Stops and goes of traffic signals

A traffic signal auditor's perspective

Land Transport NZ
Ikiiki Whenua Aotearoa

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1 Preface

Land Transport New Zealand (Land Transport NZ) commissioned Axel Wilke, Traffix, to prepare this booklet. The purpose was to contribute to the objectives of the *New Zealand Transport Strategy* by improving the efficiency and safety of the network.

Land Transport NZ has been assisting the traffic signal industry to increase its capability in design, construction, operation and maintenance of traffic signal installations. One of the components of this assistance has been to facilitate the development of an audit methodology for existing installations. Land Transport NZ commissioned audits of eight territorial local authorities' installations. Other authorities have commissioned their own audits.

This booklet summarises the findings of the audit reports. Its purpose is to assist and advise practitioners.

The author has reviewed the available audit reports, and selected the common trends and themes. While these are typical, Land Transport NZ and Traffix cannot claim to cover the full range of issues identified in the audit reports. Readers are, therefore, urged to seek specialist advice on particular matters and not rely solely on this booklet.

While every effort has been made to ensure the accuracy of this booklet, it is made available strictly on the basis that anyone relying on it does so at their own risk without any liability to Land Transport NZ or Traffix.

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2 Introduction

The Signals New Zealand User Group (SNUG) has identified a need to achieve better consistency with the design and operation of traffic signals throughout the country. Land Transport NZ funded the development of a signal audit methodology, where safety and efficiency of traffic signals were examined. A representative number of signal installations, in the area covered by nine territorial local authorities (TLA), were audited by April 2004. All audits included signals administered by the TLAs on behalf of Transit New Zealand (Transit NZ), the road controlling authority (RCA) for state highways.

A review of all nine audit reports was carried out, with the key results summarised in this booklet. Practices in need of improvement are illustrated and commented on, and backed up with examples of good design.

The purpose of this booklet is to draw attention to those elements of traffic signals that the auditors have frequently found to compromise safety and/or efficiency, and to present ways in which these deficiencies could be addressed. Appropriate standards and guidelines are in place, with Austroads Part 7 (2003) the main reference document.

The target audience group for this booklet is engineers who design, construct, install, manage and maintain traffic signals. Therefore, the audit document will contain traffic signal terminology, which will not be explained in this booklet, but may be found in the glossary of terms in Austroads Part 7 (2003).

Section 4 of this booklet details a national analysis of crashes at traffic signals, and the deficiencies that may have contributed to these crash patterns. This analysis was undertaken by Tim Hughes of Land Transport NZ.

The aim of this booklet is to contribute to safer and more efficient installations and operations of traffic signals in New Zealand.

3 Specialised tasks

3.1 Traffic signal peer reviews

While the audit process reviews the existing installations, it does not cover any new installations or major upgrades of existing sites. Therefore, Land Transport NZ and SNUG have been promoting a parallel process of traffic signal peer reviews to ensure best engineering practice is used at every new installation or major intersection upgrade. This recommendation recognises that traffic signal design is a highly specialised discipline of traffic engineering, and that there are few engineers in New Zealand with the appropriate in-depth knowledge and experience.

It should be stressed that a traffic signal peer review is not covered by the road safety audit procedures for projects (Transfund, 2004). Traffic signal peer review covers both safety and efficiency, and should be undertaken by a competent signals engineer.

It is recommended that RCAs add the requirement for a traffic signal peer review to the Austroads Part 7 (2003) design process flow chart (table 1.1).

3.2 Intersection control

The set-up of the SCATS software used for operating traffic signals is a specialised discipline. It is recommended that suitably qualified engineers should be engaged periodically to review the set-up of SCATS networked traffic signals.

Another specialised field is the programming of the traffic signal controllers. RCAs should ensure that a suitably qualified and experienced engineer is employed for this task.

3.3 Contact details

Please contact any SNUG committee member for a list of suitably qualified and experienced engineers. Contact details for SNUG committee members are availabe on the IPENZ website – www.ipenz.org.nz.

4 Crashes at traffic signals

An analysis undertaken by Tim Hughes of Land Transport NZ identified the main safety issues at traffic signals:

- right-turn-against crashes 32%
- failed to stop for red 30%
- pedestrians 14%
- cyclists 8%

Subsequent sections of this booklet will give some guidance on how the safety performance of signals can be improved.

