Cyclists at Wide Intersections

All-Red Time Extension on Demand

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Summary

The city centre of Christchurch is surrounded on three sides by multi-lane avenues, which cyclists have to cross to get to or from the central business district. This paper examines the problem of insufficient intergreen times for cyclists at the wide signalised intersections on these avenues. Without doing anything wrong or illegal, cyclists can be in the middle of a wide intersection when the cross traffic starts.

In Christchurch, all red-times are calculated on the basis of slow motor vehicle speeds and intersection widths. All-red time demands are presented in the paper in a graphical form. The same method applied to cycle speeds reveals that the all-red time requirement of cyclists is 3 to 4 seconds higher than the actual time provided at wide intersections. Injury crashes on the avenues can be found in the safety record databases where the insufficient intergreen times are the common crash cause. Some individual cyclists experience the signal setting problem often enough that it acts as a deterrent to cycling to them.

A range of options, including early cut-offs for cyclists and a general increase in all-red time, are discussed and rejected. Instead, a proposal for an all-red time extension on demand is recommended using detectors within the intersection. A procedure is developed to determine the optimum position and timings for a series of two detectors. As the technology will automatically work for the cyclists, they will not need to adapt their behaviour and no publicity campaign will be necessary. The problem can be sufficiently quantified where a favourable benefit/cost ratio can be determined. Cycle groups who have been consulted have expressed their favour for the proposal.

The author believes that of all the options explored, the proposal is the most effective and the most cycle-friendly. A trial will be implemented in Christchurch.

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TABLE OF CONTENTS

Table of Figures

1 INTRODUCTION

At signalised intersections, all intergreen times are according to Austroads 7 (Austroads, 1993) calculated on the basis of speeds of motorists and intersection width. This falls short of the fact that cyclists complying with all traffic regulations might end up to be in the middle of a wide intersection, when cross traffic starts to enter the intersection.

This paper discusses possible treatments for this problem.

2 CYCLISTS AS ROAD USERS

For calculating signal timings, it is common practice to work with the 15th percentile speed for all-red time calculations, and an 85th percentile speed for yellow times. Assumptions have to be made about reaction times and deceleration capabilities for the required length of the yellow interval. For minimum green time calculations, knowledge about acceleration capabilities is required.

2.1 Literature Review

The New Zealand standard for traffic signals (NZS 5431:1973) does not mention cyclists with regard to controller time settings.

Figure A.8 in Austroads 7 (Austroads, 1993) shows typical starting capabilities of vehicles on a dry, level pavement. According to this figure, the typical bicycle accelerates with approximately 1.7 m/s^2 up to 25 km/h. When the cruise speed of 45 km/h is reached, the mean acceleration has yielded approximately 1,0 m/s^2.

The Dutch design guide for bicycle facilities (CROW, 1993) gives the 85th percentile speed as 22 km/h. The start acceleration rate is given with 0.8 to 1.2 m/s^2, with 20 km/h to be the recommended value for clearance time calculations.

The German bicycle facilities design manual (FGSV, 1995) recommends 4 m/s (14.4 km/h) for clearance time calculations.

The AASHTO Guide (1991) specifies the use of 16 km/h for signal clearance calculations. A draft update for the guide from 1995 notes accelerations of 0.5 to 1.0 m/s^2 as minimum values.

Pein (1996) has studied cyclists' performance on an offroad path in Pinnelas Country, Florida. The crossing times from a full stop at intersections of different widths were measured using video equipment, and a linear regression model was fit to the results. Cruising speed was also determined. The 15th percentile values are 10.8 km/h for the speed after acceleration, and 0.74 m/s^2 for the acceleration. Mean values were found to be 12.7 km/h, and 1.07m/s^2. The mean crossing speed from a stop, computed by distance over time, was 8.9 km/h. A reaction time is not included in these values, as measurements were taken from the start-up. The average mid-block cruising speed was measured to be 15.4 km/h.

In Palo Alto, California, six intersections were surveyed, where clearance time accidents had occurred or were considered likely to occur based on physical characteristics of the intersection (Wachtel et al., 1995). The range of the mean crossing speed from a stop was found to be in the range from 8.4 to 14 km/h. The mean accelerations were calculated to range from 0.57 to 0.80 m/s^2 at these intersections. For a rolling start, mean speeds were in the range from 14.3 to 26.6 km/h.

2.2 **Speed Measurements**

Speed measurements of 68 cyclists were taken in a mid-block in Christchurch during a light to moderate head wind. The 15th percentile speed was determined to be 4.5 m/s or 16.2 km/h.

2.3 **Discussion**

Neither of the overseas design manual sources specifies the design values as being mean or 15th percentile. The values in Austroads 7 (cruising speed of 45 km/h for a 'typical' bicycle) are certainly not typical values as stated, but might be maximum values. Therefore, these values cannot be taken into consideration for this paper.

The results from the American studies indicate that speeds are higher for cyclists using on-road facilities than off-road paths. A possible explanation is that the more experienced, and thus faster cyclists prefer the more direct and complete network of roads over paths.

It is generally assumed that cyclists reach their cruise speed during the crossing of the intersection. This is also supported when the clearance distances are computed using the acceleration and cruising speed values from the studies above, with the following equation:

$$d_a = \frac{1}{2} * \left(\frac{v^2}{a} \right) - L_b \qquad (1)$$

where: d_a = distance cleared during acceleration (m)
L_b = bicycle length, assume 1.8 m
v = cruise speed after acceleration (m/s)
a = acceleration, assumed to be linear (m/s^2)

The 15th percentile values computed in Pinellas Country, Florida, of 10.8 km/h for the speed after acceleration, and 0.74 m/s^2 for the acceleration indicate that 4.3 m are cleared before cruise speed is reached. As the range of intersection width was from 6.4 to 32 m, with an average of 17.9 m, it could be assumed that nearly all cyclists reach their maximum speed within the intersection. However, this is contrary to the measured mid-block cruise speed of 15.4 km/h, which is 20% higher than the calculated mean speed of 12.7 km/h after acceleration.

Using the values from the other American study, the clearance distances range from 3 to 7 m. The values in the Dutch and AASHTO design guides yield clearance distances in the range from 8 to 18 m, before maximum speed is reached.

That cyclists using the Pinellas Country off-road track accelerate harder, and reach slower cruise speeds than the on-road cyclists in Palo Alto is a somewhat surprising result. Pein argues that the assumption of uniform acceleration might be the source of error.

The 15th percentile travel speed used for calculations in this paper is assumed to be 4.5 m/s, or 16.2 km/h. This is identical with the value recommended by the AASHTO guide (16 km/h) and the value measured in Christchurch, slightly higher than the German recommendation (4 m/s), but below the Dutch design speed (20km/h).

3 SIGNAL TIMINGS

The author was made aware of the problem of insufficient clearance times for cyclists when he worked for the Christchurch City Council and received a complaint from an elderly cyclist. Discussions with signal engineers revealed that over the years, numerous cyclists had criticised the signal settings. These road users were advised to stop at the solid median when they entered the intersection late in the phase. However, not every wide intersection has a solid median.

3.1 All-Red Time Calculation

The problem originates from all-red times being calculated using the 15th percentile speed of **motorists** at the termination of the yellow interval. However, as cyclists are much slower than motorists, the clearance times are insufficient for them. A method of how to determine the amount of clearance time that is missing will be presented in a graphical way in section 3.1.3.

