THE MARKING OF ADVANCED CYCLE LANES AND ADVANCED STOP BOXES AT SIGNALISED INTERSECTIONS

Research Project

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CHRISTCHURCH

Table of Contents

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1. INTRODUCTION

1.1 History of Intersection Marking Standards

In approximately 1975, the then Christchurch City Council, in conjunction with the National Roads Board, marked a cycle lane up to the intersection limit lines on the Kilmarnock Street approach to the Deans/Kilmarnock intersection in Christchurch. In 1978 the Ministry of Transport produced a draft standard for the design of cycle facilities. The draft was approved by the National Roads Board for a trial that was conducted by the Traffic Committee of the Road Research Unit, in 1980[1].

The trial involved an investigation into the operating and attitude effects of mid-block cycle lane markings, cycle symbols and cycle route signage. Although the cycle lane at the Deans/Kilmarnock intersection was part of the overall package of cycle facilities under investigation, it was not specifically studied for behavioural, safety or attitude effects. The report simply stated "the provision of a special cycle lane at signals appears justified, in our view, only when cyclists are permitted a turn which other vehicles cannot make."[2]

The report did investigate the effects on cyclists at two signalised intersections that had no specific cycle markings. Both approaches were marked with two traffic lanes – combined left-turn/straight-through and combined straight-through/right-turn (Kilmarnock/ Straven intersection). The report concluded that "the two traffic signal controlled intersections on Kilmarnock Street have been observed and while the adopted markings may be 'non-solutions' they appear to work satisfactorily."[2]

In summary, the 1980 investigation recommended no treatment at most signalised intersections, and cycle lane treatment only where cyclists were permitted a turn that vehicles could not make.

These recommendations were reflected in MOTSAM – the Transit and LTSA Manual of Traffic Signs and Markings, and the Guide to Cycle Facilities – the "blue book" published in 1983. Both of these manuals remain the effective New Zealand cycle facilities design manuals to the present day[3]. Neither explicitly state the "non-solution" solution, but indicate that cyclists should join the traffic flow at intersections without cycle specific markings. They also say that cycle lanes up to limit lines at intersections should only be used when cyclists can make a movement that vehicles cannot.

1.2 Present Day Research Requirements

Notwithstanding the recommendations of MOTSAM, since 1997, the Christchurch City Council has been marking cycle lanes up to the limit lines of signalised intersections (and calling them Advanced Cycle Lanes). The need for cycle markings at intersections grew out of a number of sources:

- Comments from cyclists that the areas they felt most exposed to vehicle manoeuvres were intersections:

[1] Gibson R.A. & Holland G.H. (1980) "An Investigation into Proposed Design Standards and Signs for Cycle Facilities", Road Research Unit Bulletin 51, National Roads Board.
[2] Ibid. p 59.
[3] It should be noted though, that there are plans under action to introduce new technical standards for cycle facilities by the end of 2002

- Collision information which clearly indicated the locations of most concern were signalised intersections (as well as roundabouts);

- Examination of overseas design manuals, conference proceedings and cycle infrastructure documents that clearly indicated improved cycle safety from cycle markings at intersections;

- Observations that cyclists will occasionally behave illegally at intersections (according to the lane markings present), to ensure their own safety.

These points clearly indicated a need to address the effects of the signalised intersection layouts on cyclists. Hence possible cycle lanes at intersections were investigated.

The marking designs chosen were based on a combination of the MOTSAM standard and designs gleaned from overseas design manuals, including Austroads 14 and the Dutch design manual CROW. There are now approximately 90 intersections in Christchurch with one or more approaches marked with cycle lanes. Designs vary from a very specifically designed "non-solution" that is a solution, to cycle lanes and storage areas that advance to signal limit lines.

In 1999 the LTSA indicated a level of disquiet with the fact that these intersection designs were being installed with no formal trials of their effects on vehicle or cycle safety. Despite originating from overseas sources, there has been no New Zealand investigation into the technical basis for the designs, nor any local research to justify their application.

Consequently, the Christchurch City Council established a research project to examine various aspects of the marking patterns, with the intention of making recommendations to the LTSA about their continued, and increasing (or not) use.

It is known that a number of other roading authorities throughout New Zealand are also creating cycle-space markings at intersections. Some are doing their own monitoring and performance investigation. This study makes no reference to other New Zealand studies. Any comparison of results should occur when each study is completed.

1.3 Scope of Project Report

The remainder of this report details the research project undertaken to assess the effects of cycle lanes and stop box markings on cyclists and vehicles. The next section of the report gives some background, showing the configurations under study and their intended uses.

Section 3 details the structure of the individual sections of the practical research, with the actual data and interpretation being included in this report's appendices. Section 4 details the key research findings, and section 5 then synthesises the independent results to gain an overall picture of the study results. The project's conclusions and recommendations will be found in Section 6.

2. OUTLINE OF CONFIGURATIONS UNDER ASSESSMENT

2.1 Configuration Terminology

The configurations used to create cycle facilities at intersections can be considered in two primary groups. The first consists of **ADVANCED CYCLE LANES (ACL).** These consist of cycle lanes, from 1.2 to 1.6m wide, which are marked either to the side or between traffic lanes, and project *forward of the traffic lane* limit lines, up to the pedestrian crossing lines. This type of configuration is shown in plans SD 253 and SD 255 below.