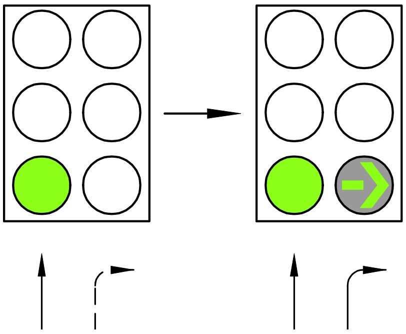
4.1 Factors contributing to right-turn-against crashes

The following factors can contribute to right–turn-against crashes:

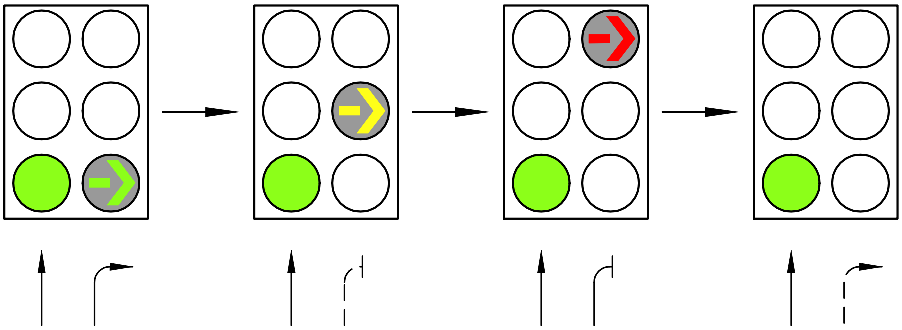
- Compromised visibility due to geometry.
- Misjudging speed, especially on multilane roads.
- Turning on yellow when one lane has stopped, but drivers in adjacent lanes proceed.
- Misjudging intentions of opposing traffic – are they proceeding through or turning left.
- Use of phasing and arrows.

Compared to full filtering, the following crash rate reductions have been identified (Hall, 1993):

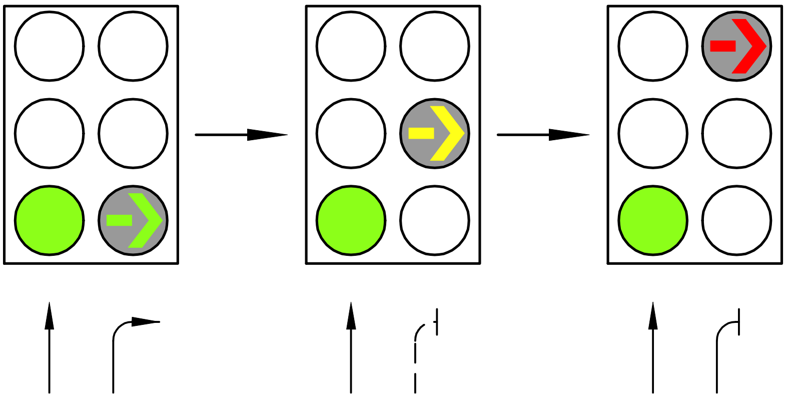
- 30 percent reduction for filter right turns, followed by a right-turn arrow (a lag right turn).



- 68 percent reduction for a right-turn arrow, followed by filtering (a lead right turn).



- 90 percent reduction for a lead right turn, followed by a red arrow (no filter).



4.2 Factors contributing to red light running

The following factors can contribute to unintentional red light running:

- Poor conspicuity of signal displays.
- Anticipation of phase progression.
- Inconsistent phasing at adjacent intersections.

In addition, drivers may be tempted into intentional red light running when they experience a poor level of service, especially when combined with a low expectation of enforcement.

4.3 Observations on cyclist crashes

- In three-quarters of the cases, the crashes are caused by motorists.
- Cyclists would benefit by having space allocated to them (especially for the through movement) and colour highlighting that space.
- Simplifying the Give Way rules would help.

4.4 Observations on pedestrian crashes

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

5 **Intersection and lane layout**

5.1 Opposed right-turn lanes

Exclusive right-turn lanes should be provided whenever possible. Opposed right-turn lanes should line up, and not be offset, allowing right turners waiting for a filter turn as much forward visibility past queued opposing right turners as possible.