3.1.1 Austroads

Austroads 7 gives an equation to calculate all-red times of traffic signals (equation A.6):

$$t_r = \frac{d + L}{V_L} - t_s \qquad (2)$$

where: t_r = all-red time (sec)
d = intersection width (m)
L = vehicle length (m)
V_L = 15th percentile speed at the termination of the yellow interval (m/s)
t_s = start-up time of cross traffic (sec)

3.1.2 Christchurch Method

A modified method is used in Christchurch to determine all-red times. Distances from the stoplines to a conflict point between clearing vehicles and cross traffic (or crossing pedestrians) are taken into account. Appendix (A) shows a worksheet for the calculation of all-red periods used in Christchurch with the equations and assumptions stated. The method is discussed in Appendix (B).

The equation on the worksheet can be simplified for the conflict with crossing vehicles, as the start-up delay and the added safety margin are both 0.5 sec and so cancel each other:

$$t_r = \frac{d_1 + L_{car}}{v_{car15}} - t_t \qquad (3)$$

where: t_r = all-red time (sec)

d_1 = distance from stopline to the conflict point for the moving vehicle (m)

L_{car} = vehicle length (m)

v_{car15} = 15th percentile speed at the termination of the yellow interval (m/s)

t_t = time for the stationary vehicle to reach the conflict point (sec)

When the values for the stationary vehicle entering the intersection are plotted, and a trend line is added, the following equation describes the trend line:

$$t_t = 0.0038 * d_l^2 - 0.1621 * d_l - 0.4341 \qquad (4)$$

As the calculations are done in a spreadsheet, the above polynom will be used.

3.1.3 **Example: Intersection Ferry Road / Fitzgerald Avenue**

The intersection between Ferry Road and Fitzgerald Avenue has been chosen, as Ferry Road is the major cycle route from the south east of Christchurch into the City. Up to 70 cyclists proceed straight ahead on Ferry Road during a 90 minutes count period. Figure 1 shows the layout of this intersection, and the distances to the conflict point between vehicles. Using 45 km/h as the speed for clearing vehicles yields an all-red requirement of 1.6 sec, when equation (3) is used. The governing conflict for motorists is that with pedestrians on the far side, therefore the actual all-red time is 2.0 sec.

Figure 2 shows a graphical presentation of the all-red time requirement. It is based on the Austroads 7 (1993) assumption that all-red times have to be calculated for vehicles crossing the limit lines at the start of the red interval. Zero on the time axis is the start of the all-red period.

The graph above the x-axis represents the vehicle clearing the intersection at the 15th percentile speed. It shows that a vehicle on Ferry Road will take 3.1 sec to travel the

34 metres to the point of conflict, assuming a vehicle length of 5 metres. The vehicle length is taken into account on the graph by starting with 0.4 sec at the origin.

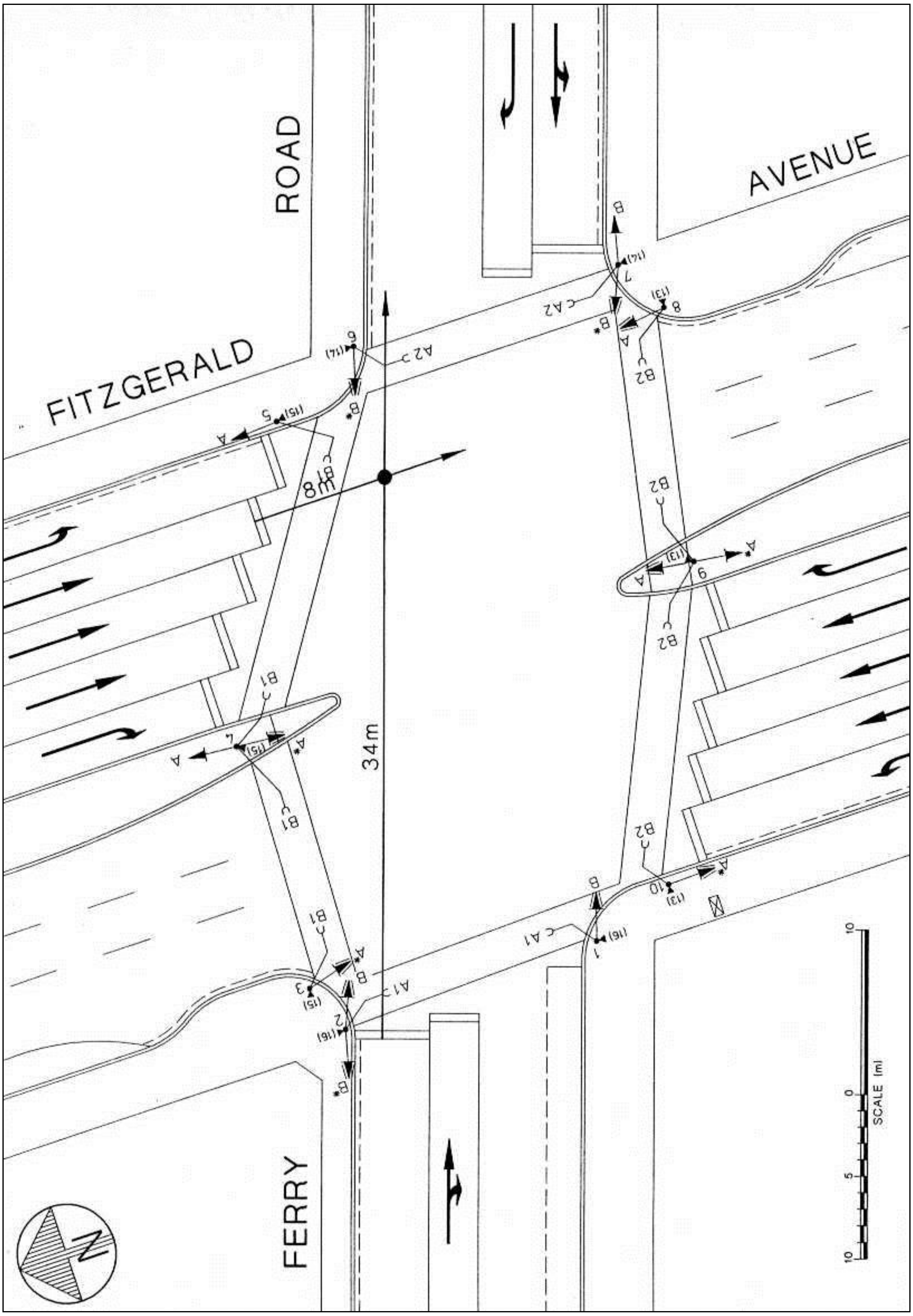

Figure 1: Intersection Layout and Conflict Point

The graph below the x-axis represents stationary vehicles entering at the start of their phase. Based on the values used in Christchurch, a stationary vehicle on Fitzgerald Avenue will take 1.5 sec to travel the 8 metres to the conflict point. The all-red time is therefore the 3.1 sec for the clearing vehicle minus the 1.5 sec for the starting vehicle, or 1.6 sec.