The second group consists of **ADVANCED STOP BOXES (ASB)**. These are areas or reservoirs marked out *directly in front of the traffic lanes* for storage of cycles waiting to proceed through the traffic signals. In most cases the advance stop boxes are directly "fed" by approaching cycle lanes, as in plans SD 254, SD 256 and SD 257, shown below. In one configuration the ASB is not "fed" by an approaching cycle lane - SD 258.

2.2 Configuration Objectives

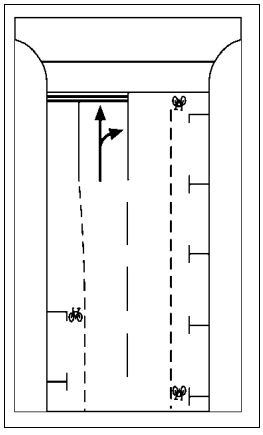
The primary objectives of cycle facilities at signalised intersections are both to improve the physical safety of cyclists using the intersection; and to reduce cyclists' perceived risk when using signalised intersections.

The secondary objectives of the facilities are to maintain or improve the physical safety of all other intersection users; and have a minimal impact on the effectiveness of the intersection operation.

The research programme detailed in the subsequent sections of this report was designed to assess whether the marking patterns used meet these objectives.

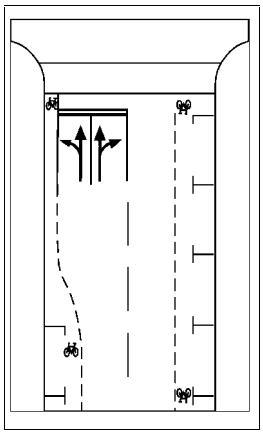
2.3 Configurations and Intended Use

The following section outlines the different configurations designed for use in Christchurch, and the anticipated method of use of the markings.



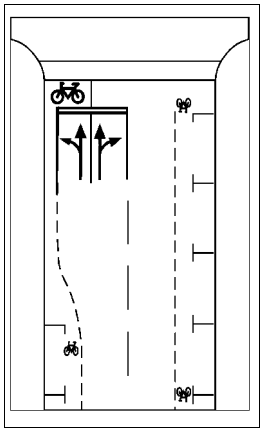
Configuration SD 252: A mid-block cycle lane continues to the intersection, with the cycle lane marking joining the vehicle lane separator line.

There is no specific cycle lane approaching the vehicle limit lines. Cyclists are expected to occupy the left-most lane for straight-through and left-turns. Vehicles tend to only use the left-most lane for left-turns or when straight-ahead travel in the right-most lane is blocked by right-turners. Vehicles cannot travel straight-through from both lanes simultaneously, as there is only single lane discharge. Some protection afforded to straight-ahead cyclists as vehicles need to cross lane line for left-turn. Right turn cyclists enter appropriate turn lane when comfortable to do so.



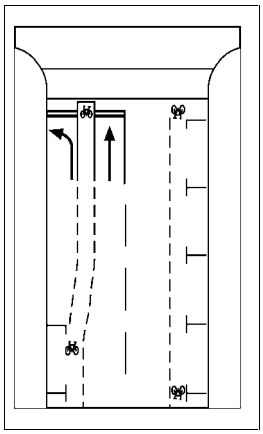
Configuration SD 253: An Advanced Cycle Lane is marked kerb-side projecting ahead of vehicle limit lines. Left-most traffic lane may be either straight or combined ahead/left (illustrated).

Vehicles are expected to queue in their traffic lane, leaving the cycle lane free for cyclists. Cyclists use the lane to reach the head of the queue when the lights are red – their presence clear to turning traffic. Cyclists approaching on green would be expected to use due caution as vehicles ahead of them may turn. Vehicles are expected to remain clear of the cycle lane when positioning for the left-turn. Right turn cyclists position themselves for their turn when they feel comfortable to do so. The ACL is not intended to help right-turning cyclists.



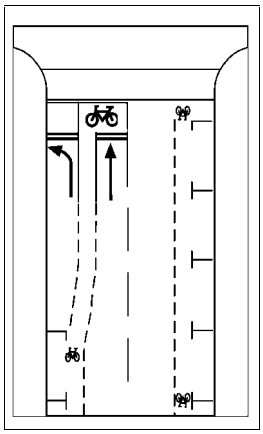
Configuration SD 254: An Advanced Stop Box is developed ahead of the left-most traffic lane, with a kerbside cycle lane.

Vehicles are expected to behave as indicated previously, both queuing in, and driving in their own marked lane, without stopping in the stop box, or driving along the cycle lane. Cyclists use the stop box area as a reservoir at a red-signal, allowing more cyclists to accumulate ahead of the stopped traffic, increasing their visibility. The ASB has no functional advantage on green signals. Right-turn cyclists would not gain any advantage from the shown configuration, but may use the ASB to reach a right-turn lane if marked.



