time losses for acceleration and deceleration were noted in this report but are not included in reported average delay values.

When the data from the AM and PM trips on both routes is considered together, the cyclist was stopped at an average of average of 54% of the signalised intersections with an average stop length of 33 seconds. When considered in 15 second time bands, trips up to 45 seconds long were very evenly spread. 25% of stops were 15 seconds or less, with 26% between 15 & 30 seconds and 26% between 30 & 45 seconds. This equates to an average delay of 18 seconds for every intersection along the route. Delay accounted for an average of 15% of the total trip time. These values represent the average delays that are likely to be experienced at traffic signals in an urban environment.

The study considered each route individually and the results indicate that a cyclist travelling on a major arterial route will experience an average delay of 13 seconds for every signalised intersection on the route compared to 23 seconds per signalised intersection on a minor arterial route. A cyclist on a major arterial route will be stopped at an average of 44% of the traffic signals with an average stop length of 31 seconds whereas a cyclist on a minor arterial route will be stopped at an average of 65% of the traffic signals with an average stop length of 36 seconds.

The cyclist on the major route will also benefit from a higher percentage of shorter stops, 31% of stops of 15 seconds or less and 61% of stops of 30 seconds or less compared to 17% and 39% respectively for the minor arterial route. The cyclist on the major arterial route benefits from a longer average available green phase of 62 seconds (56% of the signal cycle) compared to an available green phase average time of 29 seconds (34% of the signal cycle) for the minor arterial route.

These results are similar when just the inner city area is considered. It is noted however that the Route 2-PM data is an abridged version of the full inner city area data, part of which was not considered as representative of normal operation as a result of the impacts of the earthquake damaged infrastructure repairs. As such, Route 2-PM data is from a small sample size of only four signalised intersections.

The average spacing of the inner city intersections is 250 m. The results indicate that a cyclist travelling on a major arterial route will experience an average delay of 12 seconds for every signalised intersection on the route and will be stopped at an average of 40% of the traffic signals with an average stop length of 32 seconds. A cyclist travelling on a minor arterial route will experience an average delay of 19 seconds for every inner city signalised intersection and will be stopped at an average of 60% of the traffic signals with an average stop length of 33 seconds.

The study results demonstrate a clear reduction in the level of delay for a cyclist travelling on a major arterial route, which can also often have the benefit of providing a direct route to a destination. This is balanced however, by the question of cycle safety. By definition, major arterial routes carry high traffic volumes, feature multiple traffic lanes, high numbers of turning vehicles and in many cases, on-street parking; all of which create a less than encouraging environment for cyclists. Unless cycle facilities that separate them from traffic are provided on arterial routes, most cyclists are likely to accept the increased delays on a quieter route.

8.2 Travel time variability

Even without any imposed delay, there will always be some variability in trip time as a result of wind, rain and day to day energy levels. The variability between the minimum and maximum recorded trip times, when considered as a percentage of the average trip time, was very consistent on three of the routes at 17 to 19%. The exception was Route 1-AM, where the variation was much higher at 37%. This route received the most benefit for the inner city signal co-ordination, with two trips recording just three stops from the 17 signalised intersections along the route. The shortest trip recorded a total of just 51 seconds delay from 5 stops and comparing this with the longest Route1-AM trip, which recorded stops at 11 intersections results in the high travel time variability on this route.

The study found an average variability in trip time of 22% of the average trip time is likely to be experienced on routes that include multiple traffic signals in an urban environment.

8.3 Delay recording equipment

The performance of the Garmin Edge 500 GPS cycle computer selected as the recording device for the study met all expectations. The devise was easy to mount and remove from the bike, simple to operate and only required periodic recharging. The audible beep could be clearly heard at the beginning and end of each stop and the delay was accurately recorded. The trip data was easily transferred to the Garmin Connect website where each trip was labeled and stored. Where intersections were closely spaced, the locations of recorded stops were able to be confirmed using interactive route markers on the website graphics. The necessary fields of data were easy to import into excel spreadsheets for use in the study. This device performed very well on this study would be ideal for other studies of a similar nature.