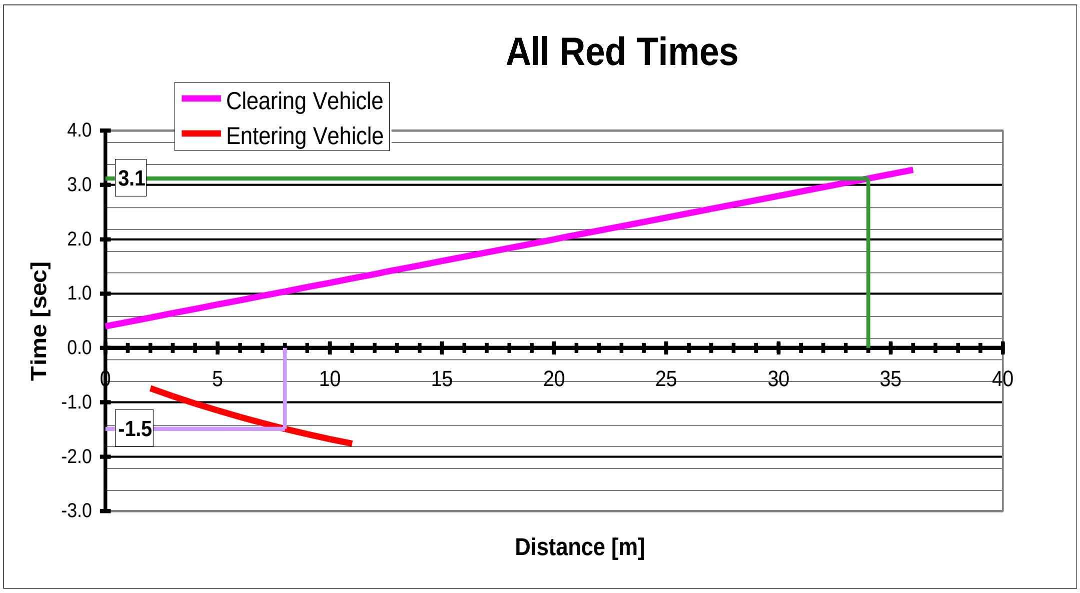

Figure 2: Graphical Presentation of All-Red Time Requirement

3.2 Yellow Time

Austroads 7 (1993) gives an equation (equation A.4, page 75) for the calculation of the yellow interval:

$$t_y = T + \frac{v_{car85}}{2*(a \pm 9.8*G)} \qquad (5)$$

where: t_y = yellow time (sec)

T = reaction time (sec)

v_{car85} = 85th percentile speed (m/s)

a = an ‘acceptable’ deceleration rate (m/s^2)

G = approach gradient (— for down-grade, and + for up-grade)

The recommended values of 1.5 sec for the reaction time, and 3.0 m/s^2 for the deceleration are in use in Christchurch.

Figure A.7 in Austroads 7 shows typical braking capabilities of vehicles on a wet pavement. The deceleration of a bicycle is given with 2.0 m/s^2, when adjusted for a level road.

3.3 Minimum Green Time Requirement

For the green time requirement, the 15th percentile values determined by Pein (1996) can be taken to compute minimum values from a standing start. The crossing then consists of the elements start-up delay, acceleration, and constant crossing speed.

$$t_{cl} = t_s + \frac{d_b - d_a}{v_{b15}} \qquad (6)$$

where:
t_{cl} = clearing time from standing start (sec)
t_s = start-up delay (sec)
d_b = distance from stopline to the conflict point for the moving bicycle (m)
d_a = distance over which the cyclist accelerates (m)
v_b = 15th percentile bicycle crossing speed (m/s)

When equation (1) for the acceleration distance is substituted, the equation yields:

$$t_{cl} = t_s + \frac{d_b - 0.5 * \frac{v_{b15}^2}{a} + L_b}{v_{b15}} \qquad (7)$$

The equation can be simplified to:

$$t_{cl} = t_s - \frac{v_{b15}}{2a} + \frac{d_b + 1.8}{v_{b15}} \qquad (8)$$

Using t_s = 2.0 sec, v_{b15} = 4.5 m/s, a = 0.8 m/s^2 as assumptions for 15th percentile values based on the discussion before, the equation further simplifies to:

$$t_{cl} = 1.3 + \frac{d_b}{4.5} \qquad (9)$$

The intersection used in the example has a distance d_b to the conflict point of 33 m. The time required for cyclists using 15th percentile values to get clear of the conflict point is 8.6 sec from the beginning of the green interval. This shows that minimum green times of 6 sec are sufficient for cyclists even at very wide intersections from a safety point of view, as the crossing can be completed during the yellow interval.

3.4 Signal Timing Requirements for Cyclists

The same intersection of Ferry Road / Fitzgerald Avenue is used to highlight the problem of signal timings for cyclists at wide intersections. The yellow time requirement is computed for slow cyclists, as they have the problem of clearing the intersection in time. This is contrary to the method used for motorists, where the 85th percentile speed is taken in order to provide an adequate period of time in which to stop.

The 15th percentile travel speed shall be taken as 4.5 m/s as discussed in section 2.3. As for motorists, a reaction time of 1.5 sec seems appropriate. The deceleration rate is taken as 2.0 m/s^2. Using equation (5), cyclists travelling at 4.5 m/s have a yellow time requirement of 1.5 sec for reaction time plus 1.1 sec for braking, adding up to 2.6 sec.

The example intersection has a yellow time of 3.8 sec. When the cyclist yellow time requirement is deducted from this, it can be seen that slow cyclists might cross the limit lines 1.2 sec before the end of the yellow interval. The chart in Figure 3 takes the bicycle length into account. It shows that cyclists are clear of the conflict point 6.8 sec after the start of the all-red time, 3.7 sec later than the time required for motorists. It can also be seen that when motorists have just passed the conflict point after 3.1 sec, the cyclists have travelled 18 m (plus the bicycle length) since crossing the limit lines - about half the width of the intersection.