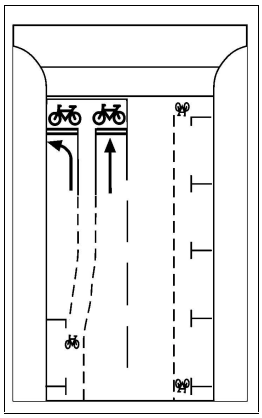
Configuration SD 255: An Advanced Cycle Lane marked between exclusive left-turn lane and straight-ahead (illustrated) Options also exist for right-side lane to be combined ahead/right or right-turn only.

Straight-ahead cyclists are expected to remain in the cycle lane right up to the limit lines. The layout is intended to allow priority for straight-ahead cyclists over left-turn vehicles. Left-turn vehicles will cross marked lane lines, and so should give way to cycles. Left-turn cyclists will need to depart the cycle lane and occupy the left-turn traffic lane. Right-turn cyclists will need to position themselves in the most appropriate traffic lane.



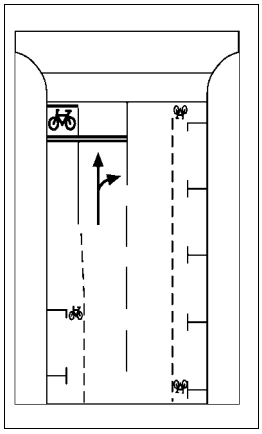
Configuration SD 256: An Advanced Stop Box is created ahead of the traffic lane marked to the right of the approaching cycle lane.

Cyclists use the ASB to provide a clear location to accumulate during red-light phases, increasing their visibility to all intersection vehicles. Typical use will allow cyclists to move straight-ahead in the lead of vehicles. Depending on the configuration of the lane immediately to the right of the stop box, the box may also assist right-turning cyclists. The ASB is not intended to offer assistance during green signal phases.



Configuration SD 257: Full width Advanced Stop Box created ahead of both traffic lanes, with approaching cycle lane. This configuration has not yet been marked in Christchurch.

This configuration is intended to provide good cycle waiting capacity in a situation of lower traffic volumes. Once in the reservoir, cyclists have the option of left, ahead and right (depending on lane configuration) prior to vehicles proceeding. Cyclists approaching the intersection on green light will need to make the appropriate lane selection depending on their intended movements.



Configuration SD 258: Advanced Stop Box marked ahead of an unmarked kerbside traffic lane.

This configuration typically marked (in Christchurch) where road width prohibits development of approaching cycle lane. Cyclists make their way to the ASB as best they are able. The ASB is intended to assist visibility of cyclists turning left or straight-ahead, but does not typically help right-turn cyclists.

This configuration is occasionally marked where vehicles are required to turn-left exclusively, but cyclists can move ahead from the same lane. In such circumstances, there must be no left-turn arrow marked on the road (cycles travelling ahead from lane marked with left turn arrow is illegal). Vehicle left-turn is indicated by signage only.

With the exception of SD252 and SD258, all of the configurations shown conform to Austroads 14.

3. OUTLINE OF RESEARCH PROGRAMME

3.1 Areas of Assessment

As the cycle lane markings used in Christchurch were based on examples from overseas design manuals, it was considered appropriate to include a research section on the use and background of such treatments overseas. In addition, the research project has been structured to include the other elements considered important in assessing the function of a new road marking. These elements are:

- Impact on safety – do collision records contain any information relevant to the changed markings?
- Attitudes to use – what are the opinions of the people who are expected to use the new configurations?
- Behaviours – do the actions and actual behaviour of the configuration users meet expectations or match stated opinions?

Section 3.3 below outlines in detail the research techniques used.

3.2 Setting Marking Success Standards

This project has been established to confirm that the ASB and ASL markings improve both physical and perceptual safety of intersections for cyclists. The areas under examination are mentioned in section 3.1 above. However, no section of study, by itself, will reveal whether the overall aims have been achieved.

Therefore, each section of the study has its own set of performance standards that the markings need to achieve. Each section clearly identifies what it sets out to study, then indicates what goals, relevant to that area, will contribute to the overall project success. It is only after each section's research is completed and then combined will it be possible to assess the overall project's success.

3.3 Structure of Research Programme

The structure of the research programme, and what has been studied in each area is as detailed below.

1. Literature Search and Overseas Examples

A literature search and a study of overseas uses of the various configurations has been conducted. The purpose of the search was to ascertain:

- Whether the proposed configurations or very similar ones are in use elsewhere;
- Whether there are any particular constraints or conditions under which one configuration is used over another?
- Whether there are statistical or anecdotal benefits or difficulties with each of the used configurations?

- Whether there are any specific recommendations or considerations that naturally arise from this information?

If the literature research revealed that there does not appear to be any *specific* criteria when one intersection configuration is used in preference to another, then the researcher was required to attempt to determine whether there are any general performance criteria that could be extracted from the research.

> **Effective Performance Standard:** The marking configurations used in Christchurch can be considered effective if they are the same, or very similar to marking configurations used elsewhere, that have created safety improvements for cyclists and not created safety hazards for other intersection users.

2. Collision Analysis

Collision information was examined for (as many as possible of) the intersections marked with cycle spaces, to evaluate whether the markings have had any influence on the cycle and general vehicle collision pattern for the intersection.

It is difficult to establish positive trends in improved cycle and general safety (i.e. reduction in collisions) due to the short time that most markings have been in place and the generally low reporting rate of collisions. However, it was hypothesised that a collision history – before and after – should show up situations if the marking changes have created a noticeably more dangerous situation.