Many 14 m carriageways had their two-lane shared approaches reconfigured to include an exclusive right-turn lane, without relocating the centre line. This resulted in the opposed right-turn lanes being offset.

Safety and efficiency issues

Poorly aligned right-turn lanes can lead to:

- poor intervisibility between right turners and opposing through traffic, resulting in a higher right-turn-against crash rate
- drivers concentrating too much on opposing through traffic, overlooking pedestrians or cyclists to whom they must also give way
- some drivers being hesitant, reducing intersection capacity
- increased inter-green time due to the longer tracking paths.

Recommended treatments

- Ensure right-turn bays line up (ie, 'back to back' design).
- Reducing the right-turn lane width minimises the offset between opposed right turners, further increasing forward visibility.
- Where opposed right-turn lanes are not possible (eg, due to the inability to ban kerbside parking or tracking paths of vehicles), consider a different phasing operation (eg, split approaches) or a right-turn ban for one direction.

Figure 1 Offset right-turn bays (and hidden primary lantern)

Figure 2 Right-turn bays incorporated into solid median achieving excellent forward visibility

5.2 Captive turn lanes

Captive turn lanes are created when a mid-block through lane leads directly into a turn lane at an intersection. It is important that advanced warning is given to motorists that they may only turn from these lanes.

Ideally, drivers should be channelled into through lanes at intersections (or shared through and turn lanes) and should not be confronted with captive turn lanes.

Captive turn lanes with insufficient warning were found quite frequently during the signal audits and appear to result from the engineering plans not showing how to tie the intersection lane layout into the existing mid-block markings.

Safety and efficiency issues

Captive turn lanes can lead to:

- erratic and undesirable driver behaviour, including sudden lane changes or through movements when only turning movements are allowed, potentially resulting in a higher crash rate
- drivers unnecessarily slowing or stopping close to the intersection for a desired lane change, impacting on the intersection capacity.

Recommended treatments

- Channel drivers into through lanes whenever possible (ensure that engineering plans show the tie-in into the mid-block layout).
- Where captive lanes cannot be avoided (eg, where two approach lanes in the mid-block lead into the stem of a T intersection with exclusive turning lanes), ensure that drivers have sufficient pre-warning by lane arrows and possibly signs.

Figure 3 Captive left-turn lane with insufficient warning to motorists

Figure 4 Lane markings advising motorists of captive turn lanes

5.3 Slip lanes

Slip lanes help to make intersections more compact, and enable traffic signal posts and lanterns to be placed closer to drivers' line of sight. Decision-making processes for motorists are generally simplified, resulting in a safer intersection layout. While some pedestrians voice reservations about slip lanes, they do remove the conflict that occurs when left turners and parallel pedestrians proceed together.

Slip lanes should comply in layout with guidance given in Austroads Part 5 (1988). For sign posting details and provisions for visually impaired pedestrians, refer to RTS 9, 1993 and RTS 14, 2003, respectively.

Safety and efficiency issues

Poorly designed slip lanes can lead to:

- poor intervisibility between pedestrians and left turners, if the crossing position is too far around the corner
- drivers having problems observing traffic to give way to if the slip lanes are not of the high-entry-angle type or if the kerb radii are too large (because some people have problems turning their heads and door pillars may obstruct visibility). Driver hesitance and increased crash rate are possible consequences
- increased turning speeds, resulting in loss of control or failure to give way
- not enough room for pedestrians (eg, during the school peak) or street furniture, if islands are undersized.

Recommended treatments

- Slip lanes should be of appropriate size and of a high-entry-angle type, with adequate corner radii.
- The location of the pedestrian crossing point should provide sufficient intervisibility.
- Pedestrian priority issues can be addressed using a signalised slip lane crossing or a priority (zebra) crossing (possibly on a raised platform).