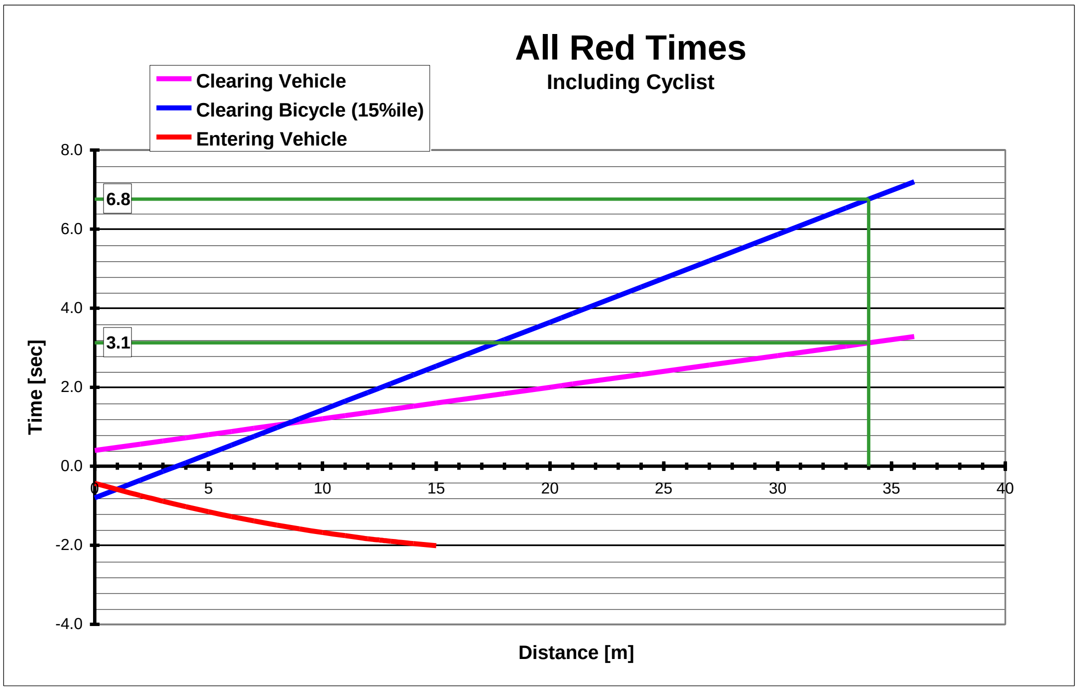

Figure 3: Graphical Presentation of All-Red Time Requirement for Cyclists

As stated earlier, the actual all-red time is 2.0 sec. This is higher than the 1.6 sec because the governing conflict is the vehicle / pedestrian conflict. For cyclists however, it is assumed that the all-red time requirement results only from a cycle / motorist conflict. Is seems appropriate to assume that slow cyclists will be able to safely filter through crossing pedestrians.

Clearly, the signal timings are insufficient for cyclists. A clearance time for a user group that is 3.3 sec too short is a major safety problem!

3.5 Evaluation of the Problem

3.5.1 Collision Risk

The following order-of-magnitude calculation gives an indication of the likelihood of not being able to clear the intersection in time. Assume that cyclists travelling with the 15th percentile speed face problems when they enter the intersection within the first 2.6 sec of the yellow time (i.e. during their yellow time requirement). If the cyclists arrive at random at the intersection, and the cycle time is 90 sec, the probability of getting into trouble for the entire cycling population is 0.15*2.6/90=4‰. However, if it is assumed that slow cyclists (i.e. the cyclists travelling at the 15th percentile speed or slower) are always travelling within this range, then this group faces a far higher probability of not being able to proceed to the far side of a wide intersection before the cross traffic starts: 2.6/90=3%.

It is acknowledged that most slow cyclists require less than 2.6 sec to stop when the signals change to yellow. However, this is compensated by the fact that not just the cyclists travelling with the 15th percentile speed have insufficient clearance times.

3.5.2 **Recorded Crashes**

A search of the crash database has been conducted in order to find collisions related to the insufficient clearance times. The following search criteria have been specified:

- A right angle collision between a motor vehicle and a cyclists on one of the three avenues surrounding the Christchurch CBD in the period between 1989 and 1998.
- The cyclist crossing the avenue, i.e. travelling through the intersection on the long distance, being hit on the departure side of the junction.
- The crash factor being that the cyclist did not stop at a steady amber light.

Only injury crashes have been investigated, as crash factors are not given for non-injury collisions.

Five crashes have been identified matching all of the above criteria. According to the report *'Cycle Use and Collisions in Christchurch'* (TNZ, 1991), a reporting rate of 21% for injury collisions involving cyclists is assumed. It follows that some 2.5 injury collisions happen due to insufficient clearance times on the avenue intersections in Christchurch each year.

3.5.3 **Mode Shift**

As the above discussion of the collision risk has revealed, the group of slow cyclists is exposed to the risk of not clearing the intersection in time at a regular occurrence. It is likely that these people are very aware of the risk they face. When cyclists loose fitness and get slower, they experience the problem more often. This might be a contributing factor in the process of getting the impression of not being able to cope with the traffic system. The final step is then to stop using the bicycle for inner-city travel. In fact, the author has spoken to a cyclist who does no longer cycle across the wide avenues surrounding the Christchurch CBD for the reason outlined above, but continues to cycle within his suburb.

3.6 Video Footage

At the example intersection of Ferry Road and Fitzgerald Avenue, a slow cyclist has been videotaped crossing the intersection.[1]

The cyclist enters the intersection at the beginning of the yellow time. The cyclist slows down a few metres into the intersection, as an opposing right turner completes the turn in front of him. When the cyclist reaches the centre of the intersection approximately 7 sec after the beginning of the yellow time, a green light has already been displayed to the cross traffic for about 1 sec. Before the cyclist reaches the far side of the intersection, two cars have pulled out in front of him.

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[1] Refer to http://viastrada.co.nz/pub/single-loop for the video.

4 POSSIBLE TREATMENTS

4.1 Increased All-Red Time

The all-red times could be increased to allow for slow cyclists to get clear of the conflict point. This means the all-red times would have to be computed using 15th percentile bicycle speed rather than 15th percentile motor vehicle speeds.

4.2 Early Cut-Off for Cyclists

An alternative approach is to indicate an early cut-off to cyclists. This requires an approach cycle lane to the stop line, as cyclists can only be asked to stop earlier than the other traffic when space is allocated for them in which to do so. An early cut-off for cyclists could be indicated to this user group in one of the following ways:

- **Single Yellow Aspect Lantern**
  Near the end of the green time for motorists, a single yellow aspect with a cycle symbol suggests to cyclists to stop.
- **Smart Studs**
  The approach cycle lane could be fitted with Smart Studs™. These raised pavement markers can be illuminated at the end of the green time.
- **Flashing Lights**
  The nearing end of the green time could be indicated to cyclists by a flashing light.

4.3 All Red Time Extension on Demand

An all-red time extension on demand relies on detection of slow cyclists going through the intersection.

4.4 Evaluation of the Options

Increasing the all-red time in general would result in the following problems:

- Austroads 7 (1993, page 77) mentions the work of Hulscher, who indicated that excessive all-red times are likely to result in a behaviour of "running the red". However, Hulscher’s work is concerned about excessive all-red times in each cycle time.
- The capacity of the intersection would be reduced.

This option has to be rejected, as the likely abuse of increased all-red times by motorists might result in more serious problems than the problems the author tries to solve.

Indicating an early cut-off to cyclists bears the following complications:

- A publicity campaign is necessary to educate cyclists and motorists about the meaning of the device in use and what behaviour is expected from each user group.
- If cyclists do not know the meaning of the signal, or choose not to obey it, nothing changes for them with respect to the timer settings compared to today. However, motorists might be less forgiving when they know that an early cut-off is displayed to cyclists.
- Motorists will get an indication that the green time is soon going to be terminated. This might lead to undesirable behaviour like speeding up in order to get through the intersection.

Therefore, displaying an early cut-off to cyclists has to be rejected.

The following points are noted about an all-red time extension on demand:

- An increased all-red time on demand would require reliable bicycle detection. Ideally, motorists should not trigger the detectors. In case of stopline detection, motorists need to comply with the lane markings. As this is not very likely, stopline detection has to be rejected.
- If detection behind the stopline is used, then motorists running a red light or opposing right turners might trigger an all-red extension.
- All-red extension on demand will delay the start of the green interval on the side street, which might conflict with co-ordination requirements.

In the next section of the paper, the author illustrates a design that takes these concerns into account.