> **Effective Performance Standard:** Where information allows, the marking configurations can be considered effective if before- and after- collision statistics show a consistent or reduced level of cycle and other collisions that can be attributed to the marking configurations. Otherwise, the marking configurations in use in Christchurch can be considered effective if the before- and after- collision statistics *do not* show a statistically significant increase in cycle and other user collisions that can be attributed to the marking configurations.

3. Cyclists' and Drivers' Perception Study

At the time of initiating this stage of the study, approximately 90 intersections had been marked, on one or more approaches, with ACL of either SD253 or SD255 configurations. Seven intersections had ASB of either SD254 or SD256 configuration marked on one or more approaches.

Cyclists and drivers were questioned through a survey to determine their thoughts and attitudes toward the marking and use of ACL and ASB. In order to reduce the complexity of the questionnaires, cyclists and drivers were only shown examples of SD253 and SD254 markings on which to base their opinions.

The survey responses were analysed to assess whether the level of knowledge could or should be improved through advertising and promotion; or whether the markings are too ineffective to ever be used properly, and should be removed

Cyclists were asked:

- Do cyclists know what the markings are indicating?
- Do cyclists believe they know how to use the new configuration appropriately?
- Do cyclists feel that they are more comfortable/less at risk while travelling through or waiting at the intersection than the non-cycle marked situation?
- Do cyclists feel that any other movements (not assisted through new lane markings) through the intersections are more or less comfortable?
- Do cyclists believe that drivers behave appropriately according to the new marking configurations?

Effective Performance Standard: The marking configurations in use in Christchurch can be considered effective if the surveys indicate that the majority of cyclists surveyed: know what the markings indicate; believe they use them appropriately; feel more comfortable than without them; and believe that they do not make any other manoeuvres more hazardous or less comfortable.

Drivers were asked

- Do drivers know what the markings are indicating?
- Do drivers know how to use the new configuration appropriately?
- Do drivers feel that the configurations make them more comfortable/less at risk while travelling through or waiting at the intersection than the unmarked situation?
- Do drivers feel the marking configurations improve the behaviour of cyclists at the intersections?
- Do drivers feel that the configurations make them more comfortable operating in close proximity to cyclists at the intersections, by comparison to the non-cycle marked situation?

Effective Performance Standard: The marking configurations in use in Christchurch can be considered effective if the surveys indicate that the majority of drivers surveyed: know what the markings indicate; believe they use them appropriately; feel more comfortable than without them; and believe that they feel more comfortable operating in close proximity to cyclists, than without the new markings.

4. Cyclist and Driver Behaviour Study

At the time of starting this research project, a number of intersections had no cycle lane markings. Cyclist and driver behaviour was monitored through video observation of movement patterns at these intersections in the unmarked state to record the “before-marking” situation.

ACL markings were then installed at the selected intersections and the behaviour of cyclists and vehicle drivers was videoed again to record the “after-marking” situation.

At the time of starting this research project, seven intersections had ASBs marked. The Automobile Association expressed some concern over these configurations, so the CCC agreed to stop marking ASB until this initial research study was completed. Subsequently, no before- study has been conducted on ASBs. A cyclist and vehicle behaviour study has been conducted at existing ASBs.

The videos were examined to determine:

- Do cyclists actually use the markings as intended?
- Do vehicle drivers use the markings as intended?
- Have cyclist and vehicle movement patterns changed with the marking of the cycle spaces?
- What is the level of violation of the marked cycle space by vehicles.

Effective Performance Standard: The marking configurations in use in Christchurch can be considered effective if the actual behaviour surveys indicate that the majority of intersection users use the laid-out road space as intended; that the level of lane/space violation is equal or less than the lane violations at non-cycle marked intersections; and that the violation levels decrease following on-going information campaigns that support the marking programme.

4. RESEARCH RESULTS – INDEPENDENT SECTIONS

4.1 Result Reporting Structure

The results from each different section of the research are reported as Appendices to this main report:

- Appendix 1 – Literature Review
- Appendix 2 – Collision Assessment
- Appendix 3 – Attitude Survey
- Appendix 4 – Behaviour Study.

Each Appendix gives an analysis of the data gathered in its research stage, and presents a discussion, assessment and conclusion on whether each stage reached the effective performance standard. A series of recommendations is also provided in each appendix.

As a method of presenting the results in this main document, this section provides an edited version of the conclusion, discussion and recommendations. An interpretation of the combined results will be found in the next section of this main report (sect. 5).

4.2 Results – Literature Review

From the studies cited, many cyclists used the ASB and ACL as intended by the design. It would appear that they are well received by cyclists. The majority of motorists respects the ACL but had less respect for the ASB. However, encroachment may have been higher in the latter because no specific education was aimed at the motorists.

The evidence so far is that ASB can be used satisfactorily at intersection approaches with motor vehicle flows of up 1000 vehicles per hour and up to three lanes. In the UK, ASB and ACL have been recommended for general use among road controlling authorities. ASB in particular are being installed at intersections throughout the UK.