9. Recommendations

9.1 Further cyclist delay research

The results of this study are based on the trip data recorded by a single cycle commuter in Christchurch between July and October 2013. Twenty trips were made during the AM and PM peaks on two different routes at an average speed of 22.5 m/h. Both routes travelled in a predominantly east – west direction.

To build on the findings of this study, it is recommended that trips are undertaken by a cross section of cyclists on commuter routes in other New Zealand cities and recorded in a similar method to this study. A broader database containing results from different routes, cycle speeds and seasonal variations will enable more robust values for intersection delay to be derived.

It may be possible to adapt a smartphone app such as CycleTracks (refer Section 2.2.2) to record intersection delay which would enable large numbers of cyclists to provide route data to a central database operated by a local authority or university.

9.2 Maximum delay limit

This study found the average stop time across all routes was 33 seconds per stop, with many actual stops much longer than this. The Highway Capacity Manual 2010 (Transportation Research Board 2010) notes that cyclists tend to become impatient when they experience a delay in excess of 30 seconds.

With the prospect of major cycleways being developed in Christchurch and other path of New Zealand in the near future, it is recommended that a target maximum level of delay is identified, with a view to being imlimented at all signalised intersections along the cycleway route.

9.3 Cyclist levels of service

The NZ Pedestrian Planning and Design Guide (Land Transport 2005) nominates levels of service based on the mean queuing delay to pedestrian for various crossing facilities. Research could investigate if similar level of service ratings could be developed for cyclists delay at intersections. Further research could be undertaken to ascertain if correlation exists between the higher levels of delay experienced by cyclists at traffic signals and red lights running.