5 DETECTOR LOOPS WITHIN THE INTERSECTION

The proposal relies on detection of slow cyclists within the intersection. The idea is to extend the all-red time when a slow cyclist is detected. The placement of the loop, and the timings are crucial, as some constraints exist:

- Slow cyclists only should trigger the loop, but not motorists who run a red light or opposing motorists who complete a filter turn at the end of the phase.
- The detection needs to happen before the end of the all-red time in order to be able to extend this period.

Initial calculations revealed quickly that the constraints can not be met with only one loop. At the intersection under investigation, the location of a single loop would be in a position where turning motorists will trigger it. Also, the timings can not ensure that motorists running a red light will also not trigger the loop. Therefore, a series of two loops has been investigated.

The concept is to extend the all-red time for a short time when the first detector is triggered, so that cyclists can reach the second detector. When the second loop detects a cyclist as well, then the all-red time needs to be extended so that the cyclist can safely get beyond the conflict point.

5.1.1 Placement of Loop 1

To establish the optimal position for the first loop, a time-distance graph similar to the one in Figure 3 can be used. The requirement is that fast cyclists must reach the loop later than slow motorists must. An 85th percentile speed for cyclists has been used in the procedure developed. The cyclists travelling at the 15th percentile speed must also be able to reach the loop before the end of the all-red time in order to call an extension. The loops should be operated as passage detectors rather than presence detectors so that the operation is independent of vehicle length.

The point at which the 15th percentile cyclist reaches just before the end of the all-red period has been determined as the most efficient placement for loop 1. At this point, the distance from the loop to the design car is the greatest:

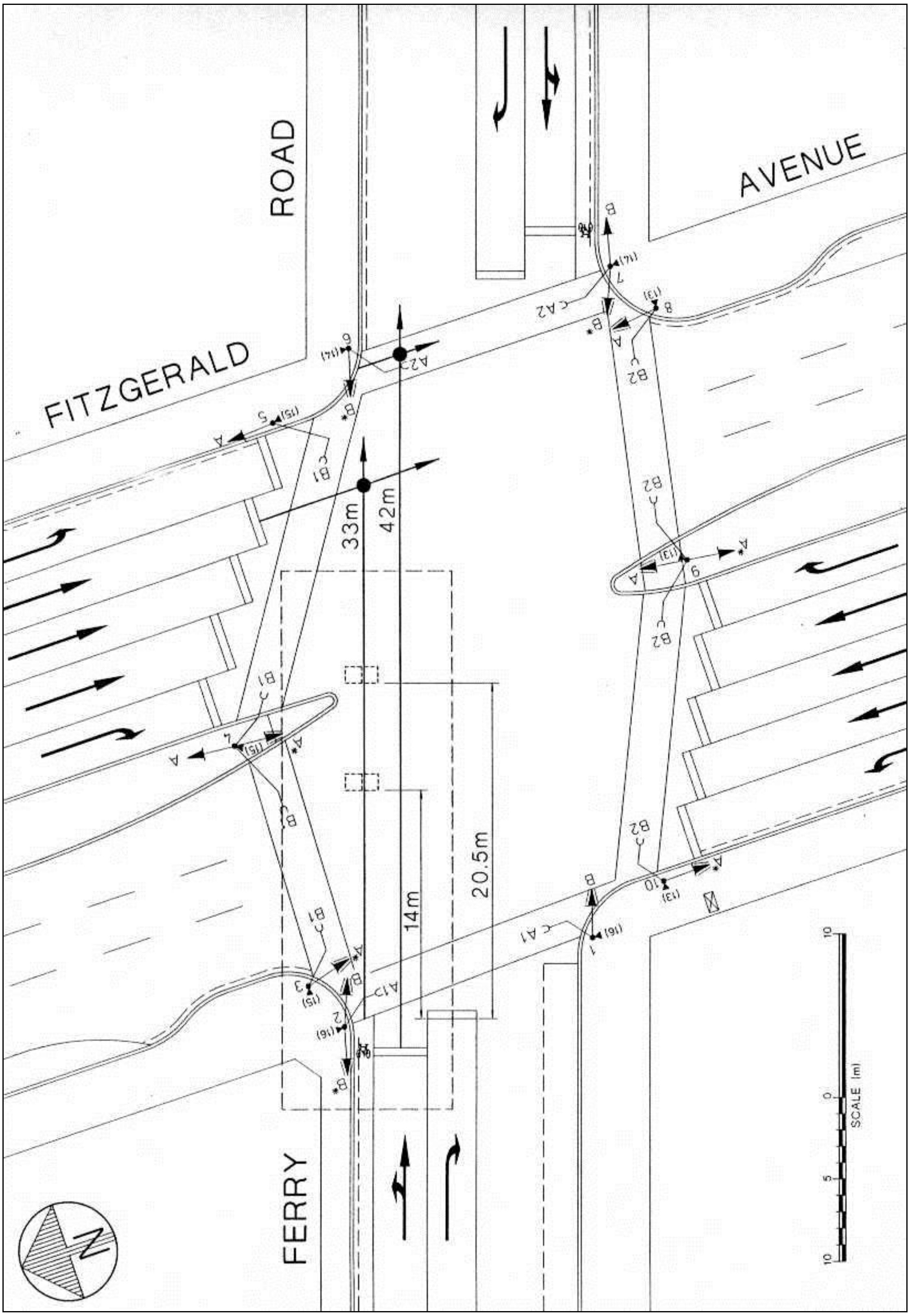

Figure 4: Proposed Intersection Layout

$$d_{loop1} = \left(t_r + t_y - t_{yb15}\right) * v_{b15} \tag{10}$$

where: d_{loop1} = distance from stopline to loop 1

t_r = all-red time (sec)

t_y = yellow time of intersection (sec)

t_{yb15} = yellow time for cyclists (sec) from equation (5)

v_{b15} = 15th percentile bicycle speed (m/s)

It is important that the result of equation (10) be rounded down. This ensures that cyclists reach the loop before the expiry of the all-red period.