Vicroads in Australia recommend that a mid-block cycle lane leading into a signalised intersection should connect to an ACL. Vicroads also suggest that if there is a bicycle storage capacity problem (more than 3 cyclists during red phase at peak), then an ASB should be marked. They will consider an ASB even if there is no approach cycle lane.

Two studies have suggested that crash reductions of 35% are achievable for all cyclists using an ACL marked intersection. There are no studies conducted to prove the crash reductions available from ASB, but conversely there is no evidence to indicate that ASB increase collisions.

Specific education programmes on ASB use, aimed at both cyclists and motorists are considered necessary. Consideration should be given to painting the ASB with a bright colour to demarcate the ASB from the rest of the road.

Literature Review Performance Standard

The versions of ASB and ACL implemented elsewhere are essentially the same as those used in Christchurch (UK simplified layout). None of the situations studied are known to cause safety concerns for either cyclists or other road users. The ACL in particular are

believed to have created safety improvements. The widespread acceptance of ACL and ASB in UK, Australia and Scandinavia indicates a level of comfort with their general use.

It is concluded that the Christchurch style Advanced Stop Boxes and Advanced Cycle Lanes meet an effective performance standard from the literature search.

Recommendations on Use of Advanced Cycle Lanes for NZ

There is no safety reason that ACL cannot be used at any signalised intersection. They could be considered for all traffic signals as a policy of providing improved facilities for cyclists while not having a significant negative impact on the motor vehicle flow.

No international data is available to suggest the maximum number of cyclists that can safely use an ACL, however, it is generally considered appropriate for lower cycle volumes. Where cycle volumes are high, the alternative ASB should be considered. There does not appear to be a limit to the number of vehicles in the lane beside an ACL.

Typically, the ACL is marked to project ahead of the vehicle limit lines by between 2 to 5m. The positioning of the ACL (either kerbside or between traffic lanes) is dependent upon the turning manoeuvres indicated by the traffic lanes.

Recommendations on Use of Advanced Stop Boxes for NZ

International research suggests that the ASB have been used successfully on traffic signal approaches with three traffic lanes. The same research suggests that ASB have been successful with traffic volumes of up to 1,000 vehicles per hour in the same direction as the cycle lane.

An ASB may be needed where there are too many cyclists to form an orderly queue in an ACL during the red signal phase. Vicroads suggest that where more than three cyclists stop in a red phase, then an ASB may be appropriate.

The main value of an ASB is likely to be in areas where there is a reasonable volume of cyclists using the lane throughout the day. If there are insufficient cyclists, motorists are more likely to encroach on the cycle space. Also, where there are few motorists, the ASB is likely to be of little value.

Recommendations – General

Both ACL and ASB should be clearly identified by cycle symbols. Research also recommends the use of coloured surfacing. Neither ACL nor ASB are believed to affect the rate of transgressions of signals by cyclists, however ASB are more subject to vehicle transgressions in times of congestion.

4.3 Results – Collision Analysis

The collision analysis has noted that:

- The traffic signal controlled intersections that had special cycle markings installed in 1997 have shown an all-vehicle crash increase of 1.0% between 1998 and

2000. The crash reduction was 40% between 1999 and 2000 for those marked in 1998, with a reduction of 24.5% observed in 2000 for those marked in 1999.

- The number of cycle crashes at the control group of traffic signal controlled intersections has shown a significant reduction since 1997.

- The number of cycle crashes at the treated intersections is less than the expected number of cycle crashes at those intersections when compared to the control group, indicating a cycle crash saving due to the cycle markings.

As the all-vehicle and cycle crash rates at the cycle marked intersections reduced more than the control group generally, it indicates that the cycle markings did not cause an increase in either all-vehicle or cycle crash rates.

Individual cycle treatments showed some variability in their success with some intersections having a slightly increased all-vehicle crash rate and others having a reduced all-vehicle crash rate. Generally, the overall trend has been for the cycle marked intersections to show a reduction in crash rate.

Collision Analysis Performance Standard

This stage of the study indicated that, overall, intersections with cycle markings (all styles combined except SD257) have shown a decrease in all-vehicle and cycle collisions, over and above the generally decreasing control collision rate.

In the few circumstances where one specific marking style (SD255) has been identified as the only cycle marking style at an intersection, there appears to be an increase in all-vehicle collisions. While this is a point for consideration, it should be noted that it is based on an observation of only four intersections.

Overall, this stage of the research programme cannot be considered to give a definitive, statistically significant finding on the safety of cycle facility marked intersections. The research programme has been unable to isolate all the factors that may influence cycle or all-vehicle collision rates:

- A range of factors are involved in the overall reduction of all-vehicle collisions of the control **and** the cycle-marked intersections.

- Some of the cycle-marked intersections had other work carried out at the same time (kerb-line changes, lane configuration changes, traffic signal upgrades) which are likely to have had an influence on intersection usage as well as collision patterns.

- The total number of cycle collisions in particular, and vehicle collisions generally, is quite low.

However, even given these factors, the clear indication is that intersections marked with cycle facilities have a cycle and all-vehicle collision rate that trends lower than the average (control) collision rate.

It is therefore concluded that the Christchurch-style Advanced Stop Boxes and Advanced Cycle Lanes meet an effective performance standard from the collision analysis.