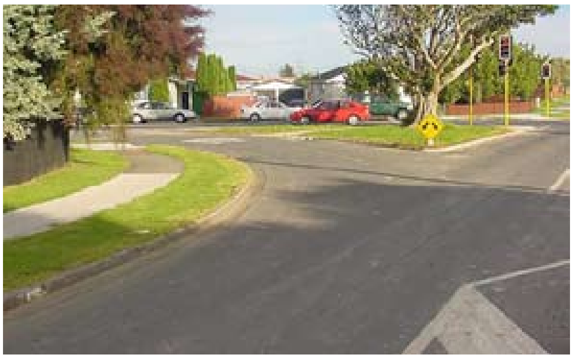


Figure 5 Pedestrian crossing around the corner – poor visibility

Figure 6 Slip lane with zebra crossing on raised platform for speed control

6 **Signal post and display location**

6.1 Post placement and signal conspicuity

Signal faces provide one or more of four functions. Motorists get information that warns them, makes them stop, indicates when to start again and indicates what manoeuvres can be undertaken. Safety is reduced if signal faces are not clearly visible from the appropriate distance.

One of the most common safety audit findings was that of signals with inadequate conspicuity. When this lack of conspicuity includes the signal faces that perform the warning and stopping functions, safety is reduced as a consequence.

Safety and efficiency issues

Poor post placement and reduced signal conspicuity can lead to:

- an increase in inadvertent red light running
- an increase in rear-end crashes
- an increase in right-turn-against crashes
- reduced efficiency.

Recommended treatments

- RCAs should have an upgrading programme for conversion to tall (5 m) posts or mast arms as appropriate.
- Kerbside posts should be located nominally 1 m (and no less than 0.6 m) from the kerb face, and close to the tangent point. Minimising corner radii can help achieve this.
- Kerb extensions should be used wherever possible to improve lantern visibility.
- Street furniture should not reduce signal conspicuity. Under-grounding aerial services, locating street lighting poles at the property boundary and using joint-use poles can all be considered. The size of trees must be taken into account both at the time of planting and at maturity, and ongoing maintenance (pruning, trimming) allowed for.

Figure 7 No signals visible to approaching drivers

Figure 8 Good conspicuity of traffic signals

6.2 Sufficient stopping and manoeuvring displays

Motorists must receive the relevant information from signal displays, regardless of the lane they are travelling in. Some redundancy has to be designed into the system, as lamps can fail and the remaining signals must still provide a safe intersection. Legislated minimum requirements also need to be met.

Safety and efficiency issues

An insufficient number of signal displays can lead to:

- compromised signal conspicuity (for motorists in some traffic lanes, for example, caused by large vehicles in adjacent lanes) and thus reduced safety
- motorists making wrong choices
- unsafe intersection operation in case of lamp failure
- RCAs opening themselves to avoidable risks when legislated requirements are not met.

Recommended treatments

- One of each type of display must be provided on an approach in the primary or dual primary position (including arrow displays).
- The minimum number of signal displays for major and minor movements is three and two, respectively. A major movement is one where the associated displays do not have an OFF state. Therefore, a right or left-turning movement that is allowed to filter is a minor movement, but a right-turning movement that is fully protected (at least during certain time periods) is classed as a major movement.
- Signal faces provide one or more of four functions (warning, stopping, starting and/or manoeuvring). One signal face does not adequately provide the function if two or more lanes of traffic separate approaching vehicles and the signal face.
- At least one aspect must be illuminated in any one signal face at any one time (ie, avoid signal faces with three arrow aspects only where filter turning occurs, as all aspects will be in the OFF state during filter turning).

Figure 9 Non-complying two-aspect display (green missing)

Figure 10 Fully protected right turn with the required three right-turn arrow displays

7 **Phasing and operational issues**

7.1 Right-turn and left-turn arrow operation

The objectives of signal phasing design are to provide safety and efficiency. As those objectives often conflict, compromises must be considered carefully. Right-turn arrows can be used for partial or full control of that movement. Left-turn arrows allow motorists to move when there is no conflict (eg, from a side street during a diamond phase operation on the main road). Arrows are also useful for partial or full pedestrian protection (eg, when a turning movement is held back for at least part of the time for parallel pedestrians crossing the road). Left-turn arrows are used to indicate to motorists when they have to give way to opposing right-turn traffic. The left-turn arrows are in the OFF state when filtering is permitted, and the left-turn green arrow is illuminated when no opposing right-turn or pedestrian movement is allowed.

There are a variety of reasons why, in some circumstances, a lag right turn at cross intersections is less safe than a lead right turn, and the default should be a lead right-turn arrangement (refer to section 4). A lag right turn may be dictated by coordination requirements or when insufficient width does not allow opposing right-turning movements to occur simultaneously.