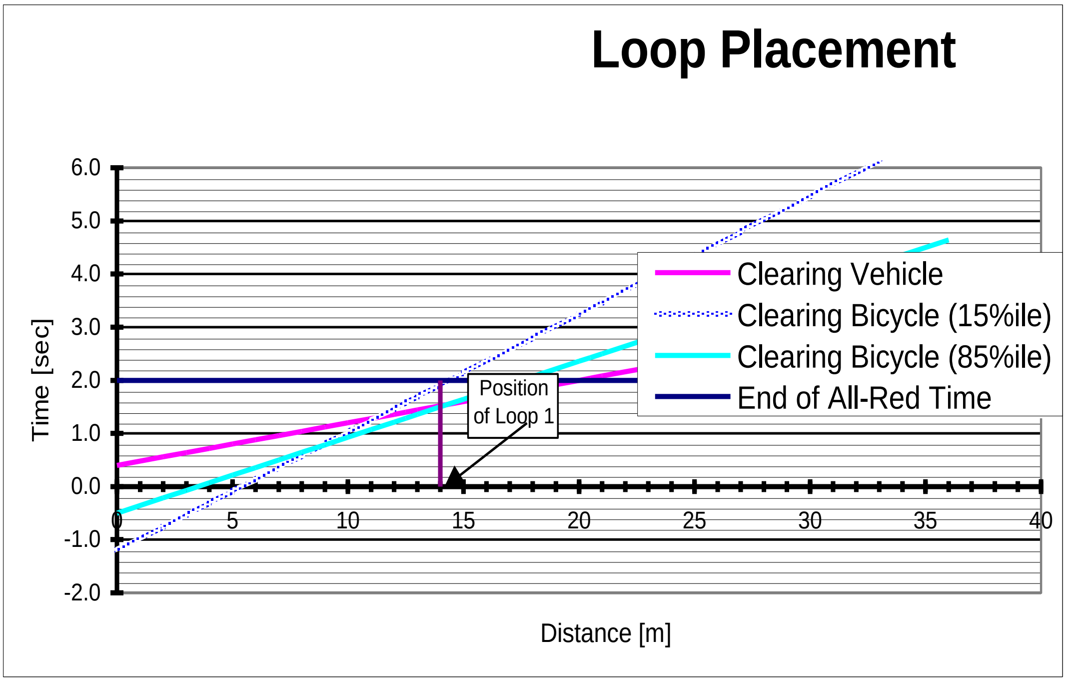

Figure 5: Loop Placement

In the example in Figure 5, the loop would have to be placed some 14.0 m beyond the limit lines in order to be reached by a slow cyclist just at the beginning of the all-red period.

5.1.2 Timing of Loop 1

At the position determined above, the 85th percentile cyclist triggers the loop:

$$t_{b85\_loop1} = \frac{d_{loop1}}{v_{b85}} - t_y + t_{y\_b85} \qquad (11)$$

where: t_{b85_loop1} = time when the 85th percentile cyclist triggers loop1

v_{b85} = 85th percentile bike speed (m/s)

t_y = yellow time of intersection (sec)

t_{y_b85} = yellow time requirement for the cyclist using equation (5)

When the same equation is used with values for the 15th percentile cyclist, the result should be just less than the existing all-red time, as the loop position was determined this way. The results specify a time period with respect to the beginning of the all-red time during which the loop should call the first all-red time extension.

5.1.3 **Placement of Loop 2**

Of concern are motorists who run red lights and call the all-red time extensions. However, it is possible to specify the maximum vehicle speed that allows triggering both loops. The placement of the second loop can be expressed as a function of this maximum vehicle speed and other parameters that have already been calculated.

The beginning of the detection period at the second loop is fixed by the travel speed of the 85th percentile cyclist. At the same time, it also determines the maximum speed of a red light runner, as a faster motorist will miss one of the two detection periods. To develop the equation for the loop placement, the start time of the detection period is expressed as a function of the travel speed of the 85th percentile cyclist:

$$t_{b85\_loop2} = \frac{d_{loop2}}{v_{b85}} - t_y + t_{y\_b85} \qquad (12)$$

where: t_{b85_loop2} = time when the 85th percentile cyclist triggers loop 2

The following equation describes a driver running a red light, and triggering the first detector at the end of the detection period, arriving at the second loop at the same time as the 85th percentile cyclist:

$$t_{b85\_loop2} = t_{b15\_loop1} + \frac{d_{loop2} - d_{loop1}}{v_{rl}} \qquad (13)$$

where: t_{b15_loop1} = time when the 15th percentile cyclist triggers loop$_1$
v_{rl} = speed of the red light runner (m/s)

The right hand sides of equations (12) and (13) equal each other, therefore:

$$\frac{d_{loop2}}{v_{b85}} - \frac{d_{loop2}}{v_{rl}} = t_y - t_{y\_b85} + t_{b15\_loop1} - \frac{d_{loop1}}{v_{rl}} \qquad (14)$$

This can be solved in a few steps for the distance from the limit lines to the second loop d_{loop2} :

$$d_{loop2} = \left(\frac{v_{rl} * v_{b85}}{v_{rl} - v_{b85}} \right) * \left(t_y - t_{y\_b85} + t_{b15\_loop1} - \frac{d_{loop1}}{v_{rl}} \right) \tag{15}$$

where: d_{loop2} = distance from the limit lines to loop 2 (m)

5.1.4 **Timing of Loop 2**

An equation similar to equation (11) can be used to calculate the timings for the second detector with respect to the beginning of the all-red period:

$$t_{b85\_loop2} = \frac{d_{loop2}}{v_{b85}} - t_y + t_{y\_b85} \tag{16}$$

where: t_{b85_loop2} = time when the 85th percentile cyclist triggers $loop_2$ (sec)

This will yield the start of the detection period. When the values for the 15th percentile cyclist are substituted, the result will give the end of the detection period.

The following equation yields the time of red light running that is required triggering both loops at the design speed:

$$t_{rl} = t_{b15\_loop1} - \frac{d_{loop1}}{v_{rl}} \tag{17}$$

where: t_{rl} = time of red light running (sec)
t_{b15_loop1} = time when the 15th percentile cyclist triggers $loop_1$ (sec)

This can be illustrated in the following figure:

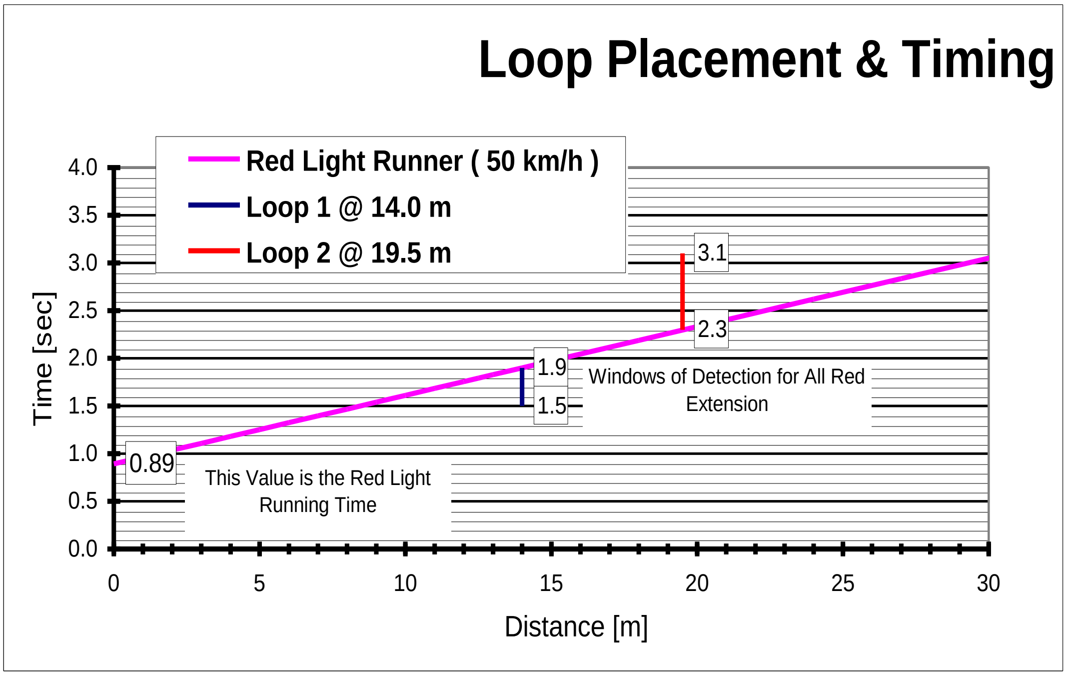

Figure 6: Loop Placement and Timing

5.1.5 All-Red Time Extensions

The all-red time extension called by the first detector must be sufficient for a cyclist to reach the second detector. Hence:

$$t_{ar\_ext1} = \frac{d_{loop2} - d_{loop1}}{v_{b15}} \qquad (18)$$

where: t_{ar_ext1} = all-red time extension called by the first detector (sec)