Recommendations

As indicated earlier, the collision study has a number of limitations based on the number of approaches marked, the number of intersections marked, the length of study period and the fact that other changes (such as works and safety programmes) have influenced vehicle and cycle safety. Despite these limitations it remains clear from the collision records, that cycle-marked intersections do not present a hazard to cyclists nor drivers.

It is recommended that they continue to be installed in Christchurch.

It is further recommended though, that collision records continue to be studied, both on an aggregate, and individual intersection basis, so that any changes in collision patterns or trends can be noted and acted upon. In particular, the slight collision pattern increase for intersections marked with SD255 ACL need to be further assessed.

4.4 Results – Attitude Survey

The drivers surveyed were generally in favour of cycle lanes, but indicated an awareness of potential conflict when a car is turning left and the cycle is going straight ahead. Only a few drivers commented on the ASB. Of these, there were equal numbers in favour and opposed to them.

Surveyed cyclists were strongly in favour of ACL, but indicated concern about turning right at traffic signals. They want more education for motorists to encourage them to have more respect for the cyclists' space and to look for them, especially when turning left.

When travelling straight or turning left, more than half of the cyclists think ASB make the intersection safer for them. When turning right, far more cyclists are in favour of the ASB than opposed to them.

Red surfacing for ASB and ACL is strongly supported by cyclists and more drivers are in favour of it than oppose it.

Attitude Survey Performance Standard

It appears fairly clear from the cyclist and driver surveys combined, that both groups of road users are generally in favour of ACL at signalised intersections. Those who responded in each group felt they offered safety improvements. There were, however, some notable departures from this, and there is concern amongst both groups about the operation of ACL when vehicles need to turn left across straight-through cyclists.

Of particular concern to cyclists and also noted by drivers, is the fact that drivers will use, and sometimes stop in cycle lanes. The cyclist and driver suggested response to this is improved information on the way to use ACL in tandem with rules or regulation to reinforce appropriate behaviour.

Cycle lanes marked to the left of vehicle lanes are also of concern to cyclists wishing to turn right. Although their development in the kerb-side position was never intended to assist right turning cyclists, some appear to believe they should, and others think that they make the right turn manoeuvre more dangerous.

ASB, overall, do not present clear indications of preferences. Cyclists generally seem to appreciate them, feeling safer at intersections because of them, and they see some merit in their use for right turning. However, even while their purpose seems clear, there is discomfort for cyclists having traffic waiting immediately behind them.

Drivers, however, do not appear to like cyclists "stacking" ahead of them, and appear unsure or non-committal about the purpose and functioning of the ASB, with questions about both cyclist and vehicle safety being raised.

The performance standard required that both ACL and ASB, for both cyclists and drivers, would be effective if the majority of those surveyed knew the purpose of the markings, believed they used them appropriately, felt more comfortable than without them, and believed they do not make other manoeuvres more dangerous.

Generally, it is possible to state that most respondents knew the purpose of the markings, and believed they used them appropriately. Cyclists and vehicle drivers tend to differ on whether they feel more comfortable than without them, and both groups have identified other manoeuvres that they feel are less safe than without the markings.

On this basis, it is concluded that the markings have only partially achieved the performance standard from the Drivers' and Cyclists' Attitude Survey.

Attitude Survey Recommendations

The fact that the performance objective was not fully achieved for all aspects of the driver/cyclist attitude survey suggests to two key points - either the ACL and ASB are actually not fulfilling their intended function (and are therefore creating physical and perceptual risks for the two groups of road users), and/or the users are not appropriately informed and exercising this information.

Based on this attitude survey, it would appear there is a role for more extensive advice and information to cyclists and vehicle drivers on the use and function of these marked cycle spaces. It would be appropriate to conduct this style of survey again, following a period of promotion and information about use of these cycle markings.

It would also be appropriate for a review of the design of ACL and ASB, to determine whether any design actions could respond to the points raised in this survey.

4.5 Results – Behaviour Study

Overall, the marking of kerbside and between-lane ACL and ASB appear to have been effective in that the majority of cyclists using the approach now use the marked lanes. The inappropriate use of the traffic lanes (e.g. straight-through cyclists using left-turn only lanes) has significantly decreased.

It is difficult to draw conclusions about whether the lanes encouraged cyclists to disobey the signals but the ASB certainly did not seem to suffer from high levels of red-signal infringement. In general though, of the cyclists who do stop, more stopped behind the limit lines (as required) than before the marking of both ACL and ASB - the ASB appeared to be most effective in this regard.

Vehicles tend to show mixed results in either driving over, or stopping in the ACL or intruding into the ASB. One intersection showed no intrusions into the ACL, whereas another had one vehicle per red-light stopping over the ACL. Unfortunately, no conclusions could be drawn about changes to vehicle intrusion beyond limit lines without ASB due to no before-marking study.

Behaviour Study Performance Standard

Generally, it is safe to say that the majority of users observed in the studies used the road markings as intended. The least compliant of users were vehicle drivers that stopped in a position where they either intruded into the ASB or partially obscured the kerb-side ACL. The rate of ACL violation by vehicles in some configurations was quite high.

It is therefore concluded that the Advanced Cycle Lanes and Advanced Stop Boxes are only partially successful in appropriately directing cyclist and vehicle behaviour at intersections.