Particular care must be taken to avoid phasing an unintentional lag right turn when the opposing right-turn movement may filter-turn. This 'right-turn trap' happens when a filter right turner (or a u-turner at a T intersection) faces a yellow circle display but the opposing through movement overlaps to a lag right-turn phase. The right turner (or u-turner at a T intersection) has no indication whatsoever that the opposing through movement is not being terminated and may turn during the amber believing the opposing through movement is stopped. This situation can occur when intervening phases are skipped, eg, during low-demand periods.

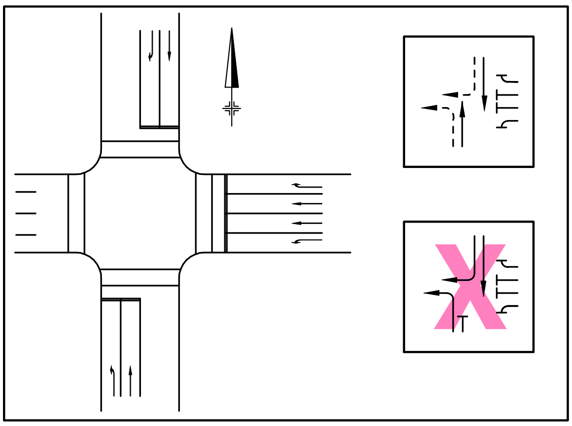


Figure 11 Bad practice of allowing protected turns into their own lanes simultaneously

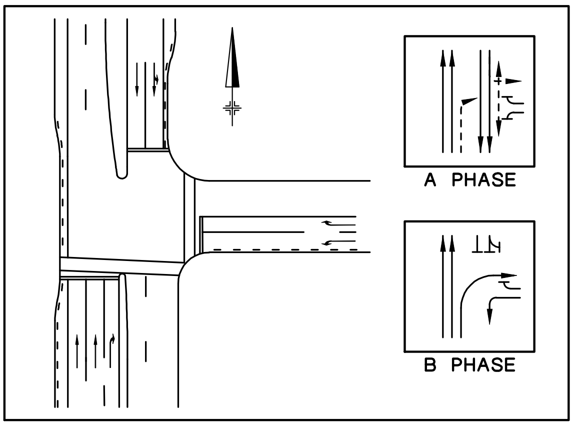


Figure 12 Avoid a 'right-turn trap' for u-turners on the north approach by either banning that u-turn or ensuring that A phase is never followed by B phase

Safety and efficiency issues

- The use of arrow displays needs to balance safety and efficiency.
- When consistency across the network is not met, motorists may be confused. Care should be taken to ensure that similar phasing philosophies are used at adjacent intersections and preferably throughout the network.
- The phasing design has to match the lane arrangement. A protected right-turn phase requires an exclusive right-turn lane (with the exception of split-approach phasing).
- A protected turn phase can only be operated when there is no conflict. It is not considered good practice to have protected but opposing movements turn into their respective nearest lanes (ie, a left-turn green arrow and an opposing right-turn green arrow should not be displayed together unless the departure lanes are physically separated by means of a solid island).
- Right turners 'cutting the corner' may drive over the right-hand approach lane of the side street, causing an unwanted side street demand.

Recommended treatments

- Where arrow displays are present, they should always be used for full or partial pedestrian protection.
- The controller personality must be set up so that an unintentional and dangerous lag right-turning sequence is not possible.
- Use a presence timer on the side street detector if it may be driven over by right-turning traffic from the main road, or offset the stoplines on the departure approach further back so the right turner does not encroach over the centreline.

7.2 Turn arrow logic

Only experienced signal designers and operators are likely to be aware of problems with turn arrow logic. Expert assistance is required in the design stage for both the physical intersection layout and phasing design. After installation, the on-street operation should be checked by a suitably experienced signal engineer. Only suitably knowledgeable and experienced engineers should be used for compiling the controller personality.

Where an opposing right-turning movement is held on a red arrow, a green left-turn arrow (when present) should indicate to approaching motorists that they have priority over the opposing right-turn movement. This is especially important when the opposing movement is allowed to filter turn some of the time, in which case the left-turn display should be in the OFF state. Similarly, where the signal hardware is available, a green left-turn arrow should be displayed to the side street traffic when the main street operates a protected right turn.