10. References

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11. Appendices

Appendix A: Example of TCX data file from GarminConnect website

@StartTime	Distance Meters	Avg Speed	Maximum Speed	Total Time Seconds	Altitude Meters	Distance Meters	Speed	Latitude Degrees	Longitude Degrees	Time
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	0	1.840	1.435	-43.51513471	172.580563	18/07/2013 19:55
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	0	11.470	4.171	-43.51511987	172.580686	18/07/2013 19:55
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	0	16.590	4.691	-43.51517226	172.580776	18/07/2013 19:55
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	0	27.620	5.086	-43.5152606	172.580924	18/07/2013 19:55
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	41.180	5.704	-43.51535666	172.581074	18/07/2013 19:55
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	51.250	5.796	-43.5154295	172.581173	18/07/2013 19:55
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	69.040	6.344	-43.51553243	172.581341	18/07/2013 19:55
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	81.190	6.41	-43.51560401	172.581455	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	105.730	6.934	-43.51573309	172.581703	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	117.450	6.501	-43.51579369	172.581821	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	135.580	6.467	-43.51588287	172.582009	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	180.600	7.526	-43.51618714	172.582383	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	187.350	7.507	-43.51623374	172.582437	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	209.240	6.573	-43.51635762	172.582654	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	241.020	6.639	-43.51651881	172.58298	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	259.390	6.839	-43.51660724	172.583173	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	288.080	6.46	-43.51674839	172.583481	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	294.820	7.333	-43.51680128	172.583526	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	306.720	6.843	-43.5168799	172.583627	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	331.890	7.08	-43.51702055	172.583869	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	345.390	7.572	-43.5170788	172.584016	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-0.600000024	351.950	7.477	-43.51711619	172.58408	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-1	367.580	6.894	-43.51721032	172.584232	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-1.399999976	373.550	6.914	-43.51724544	172.58429	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-1.799999952	378.920	6.651	-43.51727963	172.58434	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2	384.420	6.632	-43.51731752	172.58439	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	389.920	6.535	-43.51735775	172.584437	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	395.220	6.866	-43.51740444	172.584464	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	401.730	6.863	-43.51745088	172.584515	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	436.540	6.732	-43.51763922	172.58486	18/07/2013 19:56
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	481.200	7.342	-43.51788917	172.585294	18/07/2013 19:57
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	516.300	8.555	-43.51804909	172.585676	18/07/2013 19:57
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	527.200	7.354	-43.51815739	172.585732	18/07/2013 19:57
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	533.710	7.446	-43.51820223	172.585785	18/07/2013 19:57
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	572.300	8.26	-43.51844589	172.586134	18/07/2013 19:57
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	577.950	7.736	-43.51848034	172.586189	18/07/2013 19:57
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	605.770	8.142	-43.51865167	172.58647	18/07/2013 19:57
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	624.390	6.895	-43.51877404	172.586642	18/07/2013 19:57
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	647.780	6.374	-43.51890245	172.586875	18/07/2013 19:57
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	659.000	6.217	-43.51897915	172.586968	18/07/2013 19:57
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	700.340	6.225	-43.51923287	172.587343	18/07/2013 19:57
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	766.270	5.893	-43.51961919	172.587962	18/07/2013 19:57
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	832.090	6.159	-43.52000224	172.58858	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	838.400	6.175	-43.52001968	172.588655	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	857.030	6.184	-43.52003904	172.588883	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	869.630	6.199	-43.52004725	172.589039	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	930.170	5.755	-43.52011037	172.589782	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	941.480	5.461	-43.52012311	172.589921	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	954.330	3.904	-43.52010601	172.590071	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	959.030	4.418	-43.52006544	172.590087	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	981.630	5.986	-43.51986243	172.590106	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	1013.520	6.413	-43.5195772	172.590151	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	1026.360	6.679	-43.51946505	172.590191	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	1032.500	6.407	-43.51940998	172.590198	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	1058.730	6.624	-43.51917487	172.590229	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	1112.540	5.1	-43.5186924	172.590283	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	1126.550	2.006	-43.51856827	172.590313	18/07/2013 19:58
18/07/2013 19:55	6859.21	6.343	8.556	1081.319	-2.599999905	1131.060	0	-43.51852954	172.590332	18/07/2013 19:59

Appendix B: Example of signal phase timing data from Christchurch City Council

Route 1: Bealey Avenue / Durham St Road CCC Intersection No.64

Date		Start Time	End Time	Duration	Phase
Thu	12-Sep-13	7:59:14	8:00:01	47	D
Thu	12-Sep-13	8:00:01	8:00:18	17	C
Thu	12-Sep-13	8:00:18	8:00:50	32	A
Thu	12-Sep-13	8:00:50	8:01:14	24	B
Thu	12-Sep-13	8:01:14	8:01:51	37	D
Thu	12-Sep-13	8:01:51	8:02:54	63	A
Thu	12-Sep-13	8:02:54	8:03:18	24	B
Thu	12-Sep-13	8:03:18	8:03:54	36	D
Thu	12-Sep-13	8:03:54	8:04:13	19	C
Thu	12-Sep-13	8:04:13	8:04:55	42	A
Thu	12-Sep-13	8:04:55	8:05:21	26	B
Thu	12-Sep-13	8:05:21	8:05:56	35	D
Thu	12-Sep-13	8:05:56	8:06:17	21	C
Thu	12-Sep-13	8:06:17	8:07:01	44	A
Thu	12-Sep-13	8:07:01	8:07:25	24	B
Thu	12-Sep-13	8:07:25	8:08:00	35	D
Thu	12-Sep-13	8:08:00	8:08:14	14	C
Thu	12-Sep-13	8:08:14	8:08:46	32	A
Thu	12-Sep-13	8:08:46	8:09:10	24	B
Thu	12-Sep-13	8:09:10	8:09:55	45	D
Thu	12-Sep-13	8:09:55	8:10:07	12	C
Thu	12-Sep-13	8:10:07	8:10:38	31	A
Thu	12-Sep-13	8:10:38	8:11:00	22	B
Thu	12-Sep-13	8:11:00	8:11:36	36	D
Thu	12-Sep-13	8:11:36	8:11:58	22	C
Thu	12-Sep-13	8:11:58	8:12:31	33	A
Thu	12-Sep-13	8:12:31	8:12:52	21	B
Thu	12-Sep-13	8:12:52	8:13:34	42	D
Thu	12-Sep-13	8:13:34	8:13:50	16	C
Thu	12-Sep-13	8:13:50	8:14:21	31	A
Thu	12-Sep-13	8:14:21	8:14:48	27	B
Thu	12-Sep-13	8:14:48	8:15:24	36	D