There has been no study on behaviour after extended promotion/information programmes, so no performance level can be noted on this matter.

Behaviour Study Discussion

Each intersection studied in this project was slightly different, and it is believed, from direct observation and anecdotal feedback, that configuration differences may have had some impact on the study results. It is also believed that other factors, not directly related to the configuration markings may impact on some of the measured behaviours:

- **Cyclists disobeying the red light:**
  This study included a measure of how often cyclists disobeyed the red signal. Retrospectively, it is not unreasonable to assume that cycle markings would have little impact on this behaviour. Cyclists prone to ignore red lights would receive little encouragement from ACL or ASB to obey. Their illegal behaviour is more likely to occur when the cyclists considers it is safe to move, which is more dependent on crossing traffic rather than lane markings.

- **Vehicles driving over/stopping in ACL:**
  Observation has shown that vehicles approaching intersections with kerb-side ACL are more likely to stop in the ACL when the combined width of cycle and traffic lane is greater than about 4.7m. It seems that where the width is adequate for straight-through and left-turn vehicles to queue side-by-side, they will occupy the ACL. Where the combined cycle and traffic lane width is narrower, and two vehicles could not queue side-by-side, ACL violation tends to be less.

- **Cyclist behaviour depends on vehicle behaviour**
  Even though most cyclists use a kerb-side ACL when marked, not all do. Cyclists are cautious about whether vehicles will intrude in the ACL. Some will remain behind or cycle around left-turning vehicles, rather than remain in the ACL and trust vehicles not to cut them off. In this circumstance the success of the ACL is largely based on how vehicles behave around it, rather than whether its location is acceptable.

The above points tend to indicate that a before- and after- marking assessment of ACL at intersections could be conducted to clarify some of the points of the survey. For example, the SD253 (kerb-side ACL) surveys could be conducted with a comparison between sites with narrow geometric design and the wider SD253 design.

In general, while this survey did give some useful results about behaviour of cyclists and vehicles at cycle-space marked intersections, it cannot be concluded to be a definitive guide to the best geometric layout for such intersections. It did however, provide an excellent guide to identify the factors that could be investigated in future study.

Behaviour Study Recommendations

The most immediate and obvious recommendation that comes from this part of the study is to revisit the design of ACL and ASB, now that the first formal observation studies have been undertaken. The review should assess whether some of the "undesirable" behaviours of both cyclists and vehicles can be mitigated or remedied by design changes.

It is difficult to determine, simply from observation of vehicle and cycle movement, which of the "undesirable" behaviours are based on lack of knowledge about use of the markings, or equally, which "desirable" behaviours are actually based on understanding the configuration. There is research potential to conduct an information/education programme, independently of any changes that might be made to intersection configuration, and evaluate behaviour changes.

5 RESEARCH RESULTS – SUMMARISED FINDINGS

5.1 Advanced Stop Box Findings

The literature search indicates that ASB are well received by both cyclists and drivers when implemented in UK and US. However, the rate of intrusion into the ASB by vehicles when facing the red signal is a problem that overseas cyclists mention. This study tends to confirm that cyclists like the function of the ASB. This study could not make intrusion rate comparisons, but Christchurch cyclists express reservations about the fact that vehicles pull up and queue behind them when they (cyclists) are stopped ahead of the traffic lane.

Some Christchurch cyclists also indicated that they were concerned about the use of ASB for making right-turns. In most installations, ASB are not intended to assist right-turning cyclists, in other locations they are – depending on the their position relative the permitted manoeuvres of the vehicle lanes behind them. There appears to be an opportunity to clarify the purpose and best function of ASB in cyclists' minds.

Christchurch drivers on the other hand, don't appear to be too enthusiastic about having cyclists stacking ahead of them at a red signal, even though they generally understand the purpose of the ASB. The fact that recorded driver intrusion into ASB varies considerably, even though the markings were similar, speaks to some uncertainty or ambivalence on the behalf of drivers. There is also an opportunity to clarify the purpose and functioning of ASB in driver's minds too.

Despite the general variance in driver behaviour there has been no collision history at ASB intersections that would give cause for concern. As the ASB intersections used in this study were converted from roundabouts to signals (with ASBs), no before-ASB/after-ASB collision comparison can be made. However, the crash pattern at ASB intersections has not raised any concerns.

From the overseas studies, it seems all ASB marked have used coloured surfacing. None of the ASB used in this study have been coloured. Both cyclists and drivers gave positive indications about the clarity of space segregation when coloured surfaces have been used (in other circumstances). There is scope to test the effect of coloured ASB surfacing both on attitudes and behaviours of drivers and cyclists in Christchurch.

5.2 Advanced Cycle Lanes Findings

The survey of cyclists' attitudes to ASB indicated that cyclists frequently find vehicles queued over, or driving in, the cycle lane feeding the stop box. The geometry of the cycle lane is typically the same as the kerbside ACL, and the behaviour study indicated that drivers do use the lane for queuing and movement sometimes. The rate at which vehicles block the lane is unsatisfactory.

Vehicles tend to queue in, or block the ACL marked between traffic lanes less than the kerbside version – the behaviour study indicated this occurred when there were longer vehicle queues. Given the geometry of the road at these intersections, vehicles clearly have no option but to queue over ACL in these circumstances.