The all-red time extension called by the second detector has to take the time t_t into account. That is, the time it takes a stationary vehicle on the side street to reach the conflict point:

$$t_{ar\_ext2} = \frac{d_l - d_{loop2} + L_b}{v_{b15}} - t_t \qquad (19)$$

where: t_{ar_ext2} = all-red time extension called by the second detector (sec)
d_l = distance from stopline to the conflict point for cyclist (m)
d_{loop2} = distance from the limit lines to loop 2 (m)
L_b = bike length (m)
v_{b15} = 15th percentile bike speed (m/s)
t_t = time for the stationary vehicle to reach the conflict point (sec)

Substituting equation (4) yields:

$$t_{ar\_ext2} = \frac{d_l - d_{loop2} + L_b}{v_{b15}} - 0.0038 * d_l^2 + 0.1621 * d_l + 0.4341 \qquad (20)$$

5.1.6 Example Calculations

For the example intersection, the following values are assumed:

- 15th percentile bike speed v_{b15} = 4.5 m/s,
- 85th percentile bike speed v_{b85} = 7.0 m/s,
- 15th percentile car speed v_{c15} = 12.5 m/s,
- travel distance for cyclists to the conflict point d_b = 33 m,
- all-red time t_r = 2.0 sec,

Using equation (5), the yellow time requirements are t_{yb15} = 2.6 sec for 15th percentile cyclists, and t_{yb85} = 3.1 sec for 85th percentile cyclists, respectively.

The position of the first loop is given by equation (10) and yields d_{loop1} = 14.0 m. The period in which the loop calls the extension is given by equation (11), and is from t_{b85_loop1} = 1.5 sec to t_{b15_loop1} = 1.9 sec.

The values for the maximum speed of the red light runner, the placement of loop 2, and the all-red time extensions are interdependent and are shown in the table below for different speeds:

Table 1: Interdependency of Maximum Speed to Other Variables

	Variable	Unit	Reference	Choice1	Choice2	Choice3
Maximum Speed	v_{rl}	Km/h	n/a	40	45	50
Maximum Speed	v_{rl}	M/s	n/a	11.1	12.5	13.9
Placement Loop 2	d_{loop2}	m	Equation (15)	21.5	20.5	19.5
Red Light Running	t_{rl}	Sec	Equation (17)	0.64	0.78	0.89
All-Red Time Extension1	t_{ar_ext1}	Sec	Equation (18)	1.7	1.5	1.3
All-Red Time Extension2	t_{ar_ext2}	Sec	Equation (20)	1.5	1.7	1.9

It can be seen that for an increasing maximum red light running speed (v_{rl}), the first all-red time extension (t_{ar_ext1}) is decreasing. It is considered to be very important that motorists will practically not have a chance to call both all-red time extensions.

It can also be noted that the sum of the all-red time extensions is the same for all design speeds.

If v_{rl} = 45 km/h is chosen, and d_{loop2} = 20.5 m has consequently been determined, then equation (16) yields a detection period from t_{b85_loop2} = 2.4 sec to t_{b15_loop2} = 3.4 sec.

5.1.7 Co-ordination

As mentioned, an all-red time extension on demand might require delaying the start of the green time for the side street, which could in turn conflict with co-ordination requirements. To avoid this, it is recommended to program the co-ordination taking the all-red time extension into account, i.e. to have an early start on the side street in case the all-red time extension is not called.

5.1.8 Exclusive Bicycle Approach Lane

As the signal settings are based on cyclists stopping as early during the yellow period as it is possible for them, it is recommended to provide an exclusive bicycle lane on the approach to the intersection. If bikes have to share lanes with cars, but are expected to stop in front of them, then the cyclists might face the risk of getting hit from behind at the stopline.

5.1.9 Benefit/Cost Analysis

A preliminary benefit/cost analysis has been undertaken based on the Transfund NZ method (Transfund NZ, 1997). The following assumptions have formed the basis of the analysis:

- The problem occurs on all wide intersections. Therefore, all signalised intersections on the three avenues around the Christchurch CBD should be treated.
- The crash risk can be evaluated for the intersections as a whole.
- The Land Transport Safety Authority (LTSA) collision database only gives crash factors for injury accidents. As non-injury accidents cannot be quantified, these have been neglected.
- The all-red time extension on demand will impose a delay on motorists when activated. As research into the frequency and the amount of all-red time extension has yet to be done, no delay costs have been taken into account.

- The danger perceived by cyclists using the intersections at present is intangible and has not been taken into account in the quantitative analysis.
- The mode shift resulting from the perceived danger has not been quantified.
- Overall, the neglected dis-benefits (delay costs) and benefits of the treatment (reduction in perceived danger, prevention of mode shift) might cancel each other.
- The reporting rate for injury cycle accidents has been taken as 21% according to the report *'Cycle Use and Collisions in Christchurch'* (TNZ, 1991).
- The factors for adjusting the general accident trend are assumed not to cover this particular type of accident.

The provisional b/c analysis based on these assumptions plus estimates for installation and maintenance costs yields a ratio of 12.

5.1.10 **Discussion**

It is recommended that a low maximum red light running speed (v_{rl}) be chosen, say 45 km/h. It will then only be possible to call both extensions if:

- The motorist drives at exactly 45 km/h, and crosses the limit lines exactly 0.78 sec into the all-red period, or
- The motorist drives slower than 45 km/h, and has some period of time in which both all-red time extensions can be called.

For example, if a motorist is driving at 40 km/h, then both all-red time extensions will be called if the red light running occurred between 0.55 sec to 0.64 sec, i.e. within a period of one/tenth of a second. Realistically, it will not be possible for motorists to learn how to trigger both all-red time extensions.

However, it will be possible to call the first all-red time extension only. This might happen due to opposing traffic doing a filter turn late in the phase, as mentioned earlier. Traffic driving in the same direction as the cyclist will have to drive over the loop, which is not very likely if the loop can be placed in the path of the cyclists, but clear of the path of the motorist.

Furthermore, it is assumed that most motorists running a red light are speeding, i.e. red light runners will generally not even call the first all-red time extension, as they are likely to miss the beginning of the detection period.

6 CONCLUSIONS

The analysis has shown that there is a real problem of insufficient intergreen timings for cyclists. The graphs included support the need for a treatment of the problem, as 3 to 4 seconds of clearance time is missing at wide intersections.

The proposed treatment is to provide two detection loops within the intersection that can detect slow cyclists. The procedure that has been developed for the placement and timing of the loops ensures that slow cyclists will call an all-red time extension, whereas red light runners will practically not be able to learn how to call the extension. A major benefit is that cyclists do not need to adjust their behaviour to the new technology, as the system works automatically for them. Cycle groups have been consulted and have expressed their favour towards the proposal.