Route 2: Salisbury Ave / Durham St CCC Intersection No.42

Date		Start Time	End Time	Duration	Phase
Thu	12-Sep-13	7:59:58	8:00:31	33	A
Thu	12-Sep-13	8:00:31	8:01:19	48	B
Thu	12-Sep-13	8:01:19	8:01:52	33	A
Thu	12-Sep-13	8:01:52	8:02:39	47	B
Thu	12-Sep-13	8:02:39	8:03:13	34	A
Thu	12-Sep-13	8:03:13	8:03:59	46	B
Thu	12-Sep-13	8:03:59	8:04:32	33	A
Thu	12-Sep-13	8:04:32	8:05:19	47	B
Thu	12-Sep-13	8:05:19	8:05:51	32	A
Thu	12-Sep-13	8:05:51	8:06:39	48	B
Thu	12-Sep-13	8:06:39	8:07:12	33	A
Thu	12-Sep-13	8:07:12	8:07:58	46	B
Thu	12-Sep-13	8:07:58	8:08:31	33	A
Thu	12-Sep-13	8:08:31	8:09:20	49	B
Thu	12-Sep-13	8:09:20	8:09:52	32	A
Thu	12-Sep-13	8:09:52	8:10:39	47	B
Thu	12-Sep-13	8:10:39	8:11:11	32	A
Thu	12-Sep-13	8:11:11	8:11:58	47	B
Thu	12-Sep-13	8:11:58	8:12:32	34	A
Thu	12-Sep-13	8:12:32	8:13:19	47	B
Thu	12-Sep-13	8:13:19	8:13:52	33	A
Thu	12-Sep-13	8:13:52	8:14:38	46	B
Thu	12-Sep-13	8:14:38	8:15:12	34	A
Thu	12-Sep-13	8:15:12	8:15:58	46	B
Thu	12-Sep-13	8:15:58	8:16:32	34	A
Thu	12-Sep-13	8:16:32	8:17:19	47	B
Thu	12-Sep-13	8:17:19	8:17:51	32	A
Thu	12-Sep-13	8:17:51	8:18:39	48	B
Thu	12-Sep-13	8:18:39	8:19:12	33	A
Thu	12-Sep-13	8:19:12	8:19:59	47	B
Thu	12-Sep-13	8:19:59	8:20:32	33	A
Thu	12-Sep-13	8:20:32	8:21:19	47	B
Thu	12-Sep-13	8:21:19	8:21:52	33	A