The literature review found less recent study material on the introduction of ACL, but the material available did suggest that they were being used in Scandinavia and Australia

quite successfully. A Scandinavian study also indicated improvements in collision rates from their introduction. No research has been found that would suggest collision changes were a noticeable problem.

The study of Christchurch collision rates noted reductions in both cycle- and all-vehicle collisions after the introduction of ACL at a majority of intersections. One style of marking – the between-traffic lanes ACL (SD255)– was accompanied by a slight rise in all-vehicle collisions. In practical terms this increased rate was based on observation of only 4 intersections over 2 years, and would relate to one or two more collisions than anticipated. It is questionable whether this increase is statistically significant. Other potential causal factors of the collisions have not been able to be isolated.

It should also be noted that the overall collision rate reduction is based on few (approx 50) intersections over three years maximum, and that there were also other road safety improvements occurring over this period at intersections city-wide. The limitations these factors impose mean it is not possible to confirm categorically that the collision rate reduction has been exclusively due to ACL marking. However, it is possible to say confidently that the markings have not created any cause for concern in the crash rate.

The majority of cyclists and vehicle drivers are clear on the main purpose of the ACL, although some cyclists expect them to function for right-turn movements too - a function for which they were not necessarily intended.

5.3 Areas Requiring Further Analysis

The research, and anecdotal feedback collected during this study has identified areas where performance standards were not clearly reached. This failure may be attributed to a number of factors:

- deficiencies in research (including the gathering of data and the integrity of some data),
- inadequacies of the intersection markings themselves,
- changes to the overall roading environment of which these markings are a small part,
- the variance of understanding and interpretation of the road markings by drivers and cyclists.

This study was not able to fully separate the effects of each of the above factors on the behaviour, attitudes and safety of cycle markings at intersections. However, the study findings indicate that whilst some of the performance standards are only partially met, none give sufficient cause for concern that would or should restrict or limit their use in the immediate future.

Continuation of this study in the following areas would, however, reduce some of the areas of ambiguity, and may help better inform the overall results:

- Identification of the effects of coloured surfaces on behaviour patterns;
- Identification of the effects of promotion and information on behaviour patterns;
- Extended study of collision records at marked intersections;
- Identification of the effects of changes in combined cycle/traffic lane widths.

An area of further research that may also help to ultimately reach a definitive statement on the performance of cycle markings at signalised intersections is a nationally-accepted definition of the factors that should be measured in this type of study. This research identified a series of factors to measure based, in combination, on experience and studies from overseas. It is necessary to determine what is important and what is not in such a study. - for example is the rate of cyclist stopping or transgressing red-lights an appropriate measure for effective performance of ASB and ACL?

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Despite Advanced Cycle Lanes and Advanced Stop Boxes not fully meeting the stated performance standards identified at the beginning of the research it is concluded that the Christchurch marking standards are appropriate for continued installation..

Assessment of the separate elements of the research indicates that the markings have met acceptable performance standards in terms of improved safety at Christchurch's signalised intersections. The design of the markings is also very similar to overseas practice, which are installed widely and so meet performance standards in this area. The area where performance standards are only partially met are in the areas of cyclists' and drivers' behaviour and attitudes of both groups to cycle markings use.

Further analysis of the behaviour and attitude study indicates that the reason performance standards are only partially met is largely related to convenience of movement (i.e vehicles stopping in Advanced Cycle Lanes) and perceptions of discomfort of use (i.e. vehicles queuing behind cyclists at Advanced Stop Boxes). It is concluded that these levels of failure are not severe enough to prevent continued implementation of Advanced Cycle Lanes and Advanced Stop Boxes in Christchurch, but rather point to deficiencies that, if rectified, should enhance the positive benefits of installation.

However, unqualified statements of success cannot yet be made. This research has identified a number of areas of design, understanding of use and practical behaviours that need to be improved before such success can be declared. These areas require technical and promotional work and further research to determine whether improvements can be generated, or whether there are acceptable percentages of vehicle transgression and cyclist/driver uncertainty.

6.2 Recommendations

The following recommendations are made as a result of this research project:

- Advanced Cycle Lanes and Advanced Stop Boxes should continue to be marked in Christchurch as cycle facilities are installed and/or as signalised intersections come up for redesign and remarking.

- Coloured surfacing should be applied to a number of Advanced Stop Boxes and Advanced Cycle Lanes, and subsequent vehicle and cyclist behaviour studied to examine whether intended behaviours are better achieved than with non-coloured surface markings.

- A promotion, information and education programme needs to be initiated and sustained to enhance understanding of the purpose and intended function of the Advanced Cycle Lanes and Advanced Stop Boxes, and encourage compliance with their ideal use.

- The design of the kerb-side ACL needs to be reviewed in light of the combined cycle-lane/traffic-lane width. It is possible that wide lane combinations encourage vehicles to stack side-by-side and block the kerbside

cycle lane. Further study should examine whether this is indeed the case, or whether other factors encourage or discourage vehicle occupation of the cycle lane.

It is further recommended that this study and any other New Zealand research on Advanced Cycle Lanes and Advanced Stop Boxes are brought together so that and a broader perspective on the use of these configurations be developed.

The need for cycle facilities at intersections?