Another component of the proposal is the need for cycle lanes on the approaches to the intersections. The loop timings and placements are based on the assumption that cyclists stop as early in the yellow period as possible. It will only be safe for cyclists to stop earlier than the other traffic when some space is allocated to them.

7 RECOMMENDATIONS

(1) That the problem of insufficient clearance times at wide intersections be addressed urgently by the practitioners responsible.

(2) That the proposal set out in this paper be implemented as a matter of urgency.

(3) That wide intersections be reviewed to determine whether cycle lanes can be marked within the existing physical layout.

(4) That a priority list for the proposal be developed from a count program to establish user numbers, taking costs for the work into account.

8 REFERENCES

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Appendix A

Calculation Of All-Red Periods
For Traffic signals

5/12/97

Intersection No. :	##
Intersection Name	##
Date :	1/02/1999
Calculated By :	Axel Wilke

Fill in these cells where appropriate

Figure 1

d2	Tt
2	0.7
3	0.9
4	1.0
5	1.2
6	1.3
7	1.4
8	1.5
9	1.6
10	1.6
11	1.7
12	1.8
13	1.9
14	2.0
15	2.0

Definitions

Tr = Tr1 - Tr2 + Tr3
' = (d1 + L)/VL - (Ts + Tt) + 0.5
Tr = All-red time (sec)
d1 = Distance from stopline to the conflict point for the moving vehicle (m)
d2 = the distance from the stopline to the conflict point for the stationary vehicle (m
L = Vehicle length (use 5.0m)
VL = Lowest prevailing speed of the moving vehicle through the intersection (m/s)
Ts = Start-up reaction time for the stationary vehicle
= 0.5 sec for vehicles
= 0.3 sec for pedestrians
Tt = Time for a stationary vehicle to accelerate and travel distance d2 to the conflict point (sec)

Ped Timings

Ped No	Crossing Distanc	Green Phase	Speed	Yellow Time	Walk Time	Clearance 1 Time	Clearance 2 Time	Phase Length
1	12	A	55	4	6	4.7	3.3	16.0
2	17	C	55	4	6	9.2	3.0	20.2
3	19	A	55	4	4	10.5	3.3	19.8
4	16	A	55	4	6	8.0	3.3	19.3
5	17	C	55	4	6	9.2	3.0	20.2
6	13	A	55	4	6	5.5	3.3	16.8
7								
8								

Summary of All-Red Times

All-Red Periods:		Speed	Special All-Reds:		When Used
REDA =	1.3	55	SREDA =	2.9	demand for P5 only
REDB =	1.0	55	SREDB =	2.9	demand for P5 only
REDC =	1.0	55	SREDC =	1.8	demand for P3
REDD =	1.0	55	SREDD =		
REDE =	1.0	55	SREDE =		
REDF =		55	SREDF =		
REDG =		55	SREDG =		

Kilometres/Hour	25	30	35	40	45	50	55	60
Metres/Sec	6.94	8.33	9.72	11.11	12.50	13.89	15.28	16.67

Vehicle/Vehicle Conflicts

				(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Conflict No.	Green Phase	To Phase	Conflict Description	d1 (metres)	d2 (metres)	VL (in m/s)	Ts (0.5sec)	Tt See Fig1	Tr1 ={(1)+5}/(3)	Tr2 =(4)+(5)	Tr =(6)-(7)+.5
1	A/B	C	Burns Street entering	15.0	8.0	12.5	0.5	1.6	1.6	2.1	0.0
2	A/B	C	Hagart Alexander entering	16.0	8.0	12.5	0.5	1.6	1.7	2.1	0.1
3	B	A	SH traffic turning into H.A. Dve	15.0	10.0	8.3	0.5	1.6	2.4	2.1	0.8
4	A	B/C	H.A. Dve traffic turning left	21.0	9.0	12.5	0.5	1.6	2.1	2.1	0.5
5	C	A/B	SH south entering	21.0	6.0	12.5	0.5	1.2	2.1	1.7	0.9
6	C	A/B	SH north entering	20.0	6.0	12.5	0.5	1.2	2.0	1.7	0.8
7	A	C	Gladstone east entering	26.0	6.0	12.5	0.5	1.2	2.5	1.7	1.3
8	A/B	C	Gladstone west entering	17.0	8.0	12.5	0.5	1.6	1.8	2.1	0.2
9	C	A/B	SH north entering	22.0	19.0	12.5	0.5	2.0	2.2	2.5	0.2
9	E	A/B	SH north entering	22.0	19.0	12.5	0.5	2.0	2.2	2.5	0.2
10	E	A/B	SH south entering	21.0	8.0	12.5	0.5	1.6	2.1	2.1	0.5
10	C	A/B	SH south entering	21.0	8.0	12.5	0.5	1.6	2.1	2.1	0.5

Vehicle/Pedestrian Conflicts

				(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Conflict No.	Green Phase	To Phase	Conflict Description	d1 (metres)	d2 (metres)	VL (in m/s)	Ts (0.30sec)	Tt =(2)/2.0	Tr1 =(1)/(3)	Tr2 =(4)+(5)	Tr =(6)-(7)+.5
P1	C	A/B	H. A. Dve straight through	28.0	2.0	12.5	0.3	1.0	2.2	1.3	1.4
P2	A/B	C	SH northbound	19.0	2.0	12.5	0.3	1.0	1.5	1.3	0.7
P2	D	E	SH northbound	19.0	2.0	12.5	0.3	1.0	1.5	1.3	0.7
P3	C	A	Burns St straight through	26.0	1.0	12.5	0.3	0.5	2.1	0.8	1.8
P4	C	A/B	Gladstone west	28.0	6.0	12.5	0.3	3.0	2.2	3.3	-0.6
P5	A/B	C	SH southbound	37.0	0.5	12.5	0.3	0.3	3.0	0.6	2.9
P6	C	A/B	Gladstone east	21.0	0.5	12.5	0.3	0.3	1.7	0.6	1.6
P7											
P8											

The equation used in Christchurch to calculate all-red times has three components; a time for the moving vehicle to clear the intersection, a time for the starting vehicle to reach the point of conflict, and an added safety margin:

$$T_r = \frac{d_1 + L}{V_L} - (T_s + T_t) + T_{r3}$$

where: T_r = all-red time (sec)

d_1 = distance from stopline to the conflict point for the moving vehicle (m)

L = vehicle length (m)

V_L = 15th percentile speed at the termination of the yellow interval (m/s)

T_s = start-up reaction time (s)

T_t = time for a stationary vehicle or a pedestrian to reach the conflict point (s)

T_{r3} = safety margin, taken as 0.5 sec

Although Austroads 7 (1993) mentions that the travel distances to a conflict point should be taken into account, no procedure or equation is provided how to do this.

Start-up delays have been measured in Christchurch, with the values given in Appendix (A) being 5th percentile values. It is considered to be good engineering practice to work with the upper range of accelerating cars / fast responding pedestrians. The values that are recommended in Austroads 7 (1993) seem to be mean delays, as they are much higher, which reduces the safety margin.

The values in Figure 1 in Appendix (A) for the time it takes to reach the conflict point have been reproduced from Figure (A.8) in Austroads 7 (1993).

It seems appropriate to add a safety margin to the all-red calculations. The value used in Christchurch is 0.5 sec.