Appendix C: Acceleration and deceleration field testing data

Deceleration data

Test	Date	Distance (metres)	Speed (m/sec)	Speed (km/h)	Time	Stopping Time (sec)	Distance (m)	Deceleration rate (m/sec²)
1	7/09/13	386.45	6.70	24.13	3:57:17	00:06	11.06	1.12
		397.51	0.00	0.00	3:57:23			
2		980.40	6.14	22.10	3:59:37	00:05	5.69	1.02
		986.09	0.00	0.00	3:59:42			
3		1720.53	6.14	22.12	4:02:27	00:05	12.57	1.02
		1733.10	0.00	0.00	4:02:32			
4		2220.41	6.47	23.30	4:04:22	00:04	9.02	1.08
		2229.43	0.00	0.00	4:04:26			
5		2324.87	6.66	23.97	4:04:48	00:06	13.45	1.11
		2338.32	0.00	0.00	4:04:54			
6		2564.40	6.39	23.02	4:05:43	00:05	12.00	1.28
		2576.40	0.00	0.00	4:05:48			
7		2708.87	6.63	23.87	4:06:20	00:05	11.77	1.33
		2720.64	0.00	0.00	4:06:25			
8	8/09/13	531.54	5.85	21.07	5:19:06	00:05	11.36	1.17
		542.90	0.00	0.00	5:19:11			
9		818.34	6.17	22.21	5:20:11	00:05	8.37	1.23
		826.71	0.00	0.00	5:20:16			
10		1146.08	6.99	25.17	5:21:29	00:05	7.82	1.40
		1153.90	0.00	0.00	5:21:34			
11		1386.84	6.26	22.52	5:22:30	00:07	11.47	0.89
		1398.31	0.00	0.00	5:22:37			
12		1582.56	6.02	21.68	5:23:17	00:04	6.08	1.51
		1588.64	0.00	0.00	5:23:21			
13		1709.67	6.55	23.58	5:23:45	00:04	6.26	1.64
		1715.93	0.00	0.00	5:23:49			
14		1851.68	6.12	22.02	5:24:26	00:04	6.42	1.53
		1858.10	0.00	0.00	5:24:30			
15		2176.12	6.22	22.41	5:25:39	00:06	11.43	1.04
		2187.55	0.00	0.00	5:25:45			
					Average	**00:05.1**	**9.65**	**1.22**

Acceleration data

Test	Date	Distance (metres)	Speed (m/sec)	Speed (km/h)	Time	Acceleration Time (sec)	Distance (m)	Acceleration Rate (m/sec²)
1	7/09/13	397.51	0.00	0.00	3:57:29	00:17	95.25	0.36
		492.76	6.15	22.15	3:57:46			
2		884.84	0.00	0.00	3:59:20	00:17	95.56	0.36
		980.40	6.14	22.10	3:59:37			
3		986.09	0.00	0.00	3:59:44	00:14	86.41	0.44
		1072.50	6.16	22.17	3:59:58			
4		1093.94	0.00	0.00	4:00:09	00:16	88.61	0.37
		1182.55	5.90	21.24	4:00:25			
5		1733.10	0.00	0.00	4:02:44	00:18	99.69	0.35
		1832.79	6.26	22.54	4:03:02			
6		1943.20	0.00	0.00	4:03:34	00:16	95.48	0.39
		2038.68	6.27	22.57	4:03:50			
7		2230.35	0.00	0.00	4:04:32	00:15	88.01	0.41
		2318.36	6.20	22.32	4:04:47			
8		2338.81	0.00	0.00	4:05:04	00:17	101.12	0.38
		2439.93	6.54	23.54	4:05:21			
9		2577.87	0.00	0.00	4:05:58	00:18	104.21	0.35
		2682.08	6.30	22.67	4:06:16			
10		2721.05	0.00	0.00	4:06:28	00:19	94.88	0.33
		2815.93	6.22	22.40	4:06:47			
11	8/09/13	91.12	0.00	0.00	5:17:22	00:17	89.07	0.36
		180.19	6.14	22.09	5:17:39			
12		886.70	0.00	0.00	5:20:36	00:18	96.25	0.36
		982.95	6.50	23.41	5:20:54			
13		1019.26	0.00	0.00	5:21:08	00:15	88.84	0.42
		1108.10	6.28	22.59	5:21:23			
14		1588.66	0.00	0.00	5:23:24	00:17	96.60	0.37
		1685.26	6.25	22.50	5:23:41			
15		1858.95	0.00	0.00	5:24:33	00:20	109.98	0.34
		1968.93	6.75	24.30	5:24:53			
					Average	**00:16.9**	**95.33**	**0.37**