When a left turn is associated with a right-turn phase, it is good practice for the left-turn detector to also call the right-turn phase. This results in greater efficiency, as just one of the main road approaches needs to be stopped whenever there are only left-turn vehicles.

There are some standard operating procedures for turn arrow logic (Austroads Part 7, 2003), including holding the right-turn red arrow for five seconds before dropping it when changing from a protected turn to a filter turn, and bringing a red arrow up at the same time as the adjacent full red.

Safety and efficiency issues

The following safety and efficiency issues can arise:

- When left-turn arrows are not operated, motorists may be confused or may not turn when they have no conflict.
- If the side street demand can be met by a left-turn green arrow, then this would be the most efficient way to operate the intersection.

Recommended treatments

- The correct sequence for a transition from a protected right turn to a filter turn involves holding the red arrow for five seconds before it is switched off.
- If present, green left-turn arrows should be operated whenever that movement is unopposed.
- A left-turn loop should call an associated right-turn movement (but special provisions must be allowed for if force-skipping the right-turn phase via SCATS).
- Standard operating sequences should be adhered to.
- Seek expert help and ensure designs are peer reviewed by independent and suitably experienced engineers.

Figure 13 Walk and green left-turn arrow displayed simultaneously

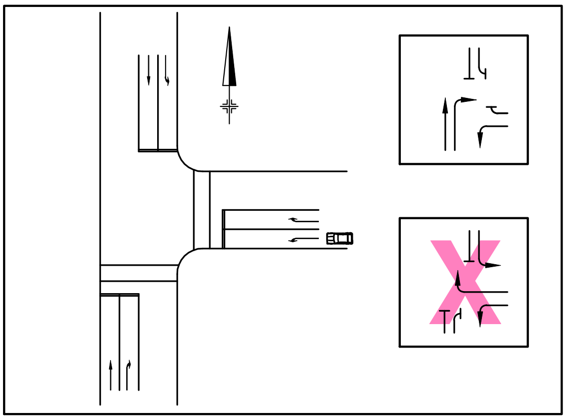


Figure 14 A left-turn demand on the side street should call the associated main road right-turn phase

8 **Pedestrian issues**

8.1 Pedestrian phase issues

Pedestrians are the most vulnerable road users and require special consideration during signal design. People who walk may be too young or too old to drive or cycle, or have a vision impairment. Turning motorists may have to filter through parallel pedestrian movements and, due to the complex demands at signalised intersections, pedestrians may be unintentionally overlooked.

Safety and efficiency issues

The following safety and efficiency issues can arise:

- Pedestrians need to be able to clear the length of the crosswalk during the clearance period to avoid conflict with crossing traffic.
- Where the number of pedestrian/vehicle conflicts is high, pedestrian protection using red arrow control should be considered.
- Late introduction or reintroduction of a pedestrian phase can catch turning motorists by surprise.

Figure 14 Bad practice of providing a crosswalk to the right of the side street at a T intersection without pedestrian protection

Figure 15 A late start of the vehicle phase provides pedestrian protection at this T intersection

Recommended treatments

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

8.2 Push button location

The correct push button location is an important aspect for pedestrians, especially for those with vision impairment (many of whom also have a hearing impairment). The correct placement is at the cutdown associated to the crosswalk, with an embossed arrow indicating the direction of travel through the intersection. The use of audio-tactile equipment requires that push buttons for different crossings are not located too close to one another.

Safety and efficiency issues

The following safety and efficiency issues can arise from poor push button locations:

- Push buttons located away from the cutdown may result in pedestrians tripping at the kerb.
- Poorly orientated embossed arrows and tactile paving may lead vision-impaired pedestrians away from the crosswalk and they may cross in the wrong direction.
- Pedestrians may be less inclined to demand their phase if the push button is poorly located.
- Wheelchair users may not be able to reach poorly positioned push buttons.
- Audio-tactile equipment for adjacent crosswalks may confuse pedestrians if the posts are positioned too close to one another.

Recommended treatments

- Install push buttons at the cutdown. Make use of short stub posts if the signal post is not in a suitable location and cannot or should not be shifted.
- Ensure that the embossed arrow and any tactile paving are orientated correctly.
- Avoid safety rails obstructing push buttons.
- Ensure audio-tactile equipment for adjacent crosswalks is at least 3 m apart.
- Ensure the recommendations of RTS 14 are followed.

Figure 16 Visually impaired pedestrians are directed away from the crosswalk by the warning paver layout. Tactile pavers should be laid at the same angle as the crosswalk

Figure 17 Use of stub post for appropriate placement of pedestrian call box adjacent to the pram crossing[1]

1. Note, however, that the stub post on the far side of the island is placed on the wrong side of the crosswalk.

9 **Cyclist issues**

9.1 Provision for cyclists

Very few audited intersections had special provisions for cyclists. Consider the following factors:

- How safe is the intersection for cyclists?
- What is the existing demand by cyclists?
- Are there reasonable alternative routes?
- Are there planned projects that could include the improvement of cyclist provisions as an incidental feature?

These factors should not determine whether an improvement is needed, as all signalised intersections should work for cyclists. Rather, the factors simply help determine which should be fixed first (adapted from US Department of Transportation, 1998).

As intersections are inherently more difficult to negotiate for cyclists, it is desirable to allow for them at intersections even when there are no connecting mid-block cycle facilities.

The key planning principle relates to the provision of adequate space for cyclists.

Safety and efficiency issues

The following safety and efficiency issues can arise from missing or deficient cycle facilities at signalised intersections:

- When cyclists are not guided through an intersection, their behaviour may be harder to predict for motorists.
- When cyclists experience stress, they may be more likely to make mistakes.

Figure 18 No safe and legal waiting position for straight-through cyclists during left-turn-only phase

Figure 19 A good example of providing for cyclists at traffic signals

- In the absence of a cycle lane, most cyclists will occupy the left-turning lane, potentially holding up motorists during a left-turn-only phase.
- It is easier for motorists and cyclists to deal with conflict points when approaching an intersection rather than at the limit lines. Truck drivers especially, when starting up, may be unaware of cyclists to their left.

Recommended treatments

- Aim for a treatment that is as far as possible suitable for cyclists with basic competence.
- All normal manoeuvres should be possible (including the option of a hook turn[2]).
- Manage conflict between left-turning motorists and straight-through cyclists. Slip lanes are a good tool for this (and in addition use a coloured surface for the cycle lane over which left turners must cross).
- Achieve an intuitive layout so that motorists and cyclists know where they are expected to be on the road. Colouring the cycle lanes at the intersection will support this.

2. This is a right turn made by cyclists, where they keep left while proceeding straight through the intersection, wait at the far left side for the lights to change, then cross with the side road traffic.

10 Conclusions

This booklet targets designers of traffic signals and RCA staff who control, operate and maintain signalised intersections. The aim is to raise awareness about commonly occurring safety and efficiency issues.

Designing signalised intersections is a highly specialised discipline. Safety and/or efficiency were compromised at many of the installations audited. Engineers should make use of all the available relevant guidelines and standards. If RCAs don't have their signals up to standard in all respects of their safety and efficiency, they will undoubtedly fall into disrepute with regular users.

The most important advice, however, is to engage a competent signal engineer for the peer review of new designs. Note that this is not covered by the road safety audit process (Transfund, 2004). It is also recommended that road controlling authorities engage suitably experienced specialists for auditing their SCATS set-ups. Contact SNUG committee members (www.ipenz.org.nz/snug) for a list of suitably qualified and experienced engineers.

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Telephone 03 964 2866 Fax 03 964 2855
Level 5, BNZ House
129 Hereford Street
PO Box 13364, Christchurch

Dunedin Office
Telephone 03 951 3009 Fax 03 951 3013
AA Centre, 450 Moray Place
PO Box 5245, Dunedin

Transport Registry Centre

Telephone 06 953 6200 Fax 06 953 6411
Level 3, IRD Building
Cnr Ashley and Ferguson Streets
Private Bag, Palmerston North

Call centres

General enquiries	0800 699 000
Driver licensing	0800 822 422
Road user charges	0800 655 644
Motor vehicle registration	0800 108 809
Overdimension permits	0800 683 774

Land Transport NZ
Ikiiki Whenua Aotearoa

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